A COMPARATIVE STUDY OF THE PHYSICO- CHEMICAL PROPERTIES AND BACTERIAL LOAD OF GREYWATER IN ESTATES IN HOMABAY TOWN AND GITHURAI ESTATE

VICTOR G. NGA' NG' A (B.Ed. Science, Hons)

REG NO: I 56/10405/2007

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN MICROBIOLOGY IN THE SCHOOL OF PURE AND APPLIED SCIENCES OF KENYATTA UNIVERSITY

NOVEMBER 2013

DECLARATION

This thesis is my original work and has not been presented for the award of a degree, diploma or certificate in any other institution.

Signature …….. **Date…….**
Victor G Ng'ang'a

We confirm that the work in this thesis was carried by the candidate under our supervision

Prof. Kiplagat Kotut

Embu University College

Signature……. **Date……**

Dr. Francis Kariuki

Department of Plant and Microbial Sciences,
Kenyatta University

Signature …… **Date……**

Dr. John M. Maingi

Department of Plant and Microbial Sciences,
Kenyatta University

Signature …… **Date……**

DEDICATION

I dedicate this thesis to my family whose understanding and support has brought me this far.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my supervisors Prof. K. Kotut, Drs. F. Kariuki and J. Maingi for their tireless encouragement, constructive criticism and contributions without which this work could not be complete. I would also like to appreciate the funding support for the study by Lake Victoria Research Initiative (VicRes). Appreciation is also given to the laboratory staff of the department of Plant and Microbial Sciences, Kenyatta University for their support and co-operation during my research work. I wish to thank Mr. Gichobi (Chief Technician, PMS Department, Kenyatta University) for his assistance during field work. I also wish to appreciate Mr. Odoyo who was my interpreter and guide during field work in Homabay. Finally I am grateful to my fellow students Catherine and Abuga for their encouragement during the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

ANOVA Analysis of Variance

APHA American Public Health Association

BOD Biochemical Oxygen Demand

CFU Colony Forming Units

CI Confidence Interval

CSBE Centre for the Study of the Built Environment

DCA Deoxycholate Citrate Agar

DO Dissolved Oxygen

EC Electrical Conductivity

EPA Environmental Protection Agency

FAO Food and Agriculture Organization

FC Fecal Coliforms

GW Greywater

MF Membrane Filter

MUG Methyl umbelliferyl- β –D-glucuronide

NEMA National Enviroment Management Authority

PMS Plant and Microbial Sciences

SPSS Statistical package for the Social Sciences

SS Salmonella-Shigella agar

TC Total Coliforms

TCBS Thiosulfate Citrate bile Salts sucrose

TSI Triple Sugar Iron

UN United Nations

USA United States of America

VIP Ventilated Pit Latrine

WDM Water Demand Management

WFP World Food Program

WHO World Health Organization

XLD Xylose Lysine Deoxycholate

ABSTRACT

In recent years concerns over dwindling reserves of ground and surface water resources coupled with an overloaded or costly sewage treatment plants has generated much interest in the reuse or recycling of greywater. Greywater is untreated household wastewater which includes water from; showers, laundry, dishwashers and washing machines. Re-use of greywater offers several advantages that include a reduction in the water bill, reduced wastewater discharge, as well as reduction in the demand on potable water supplies. Due to the insufficient supply of water, some limited reuse of greywater is practiced in rural-urban and peri-urban settlements. However, there is no information on the bacteriological quality and physico-chemical properties of the greywater produced in the selected areas. Hence the potential risk to human health arising from the reuse of greywater is unknown. Therefore this study was aimed at determining the bacriological and physico-chemical quality and safety of greywater produced by communities in a peri-urban (Githurai) and rural-urban (Homabay) settlements for reuse purposes. The bacterial load was determined using indicator organism. The method used was that of membrane filter-technique (MF) for total coliforms where bacteria count was made using colony counter. The study also investigated the presence of common pathogens in greywater. Isolation, identification and enumeration of enteric pathogens i.e. *Salmonella*, *Shigella* and *Vibrio* was carried out using appropriate techniques and procedures. Physico-chemical properties were determined using appropriate techniques and procedures. Results for electrical conductivity of samples from various estates, ranged from 60 to 4470 µS cm^{-2}. However, the difference in EC among the greywater sources was not significant, but there was a significant difference in mean EC among the greywater types. Dissolved oxygen concentration of greywater ranged from 0.0 to 8.0 mg L^{-1} with a mean value of 3.5 mg L^{-1}, an indication that it may be necessary to subject the greywater generated to some initial aeration. Greywater pH range of 5.0 to 10.3 was comparatively wider than that of the drinking water sources (6.7 to 7.5). The salinity of greywater samples was comparatively greater than that of drinking water with a range of 0.0-2.3 ml/L. There is a risk of increased salination of topsoil over the long term. An overall total coliform range of 1.3 -7.8 million CFUs recorded is comparatively lower than a value of 2.4 x 10^3 to 2.4 x 10^6 measured in the Dome distribution system in London but higher than the recommended value by WHO (6.0 x 10^3 – 1.9 x 10^5). Fecal coliform counts in greywater from various household operations ranged from 0.029x10 to 6.8x10^5 CFUs per 100 ml with a mean of 2.02 x10^5 CFUs per 100 ml. The presence of total coliforms and fecal coliforms shows fecal contamination, indicating the possible presence of pathogens. Attempts to identify specific pathogens in greywater samples tested revealed that *Salmonella*, *Shigella* and *Vibrio* species were present in various estates and greywater types. *Salmonella* was the most frequent and its presence was recorded in 29.4% of all the samples collected. *Shigella* and *Vibrio cholerae* were recorded in 19.6% and 8.8% respectively.The presence of pathogens indicates that untreated greywater may pose a health risk to residents. From the study, it is clear that bacteria load in greywater was generally high. It is recommended that simple greywater treatment technologies should be introduced to the residents of the study area.

CHAPTER ONE

INTRODUCTION

1.1 Background

For centuries man's built environment and quality of life has been closely predicated on the availability and sustainability of natural resources. As the common denominator in virtually every ecosystem, water resources likewise serve as the cornerstone of human society and its sustainment. Access to water supply and improved sanitation is one of key factors in improving health and economic productivity. However the global demand for water has increasingly exceeded the limits of its slow moving cycle, and compromization of man’s quality of life, and existence, hence making it imperative to search for new water sources (WHO, 2000). As freshwater becomes increasingly scarce, it is necessary for policy makers and leaders to shift attention to alternative sources of water and particularly among the rural and peri-urban poor.

Faced with the twin problems of water scarcity and limited access to safe alternative sources of water, some countries and many of their citizens are turning towards a formal recognition of the role that wastewater use can play in supplementing existing sources of water for irrigation. Wastewater reuse can provide alternative source of water, while at the same time reducing pollution load to water environment by discharging less wastewater. This in turn has implications on food security, particularly in urban areas where domestic wastewater is plentiful (WHO, 2000).

In Kenya, an increasing number of small and medium size towns and cities will need to address the combination of livelihoods, water resources management and environmental sanitation as they grow in size. In these towns and in highly populated rural areas there is a substantial increase in generation of wastewater. In these situations, there is a need to contain health and environmental risks through appropriate and decentralized solutions to management of wastewater treatment, use and disposal. At the same time there is increasing water scarcity and therefore competition between water for domestic and productive uses.

The dire situation of water scarcity in Kenya is well known and documented (WHO, 2000). Frequent droughts, need for irrigated agriculture and limited water resources make re-use of wastewater necessary to conserve freshwater for domestic use. Also well documented is the inadequacy of conventional, centralized waterborne sanitation and the high cost of supply driven approaches to water resource development (WHO, 2000). One implication has been the shifting of research attention to on-site management practices employed for by the poor. Wastewater reuse is a practice that offers access to an unconventional source of water for irrigation especially in urban areas such as Nairobi, Nakuru, Kisumu among others and has been shown to lead to greater income generation for the rural poor (Mutua *et al.,* 2009). Households in Homa Bay, for example, have demonstrated a willingness to pay for treated greywater (Kotut *et al.,* 2009).

Greywater, the wastewater from kitchens, bathrooms and laundry is distinct from black water (that comes from the toilet) as there are fewer health and environmental risks associated with its use. It is estimated that 65% - 90% of household water effluent is

greywater (Diener and Morel, 2006). Greywater reuse is a simple, home-based water demand management (WDM) strategy that has benefits at the household level as an alternative water resource to optimize productivity (Peasey, 2006). Greywater use is also very much a water demand management strategy (WDM) concept of 'getting the most from the water that we have', and signifies an improvement in the efficiency of water use to accomplish a specific task (Peasey, 2006).

Using greywater minimizes the need and demand for the freshwater. The most common application of untreated greywater is in crop irrigation (CSBE, 2003). However, this form of application has significant pitfalls as the untreated greywater can damage both soil and human health. As awareness of the potential and challenges associated with greywater recovery and use become apparent, more attention needs to be placed on how treatment and re-use at the household level can be promoted. Greywater fundamentally preserves the existing freshwater supply, and in that way is a significant WDM strategy. An estimate of the proportion of greywater in the household wastewater usually varies between 65% and 80% (Burnat, 2007). No matter the amount, its re-use conserves the available water by reducing the amount required from the municipal network, or, in un-served areas, from private vendors and decrease the pollution of surface water.

According to EPA (2007), greywater can be used untreated, or it can be treated to varying degree to reduce nutrients and disease-causing microorganisms. The appropriate uses of greywater depend on both the source of greywater and the level of treatment (Ahmed *et al.*, 2001). There are constraints associated with greywater reuse, which may significantly reduce the chances of successful implementation of any reuse strategy (Ahmed *et al.*,

2001). This includes infections due to microbial contamination from microorganisms such as *Salmonella typhimurium*, *Campylobacter jejuni*, *Giardia intestinalis* and *Cryptosporidium parvum* (Ottosson, 2003a).

Semi-arid areas in Kenya have problems of water shortage. Homabay town, located in a semi arid area with unreliable mean annual rainfall of 800 mm, experiences such water shortages. The main source of water for this town is Lake Victoria. The total water supply is designed to deliver about 3,500 m^3 d^{-1} of water against a total water demand of 5,100 m^3 d^{-1}. The system currently supplies 2,200 m^3 d^{-1} leaving a shortfall of 2,900 m^3 d^{-1}, which is obtained from other sources that include, shallow wells, springs and boreholes or directly from the lake (UN, 2006). Water scarcity in Homabay town means that treated greywater can be used in place of fresh water in some instances and therefore saving money.

Githurai Estate in Nairobi is a typical example of estates within the city that receive inadequate supply of water. Like in most city estates, Githurai has experienced rapid population growth that is exerting pressure on the existing water supply. Most of the residents do not receive enough water to meet their domestic demands and they have to rely on water vendors to meet the deficit. The existing water supply system was designed to serve a population of 30,000 people, but the current population is over 100,000 people (UN, 2006) hence posing a challenge to water supply. As in the case of Homabay, greywater can be used to supplement the water supply.

1.2 Problem statement and study justification

In recent years, reduced supply of potable water has generated much interest in the reuse of greywater. In Homabay and Githurai areas, owing to the insufficient supply of water, some limited reuse of greywater is practiced. However, there is no information regarding physico-chemical properties and bacteriological quality of the greywater produced in these areas. Hence the potential risk to human health arising from the reuse of greywater is unknown. This study was aimed at determining the physico-chemical properties and bacteriological quality of greywater produced by households in Homabay town and Githurai estate in Nairobi. The findings of this study will provide baseline information on whether the greywater is safe to be re-used without treatment or not. The data collected from this study will provide the residents of the two areas with empirical facts on the challenges of direct reuse of greywater. It will also assist the policy makers in formulating guidelines on reuse of greywater and form a useful baseline for the design and development of greywater treatment technologies.

1.3 Research questions

1. What is the physico-chemical quality and bacterial load of greywater produced by households at Githurai and Homabay areas?
2. Is there a significant difference in the physico-chemical quality and bacterial load of greywater from estates in Homabay town and Githurai estate?
3. Is there a relationship between physico-chemical properties and bacterial load of greywater in each study site?

1.4 Hypotheses

1. Greywater from different sources has an acceptable physico-chemical quality and no significant bacterial load.
2. There is no significant difference in the physico-chemical quality and bacterial load of greywater from estates in Homabay and Githurai.
3. There is no significant relationship between bacterial load and physico-chemical properties of greywater from estates in Homabay and Githurai.

1.5 Objectives

1.5.1 General objective

To investigate the bacterial load and physico-chemical properties of greywater generated by households in Homabay Town and Githurai Estate in Nairobi City.

1.5.2 Specific objectives

1. To determine the bacterial load and physico-chemical properties of greywater from various sources at estates in Homabay town and Githurai estate.
2. To compare the bacterial load and physico-chemical properties of greywater in estates in Homabay and Githurai.
3. To establish whether there is any relationship between bacterial load and physico-chemical properties of greywater at estates in Homabay and Githurai.

1.6 Scope of the study

The study focused on greywater from bathrooms, kitchen and laundry activities. Various standard methods were used to determine the physico-chemical and microbial properties of greywater.

CHAPTER TWO

LITERATURE REVIEW

2.1 Domestic wastewater

Domestic wastewater can be divided into two categories; blackwater and greywater. Blackwater, originates from toilets and soiled diapers, has gross faecal bacteria contamination and generally high concentrations of organic matter (Welton *et al.,* 2005). The term "greywater" refers to untreated household wastewater, which has not been contaminated by toilet waste. It includes the water from bathtubs, showers, hand basins, laundry, floor wastes, kitchen sinks, dishwashers and washing machines (Ahmed *et al.*, 2001) and constitutes the largest flow of wastewater (WHO, 2006). It is called greywater because if stored for even short periods of time, the water will often cloud and turn grey in color (Ottosson, 2003a).

2.2 Composition of greywater

The composition of greywater varies greatly, reflecting the lifestyle of the residents and the choice of household chemicals for laundry, bathing, etc. Greywater typically contains high concentrations of easily degradable organic material, such as fat and oil from cooking, and other residues from soap and other detergents. Pathogens essentially only exist in the greywater fraction if contaminated by faeces. Still, the greywater environment is favourable for bacterial growth which means that it needs to be treated before reuse. Furthermore, untreated greywater easily turns anaerobic and thus creates a foul odor

2.3 Health risk associated with greywater

The risk of introducing pathogens into greywater are mainly from faecal contaminated laundry, childcare and showering. Greywater may contain some bacteria, parasites and

viruses washed from the body and clothes (WHO, 2006). This means that greywater is capable of transmitting disease and therefore it needs to be properly managed to minimize health risk and degradation of the environment (Wood, 2008).

Greywater from bathrooms, kitchens and laundry can be contaminated with hair, soaps, shampoos, hair dyes, toothpaste, lint, body fats, oils, faecal matter, food particles, cleaning products, bacteria and viruses. The microbial quality of greywater is dependent on the occurrence of fecal contamination (Welton *et al.,* 2005; Ottosson, 2003a). Fecal contamination can be determined by the presence of common indicator bacteria, such as coliforms and enterococci. Some studies in Oman and Alaska have reported high numbers of these organism groups, which indicate substantial faecal contamination of greywater (WHO, 2006). If greywater is applied untreated to gardens, it may lead to environmental damage, and pose a threat to public health.

2.4 Environmentally hazardous substances in greywater

Although the load of metal ions and organic pollutants in greywater is generally low, levels of the same can increase if environmentally hazardous substances are added to the wastewater. Metal ions originate from the water itself, from corrosion of the pipe system and from cutlery and shampoos used in the household. Organic pollutants are present in many of our ordinary household chemicals, such as shampoos, glues, preservatives and cleaners. In this case as well, people can greatly influence the greywater content. By using environmentally friendly chemicals and not pouring hazardous substances such as paint and solvents down the drain, the levels of metals and organic pollutants in greywater can be kept low. Greywater is relatively harmless from an environmental and

hygienic point of view. Problems are often small and local. However, if not managed properly, greywater will be a strong source of smell due to the high levels of easily degradable compounds. When these compounds are broken down, natural processes can create anaerobic conditions within hours, causing bad odors.

2.5 Greywater reuse options

The total volume of greywater potentially generated each day from a household ranges from negligible to substantial for instance in Egypt it is 0.408% while in Kuwait it is 62.6% (FAO, 1997). In some communities in the west of Colorado State in USA, homes have a water line for drinking water and a second water line with non-potable treated greywater for irrigation (Whiting *et al.*, 2002). In this state, it is illegal to use greywater for landscape irrigation. Whereas the idea of direct reuse of grey water may appear new, indirect reuse has always been practiced like irrigating vegetables along greywater furrows. While most people would consider water going down the bath drain as waste water, it is destined to be used again downstream. Initially one's wastewater becomes someone else's water right, legally belonging to someone downstream. In most Colorado watersheds, water is reused a number of times by different people before it finally leaves the state.

In Langalanga estate in Nakuru, greywater is disposed of in any open spaces available. It is also disposed in septic tanks and pit latrines. As a result, most pit latrines emit foul smell and get filled very fast (Mutua *et al.,* 2009). This common practice has resulted in a major environmental and public health concern to the residents. Although the basic design requirements of greywater treatment systems are the same, individual designs will

be site specific. Biological treatment of the greywater is indispensable in order to guarantee a risk free service of water for reuse applications other than potable water (Nolde, 1999).The choice of technology in these areas for basic wastewater management is a household decision because ownership and acceptance by the household is vital to sustainable greywater treatment (Mutua *et al.,* 2009). Decentralized greywater treatment systems range in size from individual on - site systems serving one household to shared facilities serving about 40 households, or public facilities for several households sharing one sanitary facility (Sleytr *et al.,* 2009).

Greywater may contain some, bacteria, parasites and viruses washed from the body and clothes (WHO, 2006). Therefore greywater can only be used in place of fresh water to irrigate trees, shrubs, and flowers, but not to water livestock. In addition, greywater should never be applied to root crops or leafy vegetables that will be eaten raw, such as carrots, lettuce, or herbs, and it should not come in contact with the edible portion of fruits and vegetables (for instance, with root vegetables, such as radishes, potatoes, and beets). Use of greywater in fruit trees, and other plants where the edible portion is well away from the water, is permissible (Ottosson, 2003a). Lawns should not be watered with greywater using a sprinkler, or use greywater to wash patios, walkways or driveways. One option for greywater reuse is bucketing. The advantage of bucketing is that it doesn't require modification to the plumbing of the home, or installation of a greywater treatment and irrigation system. The greywater can be collected directly from the bathroom and laundry and applied to garden or lawn areas (Welton *et al.,* 2005).

2.6 Bacterial indicators of water quality

2.6.1 Total coliforms

Total coliforms are members of the Enterobacteriaceae and include genera that originate from feces; called Fecal Coliforms, such as *Escherichia*, as well as genera that are not of fecal origin, called the non-Fecal Coliforms like *Enterobacter*, *Klebsiella* and *Citrobacter*. Coliforms are facultatively-anaerobic, rod-shaped, gram-negative, non-sporulating bacteria. They are capable of growth in the presence of bile salts or similar surface agents, oxidase negative, and produce acid and gas from lactose. These mostly harmless bacteria live in soil, water, and the digestive system of animals. The historical definition of this group has been based on the method used for detection of lactose fermentation rather than on the tenets of systematic bacteriology (APHA, 2003). Some of these bacteria are pathogenic and cause enteric diseases such as bacillary dysentery, typhoid fever, cholera, and paratyphoid fever (Jefferson, 2003). In many peri-urban settlements most of the waterborne diseases result from poor wastewater disposal practices.

Since direct monitoring of all pathogens would be too slow, microbial water quality is monitored using a single or a few indicator organisms (APHA, 2003). The basis of testing greywater for microbial safety rests on the detection of coliform bacteria (Ottosson, 2003a). The word coliform means having coli-like characteristics similar to those exhibited by *Escherichia coli. E. coli* is generally used as an indicator bacterium because it is found in large numbers in animal feces and lives longer in water than enteric pathogens (Tonner *et al*., 2006). If no *E. coli* is present in the water sample, it is likely that there are no intestinal pathogens present (Ottosson, 2003a). Their presence in water

is detected through the membrane filter technique. As related to the membrane filter technique the coliform group is defined as comprising all aerobic and many facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that develop a red colony with a metallic sheen within 24 hours at 35 °C on an Endo-type medium containing lactose (APHA, 2008).

2.6.2 Fecal coliforms

Fecal coliform bacteria, which belong to the group Enterobacteriaceae are present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste (Tonner *et al.*, 2006). Fecal coliforms are falcultative anaerobes, rod-shaped, gram-negative, non-sporulating bacteria.They are capable of growth in the presence of bile salts or similar surface agents, they are oxidase negative, and produce acid and gas from lactose within 48 hours at 44 ± 0.5ºC. Though fecal coliform are usually not pathogenic, their presence may indicate the presence of other pathogenic bacteria for example, *Salmonella, Shigella,* and *Vibrio*. They are hence considered to be indicator organisms. Pathogens are typically present in such small amounts that it is impractical to monitor them directly.

Fecal coliform, like other bacteria, can usually be killed by boiling water or by treating it with chlorine. Washing thoroughly with soap after contact with contaminated water can also help prevent infections. Despite the fact that they can not be linked directly to contamination by human sewage, fecal coliform bacteria counts are often used to regulate surface waters for recreational use, shell fishing, and potability (ability to be safely consumed). Federal regulations stipulate maximun allowable numbers of these bacteria

for various uses. If fecal coliform counts are high (over 200 colonies per 100 ml of water sample) in the river or stream, there is a greater chance that pathogenic organisms are also present (APHA, 2003). A person swimming in such water has a greater chance of getting sick from swallowing disease-causing organisms, or from pathogens entering the body through cuts in skin, the nose, mouth, or the ears. Diseases and illnesses such as typhoid fever, hepatitis, gastro- enteritis, dysentery, and ear infections can be contracted in waters with high fecal coliform counts. The maximum acceptable coliform load (colony forming units colonies per 100 mL) is 1, 200, 1000, 2000 for drinking water, swimming, boating and treated sewage effluent respectively.

