# BACTERIOLOGICAL ANALYSIS OF FAECAL POLLUTION AND SOLAR RADIATION DISINFECTION OF DOMESTIC WATER SOURCES WITHIN LAKE NAIVASHA BASIN, KENYA

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## DECLARATION AND RECOMMENDATION

### DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any other institution.

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SM18/2524/09

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### RECOMMENDATION

This work has been presented for examination with our approval as university supervisors

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## DEDICATION

*I dedicate this work to my late mum, Mrs. Mary Donde,*
*Her last words of encouragement kept ringing in my mind and propelled me to this end.*
*"Mama" rest in eternal peace.*

## ABSTRACT

There is an increase in exposure of water sources to faecal contamination as a result of expanding anthrogenic activities in Lake Naivasha basin in Kenya. This contamination exposes water users in the region to a variety of health risks. This study investigated faecal pollution of community water sources (lake, rivers and boreholes) within Lake Naivasha basin through determination of the concentrations of total coliforms, *Escherichia coli*, intestinal enterococci, *Clostridium perfringens* and heterotrophic bacteria in various water sources using Membrane Filtration Technique (MFT) and Heterotrophic Plate Count (HPC) procedures. The potential of solar pasteurization in disinfecting domestic water was also explored by heating known volumes of water samples in a black solar box cooker at given time intervals. In addition, determination of *E. coli* to intestinal enterococci ratio was used in faecal pollution source tracking. Physico-chemical parameters were measured *in situ* for all water sources. Data was analysed for mean variation using Statistical Package for Social Sciences (SPSS) version 17 software. Surface water sources gave higher values for all microbiological parameters than borehole sources. Borehole direct sources showed no significant variation for all microbial parameters (*E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC) with respect to sampling sites, the same was also observed in borehole at the Points of Access (POA). Surface water sources on the other hand, showed significant spatial variation for all microbial parameters ($P<0.05$). Samples from borehole POA, households in Karagita, Mirera and Kamere villages and vendors showed no significant variation for all the microbial parameters. The use of solar radiation in water disinfection showed that temperature of 75 $^{0}$C attained after 30 minutes from pasteurization point completely eliminated *E. coli* and total coliforms from all the water sources. *E. coli* to intestinal enterococci density ratios from all the water sources were closer to 0.7; showing that non-human warm blooded animals were the most possible sources of faecal pollution into these water sources. In conclusion, there was faecal contamination of domestic water sources in Lake Naivasha basin and poor human handling practices contributed to further deterioration of the water quality. The use of solar radiation can be recommended as a cost-effective method of disinfecting water for domestic consumption to reduce likely incidences of waterborne diseases. Use of other methods such as ribotyping is also recommended in tracking the possible sources of faecal pollution into water sources in Lake Naivasha Basin.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| APHA | American Public Health Association |
| BH DIR | Borehole Direct |
| BOD | Biological Oxygen Demand |
| BST | Bacterial Source Tracking |
| *C. perfrigens* | *Clostridium perfringens* |
| CP | *Clostridium perfringens* |
| DO | Dissolved Oxygen |
| *E. coli* | *Escherichia coli* |
| EC | *Escherichia coli* |
| FC | Faecal Coliforms |
| HPC | Heterotrophic Plate Count |
| IE | Intestinal Enterococci |
| IWRM | Integrated Water Resource Management |
| LSD | Least Significance Difference |
| MFT | Membrane Filtration Technique |
| MPN | Most Probable Number |
| MTF | Multiple Tube Fermentation |
| NAWASCO | Naivasha Water and Sanitation Company |
| NEMA | National Environmental Management Authority |
| BH POA | Borehole Points of Access |
| SBC | Solar Box Cooker |
| TC | Total coliforms |
| US EPA | United States Environmental Protection Agency |
| WAPI | Water Pasteurization Indicator |
| WBD | Waterborne Diseases |
| WHO | World Health Organization |
| WRMA | Water Resource Management Authority |

# CHAPTER ONE
# INTRODUCTION

## 1.1 Background information

Naivasha is one of the fastest growing towns in Kenya. Its growth is enhanced by the increasing horticulture farming and associated businesses, especially floriculture around the lake Naivasha (JICA, 2003). In addition, the area surrounding the lake offers a mild climate and natural beauty that has attracted tourism. Lake Naivasha also supports a productive fishery that provides jobs and income as well as being an important source of fish protein for local communities. Tourism activities in the region have contributed to growth in population in Naivasha District. In addition, rural to urban migration as a result of falling farm incomes from traditional cash crops, and commercial enterprises and good prospects for job opportunities have also led to tremendous rise in population density in this District. This has risen from 43,867 persons in 1969 to 376,246 persons in 2009 (Government of Kenya Census Report, 2009). Horticultural activities employ around 30,000 people in the region and it is one of the nation's largest foreign exchange earner (Japan International Co-operation Agency (JICA), 2003; Otiang'a and Oswe, 2007).

Provision of water in any country for socio-economic and ecological sustenance is indispensable. Its availability is primarily influenced by its quantitative distribution in time and space, and by its quality. As is common with other areas in developing countries, direct surface water is still the most important source of domestic water (World Health Organization (WHO), 2002). In the case of Naivasha area, River Malewa provides water for approximately 250,000 people within the townships surrounding the lake (M'Cleen, 2001; LakeNet, 2003). Other sources of water include bore holes, rain water harvesting, shallow wells and lake water. Despite these being the main sources of water for the communities in this area, they are under threat of pollution from anthropogenic activities in the heavily populated area and from the Lake Naivasha catchment (Harper and Mavuti, 2004).

Faecal contamination from human and other animals in this area is recognized as the major water pollutant and it has a bearing on public health (M'Cleen, 2001). Lack of adequate access to sanitation, safe and clean drinking water imposes significant economic losses on the population.

The WHO has estimated that 80% of all sicknesses and diseases in the world are caused by inadequate sanitation, faecal pollution and unavailability of water. About 1.7 million annual human deaths are attributed to contaminated water supplies. Most of these deaths are due to diarrhoeal diseases which also affect 90% of children from developing countries mainly due to bacterial pathogens contamination (WHO, 2002). There is likelihood of contamination of both surface and groundwater sources within Naivasha due to inadequate sanitation as communities here depend on bushes, pit latrines and septic tanks for sewage disposal (Mireri, 2005).

In places where water is inadequate or where its quality standards does not make it available for other uses, people have conflict and fight over water. Critical to our modern civilization is the availability of a clean water supply for drinking and bathing. Unfortunately, many pathogens get transmitted through its supply. Some of these pathogens enter water from faeces of ill individuals or of healthy disease carriers, are ingested and transmitted to other people. Waterborne diseases (WBD's) such as polio, typhoid, cholera, hepatitis, shigellosis, salmonellosis and others spread in this manner and the spread may be very high in densely populated areas such as Lake Naivasha area. Other WBD's such as giardiasis, toxoplasmosis and cryptosporidiosis (all of zoonotic origin) are also becoming common as a consequence of unprecedented flooding events emanating from climate change phenomena which has increased pollution in the water sources (WHO, 2002).

Pollution as a result of anthropogenic activities and poor management of water sources have partially or totally turned aquatic environments into dumping sites for waste materials, and as a result, many water sources have been rendered unwholesome and hazardous to man and other living systems (Bakare *et al*., 2003). There is often conflict on water usage because on one hand, the fundamental fear of food shortages encourages ever greater use of water resources for agriculture while on the other hand there is need to divert water from irrigation food production to other uses and to protect the quality of the resource. Many people believe this conflict is the most critical problem to be tackled in the 21$^{st}$ century and it was a key topic for discussion of the Framework for Action exercise of the Global Water Partnership (FFA of GWP) (FFA of GWP, 2000).

Regular sampling and analysis provide data on the quality of raw water, the efficiency of water treatment and the integrity of distribution systems. The range of pathogenic micro-organisms is extensive and therefore water is examined for microbiological indicators of contamination. The use of indicator organisms is based on the assumption that if they are present then the pathogen may also be present, and if absent then the water is suitable for consumption or pose a lower risk of transmitting WBD's (Frahm *et al.*, 2003). To be useful the indicator must be present if pathogen is present and in higher numbers than pathogens. The principal bacteria indicators are the coliforms bacteria; including total coliforms, faecal coliforms and *Escherichia coli*. Other bacterial indicators include enterococci, *Clostridium perfringens* and total aerobic bacteria. The key species of the faecal coliform group is *E. coli* commonly found in the faeces of human and is thus a definitive indicator of faecal contamination (Noble *et al.*, 2003). Therefore, concern about faecal coliforms densities in water sources is of paramount importance within Naivasha region (Mireri, 2005). Ways of finding solutions to the problems of faecal contamination into water sources is essentially necessary. Major solution approaches in this case include tracking of faecal contamination sources and disinfecting water for domestic consumption.

Microbial source tracking (MST) is a technique that can help in solving faecal contamination problems. It is a measurement-based technology which also offers important advantages over source identification practices. This is because by tracking sources of faecal pollution directly, we can better target remediation efforts thereby saving time and resources (Stewart *et al.*, 2003).

Boiling of water and chemical treatment were the common ways of purifying water to make it safe for drinking. However, these methods are expensive, cause environmental damage and require skilled personnel to be applied appropriately (Acher *et al.*, 1997). There has been a major breakthrough in making solar cooking practical through development of a cheap, environmentally friendly and easily available solar box cooker for use in the tropics (http:www.solarcooker.org). Since then, the use of solar radiation as disinfection method has become a common method in purifying water for domestic consumption in developed countries (Lawand *et al.*, 1997). In developing countries, the major source of energy for cooking and boiling water is firewood which is expensive and environmentally unfriendly. Solar energy is non-degradable resource which has been put to little use for the benefit of mankind in developing

countries and hence need to be explored in the tropics for the improvement of human health (Sinton *et al.,* 2002). This study determined the densities of faecal contamination indicators in various community water sources within Lake Naivasha basin. The effects of human handling on the quality of water as well as the potential of solar radiation disinfection in water quality improvement were also explored.

### 1.2 Statement of the problem

Consumption of untreated water can result in waterborne disease outbreaks and transmission. The problem is common in densely populated areas like Lake Naivasha basin where sewage disposal problems and poor water handling practices at sources, public and domestic domains compromise domestic water quality. This also increases chances of contracting and transmitting Waterborne diseases (WBDs) (Plate 1). For this reason analysis of bacteriological quality of water sources at vendors and household domains within Lake Naivasha basin is necessary. This will help in revealing the quality status of water for domestic use and to come up with appropriate remedial measures. The easiest and quickest way of determining the safety level of water sources is by testing for the presence of faecal pollution indicators. In addition, exploring the use of solar radiation in domestic water disinfection is needed to improve the quality of water for domestic consumption. This is particularly useful to a community where the use of other methods of purifying water is not easily affordable. This study therefore determined the bacterial quality of water used by communities within Lake Naivasha basin and explored the use of solar radiation disinfection of domestic water.

**Plate 1:** Some of the activities enhancing the transmission and spread of WBD within Lake Naivasha basin.

## 1.3 Objectives

### 1.3.1 Broad objective

To determine the bacteriological quality of water utilized by communities living in Lake Naivasha basin and explore the use of solar radiation in domestic water disinfection.

### 1.3.2 Specific objectives

These were to;

**(i)** Determine the spatial and temporal variations in the levels of bacterial indicators of faecal contamination in domestic water sources within Lake Naivasha basin.

**(ii)** Assess the effects of human water handling on the density of indicators of faecal contamination in water for domestic consumption within Lake Naivasha basin.

**(iii)** Determine the ratio of *E. coli* to intestinal enterococci as a method of tracking the possible source of faecal pollution into water sources.

**(iv)** Determine exposure time and volume for effective eradication of *E. coli* and total coliforms in water for domestic consumption through solar disinfection based on the prevailing solar radiation conditions within Lake Naivasha basin.

## 1.4 Hypotheses

**(i)** There is no spatial and temporal variation in the levels of bacterial indicators of faecal contamination in domestic water sources within Lake Naivasha basin.

**(ii)** Human water handling has no effect on the density of indicators of faecal contamination in water for domestic consumption in Lake Naivasha basin.

**(iii)** The ratios of *E. coli* to intestinal enterococci are not within the recommended values for microbial source tracking.

**(iv)** Exposure time and volume does not influence eradication of *E. coli* and total coliforms in water for domestic consumption within Lake Naivasha basin based on the prevailing solar radiation conditions.