2.6.3 *E. coli*

Escherichia coli, originally known as *Bacterium coli* commune, was identified in 1885 by the German pediatrician, Theodor Escherich. *Escherichia coli* is widely distributed in the intestine of humans and warm-blooded animals and is the predominant facultative anaerobe in the bowel and part of the essential intestinal flora that maintains the physiology of the healthy host (Conway, 1995). *E. coli* is a member of the family Enterobacteriaceae (Mack, 2008) which includes many genera, including known pathogens such as *Salmonella*, *Shigella*, and *Yersinia*. Although most strains of *E. coli* are not regarded as pathogens, they can be opportunistic pathogens that cause infections in immune-compromised hosts (APHA, 2003). Some strains of *E.coli* can cause intestinal illness in healthy humans when ingested. One such strain is E. coli O157:H7, which is found in the digestive tract of cattle. In 1892, Shardinger proposed the use of *E. coli* as an indicator of fecal contamination (Doyle *et al.,* 1987). This was based on the premise that *E. coli* is abundant in human and animal feces and not usually found in other niches.

Furthermore, since *E. coli* could be easily detected by its ability to ferment lactose, it was easier to isolate than known gastrointestinal pathogens. Hence, the presence of *E. coli* in food or water became accepted as indicative of recent fecal contamination and the possible presence of frank pathogens.

2.6.4 Fecal Streptococcus

Fecal Streptococcus, another type of fecal bacteria, is a group of bacteria normally present in large numbers in the intestinal tracts of warm-blooded animals other than humans. The fecal streptococci have been used with fecal coliforms to differentiate human fecal contamination from that of other warm-blooded animals (Mara *et al.,* 2007).

2.7 Significance of greywater reuse and hazard identification

Greywater reuse reduces the amount of freshwater that is needed to supply a household and reduces the amount of wastewater entering sewer or septic system. Likely benefits include water savings, reduction in wastewater treatment costs and reduction in the threat to groundwater pollution from septic tanks (Winward *et al*., 2008). With proper management, greywater reuse could bring significant environmental and economic benefits.

In Oman, water for domestic use is produced at a very high cost. Increasing water availability by treating and reusing wastewater is a government policy since the country suffers from serious water shortage. Two mosques that hold community events regularly were investigated as part of a greywater reuse research project in Oman, and Coliform as well as *E. coli* levels were found to exceed the maximum permissible concentrations, hence requiring treatment before reuse (Ahmed *et al.,* 2001). Generally in greywater

systems, the hazard emanates from fecal cross-contamination, for example from contaminated laundry and other sources. Opportunistic bacteria known to grow in hot water systems, such as *Aeromonas*, *Pseudomonas*, Mycobacteria or *Legionella*, could pose a threat depending on reuse options. There is also a risk of introducing pathogenic bacteria from contaminated food via the kitchen sink (Ottosson, 2003b).

Problems associated with greywater reuse are: storage, contamination and separation from existing drinking water supply (Shouler, 1998). Untreated greywater should not be kept for longer than one day, unless it is disinfected (Hodges, 1998). Adequate care must be taken to avoid the contamination of underlying aquifers and neighbouring water courses and systems must be designed in such a manner that inadequately serviced systems will not harm the environment (Mustow, 1998).

Large quantities of fecal coliform bacteria in water are not harmful according to some authorities, but may indicate a higher risk of pathogens being present in the water (Ottosson, 2003b). Some waterborne pathogenic diseases that may coincide with fecal coliform contamination include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. The presence of fecal coliform tends to affect humans more than it does aquatic creatures, though not exclusively (Caigan, 2005)

Untreated organic matter that contains fecal coliform can be harmful to the environment. Aerobic decomposition of this material can reduce dissolved oxygen levels if discharged into rivers or waterways. This may reduce the oxygen level enough to kill fish and other aquatic life. Reduction of fecal coliforms in wastewater may require the use of chlorine and other disinfectant chemicals. Such materials may kill the fecal coliforms and disease

bacteria. They also kill bacteria essential to the proper balance of the aquatic environment, hence endangering the survival of species dependent on those bacteria. Higher levels of fecal coliform require higher levels of chlorine, hence threatening those aquatic organisms. (Sinton *et al.,* 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The study sites

The study was carried out in Homabay Town in Nyanza province and Githurai Estate in Nairobi City. The two sites were chosen to represent the rural-urban (Homabay) and peri-urban (Githurai) settlements.

3.1.1 Homabay

3.1.1.1 Geographical location

Homabay Town is located along the north - eastern shore of Lake Victoria. It borders the Homa Bay, from which the town derived its name. The town is bounded by Lake Victoria to the northwest, Kochia location to the east, Kanyada location to the west and to the south by the line between Kabunde airstrip and Oturbam passing through Ogande Girls Secondary School (Figure 1). Homabay Town is located 105 kilometers south of Kisumu City and 405 kilometers southwest of Nairobi, the capital city of Kenya. The town lies at an altitude of 1330 meters above sea level (a.s.l.), and covers an area of 23 km^2 out of which only 3 km^2 falls within the Central Business District while the rest consists of peri-urban settlements.

3.1.1.2 Climate, drainage and vegetation

Homabay is semi-arid with an annual rainfall of about 800 mm, which falls in two seasons, and an average temperature of 26 °C. The long rains fall between the months of March and May while the short rains fall between September and November. The area has two distinct topographic regions, the lake shore lowlands that lie between 1,143 m to 1,220 m above the sea level bordering Lake Victoria, and the upland plateau that rises

from 1,220 m to 1,560 m above the sea level. The area has a gently rolling terrain that flattens towards Lake Victoria. Most of the town waters drain westwards to the lake except the areas of Got Rabuor, Arujo and parts of Sofia, which drain into Arujo stream. The vegetation largely consists of Acacia woodland and bush-land growing over expansive black cotton soils that cover most of the town apart from the hilly areas with rock outcrops. The dominant vegetation is the Acacia woodland.

3.1.1.3 Livelihood styles

Most of the Homabay town residents run small businesses that earn them some small income, and for this reason, most of them live in low-income estates like Sofia and Shauri Yako. However, those in formal employment earn more and live in better places like Okundi estate. Fishing and fish mongering is the major source of income (over 65% of household income) in the town (FAO, 2003). Food insecurity in the town is common due to low purchasing power and lack of significant economic activities. Homabay ranks as one of the poorest district in Kenya with over 70% of its population categorized as living below the poverty line. The urban and rural areas have poverty rates of 73% and 71%, respectively (FAO, 2003; WFP, 2003).

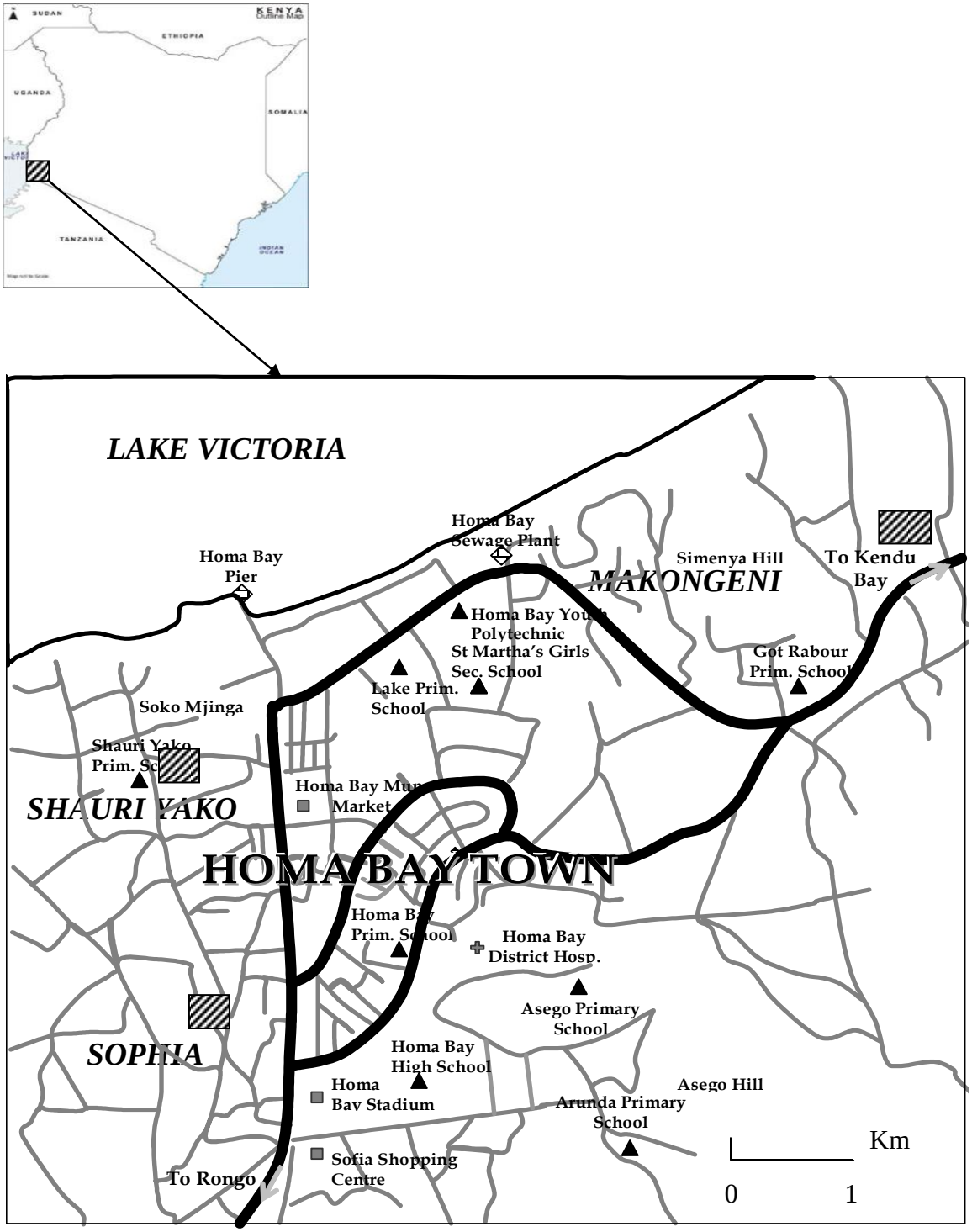

Figure 1. Map of Homabay showing sampling sites

KEY

Sampling sites

3.1.2 Githurai

3.1.2.1 Geographical Location

Githurai is located on the eastern side of Nairobi city, 20 km from the city centre, along the Nairobi-Thika Highway (Figure 2). Githurai has a rapidly growing population, which has exerted pressure on the existing sources of water resulting in frequent water shortages and dry taps. The estate lies at an altitude of 1661 meters above sea level and covers an area of 5 square kilometers (NEMA 2008).

3.1.2.2 Climate, drainage and vegetation

At an altitude of 1,661 m a.s.l, Githurai enjoys a fairly moderate climate. The high altitude results in some chilly evenings, especially in the June/July season when the temperature may drop to 10 ^{o}C. The sunniest and warmest part of the year is from December to March, when temperatures average mid-twenties during the day. The mean maximum temperature for this period is 24 °C. There are two rainy seasons; the long rains season and short rains. The cloudiest part of the year is just after the long rains, when conditions are usually overcast with a drizzle. Mean annual rainfall is about 1050 mm.

Where remnants of the indigenous vegetation exist, they comprise generally of savannah grasslands with the characteristic scattered tree species. The general area is a transitional zone from the high rainfall areas to the west (Kiambu and Nyandarua slopes) with forested areas and the semi-arid area to the east (Kitui and Machakos Districts). Due to intensive human activities, most of the natural vegetation has disappeared. A notable

feature in the area is the wetland system on Githurai River, which comprises mainly of *Cyperus papyrus* species mixed with grasses and minor shrubs (NEMA 2008).

3.1.2.3 Livelihood styles

Most of the Githurai residents are low income workers in informal employments popularly known as jua kali. Others run small businesses like vegetable and fruit vendors that earn them some small income, while some are working in the civil service as junior clerks. Food insecurity in the estate is common due to low purchasing power and lack of significant economic activities. Due to high level of unemployment insecurity is a major concern to the residents with the risk of being mugged being very high.

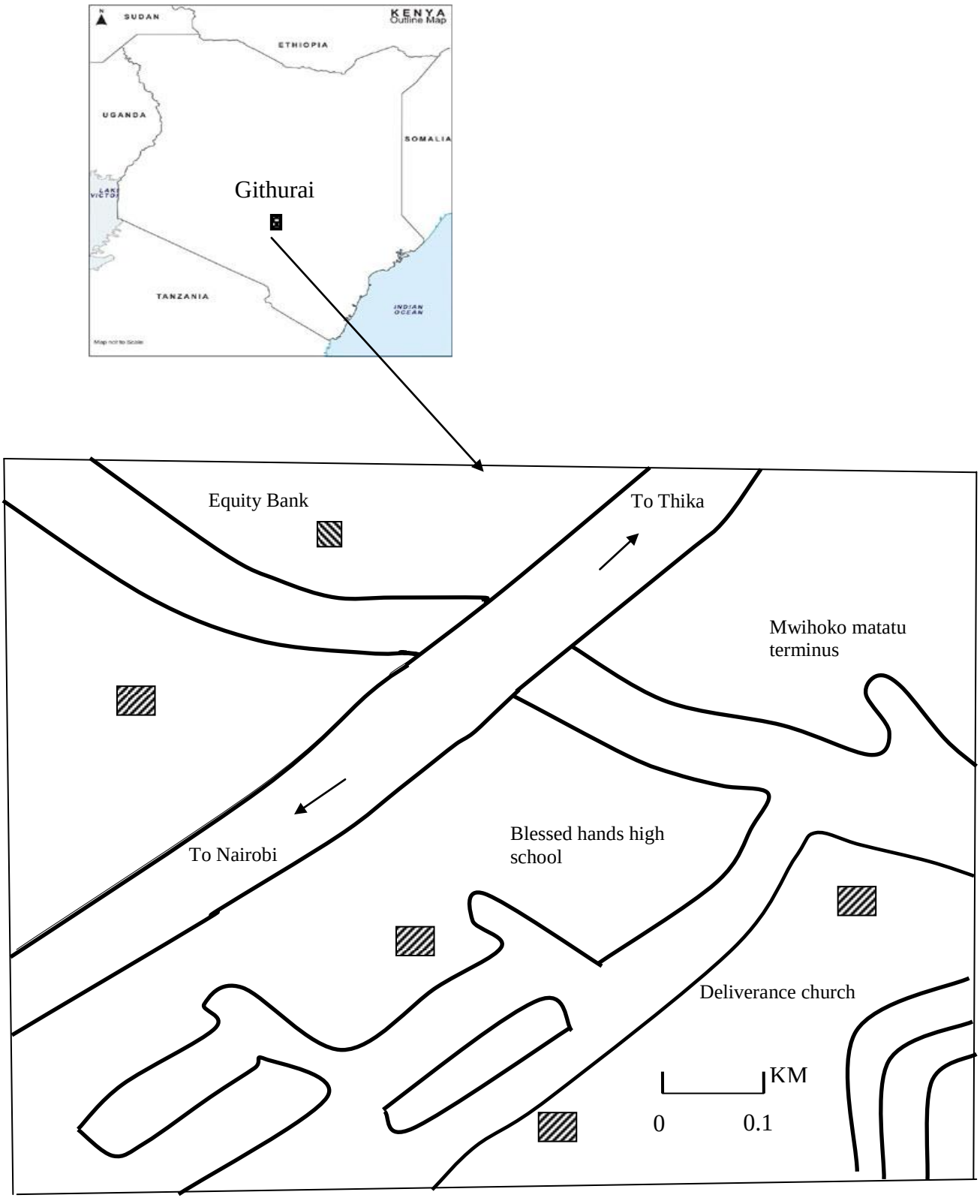

Figure 2. Map of Githurai showing greywater sampling sites

Key

Sampling sites

3.2 Selection of households

The characterization of greywater was limited to selected households in the study areas. The two sites were selected because they experience water scarcity problems necessitating alternative water sources. The sample size was determined by an earlier baseline survey. Fifteen households were selected randomly in each study area during each visit. Five households provided greywater from dishwashing, five from bath water and five from laundry water. The participating homesteads were visited once every month for a period of one year.

3.3 Bacterial analysis of greywater samples

3.3.1 Sample collection and preparation

Sampling bottles with a capacity of 250 ml (able to carry the volume of water enough for laboratory tests) were sterilized in an autoclave at 121 °C for 15 minutes while closed and wrapped in aluminum foil (APHA, 1998). Prior to sample collection, sodium thiosulphate ($Na_2S_2O_3$) dechlorination agent was added to each sample container. The role of the dechlorination agent was to neutralize any residual halogen and prevent continuation of bactericidal action during sample transit. This gave the true microbial content of water at the time of sampling. The sterilized bottles were then transported to the field aseptically while still closed and wrapped in aluminum foil. At each sampling site, the sample bottles were opened under the greywater in a suitable container, filled up and closed under water. Once collected, the samples were stored in ice box and taken to the water research laboratory at the Department of Plant and Microbial Sciences in Kenyatta University and the bacteriological examination of the samples was started within twelve hours.

3.3.2 Isolation, identification and enumeration of indicator organisms

3.3.2.1 Screening for total coliforms

The analysis of water for the presence and quantity of total coliforms was carried out using the membrane filter technique (MF). This method was preferred because; it allows for a direct count of coliform colonies, the results are accurate and can be obtained in a short time, and a large number of water samples can be processed (APHA, 1998). An amount of 0.1 mL of greywater sample was aseptically filtered with the aid of a vacuum pump through an aseptic membrane filter with a pore size of 0.45 µm. The filter was then aseptically transferred from the filtration assembly into a petri dish containing LES-Endo agar (Chan *et al.*, 1993). After incubation at 35 ºC for 24 hours, the bacteria colonies on the membrane filter were counted using a colony counter. Typical coliform colonies had a pink color with a metallic sheen.

3.3.2.2 Screening for fecal coliforms

An amount of 0.1 ml of a greywater sample was aseptically filtered through a membrane filter. The membrane filter was then aseptically transferred to a sterile snap lid petri dish containing m-FC broth (APHA, 1998). The Petri dish was sealed with a waterproof tape, inverted, placed in watertight plastic bag, and incubated in a water bath at 44.5 ºC for 24 hours. Typical colonies that were blue were counted using a colony counter. The fecal coliform density was recorded as the number of colonies per 100 mL (APHA, 1998).

3.3.2.3 Qualitative screening for *E. coli*

The positive filters from fecal coliform m-FC medium test (Section 3.3.2.2) were transferred into a nutrient agar substrate containing 4 methyl umbelliferyl- β –D-

glucuronide (MUG). The filters were incubated at 35 ºC for 22 hours. A blue fluorescence around the periphery of the colony confirmed the presence of *E. coli* (Wilson *et al.*, 2006).

3.3.3 Isolation and identification of pathogenic bacteria (*Salmonella, Shigella* and *Vibrio cholerae)*

3.3.3.1 Screening for *Salmonella* and *Shigella*

Screening for the presence of *Salmonella* and *Shigella* was carried out in three successive stages. The first stage of selective enrichment was done using the tetrathionate broth base as outlined in APHA (1998). An amount of 1mL greywater sample was mixed with 10 mL of tetrathionate broth and the mixture incubated at 35 °C for 24 hours. After incubation, a loopful of the broth was then carefully streaked on Petri-plate containing Salmonella-Shigella (SS) agar and incubated at 37 ^{o}C for 24 hours. *Salmonella* colonies were colorless with black centers while those of *Shigella* were colorless and shiny with no black centers. The suspect colonies were further subjected to various biochemical tests. First, suspect colonies from the presumptive test were streaked on Triple-Sugar-Iron (TSI) agar slants and incubated for 24 hours at 37 °C. A red slant and a yellow butt are indicative of the presence of both *Salmonella* and *Shigella* ssp. However, gas production (indicted by gas bubbles and a black color) is specific for *Salmonella*. Further confirmation involved a serological activity test. One drop of the suspected colony was placed on to a white ceramic tile and a drop of thoroughly shaken respective antiserum was added and stirred using a sterile applicator. The tile was rotated slowly and examined for clumping after 1-2 minutes. Agglutination indicated the presence of *Salmonella* or S*higella* respectively (APHA, 1998).

3.3.3.2 Screening for *Vibrio cholerae*

Presence of *Vibrio cholerae* was determined in three successive stages. An amount of 1 ml sample was enriched in sterile alkaline peptone water dispensed in 10 ml tubes and incubated for 18 hours at 35 °C (APHA, 2003). A loopful of the broth was then carefully streaked on Petri-plate containing Thiosulfate Citrate Bile Salts Sucrose (TCBS) agar and incubated at 35 °C for 24 hours. Suspect colonies that were small in size, dirty yellow with yellow halo in the centre (Stavric and Buchanan, 1995). Serological tests were carried out to confirm the suspect colonies (Sugiyama *et al*., 1987). This involved introducing a colony of suspected *V. cholera* onto a white ceramic tile followed by one drop of thoroughly shaken antiserum suspension. The ceramic tile content was mixed by stirring with a suitable sterile applicator stick. Agglutination within 10 minutes confirmed the presence of *V. cholerae.*

3.4 Physico–chemical analysis of greywater

3.4.1 pH, conductivity, salinity, temperature and dissolved oxygen

Determination of pH, conductivity, salinity and dissolved oxygen was carried out in the field using a suitable probe of a Multiline P4 (WTW, Weilheim-Germany) conductivity meter. Once the water sample was collected, a suitable amount was transferred to an appropriate container into which the Multiline probes for the measurement of each of the above attributes was lowered into the sample and allowed to stabilize for a few minutes after which the reading was taken. For temperature, a Pt-100 platinum probe was used. In the case of conductivity, an amperometric system which had two electrodes spaced one centimeter apart was used.

3.5 Data analysis

Descriptive statistics was used to summarize the data collected and to give an overview of the study findings. Appropriate graphical methods such as histograms and tables were used to present the changes in greywater quality and variations between study sites. A one way ANOVA was used to find out if there was any significant difference in Physico-chemical properties and bacterial load between the different greywater types and sources. Tukey test was used for mean separation where there was significance difference.

CHAPTER FOUR

4.0 RESULTS

4.1 Physico-chemical properties

4.1.1 Electrical conductivity

Electrical conductivity (EC) of drinking water and greywater samples collected from various estates (Shauri Yako, Sophia, Makongeni, Lake Victoria, Githurai) varied widely. The EC of drinking water ranged from 73 µS cm^{-2} (Sophia) to 320 µS cm^{-2} (Makongeni) (Table 1) while the mean EC of drinking water varied between 104.8±4.1 µS cm^{-2} (Githurai) and 227.4±28.3 µS cm^{-2} (Makongeni) (Figure 3). There was no significant ($p > 0.05$) difference in mean EC of drinking water among the estates.

Among the different residential areas, EC of dish greywater ranged from 60 µS cm^{-2} (Sophia) to 4110 µS cm^{-2} (Shauri yako) (Table 1). The mean EC values in dish greywater from different estates varied between 412.8±107 µS cm^{-2} (at the lakeside) and 992.1±305.5 µS cm^{-2} (Shauri yako) (Figure 3). Based on a one way ANOVA test, there was no significant ($F = 0.590$, $p = 0.671$, $df = 45$) difference between the mean EC for dish greywater from different estates.

Electrical conductivity of laundry greywater ranged from 225 µS cm^{-2} to 4470 µS cm^{-2}, both recorded in Shauri yako estate (Table 1). The mean EC of laundry greywater was lowest at the lakeside (995±81.6 µS cm^{-2}) and highest in Sophia (1813.0±374.3 µS cm^{-2}) (Figure.3). The difference among the estates was statistically not significant ($F=1.08$, $p= 0.370$, $df= 93$). Electrical conductivity values of bath greywater ranged from 60 µS cm^{-2} (Makongeni) to 1662 µS cm^{-2} (Sophia) while the mean EC varied between 325.4±99.1 µS

cm^{-2} (Lakeside) and 661.3±153.7 µS cm^{-2} (Shauri yako) (Figure 3). The mean EC of bath greywater from various estates did not differ significantly ($F = 0.529$, $p = 0.714$, $df = 36$).

Table 1. Conductivity (µS cm^{-2}) range of drinking water and greywater from various estates and L.Victoria

Source/ Water Type	Drinking	Dish	Laundry	Bath
Lake	102-115	159-715	796-1230	186-710
Makongeni	160-320	194-1787	323-3810	60-1520
Shauri yako	119-190	76-4110	225-4470	114-1263
Sophia	73-210	60-2250	327-4290	186-1662
Githurai	95-118	114-1503	175-4650	107-1160

Electrical conductivity for the different types of greywater (from different cleaning operations) within the same estate had great variations. In the lakeside, EC of various greywater types ranged from 159 to 715 µS cm^{-2} (dish), 186 to 710 µS cm^{-2} (bath) and 796 to1230 µS cm^{-2} (laundry), while drinking water had a range of 102-115 µS cm^{-2} with a mean of 108.5 ±65µS cm^{-2} (Table 1). Laundry greywater had the highest EC mean (995±81.6 µS cm^{-2}) with bath greywater recording the lowest mean (325.4±99.1 µS cm^{-2}) (Figure 4a). Analysis of variance (ANOVA) revealed that all greywater types had significantly ($p<0.05$) higher mean EC than drinking water. Similarly, within the same households, laundry greywater had significantly ($p<0.05$) higher mean EC levels than dish and bath greywater. While mean EC for dish and bath greywater did not differ significantly ($p=0.56$).

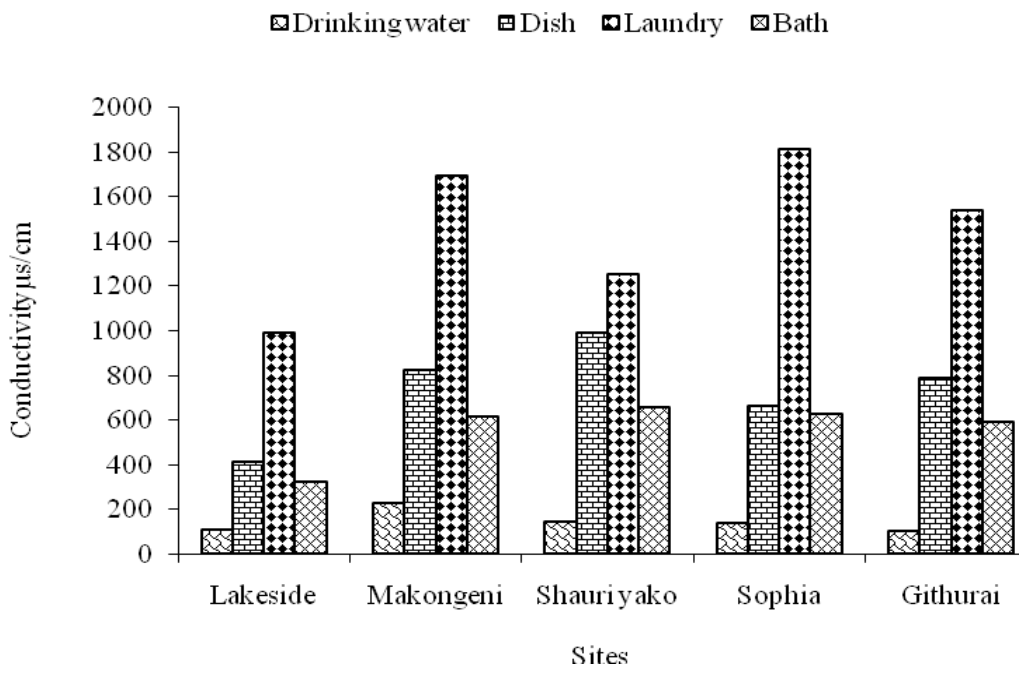

Figure 3. Mean conductivity (µS cm^{-2}) of drinking water and greywater types from the lake and various estates

In Makongeni, the electrical conductivity of greywater ranged from 194 to 1787 µS cm^{-2} (dish), 323 to 3810 (laundry) and 60 to 1520 µS cm^{-2} (bath), (Table 1). Drinking water had a range of 160-320 µS cm^{-2} with a mean of 227.4±28.3µS cm^{-2}. Mean EC of greywater from different cleaning operations in Makongeni was lowest in bath greywater (617±180.3 µS cm^{-2}) and highest in laundry (1698.3±1219.7 µS cm^{-2}) (Figure 4b). Statistical analysis suggested that the variation in EC among different greywater types was significant ($F = 4.50$, $p = 0.01$, $df = 30$). Mean separation revealed that laundry greywater had significantly higher mean EC than dish and bath greywater. However, there was no significant difference between dish and bath greywater.

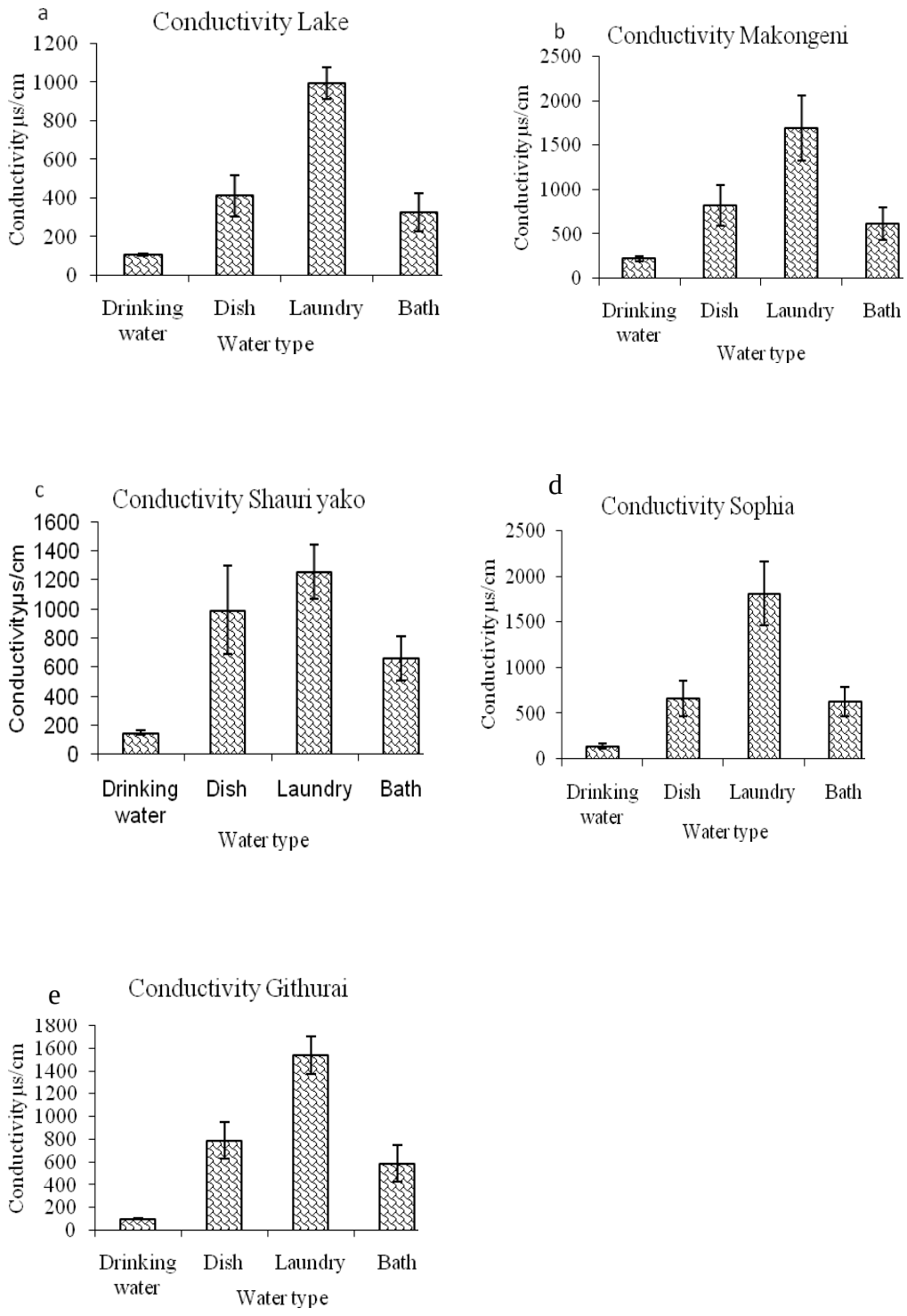

Figure 4. Mean conductivity (µS cm^{-2}) of drinking water and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d) and Githurai (e).

Dish greywater in Shauri yako had electrical conductivity range of 76 to 4110 µS cm^{-2}, with bath greywater having a range of 114 to 1263 µS cm^{-2}, while that of laundry ranged from 225 to 4470 µS cm^{-2} (Table 1). Drinking water sampled had a range of 119 to 190 µS cm^{-2} with a mean of 148.8±12.4µS cm^{-2}. Laundry greywater had the highest mean EC of 1256.1±187.6 µS cm^{-2} while bath greywater had the lowest (661.3±153.7 µS cm^{-2}) (Figure 4c). A comparison of the mean conductivity of greywater samples from Shauri yako using the ANOVA test revealed that the conductivity difference was not significant ($F= 2.47$, $p = 0.86$, $df = 52$).

In Sophia, electrical conductivity of greywater ranged from 60 µS cm^{-2} (Dish) to 4290 µS cm^{-2} (laundry) (Table 1). Drinking water sampled at Sophia had a range of 73 to 210 µS cm^{-2} with a mean of 143.2±25.9µS cm^{-2}. Laundry greywater had the highest mean EC (1813.0±374.3) with bath greywater having the lowest (628.3±157.6) (Figure 4d). Statistically the difference in mean EC among the greywater types was significant ($F =6.29$, $p =0.0014$, $df = 41$). After separation of the mean, dish and bath greywater had no significant difference ($p= 0.18$) but both had significantly lower EC mean ($p= 0.03$) than laundry greywater.

Greywater EC values at Githurai ranged from 114 to 1503 µS cm^{-2} (dish), 107 to 1160 µS cm^{-2} (bath) and 175 to 4650 µS cm^{-2} (laundry), (Table 1). Drinking water sampled recorded an EC range of 95 to 118 µS cm^{-2} with a mean of 104.8±4.1 µS $cm^{-}2$. The mean EC of greywater varied from 591.4±159.4 µS cm^{-2} (bath) to 1538.5±162.2µS cm^{-2} (laundry) (Figure 4e).

Comparison of mean EC of greywater types using the ANOVA test revealed that the difference in electrical conductivity was significant. (F =7.00 p =0.00044, df =59) with laundry greywater having significantly higher EC mean than both dish and bath greywater. Dish and bath greywater did not differ significantly. Generally, significantly higher EC values were common in greywater from laundry than from bath and dish washing in all the estates.

4.1.2 Dissolved oxygen (DO)

Dissolved oxygen (DO) concentration of drinking water and greywater samples collected from various estates (Shauri Yako, Sophia, Makongeni, Lake Victoria, Githurai) had great variation. The DO of drinking water ranged from 4.9 (Shauri yako) to 8.1 mg L^{-1} (Githurai) (Table 2) while the mean DO of drinking water varied between 6.22±0.45 (Shauri Yako) and 7.45±0.35 mg L^{-1} (Lakeside) (Figure 5). There was no significant ($p > 0.05$) difference in DO of drinking water among the estates.

Among the different residential areas, DO of dish greywater ranged from 0.7 (Makongeni) to 7.31 mg L^{-1} (Githurai). The mean DO concentration in dish greywater from different estates varied between 3.55±0.51 (at Shauri Yako) and 5.04±0.44 mg L^{-1} (at the Lakeside) (Figure 5). Based on a one way ANOVA test there was no significant (F = 0.670, P = 0.451, df = 45) difference in mean DO concentration for dish greywater from different estates.

Table 2. Dissolved oxygen (mg/l) range of drinking water and greywater from various estates and L.Victoria

Source/ Water Type	Drinking	Dish	Laundry	Bath
Lake	7.1-7.8	3.9-6.1	1.68-2.7	3.4-6.3
Makongeni	5.9-7.6	0.7-6.1	1.2-4.3	0.7-6.8
Shauri yako	4.9-7.3	0.8-6.9	0.4-7.96	0.4-6.02
Sophia	5.9-7.5	1.6-6.32	1.7-6.66	0.8-6.9
Githurai	6.8-8.1	2.46-7.31	1.97-8.19	1.64-6.04

Dissolved oxygen concentration of laundry greywater ranged from 0.4 (Shauri Yako) to 8.19 mg L^{-1} (Githurai), (Table 2). The mean DO of laundry greywater was lowest at the lakeside (2.03±0.1853) and highest in Githurai (4.91±0.31 mg L^{-1}) (Figure 5). The difference among the estates was statistically not significant ($F=1.28$, $P = 0.460$, $df = 93$). Dissolved oxygen concentration of bath greywater ranged from 0.4 (Shauri Yako) to 6.9 mg L^{-1} (Sophia) (Table 2) while the mean DO varied between 3.32±0.84 (Makongeni) and 5.1±0.492 mg L^{-1} (Lakeside) (Figure 5). The mean DO of bath greywater from various estates did not differ significantly ($F = 0.419$, $P = 0.634$, $df = 36$).

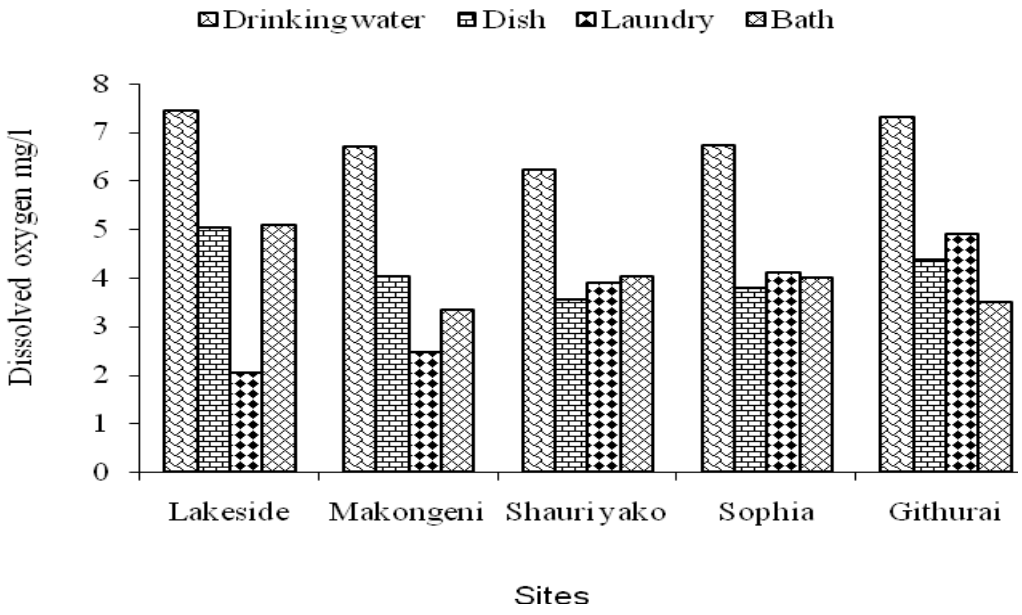

Figure 5. Dissolved oxygen (mg L^{-1}) means of drinking water and greywater types from the lake and various estates

Dissolved oxygen concentration for the different types of greywater (from different cleaning operations) within the same estate had great variations. Dissolved oxygen concentration of greywater from the lakeside ranged from 3.9 to 6.1 mg L^{-1} (dish), 3.4 to 6. 3 mg L^{-1} (bath) and 1.68 to 2.7 mg L^{-1} (laundry) (Table 2), while clean water had a range of 7.1 to 7.8 mg L^{-1} with a mean of 7.45±0.35 mg L^{-1}. The highest DO mean (5.1±0.492 mg L^{-1}) was recorded from bath greywater and the lowest (2.03±0.1853 mg L^{-1}) from laundry greywater (Figure 6a). A one way ANOVA test revealed that the difference in mean DO among greywater types from the lake was significant (F =22.8**,** P =0.031, df = 16). Mean separation revealed that laundry greywater had significantly lower DO concentration than bath and dish greywater (P=0.012). Dish and bath greywater did not differ significantly (P=0.23).

In Makongeni, dissolved oxygen concentration ranged from 0.7 to 6.1 mg L^{-1} (dish), 1.2 to 4.3 mg L^{-1} (laundry) and 0.7 to 6.8 mg L^{-1} (bath), (Table 2). Drinking water source had a range of 5.9 to 7.6 mg L^{-1} with a mean of 6.7±0.32 mg L^{-1}. Mean DO of greywater from different cleaning operations in Makongeni was lowest in laundry greywater (2.47±0.28 mg L^{-1}) and highest in dish greywater (4.04±0.79 mg L^{-1}) (Figure 6b). Statistical analysis suggested that the variation in DO among different greywater types was significant (F =7.45, P =0.0086, df =30). Mean separation revealed that dish greywater had significantly higher mean DO (P=0.031) than laundry and bath greywater. However, there was no significant difference (P=0.64) between laundry and bath greywater.

Dish greywater in Shauri yako had dissolved oxygen concentration range of 0.8 to 6.9 mg L^{-1}, with bath greywater having a range of 0.4 to 6.02 mg L^{-1}, while that of laundry ranged from 0.4 to 7.96 mg L^{-1} (Table 2). Drinking water had a range of 4.9 to 7.3 mg L^{-1} with a mean of 6.22±0.45 mg L^{-1}. Bath greywater had the highest mean DO of 4.01±0.69 mg L^{-1} while dish greywater had the lowest (3.55±0.51 mg L^{-1}) (Figure 6c). A comparison of the mean dissolved oxygen concentration of greywater samples from Shauri yako using the ANOVA test revealed that the difference was not significant (F= 2.21, P = 0.098, df = 52).

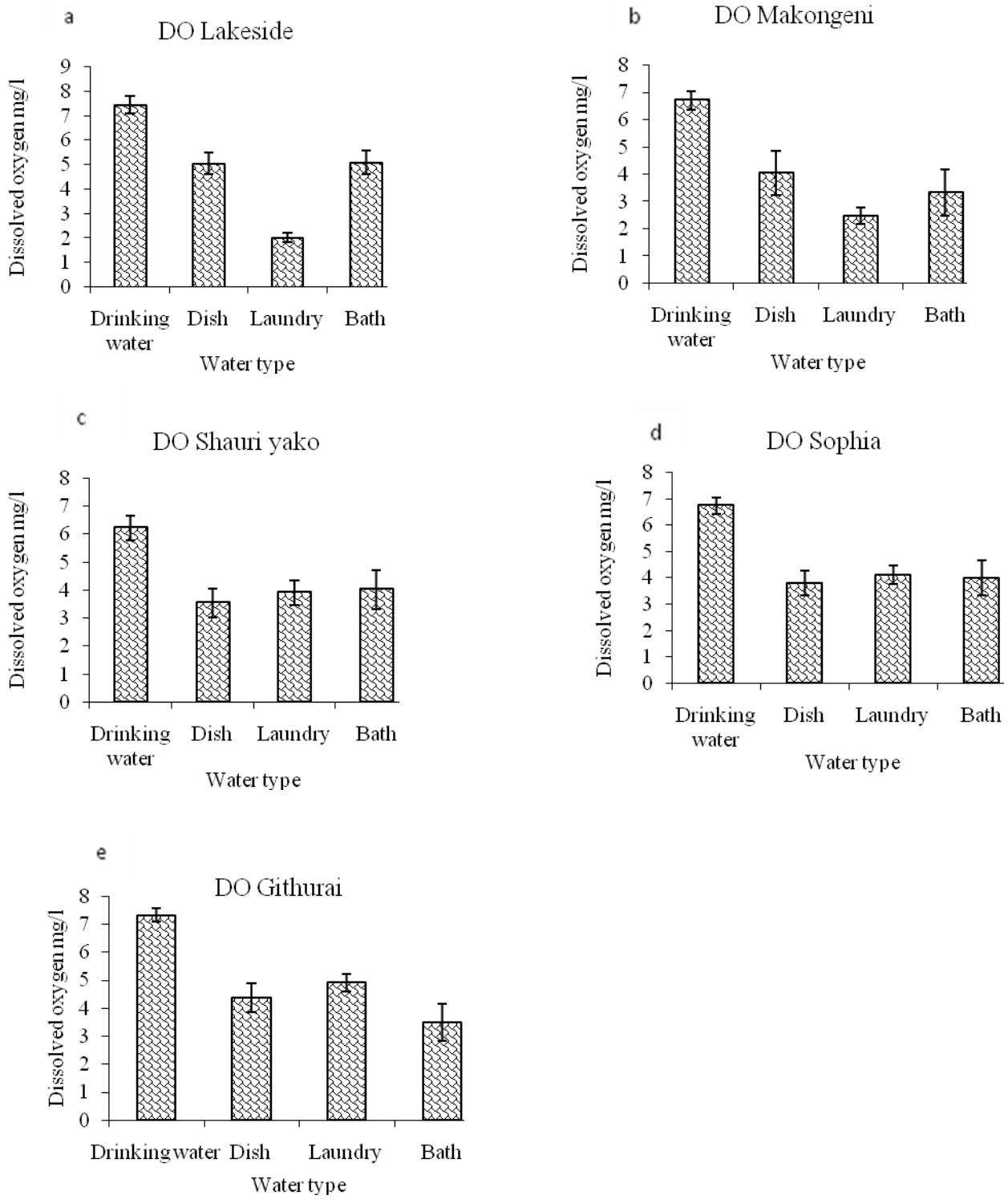

Figure 6. Mean Dissolved Oxygen (mg/l) of drinking water and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

In Sophia, dissolved oxygen concentration of greywater ranged from 1.6 to 6.32 mg L^{-1} (dish), 1.7 to 6.66 mg L^{-1} (laundry) and 0.8 to 6.9 mg L^{-1} (bath) (Table 2). Drinking water sampled at Sophia had a range of 5.9 to 7.5 mg L^{-1} with a mean of 6.74±0.30 mg L^{-1}. Among the greywater types, laundry greywater had the highest mean (4.10±0.35 mg L^{-1}) while dish greywater had the lowest (3.79±0.45 mg L^{-1} (Figure 6d). A one way ANOVA test revealed that the difference in mean DO between dish, bath and laundry greywater from Sophia was not significant (F =4.45, P =0.088, df = 41).