## 1.5 Justification

The best way to prevent waterborne disease outbreak in a community is by ensuring that water for domestic consumption is safe. To ascertain the safety of water for domestic consumption, it is critical to periodically monitor for the presence of these pathogens from all the domestic water sources. However, it would be a futile exercise, expensive and time consuming to check for the presence of individual pathogens. Instead, an indicator organism from the same habitat as the pathogen and which is easy to culture and identify is used to assay for faecal contamination of domestic water. This will give a measure of bacteriological quality of the water sources and provide information on the appropriate method to apply in order to maintain the safety of water for domestic use. Solar radiation as a method of water disinfection technique is cheap and locally available in the tropics. Therefore, there is need to know the optimum time and water volume in which the technology is most efficient under prevailing solar radiation conditions within Lake Naivasha basin.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction to Ecosystem Health

According to Karr (1999), an environment is healthy when the supply of goods and services required by both human and non-human residents is sustained. A healthy ecosystem may be defined in terms of three main features: vigour (a measure of activity, metabolism or primary productivity), resilience (the ability of a system to maintain its structure in the presence of stress), and organization (number and diversity of interactions between components of the systems) (Mageau *et al.*, 1995). A healthy aquatic ecosystem can also be defined as that which is sustainable and resilient, maintaining its ecological structure and functions overtime while continuing to meet societal needs and expectations (Meyer, 1997). According to Maddock (1999), ecosystem indicators include the ecological status, water quality (both physico-chemical and biological), hydrology, geomorphology and availability of physical habitat. All these indicators are controlled by abiotic and biotic factors. Pathogens are some of the biotic components that affect the ecosystem health since they cause diseases to man and other animals in the ecosystem. Improvements in drinking-water supplies, excreta disposal measures and nutritional hygiene can reduce the transmission of many infections hence keeping the ecosystem healthy (Oomen *et al*., 1990). Water quality improvement measures have not been addressed in Lake Naivasha basin despite the high population densities, poor sanitation and incidences of diarrheal diseases outbreaks being realised in the area (Mireri, 2005). Many studies within this area have only focused on the fisheries ecology, hydrology and chemical water quality with less focusing on bacteriological water quality (Haper and Mavuti, 2004).

## 2.2 Importance of water borne diseases

Water borne diseases are mainly microbial infections which generally arise from contamination of water by human or animal faeces or urine infested by pathogenic microbes and directly transmitted when unsafe water is drunk or used in food preparation (WHO, 2002). Like any other disease, WBDs also have a negative effect on the economic development, for example in 1993 cryptosporidiosis outbreak in Milwaukee (USA) made 403,000 Milwaukee residents developed diarrhoea reflecting an attack rate of 52% of the population (Wilconsin, 1993). Over 4,000 residents were hospitalized with cryptosporidiosis which was listed as the underlying cause of

death in 100 patients. This lowered the economic development by making 725,000 productive days to be lost costing $54 million in lost time and associated expenses for the Milwaukee community (Meinhardt, 2009). These incidences of economic and life losses are also occurring in developing countries and various measures need to be put in place to enhance water quality improvement. Integrated Water Resource Management (IWRM) is one of such measures where various dimension are put into consideration. Despite the effect of WBD outbreak on the economy, safe and clean drinking water has not been a subject of interest within Naivasha flower farm region exposing the entire population to incidences of waterborne diseases (M'cLeen, 2001). Examples and categories of some of the major WBD and their causative agents are shown in Table 1.

**Table 1:** Examples of waterborne diseases: (adopted from Grabow, 1996).

| Type of Microorganism | Disease Name | Causative Agents | Symptoms |
|---|---|---|---|
| Bacteria | Salmonellosis | *Salmonella* | Diarrhoea or vomiting. Symptoms vary with type caused. |
| | Gastroenteritis | *E. coli O1*57:H7 and other *E. coli,* | Inflamed intestine, enlarged spleen, high temperature-sometimes fatal diarrhoea. |
| | Typhoid | *Salmonella typhi* | Vomiting, severe diarrhoea, rapid dehydration, mineral loss-high mortality. |
| | Shigellosis | *Shigella* | |
| | Cholera | *Vibrio cholerae* | |
| Viruses | Hepatitis A | Hepatitis A virus | Yellowed skin, enlarged liver, fever, vomiting, weight loss, abdominal pain-low mortality, last up to four months. paralysis |
| Protozoa | *poliomyletis* | Polio virus | Diarrhoea or vomiting |
| | Viral gastroenteritis | Rotavirus | Mild diarrhea |
| | Amoebiasis | *Entamoeba histolytica* | Dysentery and extra intestinal infection. |
| | Giardiasis | *Giardia lamblia* | Diarrhoea, cramps, nausea and general weakness lasts one week to months. |
| | Cryptosporidiosis | *Cryptosporidium parvum* | Diarrhoea, stomach pain lasts days to weeks. |

## 2.3 Water quality monitoring through IWRM

Integrated Water Resource Management (IWRM) perspective ensures that social, economic, environmental and technical dimensions are taken into account in the management and development of water and its resources. Water resource development and management should be based on a participatory approach, involving users, planners and policy makers at all levels. IWRM is a sustainable approach of the water management that recognizes its multidimensional character; time, space, multidiscipline (science/technology). It also recognizes stakeholders (regulators/ users/providers/neighbours) and the necessity to address, embrace and relate these dimensions holistically so that sustainable solutions can be brought about, (Thomas and Durham, 2003). This management approach is termed integrated water resources management. It is a blend of three subsystems which are inter-related to achieve a specific objective as illustrated in the conceptualized diagram (Figure 1).

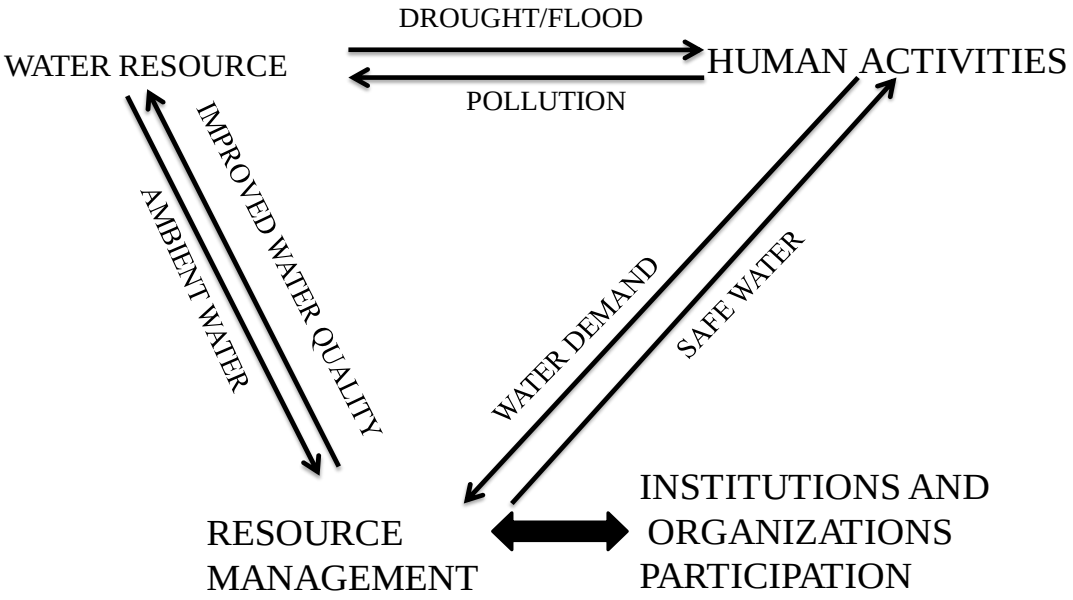



**Figure 1:** Conceptual framework on water quality monitoring through IWRM approach. (Modified from Thomas and Durham, 2003).

## 2.4 Sources and routes of water contamination

Many pathogenic bacteria (*Clostridium botulinum* type E, pathogenic *Vibrio* sp. and *Aeromonas*) are naturally present in aquatic environments, while others (*C. botulinum* type A and B and *Listeria monocytogenes)* occur in the general environment. Others (*Salmonella* spp., *Shigella* spp., *E.coli* and enteric viruses and other protozoans and helminthes) are of animal/human origin (Huss *et al*., 2000). Thus, there is often a possible likelihood that these microorganisms are passed to the consumers when untreated water is consumed or even to the food during production and processing if the water used is untreated. Insects, birds and rodents have been recognized as important carriers of pathogens and other micro-organisms, (Olsen and Hammack, 2000; Urban and Broce, 2000). In one interesting case *Salmonella* outbreak was traced back to amphibians, which had accidentally entered the production facility (Parish, 1998). Fenlon (1983) and Beveridge (1988) demonstrated that some aquatic birds spread *Salmonella* and other human pathogens in the environment indicating potential danger in consumption of untreated water.

Water, like food, is a vehicle for the transmission of many agents of diseases and continues to cause significant outbreaks of diseases in developed and developing countries world-wide (Kirby *et al*., 2003). In Canada, an outbreak of *E. coli* was reported in the year 2000 (Kondro, 2000). In the USA *Cryptosporidium* affected approximately 400,000 consumers and caused 45 deaths in 1993 due to consumption of contaminated water (Kramer *et al*., 1996; Hoxie *et al*., 1997). A cholera epidemic in Jerusalem, Israel in 1970 was traced back to the consumption of salad vegetables irrigated with raw wastewater (Shuval *et al*., 1996). It is therefore important that safe water is used throughout the production process. There should also be a monitoring program starting from the water source, through treatment, distribution and storage within the plants and at the vendors and household domains, to ensure that the water complies with internal or legislative standards (Kirby *et al*., 2003).

## 2.5 Bacterial indicators of faecal pollution

Various bacteria are natural inhabitants of the digestive tracts of animals and humans and pass into water through faeces. Some of these bacteria, such as coliforms, *E. coli* and *Enterococcus* spp., are used as hygiene indicators (Frahm *et al*., 2003). Faecal contamination indicator microorganism's numbers points to inadequate safety in the environment as their presence in

aquatic systems indicate presence of faecal and sewage pollution (Mossel *et al*., 1995). They are also used to assess food safety and water sanitation (Jay, 1992). There is no universal agreement on which indicator microorganism(s) is most useful, nor are there state regulations mandating a single standard for bacterial indicators. Thus, different indicators and different indicator levels identified as standards are used in different states, countries, and regions. Today, the most commonly measured bacterial indicators of faecal pollution into water sources are total coliforms (TC), faecal coliforms (FC), (EC) *E. coli* (a subset of the FC group) and because their presence in water is an indication of recent faecal pollution entrococci (Noble *et al*., 2003). Other bacterial indicators can survive and proliferate in the environment and their presence may not necessarily indicate recent faecal pollution. Owing to issues relating to complexity, cost and timeliness of obtaining results, testing for specific pathogens is generally limited to validation, where monitoring is used to determine whether a treatment or other process is effective in removing target organisms (Pote *et al.,* 2009). However, microbial testing included as part of operational monitoring is normally limited to that for indicator organisms, either to measure the effectiveness of control measures or as an index of faecal pollution (Jay, 1992). The concept of using indicator organisms as signals of faecal pollution is a well-established practice in the assessment of drinking-water quality (Noble *et al*., 2003). The criteria determined for such indicators and index organisms are many. They include; the organisms to be used as indicators should not to be pathogens themselves, they should be universally present in faeces of humans and animals in large numbers and not multiply in natural waters, they should persist in water in a similar manner to faecal pathogens, they should also be present in higher numbers than faecal pathogens, they should respond to treatment processes in a similar fashion to faecal pathogens and should be readily detected by simple inexpensive methods (Ashbolt *et al.,* 2001).

### 2.5.1 Coliform bacteria

Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli. They are capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24-48 hours at 35–37 $^{0}$C (APHA 2005). *E. coli* and thermotolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures, (Bonde, 1997). As part of lactose fermentation, total coliforms produce the enzyme β-galactosidase.

Traditionally, coliform bacteria are regarded as belonging to the genera *Escherichia*, *Citrobacter*, *Klebsiella* and *Enterobacter*, but the group is more heterogeneous and includes a wider range of genera, such as *Serratia* and *Hafnia* (Doyle and Erickson, 2006). The total coliform group includes both faecal and other environmental species. Total coliforms include organisms that can survive and grow in water and vegetation. Hence, they are not useful as an index of faecal pathogens, but they can be used as an indicator of treatment effectiveness and to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms, (Sueiro, 2001). Total coliform bacteria occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms. Their presence in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation as noticed in water storage containers. Their presence also shows contamination through increase of foreign material, including soil or plants (Grabow, 1996, Ashbolt *et al.,* 2001, Sueiro, 2001).