Greywater DO values at Githurai ranged from 2.46 to 7.31 (dish), 1.64 to 6.04 mg L^{-1} (bath) and 1.97 to 8.19 mg L^{-1} (laundry), (Table 2). Drinking water sampled recorded a DO range of 6.8 to 8.1 mg L^{-1} with a mean of 7.32±0.23 mg L^{-1}. The mean DO of greywater varied from 3.49±0.67 (bath) to 4.91±0.31 mg L^{-1} (laundry) (Figure 4e). Comparison of mean DO of greywater types using the ANOVA test revealed that the difference in dissolved oxygen concentration was significant (F = 4.71 P = 0.00052, df =59). Mean separation using the Tukey test revealed that bath greywater had a significantly lower DO value than dish and laundry greywater (P=0.003). Dish and laundry greywater did not differ significantly (P=0.19).

4.1.3 pH

pH of drinking water and greywater samples collected from various estates (Shauri Yako, Sophia, Makongeni, Githurai and Lake Victoria) had some variation. The pH of drinking water ranged from 6.5 (Shauri yako) to 7.3 mg L^{-1} (Sophia) (Table 3) while the mean pH of drinking water varied between 6.95±0.14 (Shauri Yako) and 7.1±0.2 (Lakeside)

(Figure 7). There was no significant ($p > 0.05$) difference in pH of drinking water among the estates.

Among the different residential areas, pH of dish greywater ranged from 5.27 (Githurai) to 10.16 (Sophia) (Table 3). The mean pH in dish greywater from different estates varied between 7.34±0.47 (at the Lakeside) and 8.611±0.52 (Makongeni) (Figure 7). Based on a one way ANOVA test there was no significant ($F = 0.648$, $P = 0.631$, $df = 49$) difference in mean pH for dish greywater from different estates

Table 3. pH range of drinking water and greywater from various estates and L.Victoria

Source/ Water Type	Drinking	Dish	Laundry	Bath
Lake	6.9-7.3	6.15-8.54	9.1-9.72	6.9-8.6
Makongeni	6.5-7.2	5.3-9.6	8.46-9.6	6.15-9.45
Shauri yako	6.5-7.3	4.95-9.75	7.4-10.29	7.06-9.65
Sophia	6.89-7.3	6.15-10.16	8.85-10.05	5.27-9.65
Githurai	6.7-7.2	5.27-10.06	4.53-10.17	6.31-8.54

pH of laundry greywater ranged from 4.53 (Githurai) to 10.29 (Shauri Yako), (Table 3). The mean pH of laundry greywater was lowest at Makongeni (8.611±0.52) and highest in Sophia (9.389±0.10) (Figure 7). The difference among the estates was statistically not significant ($F=1.37$, $P=0.520$, $df=93$). pH of bath greywater ranged from 5.27 (Sophia) to 9.65 (Shauri Yako) (Table 3) while the mean pH varied between 7.396±0.31 (Lakeside) and 8.3575±0.28 (Shauri Yako) (Figure 7). The mean pH of bath greywater from various estates did not differ significantly ($F = 0.329$, $P = 0.724$, $df = 36$).

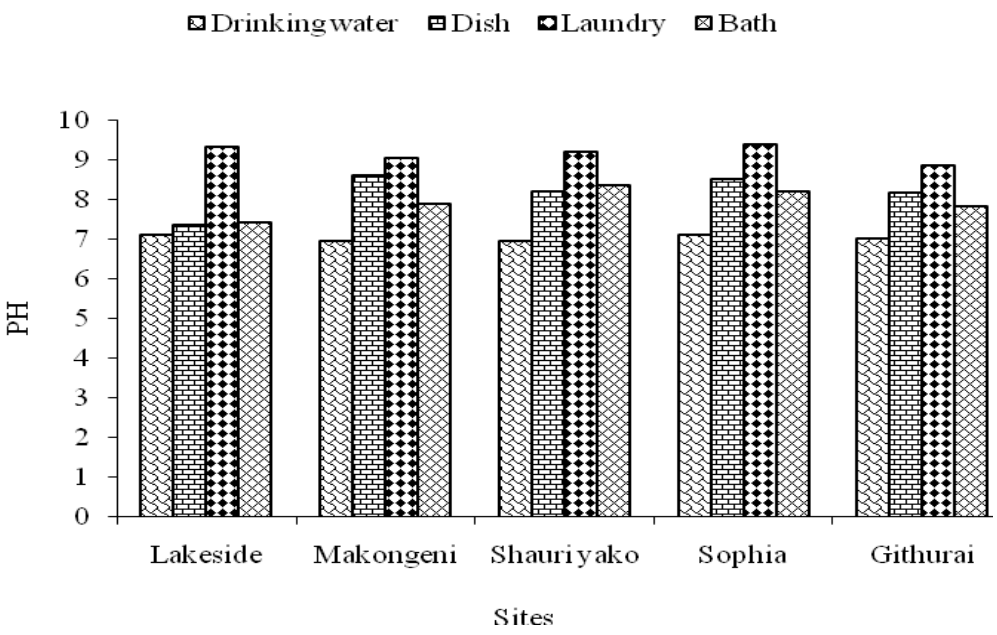

Figure 7. Mean pH levels of drinking and greywater types from the lake and various estates

pH for the different types of greywater (from different cleaning operations) within the same estate had some variations. pH of greywater from the lake ranged from 6.15-8.54 (dish), 6.9-8.6 (bath) and 9.1-9.72 (laundry), (Table 3). While drinking water had a range of 6.9 to 7.3 with a mean of 7.1±0.2. The highest pH mean (9.32±0.10) was recorded from laundry greywater and lowest (7.34±0.47) from dish greywater (Figure 8a). A one way ANOVA test revealed that the difference in mean pH among greywater types from the lake was significant ($F = 8.77$, $P = 0.0019$, $df = 16$). Separation of mean using Tukey test revealed that laundry greywater had significantly higher pH than dish and bath greywater ($P = 0.042$). Dish and bath greywater did not differ significantly ($P = 0.082$).

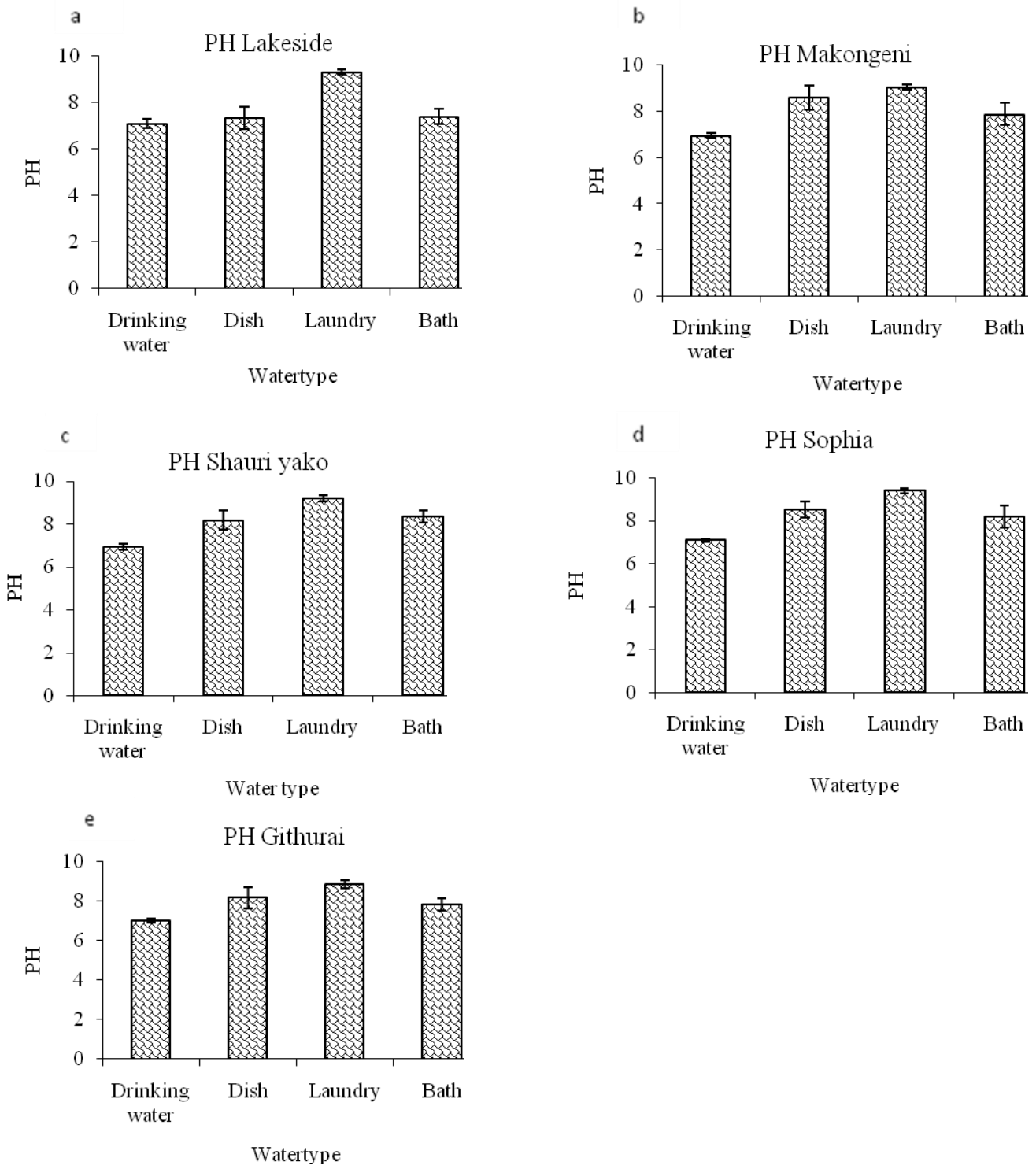

Figure 8. Mean pH of drinking and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

In Makongeni, pH ranged from 5.3 to 9.6 (dish), 8.46 to 9.6 (laundry) and 6.15 to 9.45 (bath), (Table 3). Drinking water source had a range of 6.9 to 7.3 with a mean of 6.95±0.12. Mean pH of greywater from different cleaning operations in Makongeni was lowest in bath greywater (7.88±0.48) and highest in laundry greywater (8.611±0.52) (Figure 8b). Statistical analysis suggested that the variation in pH among different greywater types was not significant ($F = 5.71$, $P = 0.086$, $df = 30$).

Dish greywater in Shauri yako had pH range of 4.95 to 9.75, with bath greywater having a range of 7.06 to 9.65, while that of Laundry ranged from 7.4 to 10.29 (Table 3). Drinking water sampled had a range of 6.5 to 7.3 with a mean of 6.95±0.14. The lowest mean pH was recorded from dish greywater (8.184±0.45), while the highest was from laundry greywater (9.19±0.14). (Figure 8c). A comparison of the mean pH of greywater samples from Shauri yako using the ANOVA test revealed that the pH difference was significant ($F=7.40$, $P = 0.00034$, $df = 52$). Mean separation using the Tukey test revealed that laundry greywater had a significantly higher pH mean value than dish and bath greywater ($P=0.043$). Dish and bath greywater did not differ significantly ($P=0.21$).

In Sophia, pH of greywater ranged from 6.15-10.16 (dish), 8.85-10.05 (laundry) and 5.27-9.65 (bath) (Table 3). Drinking water sampled at Sophia had a range of 6.89-7.3 with a mean of 7.088±0.08. Among the greywater types, laundry greywater had the highest mean (9.389±0.10) and dish greywater the lowest mean (8.515±0.37) (Figure 8d). A one way ANOVA test revealed that the difference in mean pH between dish, bath and laundry greywater from Sophia was significant ($F = 6.25$, $P = 0.0014$, $df = 41$). When mean was separated using Tukey test, it was revealed that laundry greywater had

significantly higher pH mean than dish and bath greywater (P =0.0025). The pH of dish and bath greywater did not differ significantly (P =0.092).

The pH values of greywater in Githurai ranged from 5.27 to 10.06 (dish) 6.31 to 8.54 (bath) and 4.53 to10.17 (Laundry), (Table 3). Drinking water had a lower pH range of 6.7 to 7.2 with a mean of 6.996±0.08. The mean pH of greywater from dish, bath and laundry cleaning were 8.1518±0.52, 7.815714±0.29, and 8.842±0.21 respectively (Figure 8e).Comparison of mean pH of greywater types using the ANOVA test revealed that the difference in pH was significant. (F =4.002, P =0.0118, df =59). Mean separation using the tukey test revealed that laundry greywater had a significantly higher pH than dish and bath greywater (P = 0.034). There was no significant difference in pH between dish and bath greywater.

4.1.4 Salinity

Salinity of drinking water and greywater samples collected from various estates (Shauri Yako, Sophia, Makongeni, Lake Victoria, and Githurai) showed some variations. Salinity of drinking water ranged from below the limit of detection reported as 0.0 mgL^{-1} (at the lakeside) to a maximum of 0.2 mgL^{-1} (in Makongeni) (Table 4). The mean salinity of drinking water varied between 0.0 mgL^{-1} (lakeside) and 0.06±0.04 mgL^{-1} (Githurai) (Figure 9). There was no significant ($p > 0.05$) difference in salinity of drinking water among the estates.

Among the different residential areas, salinity of dish greywater ranged from 0.0 mgL^{-1} (in all the estates) to 2.1 mgL^{-1} (Shauri yako) (Table 4). The mean salinity values in dish greywater from different estates varied between 0.07±0.028 mgL^{-1} (at the lakeside) and

0.33±0.168 mgL^{-1} (Shauri yako) (Figure 9). Based on a one way ANOVA test there was no significant (F = 0.490, P = 0.571, df = 45) difference in mean salinity for dish greywater from different estates.

Salinity of laundry greywater ranged from 0.0 mgL^{-1} (recorded in all the estates), to 2.4 mgL^{-1} recorded in Githurai estate (Table 4). The mean salinity of laundry greywater was lowest at the lakeside (0.22±0.038 mgL^{-1}) and highest in Sophia (0.77±0.773 mgL^{-1}) (Figure 9). The difference among the estates was statistically not significant (F=1.28, P= 0.470, df= 93). Salinity values of bath greywater ranged from 0.0 mgL^{-1} (recorded in all the estates) to 1.4 mgL^{-1} (Githurai) (Table 4) while the mean salinity varied between 0.06±0.027 mgL^{-1} (Lakeside) and 0.4±0.145 mgL^{-1} (Shauri yako) (Figure 9). The mean salinity of bath greywater from various estates did not differ significantly (F = 0.629, P = 0.514, df = 36).

Table 4. Salinity (mg/l) range of drinking water and greywater from various estates and L.Victoria

Source/ Water Type	Drinking	Dish	Laundry	Bath
Lake	0	0-0.13	0.1-0.31	0-0.12
Makongeni	0-0.2	0-0.7	0- 1.9	0-0.9
Shauri yako	0-0.1	0-2.1	0-2.3	0-1.2
Sophia	0-0.2	0-1.0	0-2.2	0-0.4
Githurai	0-0.2	0-1.5	0-2.4	0-1.4

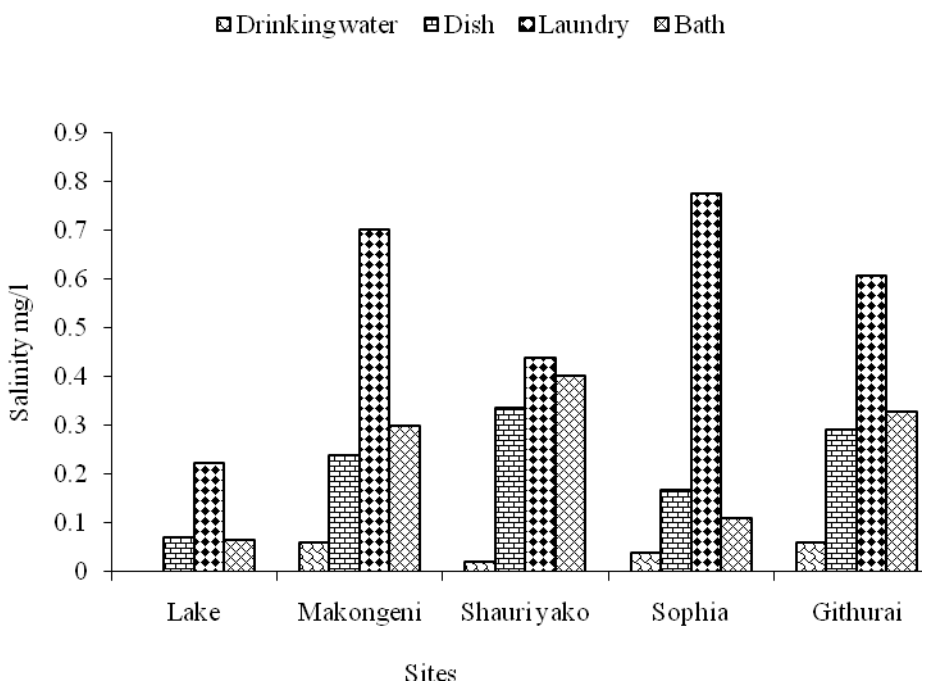

Figure 9. Mean Salinity (mgL^{-1}) levels of drinking water and greywater types from the lake and various estates

Salinity of greywater within the same estate differed from one greywater type to another. Salinity of greywater from the lake ranged from 0-0.13 mg/l (dish), 0-0.12 mg/l (bath) and 0.1-0.31 mg/l (laundry), (Table 4). While drinking water had a range of 0 mg/l with a mean of 0 mg/l. The highest salinity mean (0.22±0.038 mg/l) was recorded from laundry greywater while the lowest was from bath greywater (0.06±0.027 mg/l) (Figure 10a). A one way ANOVA test revealed that the difference in mean salinity among greywater types from the lake was significant ($F = 7.37$, $P = 0.0039$, $df = 16$). Separation of mean revealed that laundry greywater had significantly higher salinity levels than dish and bath greywater. There was no significance difference in mean salinity between dish and bath greywater ($P = 0.331$).