### 2.5.2 Thermotolerant coliform bacteria and *Escherichia coli*

Coliform bacteria that are able to ferment lactose at 44–45$^0$C are known as thermotolerant coliforms. In most waters, the predominant genus of coliform bacteria is *Escherichia*, but some types of *Citrobacter*, *Klebsiella* and *Enterobacter* are also thermotolerant. *E. coli* can be differentiated from the other thermotolerant coliforms by the ability to produce indole from tryptophan or by the production of the enzyme β-glucuronidase. *E. coli* is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution, although there is some evidence for growth in tropical soils (Ashbolt *et al*., 2001). *E. coli* are considered the most suitable index of faecal contamination. In most circumstances, populations of thermotolerant coliforms are composed predominantly of *E. coli* and are acceptable indicator of faecal pollution (Sueiro, 2001). *E. coli* (or alternatively, thermotolerant coliforms) is the first organism of choice in monitoring programmes for verification, including surveillance of drinking-water quality. *E. coli* occur in high densities in human and animal faeces ($10^9$ per gram of faeces), sewage and water subject to recent faecal pollution (George, 2001). This is because water temperatures and nutrient conditions present in drinking-water distribution systems are highly unlikely to support the growth of these organisms. The presence of *E. coli* provides

evidence of recent faecal contamination, and detection should lead to consideration of further action, which could include further sampling and investigation of potential sources such as inadequate treatment or breaches in distribution system integrity, (Grabow, 1996; Ashbolt *et al.*, 2001; George, 2001and Sueiro, 2001).

### 2.5.3 *Clostridium perfringens*

*Clostridium* spp. is Gram-positive, anaerobic, sulphite-reducing bacilli (Araujo, 2001; APHA, 2005). They produce spores that are exceptionally resistant to unfavourable conditions in water environments, including UV irradiation, temperature and pH extremes, and disinfection processes, such as chlorination (Ashbolt *et al*., 2001). The characteristic species of the genus, *C. perfringens*, is a member of the normal intestinal flora of 13–35% of humans and other warm-blooded animals. Other species are not exclusively of faecal origin. Unlike *E. coli*, *C. perfringens* does not multiply in most water environments and is a highly specific indicator of faecal pollution. In view of the exceptional resistance of *C. perfringens* spores to disinfection processes and other unfavourable environmental conditions, it has been proposed as an indicator of enteric viruses and protozoa in treated drinking water supplies (Njeminski *et al*., 2000).

In addition, *C. perfringens* can serve as an index of faecal pollution that took place recently and hence indicate sources liable to intermittent contamination (Araujo, 2001, Ashbolt *et al*., 2001). *C. perfringens* is not recommended for routine monitoring, since the exceptionally long survival times of its spores are likely to exceed those of enteric pathogens, including viruses and protozoa. *C. perfringens* spores are smaller than protozoan (oo)cysts and may be useful indicators of the effectiveness of filtration processes (Njeminski *et al*., 2000). Low numbers in some source waters suggest that use of *C. perfringens* spores for this purpose may be limited to validation of processes rather than routine monitoring. *C. perfringens* and its spores are virtually always present in sewage and they do not multiply in clean water environments. They are more often present in higher numbers in the faeces of some animals, such as dogs, than in the faeces of humans and many other warm-blooded animals (Araujo, 2001, Ashbolt *et al*., 2001). The numbers excreted in faeces are normally substantially lower than those of *E. coli*. Vegetative cells and spores of *C. perfringens* are usually detected by MFT in which membranes are incubated on selective media under strict anaerobic conditions (APHA 2005). Filtration

processes designed to remove enteric viruses or protozoa should also remove *C. perfringens*. Detection in water immediately after treatment should lead to investigation of the filtration plant performance, (Njeminski *et al*., 2000).

### 2.5.4 Enterococci as indicators of faecal pollution

Enterococci is a sub group of faecal streptococci and differentiated from other streptococci by their ability to grow in 6.5% sodium chloride at pH 9.6 and $10^0$C -$45^0$C. It is a valuable bacterial indicator for determining the extent of faecal contamination in aquatic systems (APHA 2005). Presence of faecal enterococci when *E. coli* is not detected is an indicator that there is recent faecal pollution in water.

### 2.5.5 Heterotrophic plate count

The numbers of colony forming units of heterotrophic bacteria in water are indicators of pollution with easily degradable organic matter. HPC also known as the standard plate count is a procedure for estimating the number of live heterotrophic bacteria in water and measuring changes during water treatment, distribution or in swimming pools. Colonies may arise from pairs, chains, clusters or single cells, all called colony forming units. The final count also depends on the interaction among the developing colonies, (APHA, 2005). In surface water they are an indication that water is loaded with high concentration of assimilable organic carbon (AOC) as it is normally the case with domestic sewage pollution. High densities of HPCs in water may indicate high oxygen consumption, high heterotrophic activity, high BOD and low DO (APHA, 2005).

## 2.6 Bacteriological water quality analyses methods

### 2.6.1 Membrane filtration technique

In the membrane filter method, membranes with a pore size that will retain bacteria but allow water or diluents to pass through are used. Following the collection of bacteria upon filtering a given volume, the membrane is placed on an agar plate or an absorbent pad saturated with culture medium of choice, and incubated appropriately and after growth, colonies are enumerated (Jay, 1992; APHA, 2005). This method offers rapid quantitative enumeration and more efficient than other methods. This is because it is able to work with flexible sample volume range enabling the use of large sample volume and increasing sensitivity. Water soluble impurities

interfering with the growth of target organisms are separated from the sample in the filtration step. It also gives quantitative result and good precision if the number of colonies grows adequately and further cultivation steps are not always needed. This lowers the costs and time needed for the analysis. When confirmation is needed, isolation from well separated colonies on membrane is easy. On the other hand it causes some difficulties as; quality of membranes varies, solid particles and chemicals adsorbed from sample to the membrane during filtration may interfere with the growth of the target organism, not applicable to turbid samples and scoring of typical colonies not always easy (APHA, 2005).

Total coliforms are generally measured in 100 ml samples of water. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme β-galactosidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 35-37 $^0$C and counting of colonies after 24 hours. Alternative methods include most probable number procedures using tubes or micro-titre plates and presence/absence (P/A) tests. Total coliforms should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment. *E. coli* is also generally measured in 100 ml samples of water. A variety of relatively simple procedures are available based on the production of acid and gas from lactose or the production of the enzyme β-glucuronidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 44-45 $^0$C and counting of colonies after 24 hours. Alternative methods include most probable number procedures using tubes or micro-titre plates and P/A tests, some for volumes of water larger than 100 ml (APHA, 2005). According to WHO guidelines, risk assessment is based on the levels of *E. coli*, i.e. low, moderate, high and very high risks of water borne disease infection as indicated by the following respective numbers of *E. coli* per 10 ml of water i.e. <1, 1-9, 1-10 and > 10 respectively (WHO, 2002).

### 2.6.2 Most probable number

The most probable number method consists of inoculating a series of tubes with appropriate decimal dilutions of the sample. Production of gas, acid formation or abundant growth in the test tube after a certain period of time incubation at 35 $^0$C constitutes a positive presumptive reaction. Both lactose and Laury Tryptose broths can be used as presumptive media. All tubes with

positive presumptive reaction are subsequently subjected to a confirmation test. The formation of gas in a Brilliant Green Lactose Bile (BGLB) broth fermentation tube at any time within 48 hours at 35 $^0$C constitutes a positive confirmation test. A test using an EC medium can be applied to determine TC that are FC, the production of gas after 24 hours of incubation at 44.5 $^0$C in an EC broth medium is considered a positive result (Rompré *et al*., 2002).

### 2.6.3 Flow cytometry

This is a technology in which a variety of measurements can be made on particles, cells, bacteria and other objects suspended in a liquid. In a flow cytometer, particles are made to flow one at a time through a light beam (laser beam) in a sensing region of a flow chamber. They are characterised by light scattering based on their size, shape and density. This also depend on the dyes that are used either independently or bound to specific antibodies or oligonucleotides that endow a fluorescent phenotype onto components of interest. As a particle flows through the beam, both light scattered by the particle and fluorescence light from the labelled particle is collected. This is done either by a photomultiplier or photodiode in combination with light splitters (dicroic mirrors) and filters (Vesey *et al.*, 1994). A solid phase laser scanning analyzer might be an alternative for the flow cytometry technology (Deere *et al*., 2002). The basic instrument is the flow cytometer, which is expensive and requires a skilled operator. In addition, most of the pathogenic microbes to be measured occur in drinking water at very low concentrations. When a negative sample is analyzed no particles should be detected and a sample seeded with an aliquot of organisms should have an exact number of particles added (Vesey *et al.*, 1994).

## 2.7 Effects of human handling practices on the quality of water

Faecal contamination of domestic water sources due to activities like improper waste discharge and low sanitation standards within the households renders the water unsafe for domestic usage in developing countries. Majority of people in these countries lack access to piped water and therefore are forced to transport and store the water in their house holds for varied period of time depending on the frequency of use during which the quality may be compromised (Wright *et al*., 2004). There are two major contamination domains in water supply; public and household/domestic domain which should frequently be monitored to ensure that the quality

from source is maintained at domestic level. This is because if the levels of contamination at the public domains are high, then efforts at domestic domain may be futile (Jensen *et al.*, 2002). Contamination at times enhanced by presence of vendors in the water distribution chain (Kjellen and Mc Granaham, 2006). Domestic water handling based contamination chain is as summarised in Figure 2.

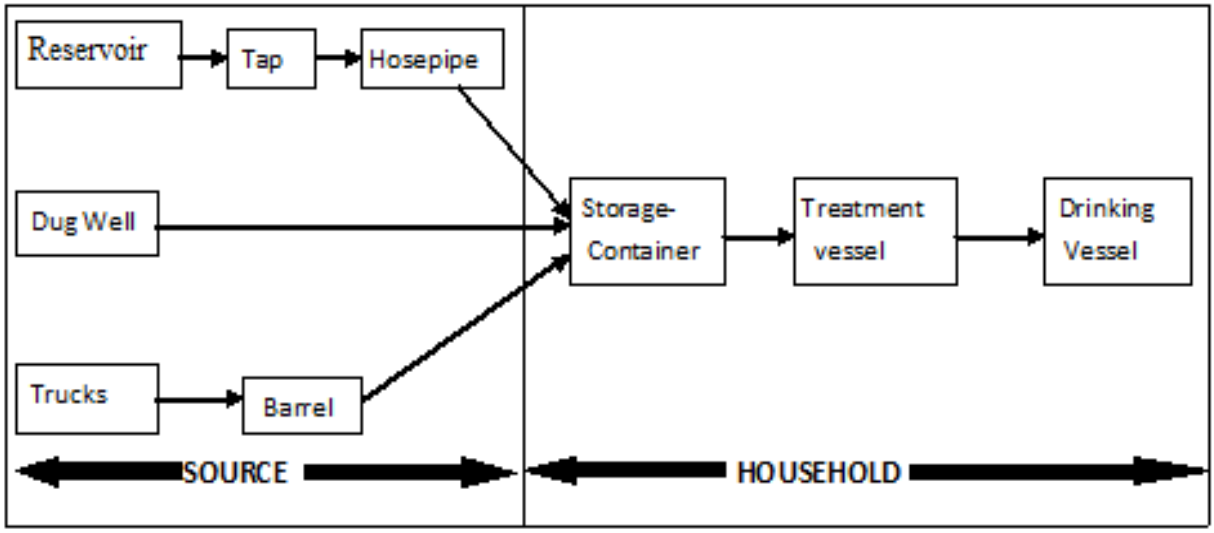



**Figure 2:** Potential drinking water contamination pathways between source and household. (Modified from Rufener *et at.*, 2010).

### 2.8 Source tracking for faecal contamination

The sources of faecal contamination are widespread and the effects are influential. Some of the possible human sources include effluents from sewage treatment plants and faulty on-site septic systems. Of equal importance are the nonhuman sources of pollution such as domestic animals which also contribute to the contamination of surface water. Surface runoff from animal grazing areas and manure-treated agricultural land for example can find its way into nearby bodies of water. Other domesticated animals including cats and dogs must also be considered possible sources. Finally, wildlife can contribute significant amounts of faecal contamination to otherwise pristine environments that are minimally impacted by humans (Weaver *et al.*, 2005).

Several methods of source tracking of faecal contamination have been proposed, and the strengths and weaknesses of these methods have been reviewed (Scott *et al.*, 2002). These methods are grouped into; non molecular library independent methods, molecular library

dependent methods, molecular library independent methods and chemical methods. Non molecular library independent methods include the use of faecal bacterial ratios and non-molecular host specific indicators. Molecular library dependent methods are repetitive polymerase chain reaction, pulse field gel electrophoresis, ribotyping and randomly amplified polymorphic DNA. Molecular library independent methods are bacteriophage indicators and virus (human pathogen) indicators (Simpson *et al.,* 2002).

Faecal bacterial ratios is one of the techniques developed in the source tracking field and is mainly based on the ratios of faecal coliform (*E. coli*) to fecal streptococci (intestinal enterococci) (FC:FS). In this method CFUs (Colony Forming Units) of faecal coliforms and faecal streptococci are counted on plates and a ratio between the two is determined. A ratio of more than 4 is considered human contamination and a ratio of less than 0.7 suggests non-human sources. Die-off rates are monitored through time and the change in the FC:FS ratio is then used to further interpret possible sources. FC:FS ratios is still useful as a general indicator of human verses non-human faecal bacterial contamination (Weaver *et al.,* 2005).

**2.9 Solar pasteurization**

Microorganisms are heat sensitive and require temperatures of between 50-75 $^0$C for 99.9% elimination (Negar and Metcalf, 1999). The most favourable region for solar disinfection lies between latitudes $15^0$ N/S and $35^0$ North and South of the Equator. These semi-arid regions are characterised by high solar radiation (3000 hours sunshine per year) and limited cloud coverage and rainfall. The second most favourable region lies between the equator and latitude $15^0$ North and South of the Equator, the scattered radiation in this region is quite high (2500 hours sunshine per year). The need for a low-cost, low maintenance and effective disinfection system for providing safe drinking water is paramount, especially for the developing countries. Previous studies had also found that river water in 4 litres cooking pots could be heated to 80 $^0$C or more in 2 hours in a Solar Box Cooker (SBC), killing all coliform and faecal coliform bacteria (Metcalf and Logvin 1999). Metcalf and Logvin (1999) explored the use of an SBC and built one which was deep enough to hold three to four 3.7-liter (1-gallon) jugs and investigated what temperatures would be reached in 1, 2, and 3 jugs of water in SBC at various times of the year and under different weather conditions. They also investigated what time-volume combinations

would be sufficient to kill coliform bacteria in river water and used the heat inactivation of coliforms as an index of water pasteurization. It has also been found that heating water to a temperature of 65 $^{0}$C with no specific time duration and volume will pasteurize water and make it safe for drinking (Robert, 2005).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study area

### 3.1.1 Geographical location

This study was carried out in Lake Naivasha basin (Fig. 3) within Africa. The basin is in Rift Valley Province of Kenya. The lake is one of the major water bodies in Kenya besides Lake Victoria, Lake Turkana, Lake Baringo, lake Bogoria, and Lake Elementaita. Lake Naivasha is a fresh water lake though it lacks a well established outlet. It is located within the Kenyan Rift Valley and its watershed covers parts of both, the Rift Valley and the Central Provinces. Lake Naivasha watershed is mainly a semi-arid environment with scarce surface and underground water resources. The lake basin extends $6^0$ North from the Equator and lies between $36^0 07'$ and $36^0 47'$ East of Greenwich Meridian.

### 3.1.2 Rainfall and temperature patterns

Lake Naivasha is located in the rain shadow of the Aberdare Range with a mean annual rainfall of about 650 millimetres and experiences long rains in months of March to May and short rain in the months of September to October. The mean annual rainfall in Lake Naivasha area as well as in the Aberdare Range is 1350 millimetres. The mean temperature around Lake Naivasha is approximately 25 $^0$C with a maximum temperature of 30 $^0$C, with the months of December – March being the hottest period. July is the coldest month with a mean temperature of 23 $^0$C. (Mireri, 2005).

### 3.1.3 Water sources

The Lake Naivasha watershed is mainly drained by only two perennial rivers, namely Malewa and Gilgil with catchment areas of 1700 km$^2$ and 400 km$^2$ respectively. These two rivers drain into the lake at its Northern side. In addition, the lake is also drained by other seasonal rivers and streams with the major one being River Karati to the North. The lake, rivers, shallow wells and ground water sources are key to sources of water to the Naivasha and Nakuru municipalities as well as other adjoining human activities (Mireri, 2005).

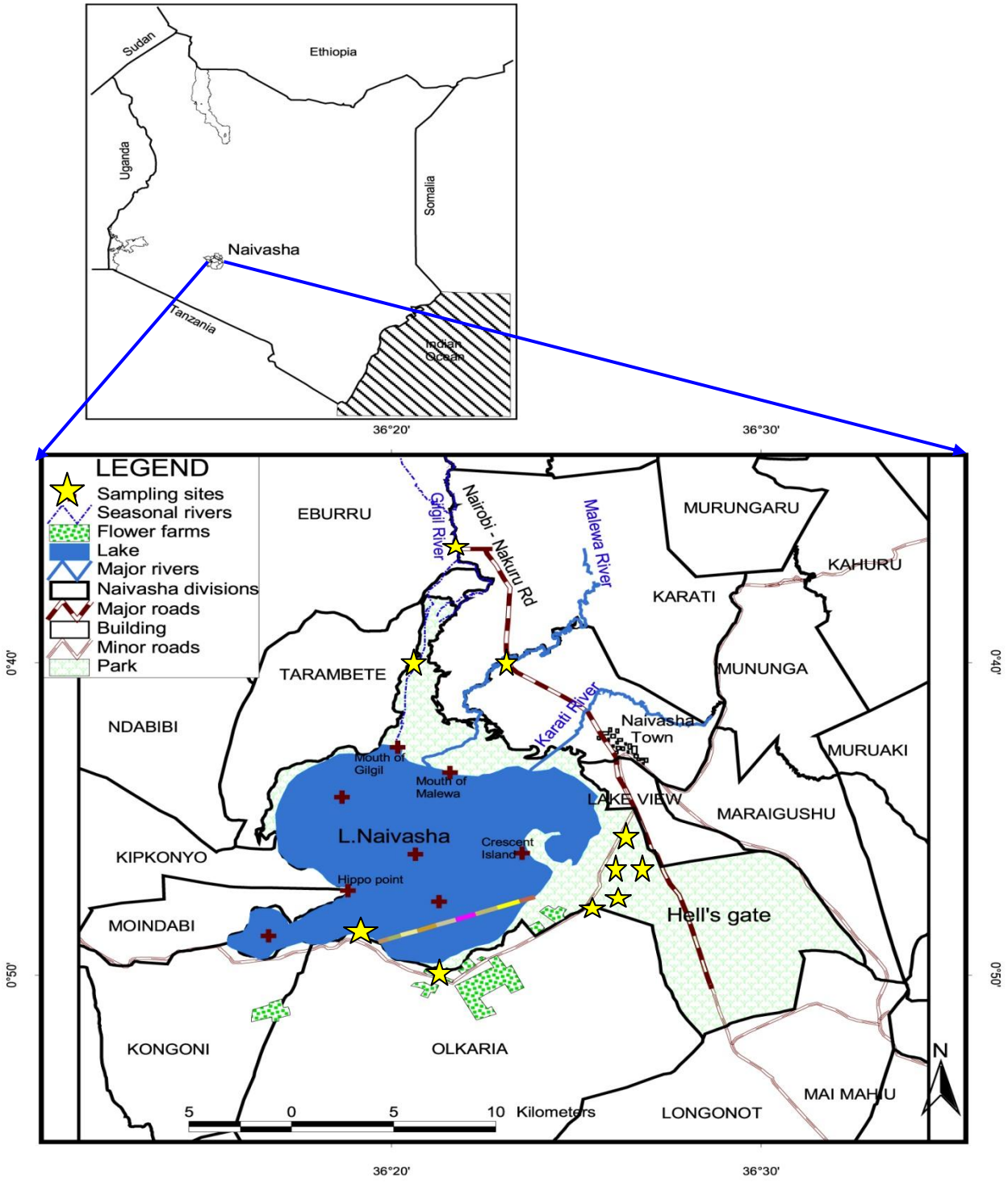



**Figure 3:** Map of Lake Naivasha basin showing the study sites.
(modified from Mireri, 2005).

### 3.2 Study design

#### 3.2.1 Sampling

Water samples were obtained in duplicate from the following sources; Lake Naivasha (at Kamere beach), River Malewa (at the Naivasha-Nakuru highway bridge), River Gilgil (downstream at the bridge near the New Rift Valley Lodge and upstream at the bridge along Naivasha-Nakuru Highway) as well as boreholes, vendors and households in Karagita, Mirera and Kamere villages. For all the sources, sampling was done weekly for four months (April to July 2011) to cover the rainy season (April- May) and dry season (June- July). The sampling sites were located using a GPS. Sterilized 500ml polyethylene water sample bottles were used to collect water sample. This was done at 30 centimetres below the surface from the rivers and lake. From boreholes direct sources, samples were obtained by first sterilizing the nozzle with 70% alcohol. The bottles were aseptically filled up. Borehole points of access were samples in the same manner the community access the water, sterilization was not involved. In addition, 25 households and 5 vendors from each of the three villages were randomly selected for the study. Household water was sampled from drinking water storage containers while water from vendors was sampled through the same delivery hose pipes used in transferring water into the consumers' containers. Water temperature, dissolved oxygen, percentage saturation of dissolved oxygen and pH were measured *in situ* using a WTWÒ microprocessor pH/temperature meter. The meter was calibrated with pH 4 and 7 using standard buffer solutions according to manufacturer's instructions (WTW, Vienna, Austria). The electrode was rinsed with distilled water between samples. Electrical conductivity was measured using a WTWÒ microprocessor conductivity meter calibrated at 25°C. All the water samples were stored in a cool box with ice and transported to Egerton University, Department of Biological science laboratory for analysis.

### 3.2.2 Description of sampling sites and water sources

The location and categories of water sources sampled were as described in Table 2.

**Table 2:** Description and location of study sites

| CODE | FULL NAME OF THE SOURCES | LOCATION |
|---|---|---|
| KRBHI -DIR | Karagita borehole I-direct source | S00$^0$,46',48.8"/E036$^0$,26',17.7" |
| KRBHI -POA | Karagita borehole I-point of access | S00$^0$,46',48.8"/E036$^0$,26',17.7" |
| KRBHII- POA | Karagita borehole II-point of Access | S00$^0$,46',40.4"/E036$^0$,26',09.2" |
| KRBHIII -DR | Karagita borehole III-direct source | S00$^0$,46',29.7"/E036$^0$,26',10.7" |
| KRBHIII-POA | Karagita borehole III-point of Access | S00$^0$,46',36.5"/E036$^0$,26',07.5" |
| KRBHIV-DIR | Karagita borehole IV direct source | S00$^0$,46',50.2"/E036$^0$,26',01.4" |
| KRBHV-POA | Karagita borehole V point of Access | S00$^0$,46',42.8"/ E036$^0$,25',43.1" |
| DCK-DIR | DCK direct source | S00$^0$,49',59.1"/E036$^0$,20',57.8" |
| KMBEACH | Kamere beach | S00$^0$,48',53.2"/ E036$^0$,19',28.4" |
| MAL RVR | River Malewa | S00$^0$,40.0',8.8"/E036$^0$,23.0',18.7" |
| GL RVR-UP | River Gilgil upstream | S00$^0$,33.0',38.8"/E036$^0$,21.0',28.0" |
| GL RVR-DWN | River Gilgil downstream | S00$^0$,32.0',18.8"/E036$^0$,23.0',12.6" |

#### (i) Borehole water - Direct (DIR) Sources

For direct borehole waters, samples were obtained directly from the boreholes as it was being pumped. This involved opening of the metal pipes from the valves/points where they are joined using an adjustable spanner. The pipe was sterilized with ethanol before the samples were obtained.


**Plate 2:** Direct borehole sites; (a) DCK and (b) KRBH III

**(ii) Borehole water sources- points of access (POA)**

Various boreholes waters were also sampled at the consumers' uptake points (points of access). This was done through delivery hose pipes. The water sampled at these points was generally from the reservoirs which acted as temporary storage for the water pumped from the borehole direct sources. At this points water sampling bottles were filled up in the same way the community is supplied, with no sterilization done prior to sampling.


**Plate 3:** Borehole points of access; (a) KRBH-II and (b) KRBH-V.

**(iii) River Malewa**

The sampling site along the river Malewa was located at the bridge along Naivasha-Nakuru highway. Water samples were obtained 30cm below the water surface. The site is a major access point to both human and animals.

**Plate 4:** River Malewa sampling site (MAL RVR)

**(iv) River Gilgil**

Two sites were sampled along River Gilgil; downstream site at the bridge along Morendat Training and Conference Centre towards the new Rift Valley Lodge road and the up-stream site at the bridge along Naivasha- Nakuru highway. The upstream site was noted to be the major access point for both animals and man.


**Plate 5:** River Gilgil sampling sites.
(a) Upstream (GL RVR-UP) (b) downstream (GL RVR-DWN).

**(v) Kamere Beach**

This site was at the northern side of Lake Naivasha. It is the main access point to the lake and was noted to be harbouring several activities ranging from laundry work, fish landing, watering and grazing of both domestic and wild animals as well as washing of tracks. Water for domestic use was also being obtained from the same point by some vendors and households.

**Plate 6:** Sampling site within Lake Naivasha at Kamere Beach (KMBEACH)

### (vi) Vendors

Water from vendors was sampled through a delivery hose pipe. This was also done in the same way the water is filled into the consumers' containers. In total water samples were obtained from five vendors from each of the three villages (Karagita, Mirera and Kamere), totalling to fifteen vendors.

**Plate 7:** Water sampling from vendors' domain

### (vii) Households

At the household level, water samples were obtained in the same manner by which the households access it. Most of the storage containers were noted to be open with no lids. In total, water samples were obtained from twenty five households from each of the three villages (Karagita, Mirera and Kamere), totalling seventy five households.