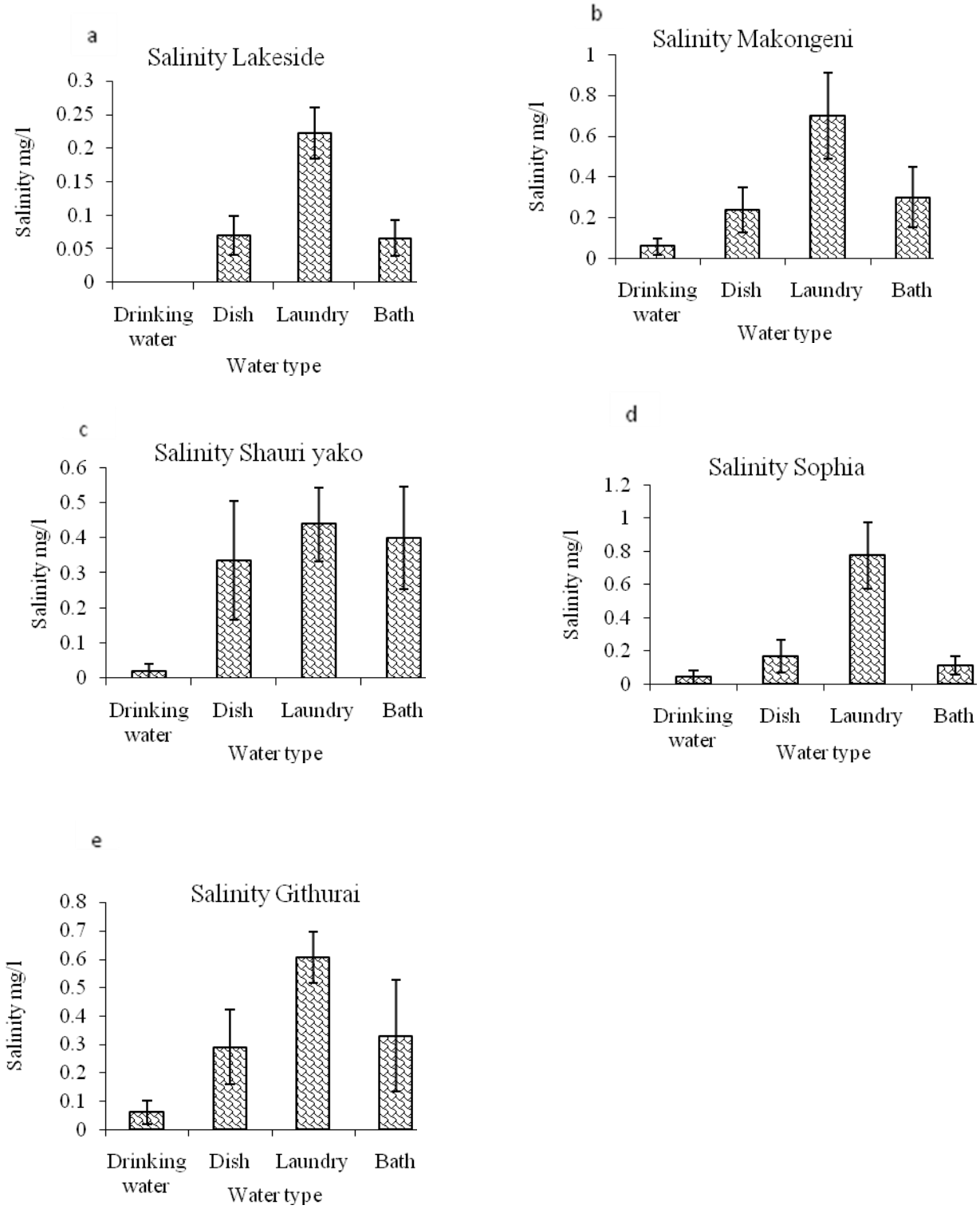

Figure 10. Mean Salinity levels (mg/l) of drinking and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

In Makongeni Salinity ranged from 0 to 0.7 mg/l (dish), 0 to 1.9 mg/l (laundry) and 0 to 0.9 mg/l (bath), (Table 4). Drinking water source had a Salinity range of 0-0.2 mg/l with a mean of 0.06±0.04 mg/l. Mean salinity of greywater from different cleaning operations in Makongeni was highest in laundry (0.70±0.212 mg/l) and lowest in dish (0.23±0.111 mg/l) (Figure 10b). Using a one way ANOVA test the difference in mean salinity between dish, bath and laundry greywater from Makongeni was not significant (F =2.5, P =0.080, df =30).

In Shauri yako greywater salinity ranged from of 0 to 2.1 mg/l (dish), 0 to 1.2 mg/l (bath), and 0 to 2.3 mg/l (laundry) (Table 4). Drinking water had a salinity range of 0 to 0.1 mg/l with a mean of 0.02±0.02 mg/l. Mean salinity of greywater was highest in laundry (0.43±0.105 mg/l) and lowest in dish (0.33±0.168 mg/l), (Figure 10c). A comparison of the mean salinity of greywater samples from Shauri yako using the ANOVA test revealed that the salinity difference was significant (F=2.911, P = 0. 042, df = 52). Mean separation using Tukey test revealed that dish greywater had significantly lower salinity levels (P = 0. 022) than laundry and bath greywater. Salinity for laundry and bath greywater did not differ significantly (P = 0. 092).

In Sophia, salinity of greywater ranged from 0 to 1.0 mg/l (dish), 0 to 2.2 mg/l (laundry) and 0 to 0.4 mg/l (bath) (Table 4). Drinking water sampled at Sophia had a range of 0 to 0.2 mg/l with a mean of 0.04±0.04 mg/l. Among the greywater types, laundry greywater had the highest mean (0.77±0.773 mg/l) while bath greywater had the lowest (0.11±0.11 mg/l) (Figure 10d). A one way ANOVA test revealed that the difference in mean salinity between dish, bath and laundry greywater from Sophia was significant (F =5.23, P

=0.004, df = 41). When mean was separated using Tukey test, it was revealed that laundry greywater had significantly higher salinity mean than dish and bath greywater (P =0.012). There was no significance statistical difference in mean salinity between dish and bath greywater (P =0.132).

The salinity values of greywater in Githurai ranged from 0 to1.5 mg/l (dish), 0 to 1.4 mg/l (bath) and 0 to 2.4 mg/l (Laundry), (Table 4). Drinking water recorded a lower salinity range of 0 to 0.2 mg/l with a mean of 0.06±0.04 mg/l. The mean salinity of greywater from bath washing was the lowest (815714±0.29 mg/l) while that from laundry was the highest (8.842±0.21 mg/l) (Figure 10e). Comparison of mean salinity of greywater types using the ANOVA test revealed that the difference in salinity was significant (F =4.002, P =0.0118, df =59). Mean separation using the Tukey test revealed that laundry greywater had a significantly higher salinity level than dish and bath greywater (P =0.021). There was no significant difference in mean salinity between dish and bath greywater (P =0.231).

4.1.5 Temperature

Temperatures of drinking water at the time of collection ranged from 20.0°C (Shauri yako) to 28.1 °C (Makongeni). While mean temperatures varied from 22.8±1.28°C (Shauri yako) to 25.7±0.85°C (Makongeni), (Table 5). There was no significant ($p > 0.05$) difference in mean temperatures of drinking water among the estates.

Among the different residential areas, temperatures of dish greywater ranged from 13.6°C (Shauri yako) to 28.0°C (Sophia). The mean temperature in dish greywater from different estates varied between 23.7±0.67°C (Makongeni) and 26.2±0.46°C (lakeside)

(Table.9&10). Based on a one way ANOVA test there was no significant (F =0.548, P =0.731, df = 49) difference in mean temperatures for dish greywater from different estates

Temperatures of laundry greywater ranged from 13.9°C (Shauri Yako) to 27.8 °C (Sophia), The lowest mean temperature of laundry greywater was 24.2±1.09°C (lake side) and the highest was 25.3±0.42°C (Makongeni) (Figure 11). The difference among the estates was statistically not significant (F=1.47, P=0.620, df =93). Temperatures of bath greywater ranged from 21.2°C (Shauri Yako) to 24.9°C (Makongeni) (Table 5) while the mean temperatures varied between 25.5±0.89°C (Lakeside) and 26.3±0.50°C (Makongeni) (Figure 11). The mean temperatures of bath greywater from various estates did not differ significantly (F = 0.429, P = 0.824, df = 36).

Table 5. Temperature (°C) range of drinking and greywater from various estates and L.Victoria

Source/ Water type	Drinking	Dish	Laundry	Bath
Lake	24.2-25.8	25.3-28	21.2-27.3	22.1-26.9
Makongeni	23.2-28.1	20.2-26.2	22.5-27.1	24.9-28.6
Shauri yako	20-26.3	13.6-27.1	13.9-27.7	21.2-28.3
Sophia	22.5-26.4	19.1-28	18.8-27.8	22.3-28.6
Githurai	25-25.6	15.3-25.7	23.526.4	23.4-28.2

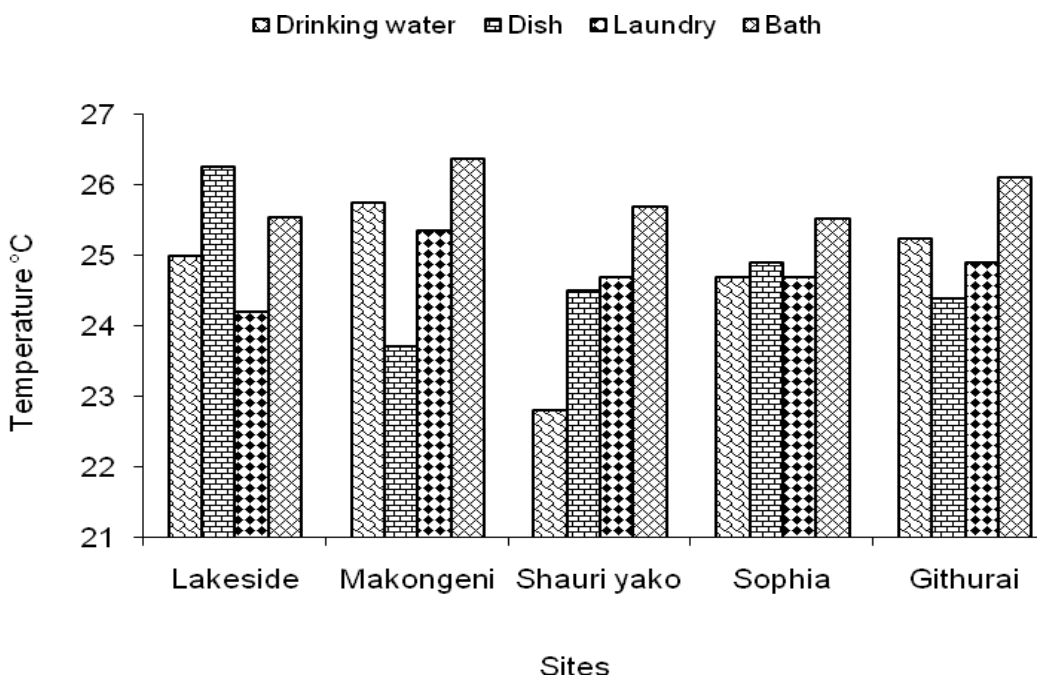

Figure 11. Mean temperatures (°C) of drinking and greywater types from the lake and various estates

When comparing the different greywater types within the same estate it was found that temperatures of greywater from the lakeside ranged from 25.3 to 28°C (dish), 22.1 to 26.9°C (bath) and 21.2 to 27.3°C (laundry), (Table 5). While drinking water had a range of 24.2 to 25.8°C with a mean of 25±0.80°C. The highest mean temperature (26.2±0.46°C) was recorded from dish greywater and the lowest (24.2±1.09°C) from laundry greywater (Figure 12a). A one way ANOVA test revealed that the difference in mean temperature among greywater types from the lake was not significant ($F = 1.05$, $P = 0.400$ $df = 16$).

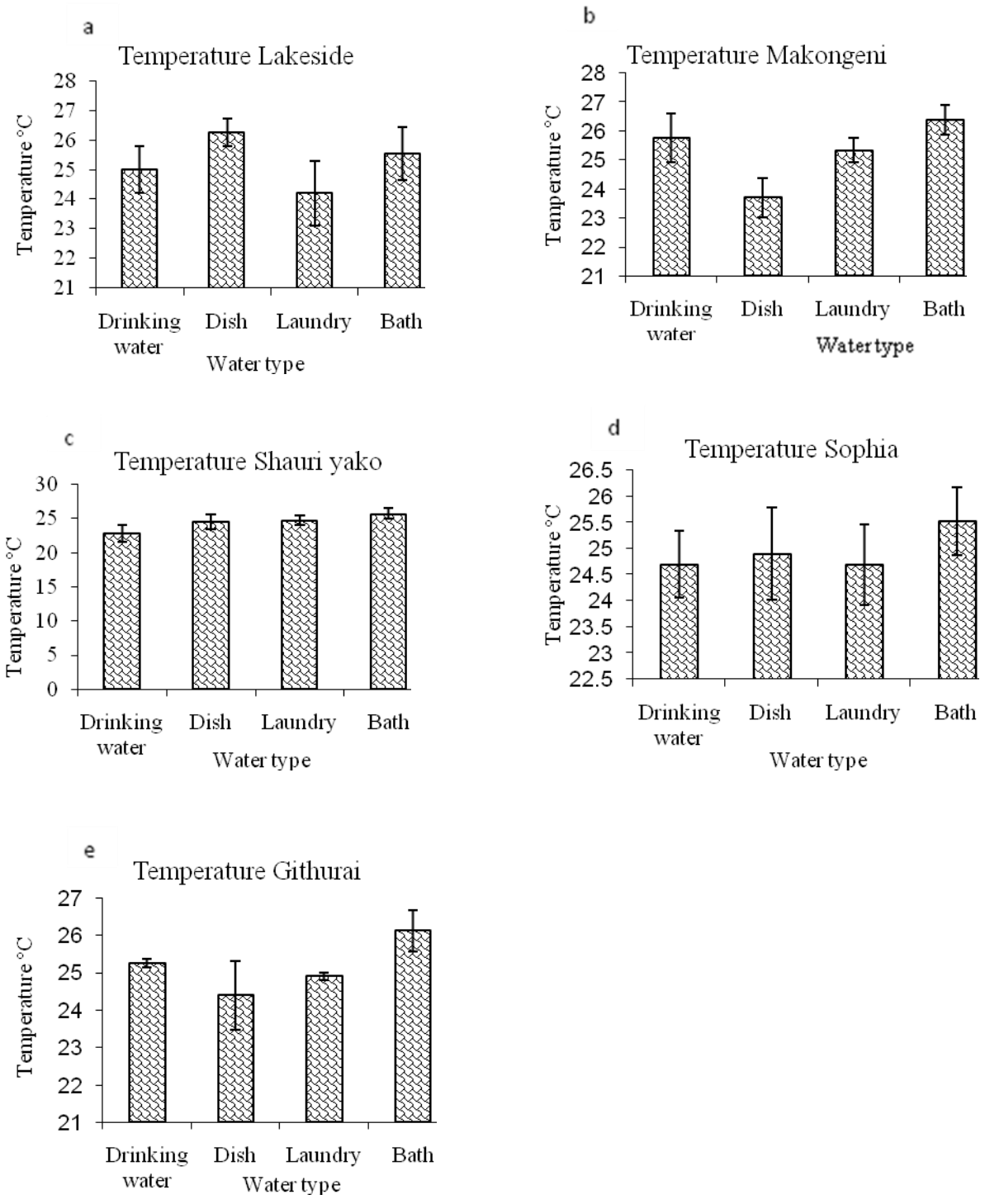

Figure 12. Mean Temperatures (°C) of drinking water and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

In Makongeni temperature ranged from 20.2-26.2 °C (dish), 22.5-27.1 °C (laundry) and 24.9-28.6 °C (bath). Drinking water source had a temperature range of 24.9-28.6 °C with a mean of 25.7±0.85 °C (Table 5). The highest mean temperature of greywater from different cleaning operations in Makongeni was 26.3±0.50 °C (bath) and the lowest was 23.7±0.67 °C (dish), (figure 12b). Using a one way ANOVA test the difference in mean temperature between dish, bath and laundry greywater from Makongeni was not significant ($F = 3.76$, $P = 0.072$, $df = 30$).

Dish greywater in Shauri yako had temperature range of 13.6 to 27.1 °C, with bath greywater having a range of 21.2 to 28.3 °C, while that of Laundry ranged from 13.9 to 27.7 °C (Table 5). Clean water sampled had a range of 20 to 26.3 °C with a mean of 22.8±1.28 °C. The highest mean temperature was from bath greywater (25.7±0.77 °C) and the lowest from dish greywater (24.5±1.06 °C) (Figure 12c). A comparison of the mean temperature of greywater samples from Shauri yako using the ANOVA test revealed that the temperature difference was not significant ($F=0.763$, $P = 0.52$, $df = 52$).

In Sophia, temperature of greywater ranged from 19.1 to 28°C (dish), 18.8 to 27.8 (laundry) and 22.3 to 28.6°C (bath) (Table 5). Drinking water sampled at Sophia had a range of 22.5 to 26.4°C with a mean of 24.7±0.64°C. Among the greywater types, bath greywater had the highest mean (25.5±0.65°C) while laundry greywater had the lowest (24.7±0.77°C) (Figure 12d). A one way ANOVA test revealed that the difference in mean temperature between dish, bath and laundry greywater from Sophia was not significant ($F = 0.202$, $P = 0.893$, $df = 41$).

The temperature values of greywater in Githurai ranged from 15.3 to 25.7°C (dish), 23.4 to 28.2°C (bath) and 23.5 to 26.4°C (Laundry), (Table 5). Drinking water recorded a temperature range of 25-25.6°C with a mean of 25.2±0.11°C. The mean temperature of greywater from dish, bath and laundry cleaning were 24.4±0.91°C, 26.1±0.56°C and 24.9±0.11°C respectively (Figure 12e). Comparison of mean temperature of greywater types using the ANOVA test revealed that the difference in temperature was not significant. (F =1.97, P =0.128, df =59).

4.2 Bacterial properties

4.2.1 Total coliforms

Total coliform (TC) of drinking water ranged from 1.1 to 3.4 x 10^6 CFUs per 100 ml (both in Makongeni) (Table 6) while the mean TC of drinking water varied between1.3±0.1 x 10^6 CFUs per 100 ml (lakeside) and 1.96±0.22 x 10^6 CFUs per 100 ml (Githurai) There was no significant ($p > 0.05$) difference in TC of drinking water among the estates.

Among the different residential areas, TC of dish greywater ranged from 1.3 x 10^6 CFUs per 100 ml (Sophia) to 7.6 x 10^6 CFUs per 100 ml (Shauri yako) (Table 6). The mean TC values in dish greywater from different estates varied between 2.2±0.29 x 10^6 CFUs per 100 ml (at the lakeside) and 5.22±0.28 x 10^6 CFUs per 100 ml (Githurai) (Figure 12). Based on a one way ANOVA test there was no significant (F = 0.590, P = 0.671, df = 45) difference in mean TC for dish greywater from different estates.

Total coliform of laundry greywater ranged from1.6 x 10^6 CFUs per 100 ml (Makongeni) to 7.8 x 10^6 CFUs per 100 ml (Githurai), (Table 6). The mean TC of laundry greywater

was lowest in Makongeni (4.11±0.45 x 10^6 CFUs per 100 ml) and highest in Githurai (5.34±0.22 x 10^6 CFUs per 100 ml), (Table. 11 &Fig.13). The difference in mean total coliform among the estates was statistically not significant (F=1.08, P= 0.370, df= 93). Total coliform values of bath greywater ranged from1.6 x 10^6 CFUs per 100 ml (lakeside) to 7.6 x 10^6 CFUs per 100 ml (Sophia) (Table 6) while the mean TC varied between 3.6±0.66 x 10^6 CFUs per 100 ml (Makongeni) and 4.64±0.70 x 10^6 CFUs per 100 ml (Sophia) (Figure 13). The mean TC of bath greywater from various estates did not differ significantly (F = 0.529, P = 0.714, df = 36).

Table 6. Total coliforms (cfu x 10^6) range of drinking water and greywater from various estates and L.Victoria

Source/ Water Type	Drinking	Dish	Laundry	Bath
Lake	1.2-1.4	1.5-3.2	3.5-6.4	1.6-5.3
Makongeni	1.1-3.4	2.6-6.4	1.6-4.4	1.8-7.2
Shauri yako	1.1-2.3	1.8-7.6	3.2-6.8	1.8-7.2
Sophia	1.2-2.3	1.3-7.0	1.9-6.5	1.8-7.6
Githurai	1.3-2.5	3.3-6.5	2.8-7.8	1.8-6.6

Total coliform of greywater within the same estate differed from one greywater type to another. At the lakeside, total coliform ranged from 1.5 to 3.2 x 10^6 CFUs per 100 ml (dish), 1.6 to 5.3 x 10^6 CFUs per 100 ml (bath) and 3.5 to 6.4 x 10^6 CFUs per 100 ml (laundry), (Table 6). While drinking water had a range of 1.2 to 1.4 x 10^6 CFUs per 100 ml with a mean of 1.3±0.1 x 10^6 CFUs per 100 ml. The highest total coliform mean (4.86±0.50 x 10^6 CFUs per 100 ml) was from laundry greywater while the lowest was from dish greywater (2.2±0.29 x 10^6 CFUs per 100 ml) (Figure 14a). A one way ANOVA

test revealed that the difference in mean total coliform among greywater types from the lake was significant (F =8.021**,** P =0.0027, df = 16). Separation of mean using Tukey test revealed that dish greywater had significantly lower total coliform levels than laundry and bath greywater. (P =0.0038) There was no significance difference in total coliform mean between laundry and bath greywater (P =0.435).

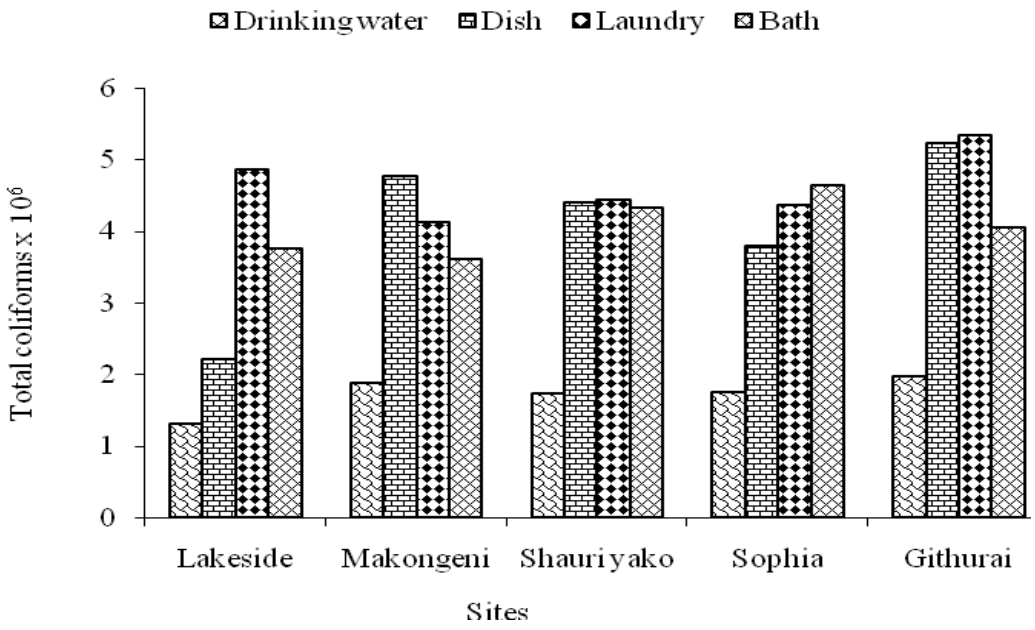

Figure 13. Total coliform (x 10^6 CFUs per 100 ml) means of drinking water and greywater types from the lake and various estates

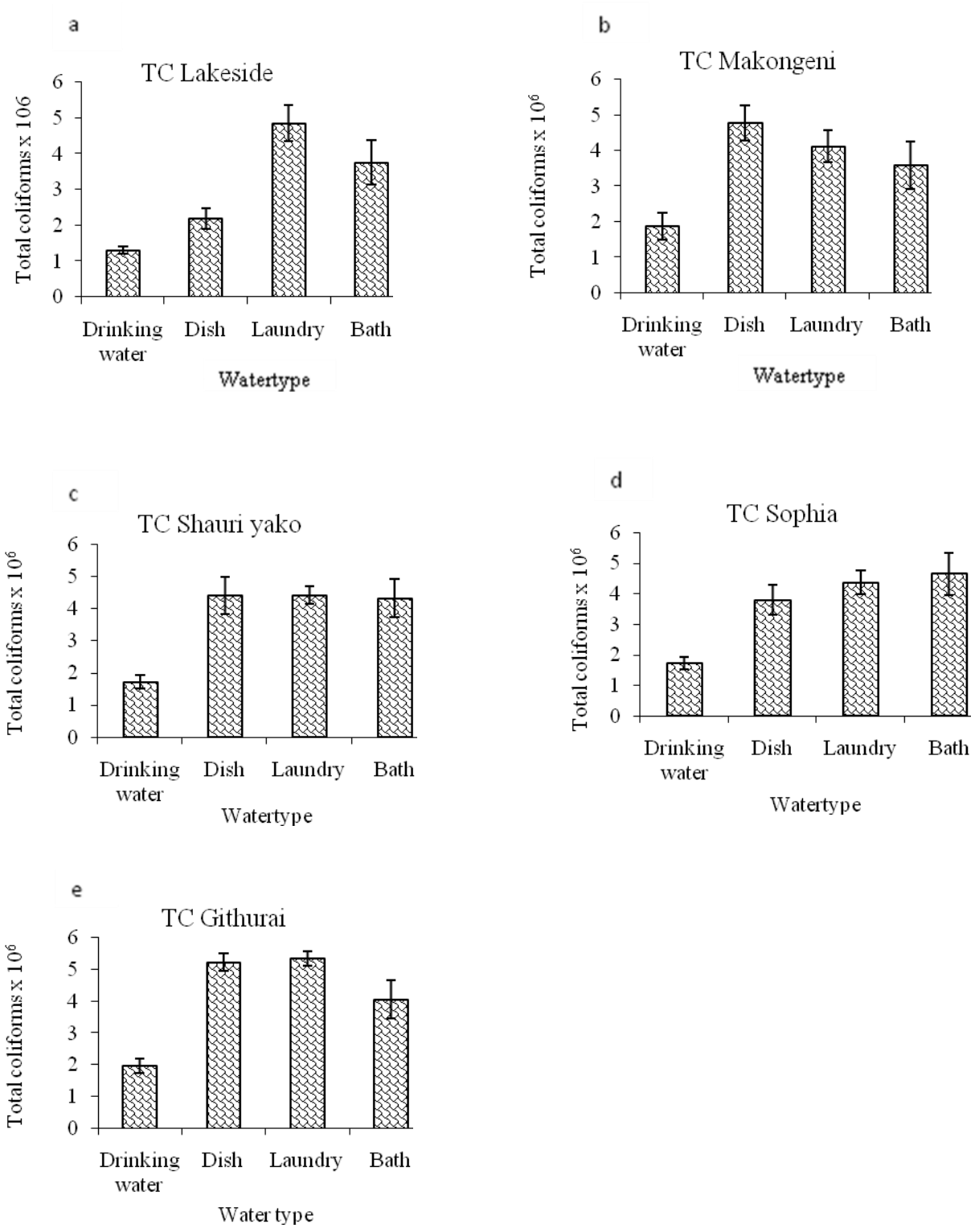

Figure 14. Mean Total coliforms (cfu x 10^6) of drinking and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

In Makongeni total coliform of greywater ranged from 2.6-6.4 x 10^6 CFUs per 100 ml (dish), 1.6-4.4 x 10^6 CFUs per 100 ml (laundry) and 1.8-7.2 x 10^6 CFUs per 100 ml (bath), (Table 6). Drinking water source had a total coliform range of 1.1-3.4 x 10^6 CFUs per 100 ml with a mean of 1.88±0.36 CFUs per 100 ml. The highest total coliform mean of greywater from Makongeni was 4.77±0.49 CFUs per 100 ml (dish), while the lowest was 3.6±0.66 CFUs per 100 ml (bath) (Figure 14b). Using a one way ANOVA test the difference in mean total coliform between dish, bath and laundry greywater from Makongeni was not significant (F =4.9, P =0.070, df =30).

Dish greywater in Shauri yako had total coliform range of 1.8-7.6 x 10^6 CFUs per 100 ml, with bath greywater having a range of 1.8-7.2 x 10^6 CFUs per 100 ml, while that of Laundry ranged from 3.2-6.8 x 10^6 CFUs per 100 ml (Table 6). Drinking water sampled had a range of 1.1-2.3 x 10^6 CFUs per 100 ml with a mean of 1.72±0.21 CFUs per 100 ml. laundry greywater had the highest Mean total coliform (4.43±0.27 CFUs per 100 ml), while bath greywater had the lowest (4.32±0.58 CFUs per 100 ml) (Figure 14c). A comparison of the mean total coliform of greywater samples from Shauri yako using the ANOVA test revealed that the total coliform difference was not significant (F=4.01, P = 0.096, df = 52).

In Sophia, total coliform count of greywater ranged from 1.3 to 7.0 x 10^6 CFUs per 100 ml (dish), 1.9 to 6.5 x 10^6 CFUs per 100 ml (laundry) and 1.8 to 7.6 x 10^6 CFUs per 100 ml (bath) (Table 6). Drinking water sampled at Sophia had a range of 1.2 to 2.3 x 10^6 CFUs per 100 ml with a mean of 1.74±0.20 x 10^6 CFUs per 100 ml. Among the greywater types, bath greywater had the highest mean (4.64±0.70 x 10^6 CFUs per 100

ml). The lowest mean was from dish greywater (3.79±0.48 x 10^6 CFUs per 100 ml) (Figure 14d). A one way ANOVA test revealed that the difference in mean total coliform between dish, bath and laundry greywater from Sophia was significant (F =3.70, P =0.0196, df = 41). When mean was separated using Tukey test, it was revealed that dish greywater had significantly lower total coliform mean (P =0.025) than laundry and bath greywater. There was no significance difference in total coliform mean between laundry and bath greywater (P =0.513).

The total coliform values of greywater in Githurai ranged from 3.3 to 6.5 x 10^6 CFUs per 100 ml (dish), 1.8 to 6.6 x 10^6 CFUs per 100 ml (bath) and 2.8 to 7.8 x 10^6 CFUs per 100 ml (Laundry), (Table 6). Drinking water sampled recorded a lower total coliform range of 1.3 to 2.5 x 10^6 CFUs per 100 ml with a mean of 1.96±0.22 x 10^6 CFUs per 100 ml. The mean total coliform of greywater from bath greywater was the highest (5.34±0.22 x 10^6 CFUs per 100 ml) while that from laundry greywater was the lowest (4.05±0.60 x 10^6 CFUs per 100 ml), (Figure 14e). Comparison of mean total coliform of greywater types using the ANOVA test revealed that the difference in total coliform was not significant. (F =11.73, P =4.51, df =59).

4.2.2 Fecal coliforms

Fecal coliform (FC) of drinking water ranged from 0.0 x 10^5 CFUs per 100 ml (in all the estates) to 0.08 x 10^5 CFUs per 100 ml (lakeside) (Table 7), while the mean FC of drinking water varied between 0.001±0.001 x 10^5 CFUs per 100 ml (Sophia) and 0.06±0.02 x 10^5 CFUs per 100 ml (lakeside). There was no significant ($p > 0.05$) difference in FC of drinking water among the estates.

Among the different residential areas, FC of dish greywater ranged from 0.029 x 10^5 CFUs per 100 ml to7.6 x 10^5 CFUs per 100 ml (both in Githurai) (Table 7). The mean FC values in dish greywater from different estates varied between 1.81±0.55 x 10^5 CFUs per 100 ml (Shauri yako) and 2.22±0.71 x 10^5 CFUs per 100 ml (Githurai) (Figure 15). Based on a one way ANOVA test there was no significant ($F = 0.580$, $P = 0.751$, $df = 45$) difference in mean FC for dish greywater from different estates.

Fecal coliform of laundry greywater ranged from 0.029 x 10^5 CFUs per 100 ml (Makongeni) to 7.4 x 10^5 CFUs per 100 ml (Sophia), (Table 7) The mean FC of laundry greywater was lowest in Shauri yako (2.07±0.43 x 10^5 CFUs per 100 ml) and highest at lakeside (2.83±0.89x 10^5 CFUs per 100 ml), (Figure 15). The difference in mean fecal coliform among the estates was statistically not significant ($F=1.06$, $P= 0.460$, $df= 93$). Fecal coliform values of bath greywater ranged from 0.029 x 10^5 CFUs per 100 ml to 5.3 x 10^5 CFUs per 100 ml (both from Sophia) (Table 7) while the mean FC varied between 1.94±0.49 x 10^5 CFUs per 100 ml (Shauri yako) and 2.38±0.34 x 10^5 CFUs per 100 ml (Makongeni) (Figure 14). The mean FC of bath greywater from various estates did not differ significantly ($F = 0.828$, $P = 0.816$, $df = 36$).

Table 7. Fecal coliforms (cfu x 10^5) range of drinking water and greywater from various estates and L.Victoria

Source/ Water type	Drinking	Dish	Laundry	Bath
Lakeside	0.04-0.08	0.12-3.4	0.35-4.8	0.49-4.3
Makongeni	0-0.06	0.049-4.1	0.029-6.3	0.9-3.5
Shauri yako	0-0.02	0.3-5.9	0.042-6.3	0.29-3.5
Sophia	0-0.006	0.34-5.6	0.037-7.4	0.029-5.3
Githurai	0-0.07	0.029-6.3	0.29-5.9	0.46-5.2

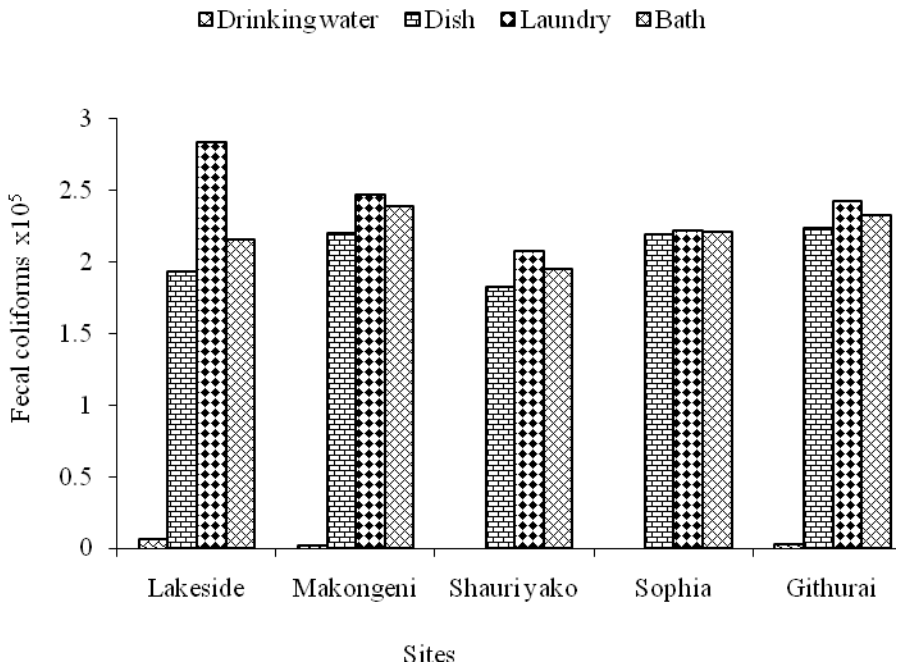

Figure 15. Fecal coliform (x 10^5 CFUs per 100 ml) means of drinking water and greywater types from the lake and various estates

Fecal coliform for the different types of greywater within the same estate varied slightly. Fecal coliform of drinking water from the lake had a range of 0.04 to 0.08 x 10^5 CFUs per 100 ml with a mean of 0.06±0.02 x 10^5 CFUs per 100 ml. Fecal coliform of greywater from the lake ranged from 0.12 to 3.4 x 10^5 CFUs per 100 ml (dish), 0.49 to 4.3 x 10^5 CFUs per 100 ml (bath) and 0.35 to 4.8 x 10^5 CFUs per 100 ml (laundry), (Table 7). The highest fecal coliform mean (2.83±0.89 x 10^5 CFUs per 100 ml) was from laundry greywater and the lowest from dish greywater (1.93±0.66 x 10^5 CFUs per 100 ml) (Figure 16a). A one way ANOVA test revealed that the difference in mean fecal coliform among greywater types from the lake was not significant ($F = 1.30$, $P = 0.315$, $df = 16$).

Drinking water source in Makongeni had a fecal coliform range of 0 to 0.06 x 10^5 CFUs per 100 ml with a mean of 0.01±0.01 CFUs per 100 ml. Fecal coliform count of greywater ranged from 0.049 to 4.1 x 10^5 CFUs per 100 ml (dish), 0.029 to 6.3 x 10^5 CFUs per 100 ml (laundry) and 0.9 to 3.5 x 10^5 CFUs per 100 ml (bath), (Table 7). Mean fecal coliform of greywater from different cleaning operations in Makongeni was in dish greywater (2.19±0.48 CFUs per 100 ml) and highest in laundry greywater (2.46±0.78 CFUs per 100 ml) (Figure 16b). Using a one way ANOVA test the difference in mean fecal coliform between dish, bath and laundry greywater from Makongeni was not significant ($F = 2.45$, $P = 0.0849$, $df = 30$).

Drinking water sampled in Shauri yako had fecal coliform range of 0 to 0.02 x 10^5 CFUs per 100 ml with a mean of 0.005±0.003 CFUs per 100 ml. Dish greywater in Shauri yako had fecal coliform range of 0.3 to 5.9 x 10^5 CFUs per 100 ml, with bath greywater having

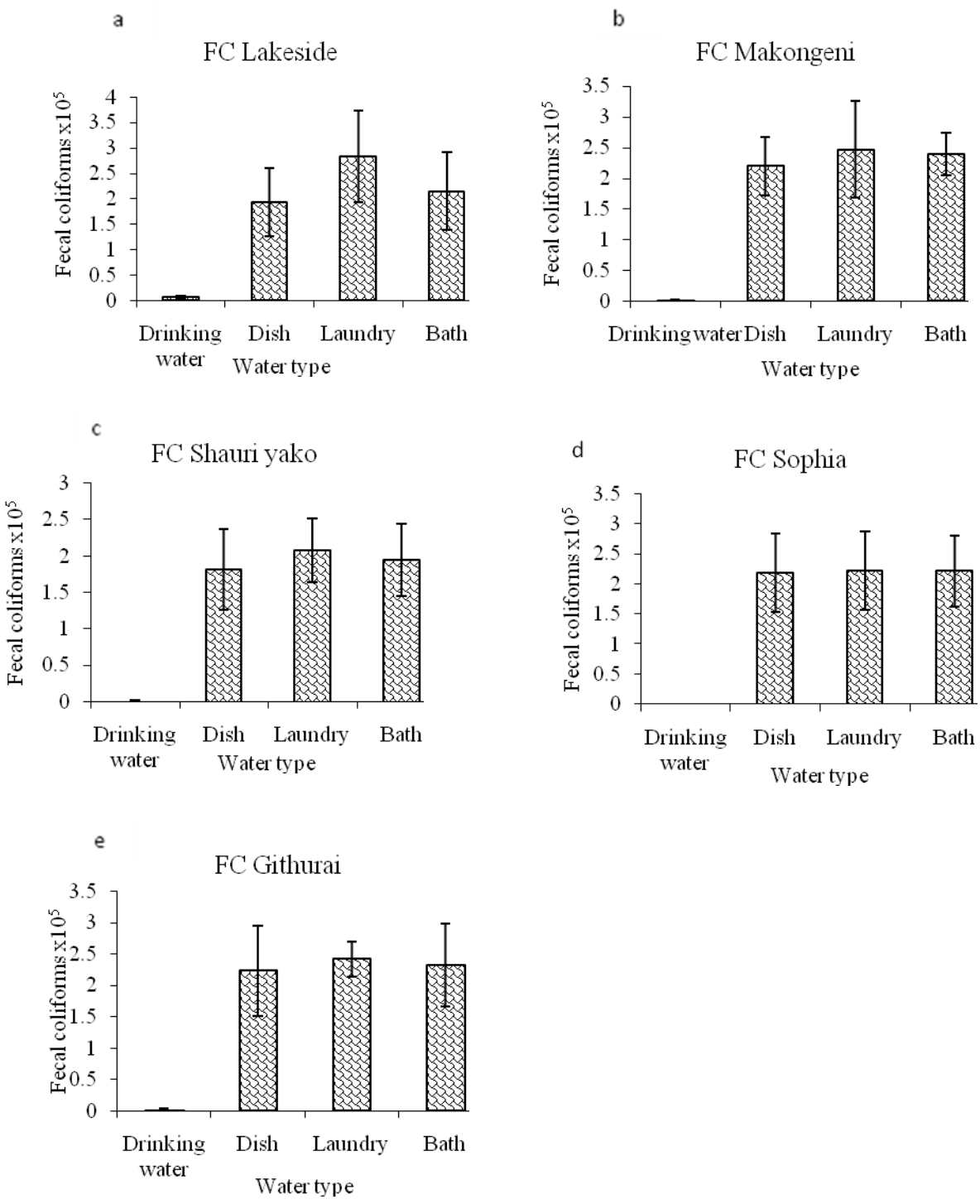

Figure 16. Mean Fecal coliforms (cfu x 10^5) of drinking and greywater from L.Victoria (a), Makongeni (b), Shauri yako (c), Sophia (d), and Githurai (e).

a range of 0.29 to 3.5 x 10^5 CFUs per 100 ml, while that of Laundry ranged from 0.042 to 6.3 x 10^5 CFUs per 100 ml (Table 7). Laundry greywater had the highest mean fecal coliform (2.07±0.43 CFUs per 100 ml) while dish had the lowest (1.81±0.55 CFUs per 100 ml), (Figure 16c). A comparison of the mean fecal coliform of greywater samples from Shauri yako using the ANOVA test revealed that the fecal coliform difference was not significant (F=1.53, P = 0.218, df = 52).

In Sophia, fecal coliform count of greywater ranged from 0.34 to 5.6 x 10^5 CFUs per 100 ml (dish), 0.037 to 7.4 x 10^5 CFUs per 100 ml (laundry) and 0.029 to 5.3 x 10^5 CFUs per 100 ml (bath) (Table 7). Drinking water sampled at Sophia had a range of 0 to 0.006 x 10^5 CFUs per 100 ml with a mean of 0.001±0.001 x 10^5 CFUs per 100 ml. Among the greywater types, bath greywater had the highest mean (2.20±0.58 x 10^5 CFUs per 100 ml) and dish greywater with the least (2.18±0.65 x 10^5 CFUs per 100 ml) (Figure 16d). A one way ANOVA test revealed that the difference in mean fecal coliform between dish, bath and laundry greywater from Sophia was not significant (F =1.51, P =0.225, df = 41).

The fecal coliform values of greywater in Githurai ranged from 0.029 to 6.3 x 10^5 CFUs per 100 ml (dish), 0.46 to 5.2 x 10^5 CFUs per 100 ml (bath) and 0.29 to 5.9 x 10^5 CFUs per 100 ml (Laundry), (Table 7). Clean water sampled recorded a lower fecal coliform range of 0 to 0.07 x 10^5 CFUs per 100 ml with a mean of 0.02±0.01 x 10^5 CFUs per 100 ml. The mean fecal coliform of greywater was highest from laundry cleaning (2.41±0.27 x 10^5 CFUs per 100 ml) while the lowest mean fecal coliform was from dish greywater (2.22±0.71 x 10^5 CFUs per 100 ml), (Figure16e). Comparison of mean fecal coliform of

greywater types using the ANOVA test revealed that the difference in fecal coliform was not significant. (F =2.74, P =0.0516, df =59).

4.2.3 Pathogenic bacteria

The three pathogenic bacteria investigated were absent in all the drinking water samples collected in Homabay, except for the presence of *Vibrio cholerae* in a rain water sample from Sophia Estate. *Salmonella*, *Shigella* and *Vibrio cholerae* were present in 30, 20 and 13.3% percent of greywater samples from Makongeni Estate and in 24, 19.6 and 6.5 percent of samples from Shauri Yako Estate in the same order. In greywater samples from Sophia Estate, *Salmonella*, *Shigella* and *Vibrio cholerae* were present in 38.5, 15.4 and 7.7 percent of the greywater samples respectively. Greywater samples from the lake had *Salmonella, Shigella* and *Vibrio cholera in* 28, 18 and 6.1 percent respectively (Figure 17).

When investigating the presence of pathogenic bacteria in the different greywater types, it was found that *Salmonella*, *Shigella* and *Vibrio cholerae* were present in 32.7, 18.2 and 7.3 percent of greywater samples from laundry activities respectively and in 30.6, 25 and 11 percent of greywater from dish washing activities in the same order (Figure 18). *Salmonella* and *Vibrio cholerae* were both present in 33.3 percent of greywater from bathing activities while *Shigella* was absent.