**Plate 8:** Water storage container at the household domain

### 3.3 Bacteriological samples analysis

Analysis of water samples for various types of microbiological indicators of pollution followed guidelines outlined in APHA, 2005; Scott *et al.,* 2002 and Lawand *et al.,* 1997. This was done within 6-24 hours after sampling to avoid changes of the bacteria count due to growth or die off. Aseptic techniques were observed in all the analysis. Analysis involved the use of heterotrophic plate count (HPC) procedure to estimate the number of live heterotrophic bacteria. Membrane Filtration Technique (MFT) was also used in the analysis of samples for the presence of indicator organisms. The nutrient and selective media was prepared in advance for each procedure as per the manufacturer's instructions. Serial dilutions of samples were made as appropriate for each test depending on the water source. Disinfection of the water samples was done through solar radiation. Tracking of possible faecal contamination sources of domestic water sources was achieved through determination of the ratio of *E. coli* to faecal streptococci.

#### 3.3.1 Heterotrophic plate count procedure

1 ml of each sample or its dilution was placed onto 80 mm diameter plates with plate count agar and incubated at $37^0$C for 48 hours. Colonies forming units (CFU) (plate 9) were counted and expressed as CFU per 1ml (APHA, 2005).

**Plate 9:** Colony forming units for Heterotrophic Plate Counts

### 3.3.2 Membrane filtration technique

Aseptic filtration was done separately for each dilution by passing the sample through a membrane filter (47mm diameter, 0.45µm pore size) on a filtration unit. The filter was taken off using a pair of forceps and placed on the surface of the corresponding culture media. For total coliforms and *E. coli* counts, filters were placed onto chromocult agar (Merck) plates and incubated at $37^0$C for 18-24 hours. Typical colonies appearing pink and dark blue as in plate 10 (a) below were counted as total coliforms. *E. coli* were the blue colonies only. Numbers of cells were expressed as CFU's /100ml (APHA, 2005). For intestinal enterococci counts, filters were placed onto enterococci agar (Merck) plates and incubated at $44^0$C for 24-48 hours. Typical colonies appearing pink as in plate 10 (b) below were counted as intestinal enterococci and numbers expressed as CFU's /100ml (APHA, 2005). For *C. Perfringens* counts, filters were placed onto Tryptose Sulphite Cyclocerine (TSC) agar (Merck) plates. The filters were then placed in an anaerobic jar containing anaerocult strip and incubated at $44^0$C for 18-24 hours. Black fluorescent counts of *C. perfringens* as in plate 10 (c) below were made under 360nm UV light. Colonies forming units (CFU) counted were expressed as CFU/100ml as stipulated in (APHA, 2005).

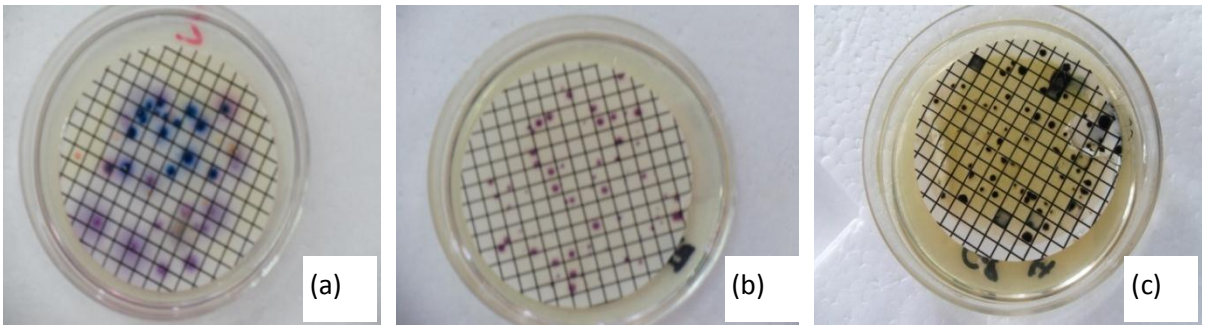



**Plate 10:** Plates of MFT showing CFUs.
(a) total coliform and *E. coli*, (b) intestinal enterococci and (c) *C. perfringens*

### 3.4 Solar disinfection

Solar pasteurization was done using pasteurization kit comprising of aluminium "sufuria" (sauce pan) with a lid, all painted black on the outside and fixed with water pasteurization indicator (WAPI) which is basically candle wax that melts at pasteurization temperature. A thermometer was also included to give actual temperature readings. The sauce pan was placed onto a reflector

panel made of a hard shinny cardboard of 0.5×0.5×0.2 metres in dimensions. The reflector was used to maximally direct the sun's rays to the saucepan (Plate 11). The experiment was carried out on water samples from the lake, river and borehole. The kit was set up and exposed to direct sunlight on a clear day and left to stand until the wax in the indicator melted. This experiment was set up within Lake Naivasha area. Different water volumes of 1 litre, 2.5 litres and 5 litres were subjected to this pasteurization procedure. After the melting of WAPI indicator, samples were picked from these volumes at 0, 15 and 30 minutes time intervals (Acher *et al.*, 1997) and subjected to membrane filtration technique to determine the density of total coliforms and *E. coli*. Optimum volume and time for solar radiation in water disinfection was determined by finding the volume-time combination with least number/zero colony counts.

**Plate11:** Solar pasteurization kit

### 3.5 Tracking of faecal contamination sources

Source identification for faecal contamination was achieved through *E. coli*: intestinal streptococci ratio determination based on their CFU values. This was done on water from borehole, lake and river. It was based on the knowledge that a ratio of above 4 was to indicate high levels of human faecal contamination while below 0.7 was to indicate contamination by faeces from non-human sources (Scott *et al.*, 2002; Simpson *et al.*, 2002).

### 3.6 Data analysis

Statistical tests and data analysis were done using Statistical Package for Social Sciences (SPSS) statistical analysis software version 17. In all the analysis, 95% level of significance was used as the critical point (P= 0.05). The collected data on the density of indicator organisms and HPC from the water sources were computed for both the raw water samples and water samples

pasteurized at different duration of time time (0, 15 and 30 minutes) and volumes (1 , 2.5 and 5 litres) to find the mean densities from each sampling site and for each water source. Data on physical and chemical parameters (pH, Temperature, DO and Conductivity) were also computed for all the water sources to find the variation in mean values. One way Analysis of Variance (ANOVA) was used to compare means recorded at different sampling dates and/or sites for various selected variables. Student's t-test was used to compare the means of microbiological parameters between borehole direct sources and borehole points of access. Means were separated using least significance difference (LSD) as the *post hoc* test. Correlation analysis was used to compare relationship between the densities of microbial parameters and physico-chemical parameters.

# CHAPTER FOUR
# RESULTS

## 4.1 Physical and chemical parameters

The results on mean values for physical and chemical parameters from all the sampled boreholes and surface sources, households and vendors are shown in Table 3. For all water sources, the range of values were as follows; temperature ranged between 17.9-32.0 $^0$C with borehole waters giving slightly higher values than water from rivers and lake. Dissolved oxygen values were in the range of 1.73-8.10 mgl$^{-1}$ and as expected, samples from rivers gave higher values for DO. Similar results were observed with their corresponding percentage oxygen saturation values. The range for pH values was 7.85-8.88. The values for electrical conductivity were highest in borehole water sources with values ranging between 1003.00 and 1860.00 μscm$^{-1}$. Surface sources (rivers and lakes) on the other hand recorded lower electrical conductivity values of between 123.00- 442.00 μscm$^{-1}$ which was approximately four to six times less than conductivity of borehole waters.

All the physicochemical parameters for the borehole direct sources showed significant variation between the sampling sites (F= 5.91, 5.36, 5.39 and 6.75 for temperature, dissolved oxygen, pH and electrical conductivity respectively, df = 3, 63 and P< 0.05) as shown in Table 4. For borehole points of access sources, all the physico-chemical parameters except temperature showed significant variation between the sampling sites (F= 1.71, 9.44, 3.10 and 29.83 for temperature, dissolved oxygen, pH and electrical conductivity respectively, df = 3, 63 and P< 0.05), as in Table 5. From these results conductivity was generally similar in all the boreholes. For the surface sources, all the physicochemical parameters except pH showed significant variation between the sampling sites (F= 6.71, 6.33, 0.18 and 12.08 for temperature, dissolved oxygen, pH and electrical conductivity respectively, df = 3, 63 and P< 0.05), as in Table 6.

In samples from households, temperature values were generally similar and in the range of; 19.20 to 24.50, 20.60 to 25.60 and 19.10 to 26.30 $^0$C for Karagita, Mirera and Kamere villages respectively. The samples from the above villages also had the following respective range of values for other physico-chemical parameters; 3.60 to 7.70, 3.90 to 7.00 and 1.90 to 7.90 mgl$^{-1}$ for dissolved oxygen, 7.90 to 8.50, 7.30 to 8.50 and 7.20 to 8.50 for pH and 65.00 to 1680.00,

384.00 to 1232.00 and 22.00 to 1667.00 $\mu scm^{-1}$ for electrical conductivity. Water samples from vendors had the following range for physical and chemical parameters; 17.90 to 23.10 $^{0}C$, 1.90 to 5.00 $mgl^{-1}$, 6.90 to 8.60 and 250.00 to 1435.00 $\mu scm^{-1}$ respectively for; temperature, dissolved oxygen, pH and electrical conductivity.

**Table 3:** Values for physical and chemical parameters from different water sources, households and vendors

| Water sources | Temperature (°C) | | DO ($mgl^{-1}$) | | pH | | Conductivity ($\mu Scm^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE |
| KRBH I-DIR | 22.2±0.6 | 21.2-22.9 | 4.13±0.33 | 3.61-4.60 | 8.16±0.20 | 7.85-8.50 | 1326.8±140.1 | 1215-1616 |
| KRBH I-POU | 22.0±0.8 | 20.7-23.4 | 5.68±0.80 | 4.17-7.62 | 8.40±0.30 | 7.95-8.88 | 1284.4±96.7 | 1190-1448 |
| KRBH II-POU | 22.4±1.1 | 21.0-24.2 | 5.03±0.83 | 4.03-6.35 | 8.38±0.20 | 7.95-8.80 | 1250.8±107.8 | 1145-1435 |
| KRBH III-DIR | 23.2±0.9 | 20.5-24.4 | 3.06±1.01 | 1.93-5.02 | 8.10±0.15 | 7.95-8.27 | 1242.9±87.9 | 1155-1426 |
| KRBH III-POU | 22.6±1.4 | 19.7-25.3 | 4.47±0.80 | 2.85-5.42 | 8.2±0.22 | 7.95-8.72 | 1227.8±86.8 | 1150-1399 |
| KRBH IV-DIR | 22.3±1.6 | 20.0-25.0 | 3.27±0.53 | 2.35-4.17 | 8.35±0.18 | 7.95-8.61 | 1260.6±92.1 | 1165-1413 |
| KRBH V-POU | 22.8±1.0 | 20.8-24.7 | 4.47±0.54 | 3.66-5.70 | 8.23±0.18 | 7.95-8.60 | 1580.9±172.6 | 1380-1860 |
| DCKBH-DIR | 24.4±2.8 | 21.1-32.0 | 3.80±1.20 | 1.73-7.17 | 7.50±0.27 | 7.95-7.97 | 1145.3±132.1 | 1003-1453 |
| KM-BEACH | 22.7±1.3 | 20.6-25.1 | 5.13±1.81 | 3.20-7.75 | 8.05±0.62 | 7.95-8.87 | 283.6±48.9 | 248.0-442.0 |
| MAL RVR | 21.5±1.8 | 17.9-25.0 | 6.56±0.77 | 4.17-7.61 | 8.03±0.44 | 7.95-8.43 | 212.4±39.9 | 123.0-273.0 |
| GL RVR-UP | 21.9±1.7 | 18.9-24.6 | 6.93±1.00 | 4.17-8.10 | 8.13±0.30 | 7.95-8.54 | 205.6±43.3 | 129.0-276.0 |
| GL RVR-DWN | 20.5±1.0 | 18.2-22.0 | 6.26±1.13 | 4.03-7.82 | 8.08±0.14 | 7.95-8.27 | 212.8±36.9 | 134.0-270.0 |
| HH KARAGITA | 21.9±1.6 | 19.2-24.5 | 5.50±1.20 | 3.60-7.70 | 8.38±0.30 | 7.90-8.50 | 1346.8±312.2 | 65.0-1680.0 |
| HH MIRERA | 22.4±1.6 | 20.6-25.6 | 5.60±1.10 | 3.90-7.00 | 8.00±0.40 | 7.30-8.50 | 1080.4±196.2 | 384.0-1232.0 |
| HH KAMERE | 21.7±2.0 | 19.1-26.3 | 5.40±1.90 | 1.90-7.90 | 7.90±0.40 | 7.20-8.50 | 735.2±617.8 | 22.0-1667.0 |
| VENDORS | 20.6±1.6 | 17.9-23.1 | 2.90±0.90 | 1.90-5.00 | 7.60±0.50 | 6.90-8.60 | 990.8±403.5 | 258.0-1435.0 |