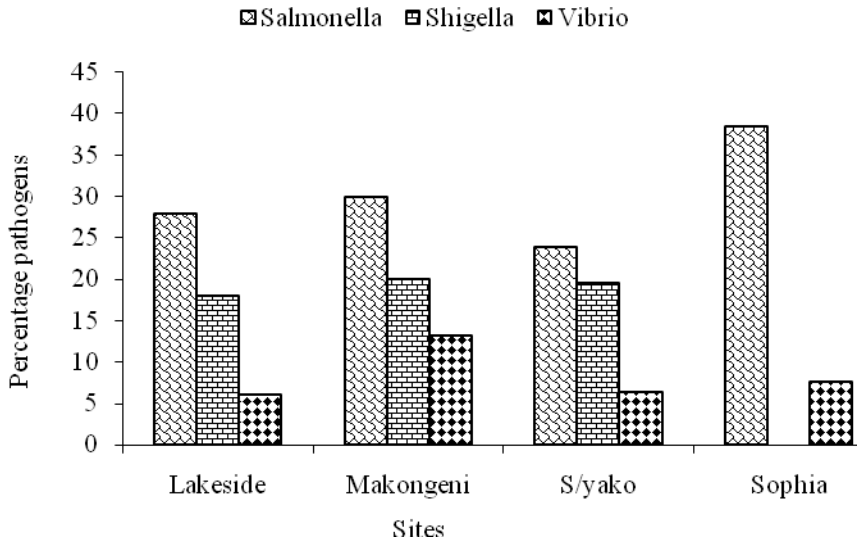

Figure 17. Percentage of Pathogenic bacteria present in greywater from different sites in Homabay

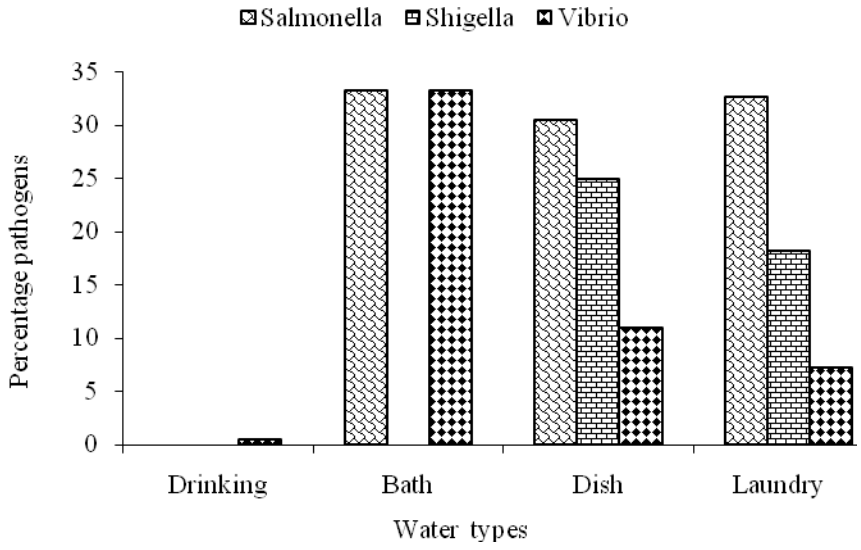

Figure 18. Percentage of pathogens in different GW types in Homabay

In the present investigation it was again found that *Salmonella* was the most frequent pathogen in all greywater types while *Vibrio cholerae* was the least frequent. *Salmonella, Shigella and Vibrio cholerae* was present in 29.4, 19.6 and 8.8 percent respectively. (Figure 19)

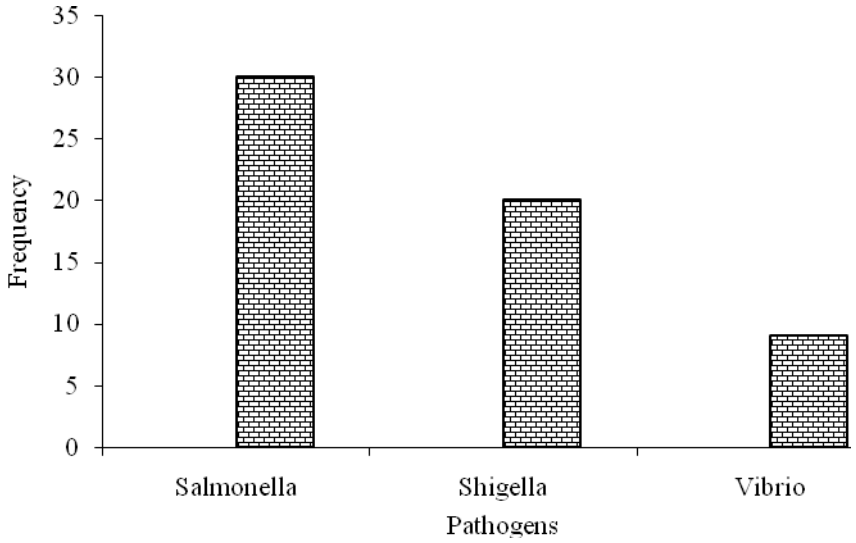

Figure 19. Frequency of pathogen occurrence in greywater samples from Homabay

In Githurai some pathogenic bacteria from the genera *Salmonella*, *Shigella* and *Vibrio* were identified and recorded in greywater from the various cleaning operations over the study period. Overall, *Salmonella* was the most frequent and its presence was recorded in 39.6% of all the samples collected. *Shigella* and *Vibrio cholerae* were recorded in 22.9% and 25% of all the greywater samples collected over the study period respectively (Figure 20). In comparing the presence of the three potentially pathogenic bacteria in different greywater sources, dish greywater had more pathogenic bacteria than laundry and bath

greywater samples. *Salmonella* had 8.3%, 45.5%, 37.8% and 34.2% in drinking water, dish, laundry and bath greywater respectively. *Shigella* had 5.1%, 27.3% 21.6 % and 23.1% in drinking water, dish, laundry and bath greywater respectively. *Vibrio cholerae* had 3.2%, 54.5 %, 16.2 % and 14.3% in drinking water, dish, laundry and bath greywater respectively (Figure 21).

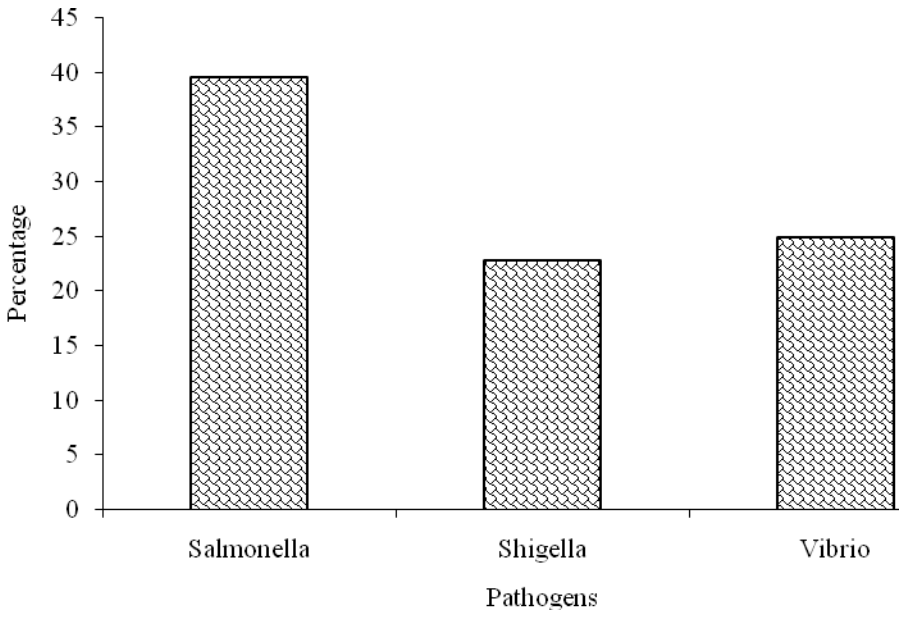

Figure 20. Percentage of pathogens in GW from Githurai

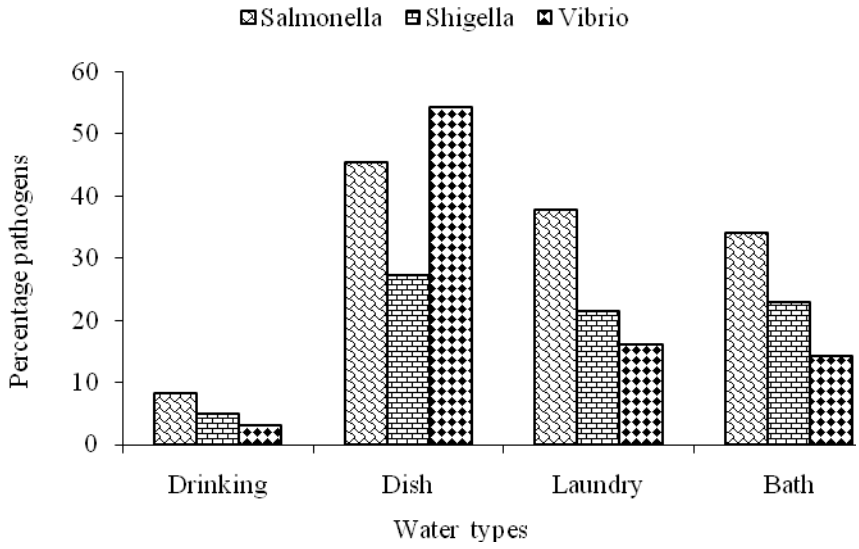

Figure 21. Percentage of pathogens in Drinking water and different GW types in Githurai

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Physico-chemical properties

5.1.1 Conductivity

The chemical composition of greywater varies greatly based on numerous factors including the original quality of the water coming to the home, personal habits of the family members, the number of occupants, the age distribution of the members, their lifestyle, type of chemical products used, the activities in the household, the difference in the intensity of use of water before it qualifies to be discarded, as well as the differences in the origin of dirt that the items being cleaned were exposed to (Bennett *et al*., 2002). Laundry greywater had the highest mean EC among all the estates. Drinking water had the lowest EC of 104.8±4.1 µS cm^{-2} recorded in Githurai. High EC in laundry operations could be due to use of chemical detergents which have high conductivity. Dish and bath GW mostly use soap which naturally has lower conductivity (Jeppesen, 1996). However there were some incidences where the laundry EC was low when laundry soaps were used instead of detergents (60 µS cm^{-2} in Sophia).

Absence of a significant variation in the electrical conductivity of greywater samples from the different residential areas of Homabay suggests that there is no significant variation in concentration of dissolved inorganic salts in the detergents used as well as the dissolved salt content of dirt contaminants of different residential areas. This could be due to the fact that the residential areas covered by the study had the same level of income and same lifestyle. A significant difference in EC of greywater from different

cleaning operations can be attributed to the possible difference in the quantity of dissolved ion in the detergents used for the different cleaning operations. There was an exception in the case of Lakeside greywater which had low mean EC in all the greywater types. This could be due to the availability of large quantities of lake water which dilute the chemical detergents thus lowering the EC.

The results of this study are consistent with those reported by Waite *et al.* (2006) where the EC ranged between 260 to 4520 µS cm^{-2}. Other studies conducted by Mushtaque Ahmed (2003) on greywater in two sites in Oman had mean EC of 817 µS cm^{-2} and 1045.2 µS cm^{-2} respectively which is also consistent with my results. Various studies into greywater quality in different countries have been published and the EC ranges from 325-1140 µS cm^{-2} (Jespersen 1996). According to the standard classification of EC of greywater, the results from the study site are within the range of non saline, (0 - 2,000) to slightly saline, (4,000 - 8000). If the greywater is used for garden irrigation and the EC increases on a frequent basis, and for a prolonged period, certain sensitive plants could suffer salt injury (Eriksson *et al*., 2002).

5.1.2 Dissolved oxygen (DO)

Adequate dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop to below 5.0 mg/l, aquatic life is put under stress. The lower the concentration of dissolved oxygen, the greater the stress. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills (Ayers**,** *et al*., 1989). Naturally dissolved oxygen

may vary from 0 to 18 mg L^{-1}. Readings above 18 mg L^{-1} are physically impossible. The WHO has classified DO concentration in greywater into the following classes: 0.0 to 4.0 mg L^{-1}- poor (Some fish and macroinvertebrate populations will begin to decline), 4.1 to 7.9 mg L^{-1} - fair, 8.0 to 12.0 mg L^{-1}- good, 12.0 mg L^{-1} and above -water may be artificially aerated (Petterson and Ashbolt, 2006)

In the present study, since the mean greywater DO value was below 4.0 mg L^{-1}, it may be necessary to subject the greywater generated to some initial aeration before being discarded into the environment to avoid deoxygenation and associated toxicity of the receiving water. Reduced DO levels in greywater may be because the water is too warm especially in dish greywater (Rose *et al*., 1991). The increased molecular activity of the warm water pushes the oxygen molecules out of the spaces between the moving water molecules. Decreased DO levels can also be attributed to the high biological oxygen demand, which use up DO. If the greywater with low DO finds its way into water bodies, it may cause major shifts in the kinds of aquatic organisms found in such water bodies. Species that cannot tolerate low levels of DO such as mayfly nymphs, stonefly nymphs, and beetle larvae will be replaced by a few kinds of pollution-tolerant organisms, such as worms and fly larvae **(**Howard, *et al*., 2005). Nuisance algae and anaerobic organisms (that live without oxygen) may also become abundant in waters with low levels of DO (Casanova *et al*., 2000). The effect of storage on greywater quality was studied by Dixon *et al*. in 1996. They discovered that storage of greywater for over 48 hours could be problematic due to decreased dissolved oxygen levels. Aeration of the graywater could minimize any deleterious effect of storage.

Low dissolved oxygen levels encourage the growth of anaerobic bacteria. These bacteria generate sulphide gases, which are a principal cause of the infamous 'rotten egg', dirty drain odour that ultimately leads to acidic conditions and corrosion. When dissolved in water, sulphide gas forms sulphuric acid that will eventually eat away the internal walls of metal drain pipes, fittings, manhole covers, concrete benching and masonry **(**Lindstrom *et al*., 2000). When irrigated onto vegetation, water in this state will progressively destroy plants as surely as industrially-generated acid rain. As a result, it is essential to ensure that stored greywater is treated so that it doesn't become damaging, stale and stinky (Rose, *et al*., 1991).

5.1.3 pH

Although the pH of greywater strongly depends on the pH of the water supply, use of water for cleaning usually influences the pH of GW discharged (Christova-Boal *et al.*, 1996). In the present study, laundry GW was observed to have higher pH mean values than dish and bath greywater. This has partly been attributed to the sodium hydroxide-based soaps and bleach used in laundry cleaning. The low pH values recorded (4.9, Shauri yako) was mostly from dish washing and possibly resulted from occasions when the dishes with food remains were soaked overnight and washed in the morning. The low pH values were recorded in instances when cut lemon pieces were found in dish greywater. The acid in the lemon was responsible for the drop in pH.

Generally the greywater was moderately alkaline with the laundry water having pH values (7.4 - 10.29) that fall outside the effluent discharge standard of 6 to 8, (NEMA, 1999) but is in line with the range of 8 to 10 observed by Eriksson *et al*., (2002). The high

pH values of the laundry water may be due to the alkalinity of the detergents and or soaps that are used (Christova‐Boal *et al*., 1996). Sodium, potassium and calcium are alkaline chemicals and their presence in laundry detergent, tends to raise alkalinity of the greywater. A significant portion of the greywater exceeded the NEMA effluent discharge standard of 6 to 8 pH range and would therefore require treatment before reuse. To avoid negative impacts on soil and plants when reused, raw untreated GW should have a pH in the range of 6.5–8.4 (FAO, 1985; USEPA, 2004).

5.1.4 Salinity

Saline soils are among the serious concerns to irrigated agriculture in arid and semi-arid regions of the world (Mareels *et al.*, 2005). In Iran, approximately 44.5 M ha of arable land are affected by dry land salinity (Banaei *et al.*, 2005). Salinity becomes a problem when enough salts accumulate in the effective crop root zone to negatively affect plant growth. Excess salts in the effective crop root zone hinder plant roots from withdrawing water from surrounding soil. This lowers the amount of water available to the plant, regardless of the amount of water actually in the effective crop root zone (Sumner, 1993).

In the current study, water use for various cleaning operations increased greywater salinity by different magnitudes depending on the intensity of use and type of use. The salinity is higher in laundry water followed by bathroom and dish water in that order. The high laundry salinity values may be a result of the type of detergents or soaps used. Long term application of water with a high salinity can be detrimental to the hydraulic conductivity and physical properties of soils and associated plant systems (Wiel‐Shafran *et al*., 2006). Most commercially available bathroom/laundry products

are currently manufactured using various types and quantities of sodium salts. Household cleaning products often are sources of sodium, chloride and other salts. When sub-irrigation is used, sodium and chloride higher than 100 and 140 mg/L, respectively, may cause toxic effects to the sensitive plants (Ayers and Westcot, 1985). Salinity bites into the productivity of the agricultural enterprise, and most plants will not survive in highly saline soils. There is a risk of increased salination of topsoil over the long term and hence the need to apply freshwater to the gardens as a control measure against soil damage (clogging).

5.1.5 Temperature

Mean temperature for various types of GW across the estates did not differ significantly. But in some instances higher temperatures were recorded (28 $^{\circ}$C dish, Sophia). This could be attributed to the water coming from the kitchen. Bath greywater was relatively warm; the reason could be that the water had been warmed for bathing. The temperature is relatively lower for laundry greywater. The probable explanation for this is that water for laundry purposes in normally not warmed up.

5.2 Bacterial properties of greywater

5.2.1 Greywater indicator bacteria

The plate counts and indicator organism concentrations for untreated greywater were high with mean total and fecal coliforms of 5.34×10^{6} and 2.83×10^{5} cfu/100 ml respectively (Table 18 & 19). Fecal coliform counts were highest in laundry greywater. This could be due to some households mixing children diapers with other clothes during cleaning. There was high presence of fecal bacteria in all the samples collected, a sign of

human faeces in greywater. The presence of total coliforms and faecal coliforms shows faecal contamination, indicating the possible presence of pathogens. The findings of the total coliform measurements revealed that the cleaning operations on most occasions increased the bacterial load of the water. Among the factors observed to contribute to variation in the TC counts included differences in hygiene conditions, variation in water economy (some households recycle cleaning water more than others), variation in the period in which the items being cleaned had been left soaking in the cleaning water. Food remains and possibly overnight soaking of used utensils contributed to the comparatively higher TC counts in dish greywater.

On the other hand, the comparatively lower TC counts in greywater samples obtained from cleaning operations next to Lakeside can be attributed to the greater volume of water used in cleaning operations carried out next to the lake. During the study, it was observed that people washing near the lake tend to use more water in the cleaning resulting in more dilute greywater as compared to that produced by cleaning operations at home where water economy is important. An unusually high TC counts in a rain water sample collected at Sofia Estate (2.4×10^6 CFU/100 mL) suggests that the rain water would have been exposed to some form of bacterial contamination. However, absence of a significant difference in TC counts in greywater samples from different residential areas as well as different household cleaning operations suggests the level of hygiene in the different residential areas is more-or-less similar. An overall TC range of 1.3×10^6 to 7.8×10^6 CFU is comparatively lower than a value of 2.4×10^3 to 2.4×10^6 measured in the Dome distribution system, in London (Birks *et al*., 2004).

The untreated GW was not within the allowable limits set in the WHO guidelines for the safe use of wastewater in agriculture (for irrigation of crops likely to be eaten uncooked, sports fields, public parks) and the ≤200 fecal coliforms per 100 ml guideline for use in public lawns, such as hotel lawns, with which the public may come into direct contact (Finley *et al*., 2009). The characteristics of greywater vary over time and space with three factors affecting its composition; water supply quality, the composition of the system that transports both greywater and drinking water and the activities in the house (Eriksson *et al*., 2002). Greywater originating from showers and sinks used for hand washing typically have the lowest concentrations of bacteria and chemicals while greywater originating from kitchen sinks is typically higher in bacteria, organic carbon and solids (Trujillo *et al*., 1998). In many households, greywater originating from kitchen sinks may also contain high concentrations of fats, oils and grease (Wilderer 2004). These characteristics make the use of greywater originating from kitchen sinks challenging since it may not be well suited for reuse in most types of greywater systems and thus for reuse of greywater, separation at the source may be required. Although exclusion of either the bath or shower lowered the concentration of fecal coliforms as both were significant sources of fecal coliforms (Birks *et al*., 2004), greywater from separate sources (bath, dish washing and laundry) from the study sites showed no significant ($p>0.05$) difference in terms of total and fecal coliforms. Therefore, the exclusion of either sources of greywater is not expected to significantly lower the contamination.

A note of concern is that fecal and total coliforms were detected in drinking water in levels way above the WHO limits which could be a significant source of contamination eventually found in greywater. The 1.96×10^6 and 0.06×10^5 cfu/100 ml (appendix 6 and

7) for total and fecal Coliforms respectively is an indication of contaminated drinking water and possible source of frequent outbreak of cholera experienced in Homa Bay (Kotut *et al*., 2009). The presence of fecal coliforms and *Escherichia coli* may indicate a pathogenic risk in potable water as these organisms have previously been used to assess the safety of greywater recycling (Rose *et al*., 1991).

5.2.2 Bacteria pathogens

Presence of fecal coliforms is usually considered to be a specific indicator of fecal contamination of water samples as well as the possible presence of pathogenic bacteria (Maier *et al*., 2000). Further evidence for the presence of human fecal contamination in Homa Bay and Githurai was provided by the ratio of fecal coliform to total coliforms, which exceeded a value of 0.1 (APHA, 2003). This was confirmed when untreated greywater was analyzed for the presence of the potentially pathogenic bacteria from the genera *Salmonella, Shigella* and *Vibrio* and was detected (appendix 8 and 9).

Positive count of Salmonella which is a common species associated with food poisoning from partially cooked meat and shellfish and presumably passed into the greywater by an infected person washing or possibly the washing of uncooked meat in a bathroom washbasin have been found in untreated GW (Birks *et al*.,2007) . Fish is a common meal in Homa Bay households and it may be the most likely source of *Salmonella* sp.

The presence of pathogenic bacteria, *Salmonella, Shigella* and *Vibrio* in various estates and water sources is in agreement with findings of other greywater studies from similar sources (Rose *et al.,* 1991). *Salmonella* was the most frequent and its presence was recorded in 29.4% of all the samples collected. *Shigella* and *Vibrio cholerae* were

recorded in 19.6% and 8.8% of all the greywater samples collected in Homabay over the study period. In Githurai *Salmonella* was also the most frequent and its presence was recorded in 39.6% of all the samples collected. *Vibrio cholerae* and *Shigella* were recorded in 25% and 22.9% of all the greywater samples collected in Githurai.

In some households, squeezed cut lemon pieces were found in dish greywater and were used to make porridge sour. Such samples had significant reduction in bacteria growth. The acid in the lemon acted as antiseptic. It is clear that faecal contamination of greywater is a common occurrence and therefore the potential exists for a range of faecally-transmitted pathogens to be passed into greywater. However, the absence of enteric pathogens in the lake samples during the study is probably because greywater was highly diluted due to the availability of plenty of water from the Lake during washing. The opportunistic pathogen *Salmonella* was consistently present in the tested greywater suggesting a high level of human bacterial contamination (from bacteria on the skin, faecal contamination etc.). The presence of opportunistic pathogens in greywater indicates that inadequately treated and disinfected greywater may pose a particular risk to vulnerable individuals within households reusing greywater particularly in susceptible individuals, such as the elderly, young, and immune-compromised (Lee *at al*,.1985)

The potentially pathogenic bacteria *Shigella dysenteriae* causes shigellosis or bacillary dysentery. It is seen most often in pre-school-age children. This is a serious diarrhea disease which is very common in the study areas. The principal reservoir of the infection for man is other humans that are sick or carriers. *Salmonella* spp is the other pathogen and causes typhoid fever which is very common in the study areas. The main reservoirs

for human infection are poultry, cattle, sheep and pigs. *Salmonella* spp are common in animal faeces and wastes from slaughter houses and poultry processing plants (Brian, 1980). The high frequency of occurrence of *Salmonella* could be due to the large number of animals and birds loitering in the study areas.

Vibrio cholerae, the causative agent of cholera, is primarily transmitted through consumption of contaminated drinking water or food. The source of the contamination is typically from other human beings suffering from cholera when their untreated diarrheal discharge is allowed to get into waterways or into groundwater or drinking water supplies. *Vibrio cholerae* are native to coastal and estuary environments with shallow waters and thriving planktonic eco-systems. In this situation, they naturally attach to small planktonic crustaceans called "copepods." These copepods feed on algae in the waters and as they flourish so do the *Vibrio cholerae* bacteria. Populations rise and fall with the rise and fall of available algae. Organic pollutants, in particular human and animal fecal wastes, provide nutrients to encourage algae blooms.

The combination of an organically rich environment, coupled with the perfect temperatures and salinity levels cause natural cholera epidemics to be associated with seasonal shifts: a densely populated coastline coupled with the natural temperatures and saline levels of spring and fall ensure the best possible chances of an outbreak. Several cases of *Vibrio cholerae* were found in greywater samples collected during the rainy season due to the stagnant rain waters.

A high percentage of greywater samples in which pathogenic bacteria were recorded (up to 30% for *Salmonella*) demonstrates the risk that handlers of greywater are exposed to and confirms the need for the disinfection of greywater. Since the pathogenic bacteria were absent in most drinking water samples collected during the sampling period, it is clear that contamination occurred in the course of the cleaning operations. Presence of *Vibrio cholerae* in the rain water sample was a rather unusual occurrence that supports the suspicion that the water sample would have been contaminated by fecal wastes.

5.3 Conclusions

1. Greywater from different sources had some physico-chemical properties above accepted levels like high salinity and low pH.
2. The research showed that consistently high levels of potable water indicator organisms (total coliforms, fecal coliforms) can be found in raw untreated greywater and the potential for human pathogens to be present in detectable numbers in greywater was confirmed.
3. The results reported in this study indicate that common households produced greywater with high EC, high salinity and low pH which inhibited the growth of pathogenic bacteria.
4. The quality of greywater varies from one household to another depending on the general hygiene of households as well as the level of recycling that the water is taken through before being discarded.
5. Reuse of greywater appears to be a common practice in the region. Hence an outbreak of waterborne diseases can spread faster in these areas.

6. The results obtained from the two study sites indicated that there is no significant difference in the physico-chemical quality and bacterial load of greywater.

5.4 Recommendations

1) This study made clear that the contribution of greywater to the total domestic pollution load is significant, and the current sanitation systems do not take that fact into account, as greywater being discharged without treatment into the environment. Measures such as phosphorous ban in detergents or greywater treatment in septic tank should be effected so as to significantly reduce negative impacts on environment and public health.
2) Given the greywater characteristics presented in this study, greywater should be properly managed to prevent contamination of the environment and disease prevalence.
3) Given the positive response to the application of greywater in gardens in Homabay, there is need to increase sensitization of the community on greywater reuse and associated benefits to scale up this response.
4) There is a risk of increased salination of topsoil over the long term; however, this should be mitigated by assessing the characteristics of the soil and taking precautionary measures, such as applying humus to fixate the ions into the soil.
5) In dry areas, greywater may be a potential source of water for selected uses. It is recommended that more studies should be carried out on greywater treatment technologies to be used by the residents of the study areas.

REFERENCES

Ahmed, M., Prathapar, S. Al-Jamrah, A. Al-Maskiri, A. and Al-Belushi, A. (2001) Greywater Reuse in Arid Countries: Problems and Possibilities. Sultan Qaboos University.

Al-Obaidani S.B.S., and Atta T.H.A., Water Resources Management in Oman, Country paper presented at Ministerial Conference on the Occasion of the 3rd World Water Forum, Kyoto, Japan, 22-23 March, (2003).

American Public Health Association. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA, Washington, DC.

American Public Health Association. 2003. Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA, Washington, DC.

Ayers RS & Westcot DW, 1989, *Water Quality for Agriculture*, FAO Irrigation and Drainage Paper 29

Ayers, RS & Westcot, DW 1985, Water Quality for Agriculture, Irrigation and Drainage Paper 29 Rev. 1,

Bennett E.R. and Linstedt K.D."Individual Home Wastewater Characterization and Treatment".QWRT Project

Birks R. and S. Hills, "Characterisation of Indicator Organisms and Pathogens in Domestic Greywater for Recycling", Environmental Monitoring and Assessment, vol. 129, pp. 61-69, 2007.

Birks, R., Colbourne, J., Hills, S., & Hobson, R. (2004). Microbiological water quality in a large in- building recycling facility.Water Science and Technology, 50(2), 165–172.

Blumentha U. J. l, D. Mara, A. Peasey, G. Ruiz-Palacios and R. Stott, 'Guidelines for the microbiological quality of treated wastewater used in agriculture: Recommendations for revising the WHO Guidelines', *Bulletin of the World Health Organization*, vol 78, no 9, pp1104–16, 2000.

Caigan M, "CDC looks at links between wastewater and disease", *Small Flows Quart.*, vol. 6, no. 3, pp. 18 -21, 2005.

Casanova, Lisa M., Gerba, Charles P. and Karpiscak, Martin. 2000. *Chemical and MicrobialCharacterization of Household Graywater.* Departement of Soil, Water and Environmental Science,

Chang, G.W., J. Brill, and R. Lum. 1989. Proportion of beta-glucuronidase-negative *Escherichia coli* in human fecal samples. Appl. Environ. Microbiol. 55:335-339.

Christova-Boal, D., Eden, R. E., & McFarlane S. (1996). An investigation into greywater reuse for urban residential properties. Desalination, 106, 391–397.

Conway, P.L. 1995. Microbial ecology of the human large intestine. In: G.R. Gibson and G.T. Macfarlane, eds. p.1-24. Human colonic bacteria: role in nutrition, physiology, and pathology. CRC Press, Boca Raton, FL.

CSBE (Centre for the Study of the Built Environment), Graywater Reuse in Other Countries and its Applicability to Jordan. CSBE,2003.

Dixon, A., Butler, D. & Fewkes, A. (1999). Water saving potentials of domestic water reuse systems using greywater and rainwater in combination. *Water Sci Tech*, 39(5), 25-32.

Doyle, M.P. and J.L. Schoeni. 1987. Isolation of *Escherichia coli* O157:H7 from retail meats and poultry. Appl. Environ. Microbiol. 53:2394-2396.

Eriksson E., K. Auffarth, M. Henze and A. Ledin, "Characteristics of grey water", *Urban water*, vol. 4 (1), pp. 85-104, 2002.

Ewing, W.H. 1986. Edwards and Ewing's Identification of *Enterobacteriaceae*, 4th ed. Elsevier, New York.

FAO, "Water quality for agriculture: Irrigation and Drainage paper 29 Rev. 1", Food and Agriculture Organization of the United Nations,Rome, pp. 174, 2003.

FAO, Irrigation in the Near East Region in figures, Water Report 9, Rome, (1997).

Finley, S., S. Barrington, and D. Lyew. 2009. Reuse of domestic greywater for the irrigation of food crops. Water Air and Soil Pollution 199:235-245.

Gross, A. Shmueli, O. Oron, G. Ronen, Z. and Raveh, E (2004). Recycled Vertical Flow Constructed Wetland (RVFCW) - a novel method of recycling greywater for landscape irrigation in small communities and households. Ben-Gurion University of the Negev, Israel.

Haas, C. N., Rose, J. B. & Gerba, C. P. (1999). *Quantitative Microbial Risk Assessment*. John Wiley and Sons Inc., New York.

Hodges D., Safe Use Of Household Greywater. *Water & Environment Manager,* November, (1998), pp 15-17.

Howard, E, et al. 2005**.** *Laundry Grey Water Potential Impact on Toowoomba Soils - Final Report.*

Jefferson, B, Palmer, A, Jeffrey, P, Stuetz, R and Judd, S (2003). Greywater Characterization and its Impact on the Selection and Operation of Technologies for Urban Reuse. Bedfordshire: Cranfield University.

Jeppesen B., Domestic greywater re-use: Australia's challenges for the future, *Desalination (106), (1996),* pp 311-315.

Kotut K., E. Chaggu, M. S. Nabacwa, F. Kariuki, C. Nkata and V. Ng`ang`a, "Greywater treatment and reuse for agricultural production and environmental protection in the Lake Victoria Basin" A Lake Victoria Initiative Proceedings of VicRes Pollution and Heavy Metal Cluster Workshop, 2009, pp. 231-250.

Lee JV, Bashford DJ, Donovan TJ, Furniss AL, West PA. The incidence of Vibrio cholerae in water, animals and birds in Kent, England. J Appl Bacteriol. 1982

Lindstrom, Carl R. 2000. Greywater Pollution. *GREYWATER What it is, how to treat it, how to use it.*

Mack W.N. (2008) "Total Coliform Bacteria in "Bacterial Indicators/Health Hazards Associated with Water". A.W.

Maier R. M., I. L. Peper and C. P. Gerba, Environmental Microbiology: Academic Press, 2000.

Mara, D. and Cairncross, S. (2007) Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: measures for public health protection. Geneva: World Health Organization.

Mareels, I., E. Weyer, et al. (2005). "Systems engineering for irrigation systems: Successes and challenges." Annual Reviews in Control

Morel A. and S. Diener, "Greywater Management in Low and Middle Income Countries, Review of Treatment Systems for Households or Neighbourhoods", Sandec (Swiss Federal Institute of Aquatic Science and Technology), Dubendorf, Switzerland,2006.

Mustow S., Water Standards for Greywater Systems, *In Research Publication (21AD/WATER) from Oxford Brookes University,* U.K., (1998).

Mutua, Raude, Chemelil, Kraft, Sleytr (2009), Household greywater treatment for peri-urban areas of Nakuru Municipality, Kenya

National Enviroment Management Authority (NEMA). Kenya Environmental Information Network annual report 2008

Nolde E. N., "Greywater reuse systems for toilet flushing in multistory buildings—over ten years experience in Berlin", *Urban Water*,vol. 1, pp. 275-284, 1999.

Ottosson, J. (2003a). Faecal contamination of greywater - assessing the treatment required for hygienically safe reuse or discharge. Swedish Institute for Infectious Disease Control.

Ottosson, J. (2003b). Hygiene Aspects of Greywater and Greywater Reuse. Stockholm: Swedish Institute of infectious disease control.

Peasey A (2000). Human Exposure to A*scaris* Infection through Wastewater Reuse in

Petterson, S.A. and Ashbolt, N.J. 2006. *WHO Guidelines for the Safe Use of Wastewater and excreta in Agriculture.* World Health Organization. France : WHO, 2006. Guidelines.

Rose J. B., G. S. Sun, C. P. Gerba and N. A. Sinclair,"Microbial quality and persistence of enteric pathogens in graywater from various sources household sources", *Water Research*, vol. 25(1), pp. 37–42, 1991.

Rose, J. B., Sun, G. S., Gerba, C. P., & Sinclair, N. A. (1991).Microbial quality and persistence of enteric pathogens in graywater from various household sources. WaterResearch, 25(1), 37–42.

Shouler M.C., and Griggs J.C., *Water Conservation*, Internal publication of building research establishment ltd., BRE, U.K., (1998).

Sinton L. W., R. K. Finlay and D. J. Hannah, "Distinguishing human from animal fecal contamination in water: a review", *New Zealand Journal of Marine and Freshwater Research,* vol. *32:* 3pp. 23-348, 1998.

Sinton W, R. K. Finlay and D. J. Hannah, "Distinguishing human from animal fecal contamination in water: a review", *New Zealand Journal of Marine and Freshwater Research,* vol. 32, pp. 23-348, 1998

Stavric, S. and Buchanan, B., (1995). The Isolation and Identification of *Vibrio Cholerae* 01 and Non-01 from foods.

Sugiyama J, Gondaira F, Matsuda J, Soga M, Terada Y. New method for serological typing of Vibrio cholerae 0:1 [corrected] using a monoclonal antibody-sensitized latex agglutination test. Microbiol Immunol. 1987; 31(4):387–391.

Trujillo, S., A Hanson, A., Zachritz, W. & Chacey, R. (1998). Potential for greywater recycle and reuse in New Mexico. *New Mexico JSci*, 38, 293-313.

United Nations, "Lake Victoria City Development Strategies for Improved Environment and Poverty Reduction", Homa Bay Town Profile, 2006.

United States Environmental Protection Agency (USEPA). 1986. Ambient Water Quality Criteria for Bacteria--1986. EPA-440/5-84-002, U.S. Environmental Protection Agency, Washington, D.C.

Waite T.D, Tangsubkul N, K. Parameshwaran, S. Lundie, A.G. Fane, Environmental Life Cycle Assessment of the Microfiltration Process, Journal of Membrane Science,Volume 284, Issues 1-2, 1 November 2006,

Welton, S, Borsari, B, Doherty, S, Kefeli, V, Reynolds, T (2005). Greywater treatment at the Robert A. Macoskey center: Assessment and approaches to a renovated system design. Pennsylvania: Community College of Vermont.

Whiting, D., Tolan, R and Bauer, M. (2002). Colorado's Water Situation. Colorado State University Cooperative Extension.

WHO, (2006). Overview of greywater management Health considerations. Amman: Regional Office for the Eastern Mediterranean Centre for Environmental Health Activities.

WHO: WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume IV, Excreta and Greywater Use in Agriculture. Geneva, Switzerland, WHO Press, 2000.

Wiel-Shafran, A., Z. Ronen, N. Weisbrod, E. Adar, and A. Gross. 2006. Potential changes in soil properties following irrigation with surfactant-rich greywater. Ecological Engineering 26:348-354.

Wilderer P. A., "Applying sustainable water management concepts in rural and urban areas: Some thoughts about reasons, means and needs*", Water Science and Technology,* vol. 49(7), pp. 7-16, 2004.

Wilson, G., Easow, J.M., Mukhopadhyay, C. and Shivananda, P.G., (2006). Isolation & antimicrobial susceptibility of Shigella from patients with acute gastroenteritis in western Nepal. Indian J Med Res. Vol.6.PP 145-150.

Winward G.P., L.M. Avery, R. Frazer-Williams, M. Pidou, P.Jeffrey, "A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse", *Ecological Engineering,* vol. 32, pp. 187-197, 2008.

Wood, P (2008). Water resources: Reusing greywater and harvesting rainwater. The Environment Agency.

APPENDICES

Appendix 1: Mean levels of Conductivity (µS cm^{-2}) for drinking water and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	108.5±65 [a]	412.8±107 [b]	995±81.6[c]	325.4±99.1 [b]
Makongeni	227.4±28.3[a]	827.7±229.0[b]	1698.3±367.7[c]	617±180.3[b]
Shauri yako	148.8±12.4[a]	992.1±305.5[b]	1256.1±187.6[c]	661.3±153.7[b]
Sophia	143.2±25.9[a]	663.5±199.6[b]	1813.0±374.3[c]	628.3±157.6[b]
Githurai	104.8±4.1[a]	789.9±162.2[b]	1538.5±162.2[c]	591.4±159.4[b]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI.

Appendix 2: Mean levels of Dissolved Oxygen (mg/l) for drinking water and various greywater types collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	7.45±0.35[a]	5.04±0.44[b]	2.03±0.1853[c]	5.1±0.492[b]
Makongeni	6.07±0.32 [a]	4.04±0.79[b]	2.47±0.28[c]	3.32±0.84[b]
Shauri yako	6.22±0.45 [a]	3.55±0.51[b]	3.90±0.43[b]	4.01±0.69[b]
Sophia	6.74±0.30 [a]	3.79±0.45[b]	4.10±0.35[b]	3.99±0.68[b]
Githurai	7.32±0.23 [a]	4.37±0.50[b]	4.91±0.31[b]	3.49±0.67[c]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI

Appendix 3: Mean levels of pH for drinking water and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	7.1±0.2[a]	7.34±0.47[b]	9.32±0.10[c]	7.39±0.31[b]
Makongeni	6.95±0.12 [a]	8.61±0.52[b]	8.61±0.52[b]	7.88±0.48[b]
Shauri yako	6.95±0.14 [a]	8.18±0.45[b]	9.19±0.14[c]	8.35±0.28[b]
Sophia	7.08±0.08 [a]	8.51±0.37[b]	9.38±0.10[c]	8.17±0.52[b]
Githurai	6.99±0.08 [a]	8.15±0.52[b]	8.84±0.21[c]	7.81±0.29[b]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI

Appendix 4: Mean levels of Salinity (mg/l) for drinking water and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	0±0[a]	0.07±0.028[b]	0.22±0.038[c]	0.06±0.027[b]
Makongeni	0.06±0.04 [a]	0.23±0.111[b]	0.70±0.212[c]	0.3±0.148[b]
Shauri yako	0.02±0.02 [a]	0.33±0.168[b]	0.43±0.105[c]	0.4±0.145a[b]
Sophia	0.04±0.04 [a]	0.16±0.166[b]	0.77±0.773[c]	0.11±0.11[b]
Githurai	0.06±0.04 [a]	0.29±0.132[b]	0.60±0.089[c]	0.32±0.196[b]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI

Appendix 5: Mean levels of Temperature (°C) for drinking and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	25±0.80	26.2±0.46	24.2±1.09	25.5±0.89
Makongeni	25.7±0.85	23.7±0.67	25.3±0.42	26.3±0.50
Shauri yako	22.8±1.28	24.5±1.06	24.7±0.67	25.7±0.77
Sophia	24.7±0.64	24.9±0.87	24.7±0.77	25.5±0.65
Githurai	25.2±0.11	24.4±0.91	24.9±0.11	26.1±0.56

Appendix 6: Mean levels of Total coliforms (cfu x 10^6) for drinking water and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lake	1.30±0.10[a]	2.20±0.29[b]	4.86±0.50[c]	3.76±0.62[c]
Makongeni	1.88±0.36 [a]	4.77±0.49[b]	4.11±0.45[b]	3.60±0.66[b]
Shauri yako	1.72±0.21 [a]	4.40±0.58[b]	4.43±0.27[b]	4.32±0.58[b]
Sophia	1.74±0.20 [a]	3.79±0.48[b]	4.36±0.39[c]	4.64±0.70[c]
Githurai	1.96±0.22 [a]	5.22±0.28[b]	5.34±0.22[b]	4.05±0.60[b]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI.

Appendix 7: Mean levels of fecal coliforms (cfu x 10^5) for drinking water and greywater samples collected from different estates and Lake Victoria

Source/Water type	Drinking	Dish	Laundry	Bath
Lakeside	0.060±0.020[a]	1.93±0.66[b]	2.83±0.89[b]	2.14±0.76[b]
Makongeni	0.010±0.010 [a]	2.19±0.48[b]	2.46±0.78[b]	2.38±0.34[b]
Shauri yako	0.005±0.003 [a]	1.81±0.55[b]	2.07±0.43[b]	1.94±0.49[b]
Sophia	0.001±0.001 [a]	2.18±0.65[b]	2.21±0.65[b]	2.20±0.58[b]
Githurai	0.020±0.010 [a]	2.22±0.71[b]	2.41±0.27[b]	2.31±0.65[b]

NB: Mean values in the same row denoted by the same letters are not significantly different at 95% CI.

Appendix 8: Percentage of Pathogenic bacteria present in drinking and greywater from different sites and from various cleaning operations in Homabay

	Percentage of Pathogenic bacteria present in various water types				Percentage of Pathogenic bacteria present in greywater from different sites			
Pathogen	**Drinking**	**Bath**	**Dish**	**Laundry**	**Lakeside**	**Makongeni**	**S/yako**	**Sophia**
Salmonella	0	33.3	30.6	32.7	28	30	24	38.5
Shigella	0	0	25	18.2	18	20	19.6	15.4
Vibrio	0.5	33.3	11	7.3	6.1	13.3	6.5	7.7

Appendix 9: Frequency of occurrence for pathogenic bacteria in greywater samples from Homabay

Pathogen	Frequency	% in different samples
Salmonella	30	29.4
Shigella	20	19.6
Vibrio	9	8.8

Appendix 10: Pathogenic bacteria present in greywater samples in Githurai

Pathogen	No. of occurrence	Percentage
Salmonella	19	39.6
Shigella	11	22.9
Vibrio	12	25

Appendix 11: Percentage of pathogenic bacteria present in drinking and greywater types in Githurai

Pathogen/watertype	Drinking	Dish	Laundry	Bath
Salmonella	8.3	45.5	37.8	34.2
Shigella	5.1	27.3	21.6	23.1
Vibrio	3.2	54.5	16.2	14.3

Appendix 12: Greywater sampling sites in Homabay

Appendix 13: Measuring physical chemical parameters in a greywater sample in the field using a Multiline P4 (WTW, Weilheim-Germany) conductivity meter.

Appendix 14: Membrane filter apparatus for filtering greywater

Appendix 15: Sample analysis in the lab by the researcher

Appendix 16: Total coliforms colonies on a membrane filter.CFU displaying the green metallic sheen

Appendix 17: Screening for Salmonella and Shigella using TSI