**Legend:** HH (households)

**Table 4:** Spatial variation of physico-chemical parameters in borehole direct water sources

| Water sources | Temperature | DO | pH | Conductivity |
|---|---|---|---|---|
| KRBH I-DIR | 22.22a | 4.13a | 8.17a | 1326.81a |
| KRBH III-DIR | 23.23a | 3.07b | 8.10a | 1242.88b |
| KRBH IV-DIR | 22.36a | 3.27bc | 8.35b | 1260.69ab |
| DCK-DIR | 24.46b | 3.80ac | 8.23c | 1145.31c |

**Legend:** Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

**Table 5:** Spatial variation of physico-chemical parameters in the borehole points of use sources

| Water sources | Temperature | DO | pH | Conductivity |
|---|---|---|---|---|
| KRBH I-POU | 22.03a | 5.69a | 8.41a | 1284.44a |
| KRBH II-POU | 22.49ab | 5.04b | 8.38ac | 1250.81a |
| KRBH III-POU | 22.68ab | 4.48c | 8.20b | 1227.81a |
| KRBH V-POU | 22.88b | 5.01c | 8.23cb | 1580.94b |

**Legend:** Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

**Table 6:** Spatial variation of physico-chemical parameters in surface water sources

| Water sources | Temperature | DO | pH | Conductivity |
|---|---|---|---|---|
| KAMERE | 22.76a | 5.13a | 8.05a | 283.63a |
| MAL-RVR | 21.59bc | 6.56b | 8.04a | 212.44b |
| GIL RVR-UP | 21.99abd | 6.94b | 8.14a | 205.56b |
| GIL RVR-DWN | 20.56cd | 6.26b | 8.08a | 212.81b |

**Legend:** Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

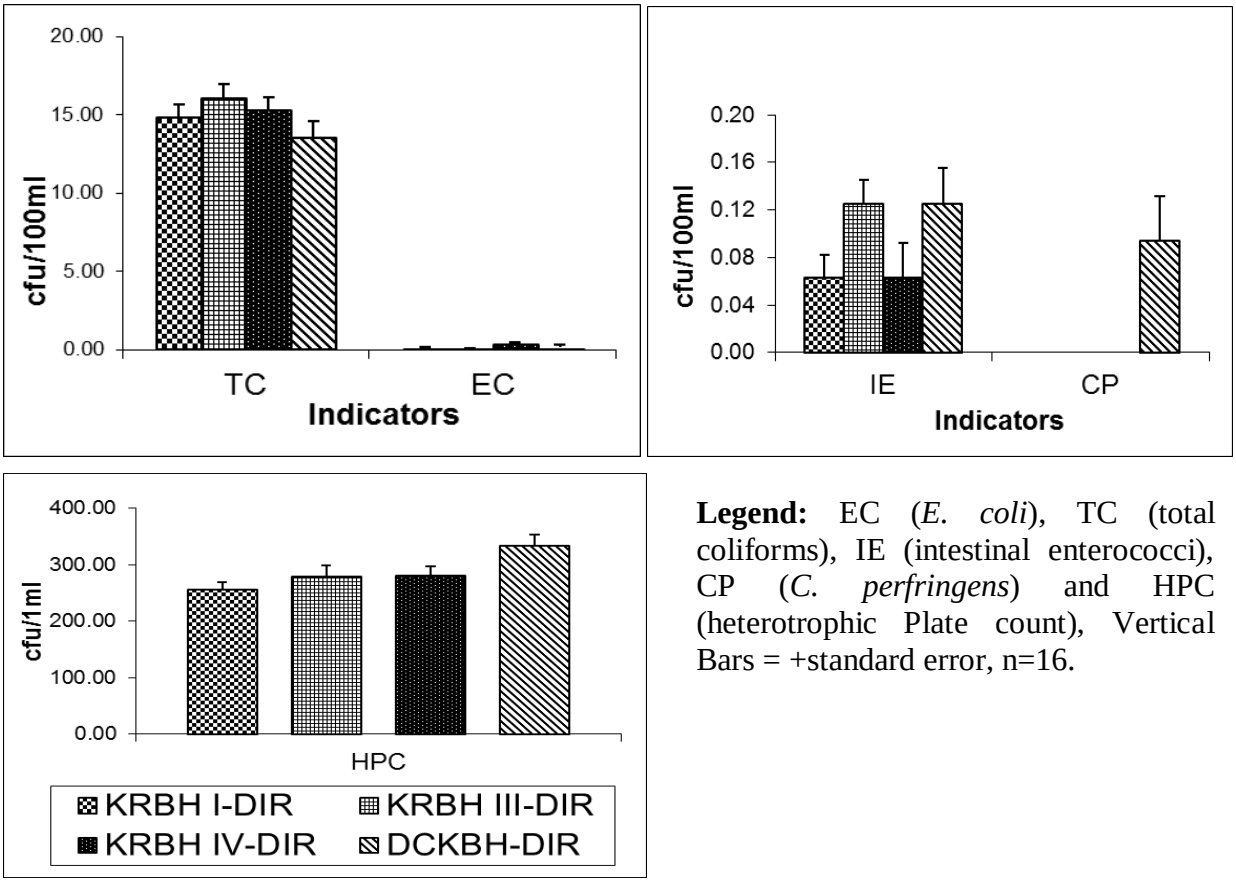
### 4.2. Microbiological parameters

#### 4.2.1 Boreholes

##### 4.2.1.1 Spatial variation

Results for values of microbiological parameters in water samples from borehole-direct sources (BH-DIR) are shown in Figure 4 and Appendix 3. Lower values of the following range; 0-2.00 CFU/100 ml, 6.00-25.500 CFU/100 ml, 0-2.00 CFU/100 ml, 0-1.00 CFU/100 ml and 60.00-460.00 CFU/100 ml were recorded for *E. coli*, total coliforms, intestinal enterococci, *C. perfringens* and HPC respectively. From these results, samples from Denmark Company of Kenya (DCK) borehole gave higher values for all the microbiological parameters than the other borehole direct sources. The means for borehole direct sources (BH-DIR) had no significant

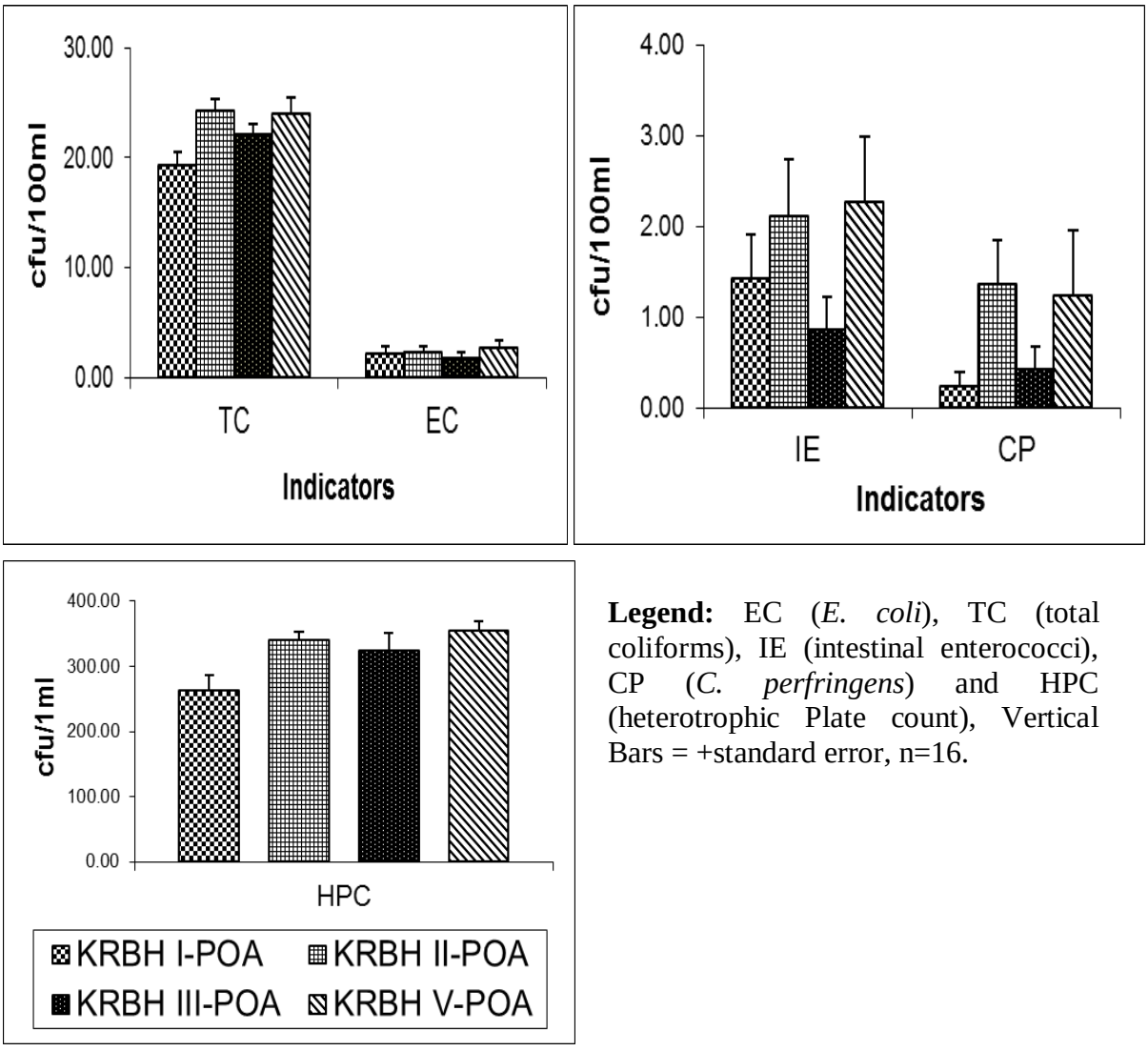
variation with respect to sites (F= 0.427, 0.291, 0.977, 0.124 and 0.053 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df= 3, 63 and P>0.05). During the four months of the weekly sampling period 12% positive result on faecal contamination indicators was obtained from these BH-DIR sources.




**Legend:** EC (*E. coli*), TC (total coliforms), IE (intestinal enterococci), CP (*C. perfringens*) and HPC (heterotrophic Plate count), Vertical Bars = +standard error, n=16.

**Figure 4**: Densities of faecal contamination indicators in borehole direct water sources.

Results for microbiological parameters values in water samples from borehole points of access (BH-POA) sources are given in Figure 5 and Appendix 4. For all the boreholes-point of access sources (BH-POA), all the microbiological parameters showed significant variation with respect to sites (F= 4.358, 13.101, 3.519, 3.165 and 6.165 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df= 3, 63 and P<0.05), as in Table 7. During the four months of sampling, 39% positive result on faecal contamination indicators was obtained from these BH-POA sources.




**Legend:** EC (*E. coli*), TC (total coliforms), IE (intestinal enterococci), CP (*C. perfringens*) and HPC (heterotrophic Plate count), Vertical Bars = +standard error, n=16.

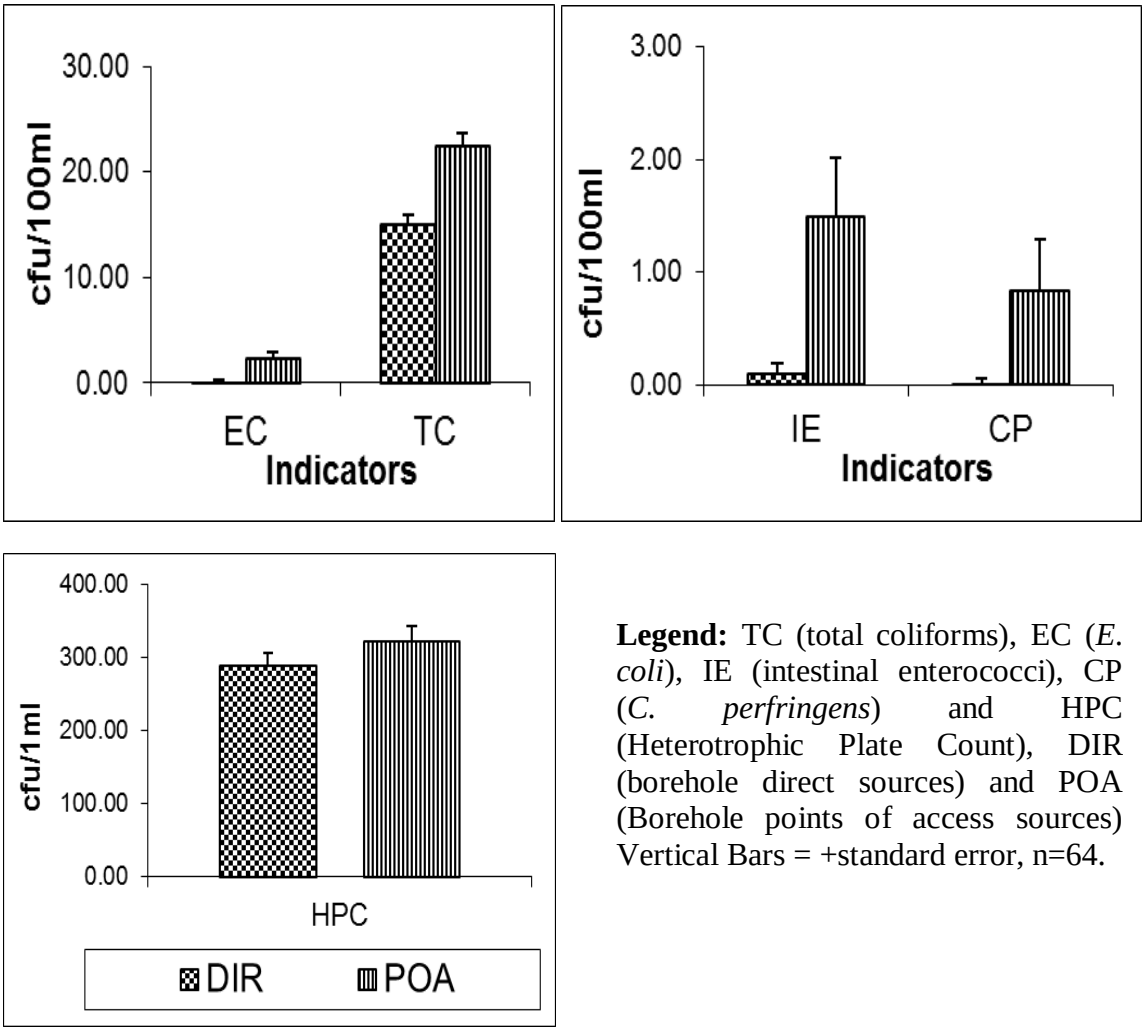
**Figure 5:** Densities of indicators of faecal contamination in boreholes points of access sources.

**Table 7:** Spatial variation on the microbial parameters for the borehole points of access sources.

| SOURCES | EC | TC | IE | CP | HPC |
|---|---|---|---|---|---|
| BH I -POA | 2.18a | 19.31a | 1.44a | 0.25a | 262.81a |
| BHII -POA | 2.31a | 24.22b | 2.13b | 1.38b | 340.00b |
| BH III -POA | 1.75a | 22.13ab | 0.88a | 0.44a | 324.69a |
| BH V -POA | 2.63b | 23.97b | 2.28b | 1.25b | 355.31b |

**Legend:** Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

Mean values for microbiological parameters in the samples from borehole-POA sources were higher than borehole-DIR sources (Figure 6). All the mean values of microbiological parameters except HPC showed significant variation between Borehole-POA and borehole-DIR sources on a t-test (t= 6.905, 8.178, 5.906, 4.338 and 1.927 respectively for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC, df=126 and $p<0.05$).




**Legend:** TC (total coliforms), EC (*E. coli*), IE (intestinal enterococci), CP (*C. perfringens*) and HPC (Heterotrophic Plate Count), DIR (borehole direct sources) and POA (Borehole points of access sources) Vertical Bars = +standard error, n=64.

**Figure 6:** Densities of faecal contamination indicators in borehole-direct sources verses borehole points of access

#### 4.2.1.2 Temporal variation

Since there was no significant difference in spatial variation in the densities of faecal contamination indicators for BH-DIR sources, the values from all the sources in this category were pooled to check on temporal pattern. The result is as presented in Figure 7. There was no

significant variation in the means densities of faecal contamination indicator organisms from borehole-direct sources with respect to time (months) of sampling; April, May, June and July, (F= 1.951, 1.841, 0.450, 0.706 and 4.233 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df= 3, 63 and P>0.05).

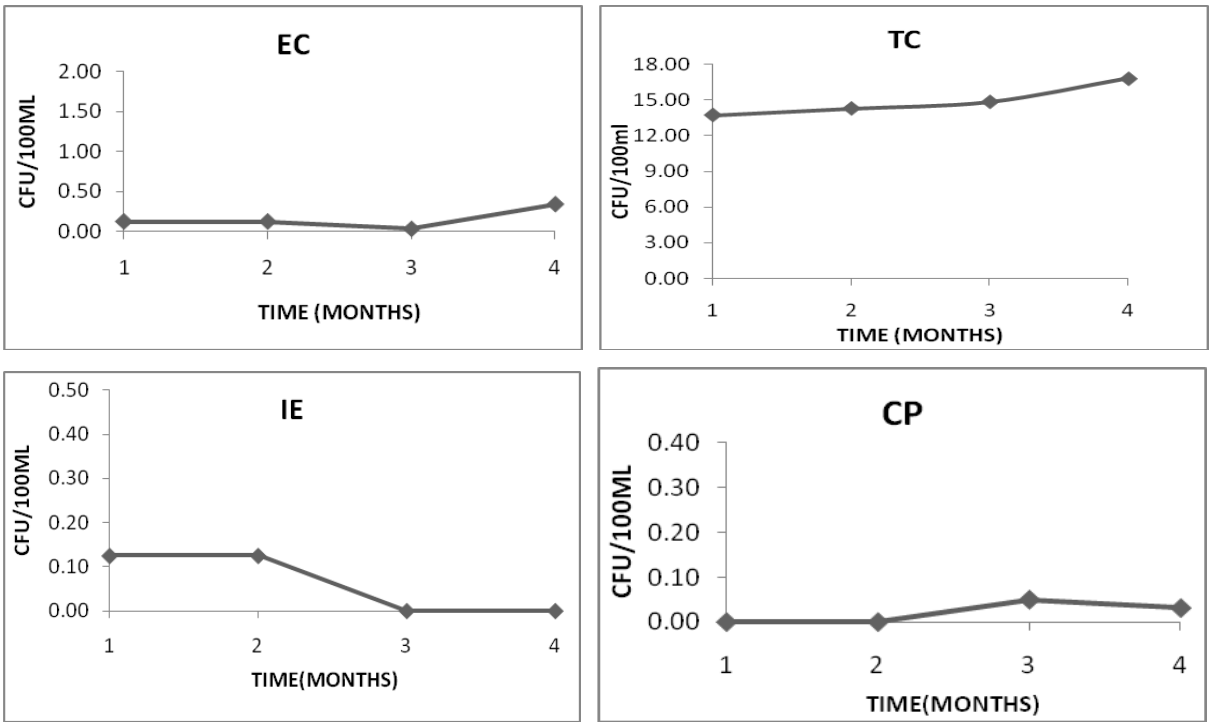



**Figure 7:** Temporal patterns of microbiological indicators of faecal pollution in BH-DIR sources during the sampling time.
**Legend:** Time in Months i.e 1, 2, 3 and 4 for April, May, June and July respectively.

The monthly means densities of faecal contamination indicator organisms for BH-POA sources are shown in Figure 8. Samples from Borehole Points of Access (BH-POA) showed no significant variation in the mean densities of faecal contamination indicator organisms with respect to sampling time (Months), (F= 0.475, 1.518, 0.203, 1.825, and 1.129 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df=3,63 and P>0.05).

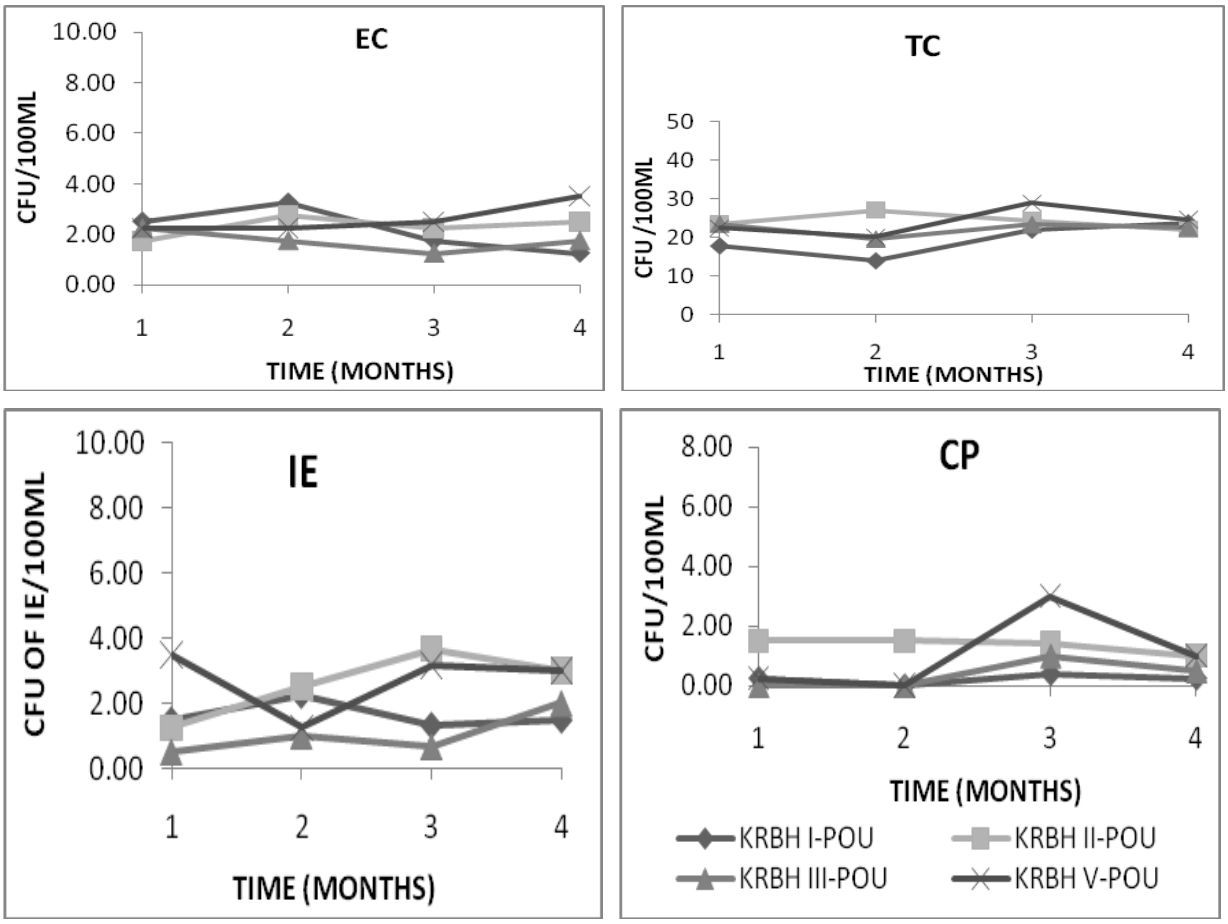


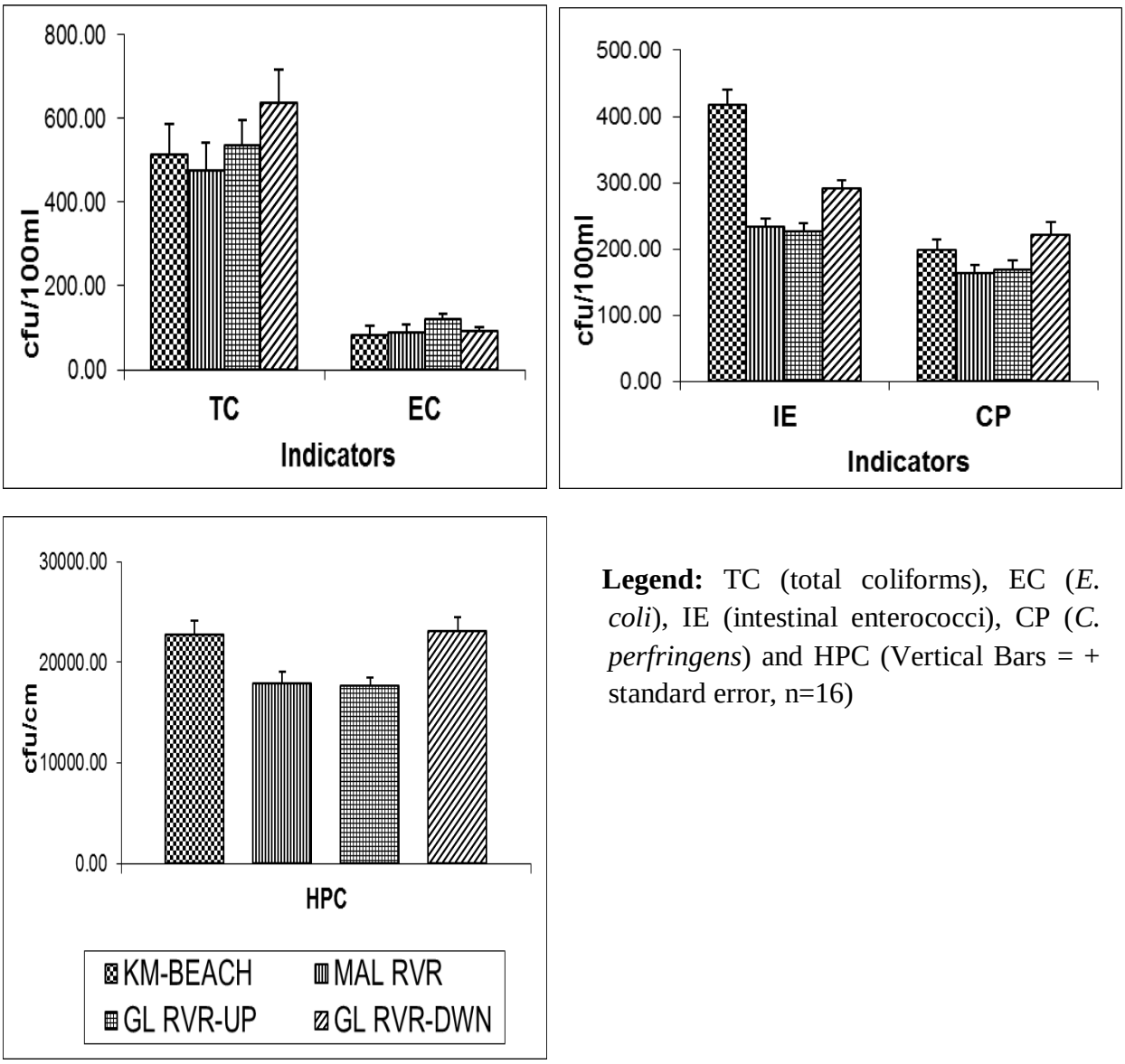

**Figure 8:** Temporal pattern of microbiological indicators of faecal pollution in BH-POU sources.
**Legend:** Time in Months i.e. 1, 2, 3 and 4 for April, May, June and July respectively

### 4.2.2 Surface sources

#### 4.2.2.1 Spatial variation

Results on microbiological parameters in water samples from surface sources are shown in Figure 9 and Appendix 5. Higher values of all the parameters were recorded for surface sources compared to borehole water sources. From these results, River Gilgil downstream (GILRVR-DWN and Kamere beach (KH-BEACH) gave higher mean values of microbiological parameters than Malewa River (MAL-RVR) and Gilgil River upstream (GILRVR-UP). For all these surface sources, means were significantly different with respect to sites, (F= 5.734, 8.345, 27.057, 2.868, and 3.941 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df= 3, 63 and $P<0.05$) are shown in Table 8. During the four months of sampling, 100% positive result on faecal contamination indicators was obtained in samples from these surface sources.

Within River Gilgil, samples from down stream had a higher mean values for microbial parameters than upstream and these means were significantly different for all the parameters except HPC on t-test, (t=5.48, 2.93, 3.36, 2.32 and 2.73 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df=30 and $p<0.05$).




**Legend:** TC (total coliforms), EC (*E. coli*), IE (intestinal enterococci), CP (*C. perfringens*) and HPC (Vertical Bars = + standard error, n=16)

**Figure 9:** Densities of faecal contamination indicators in water samples from surface sources

**Table 8:** Spatial variation of microbiological parameters within the surface sources

| SOURCES | EC | TC | IE | CP | HPC |
|---|---|---|---|---|---|
| Kamere beach | 300.31a | 512.81ac | 417.81a | 198.13ab | 22701.56a |
| River Malewa | 267.19a | 475.94bc | 237.06b | 164.06a | 17940.63b |
| River Gilgil-Up | 255.94a | 537.19b | 226.84b | 168.28a | 17671.88b |
| River Gilgil-Dwn | 317.19b | 639.38a | 290.94c | 221.56b | 23118.75a |

**Legend:** Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

### 4.2.2.2 Temporal variation

The Monthly means for microbiological parameters of surface sources are shown in Figure 10. The means for all the microbial parameters except intestinal enterococci within the surface water sources showed significant variation with respect to time/month of sampling (April, May, June and July), (F= 5.872, 2.816, 1.656, 16.098, and 8.983 for *E. coli*, total coliform, intestinal enterococci, *C. perfringens* and HPC respectively, df= 3,63 and $P<0.05$).

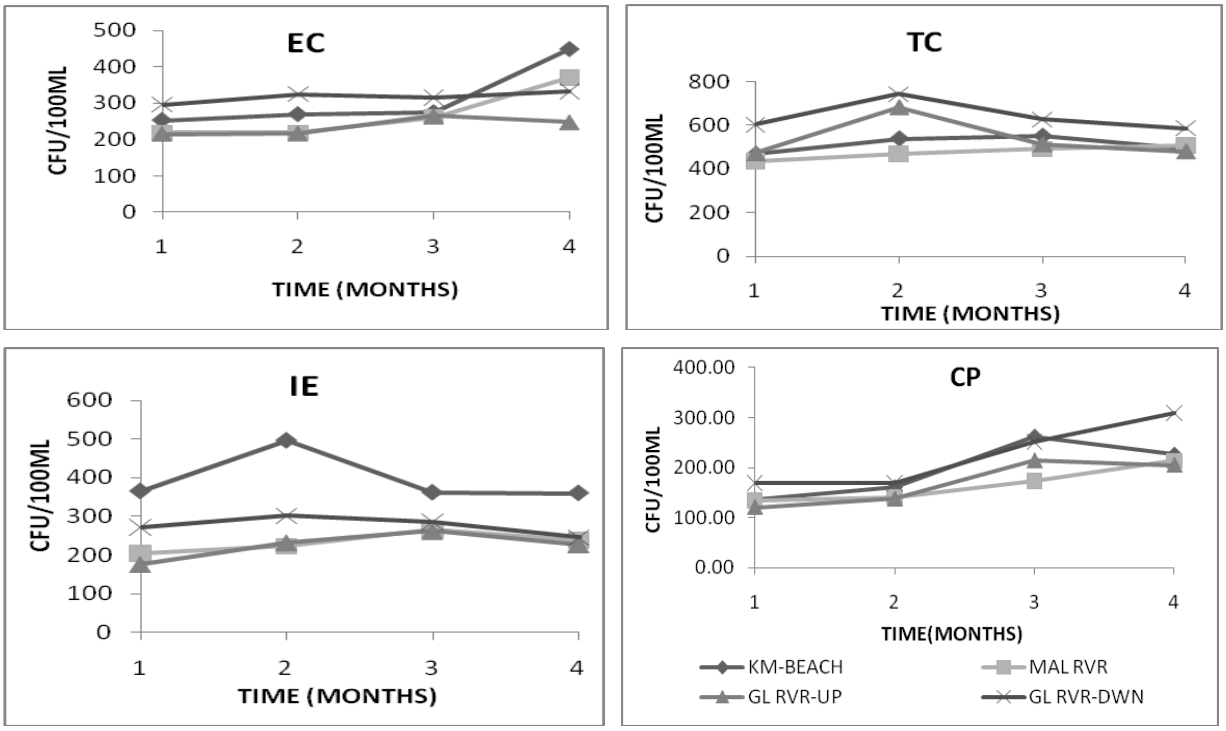



**Figure 10:** Trends of microbiological indicators of faecal pollution in surface water sources during the sampling time

**Legend:** Time in Months i.e. 1, 2, 3 and 4 for April, May, June and July respectively.

### 4.3 Effects of human water handling practices on its microbial quality

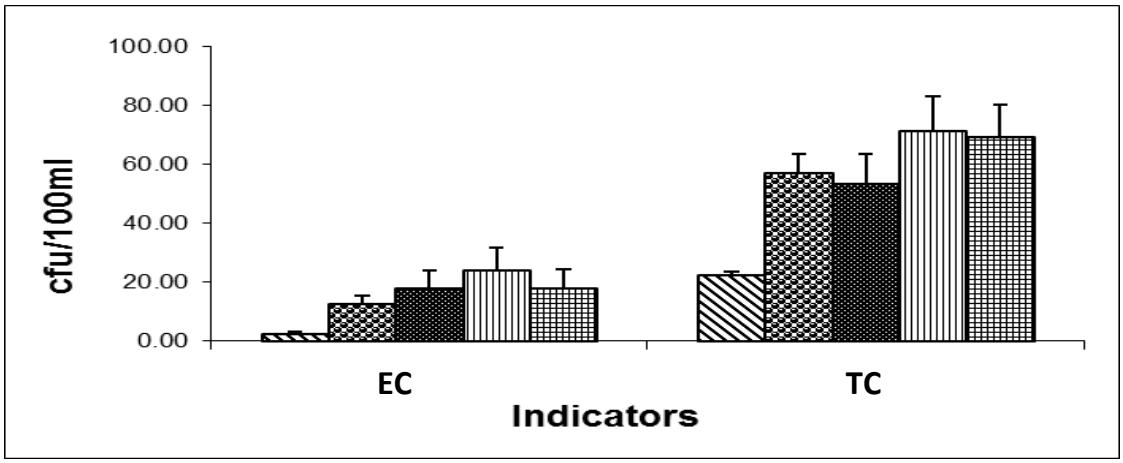
The values for microbiological parameters based on handling at domestic and vendors' domain are given in Table 9.

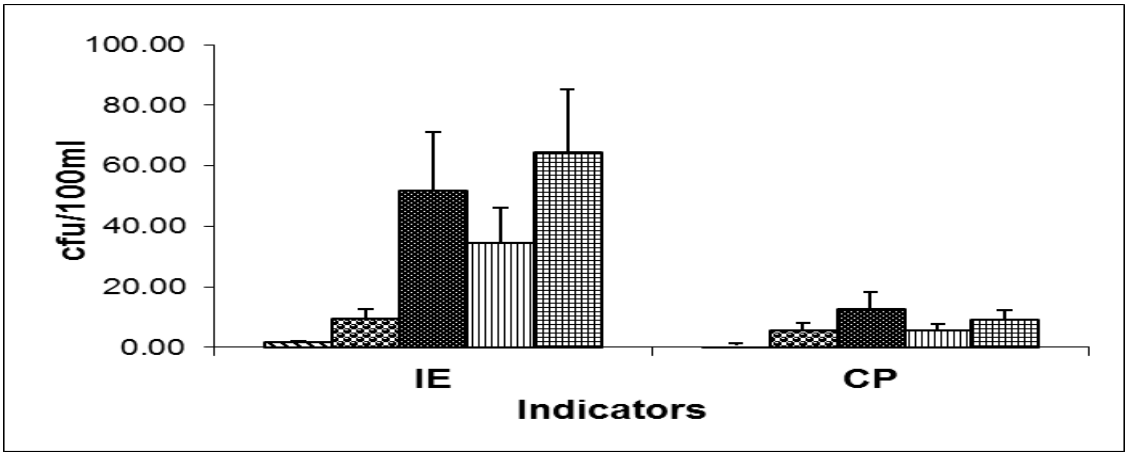
**Table 9:** Values of microbiological parameters in samples from vendors and households

| | VENDORS | | HH-KARAGITA | | HH-MIRERA | | HH-KAMERE | |
|---|---|---|---|---|---|---|---|---|
| | MEAN± SD | RANGE | MEAN± SD | RANGE | MEAN± SD | RANGE | MEAN± SD | RANGE |
| EC | 12.7±13.6 | 0.0-38.0 | 17.9±30.5 | 0.0-110.0 | 24.1±38.5 | 0.0-160.0 | 17.8±33.1 | 0.0-102.0 |
| TC | 57.0±33.1 | 23.0-142.0 | 53.4±50.9 | 4.0-177.0 | 71.6±57.7 | 11.0-240.0 | 69.48±54.9 | 12.0-234.0 |
| IE | 9.5±14.8 | 0.0-50.0 | 51.6±97.3 | 0.0-460.0 | 34.6±58.0 | 0.0-210 | 64.36±103.6 | 0.0-360.0 |
| CP | 5.7±12.1 | 0.0-46.0 | 12.8±27.7 | 0.0-125.0 | 5.48±10.7 | 0.0-42.0 | 9.16±15.4 | 0.0-47.0 |
| HPC | 552.0±256.4 | 190.0-1020.0 | 553.0±264.4 | 100.0-1145.0 | 583.2±197.8 | 250.0-910.0 | 510.4±281.3 | 110.0-1130.0 |

**Legend:** HH-Karagita are households within Karagita village, HH-MIRERA are households within Mirera village and HH-KAMERE are households within Kamere village.

Based on data from handling by the vendors and at the household domain, it was observed that the microbiological quality of the water was poorer within the households and vendors when compared to the water quality at the borehole point of access from where the majority of vendors and household obtained their water (Figure 11). However, the differences in the mean densities of faecal contamination indicator organisms in water sampled from BH-POA, the households within the three villages (Karagita, Mirera and Kamere) and vendors varied significantly, ($F= 5.98, 24.34, 6.64, 4.49$, and $77.11$ for *E. coli*, total coliforms, intestinal enterococci, *C. perfringens* and HPC respectively, $df= 4,149$ and $P< 0.05$). Significant means under this case were separated using (Table 10).



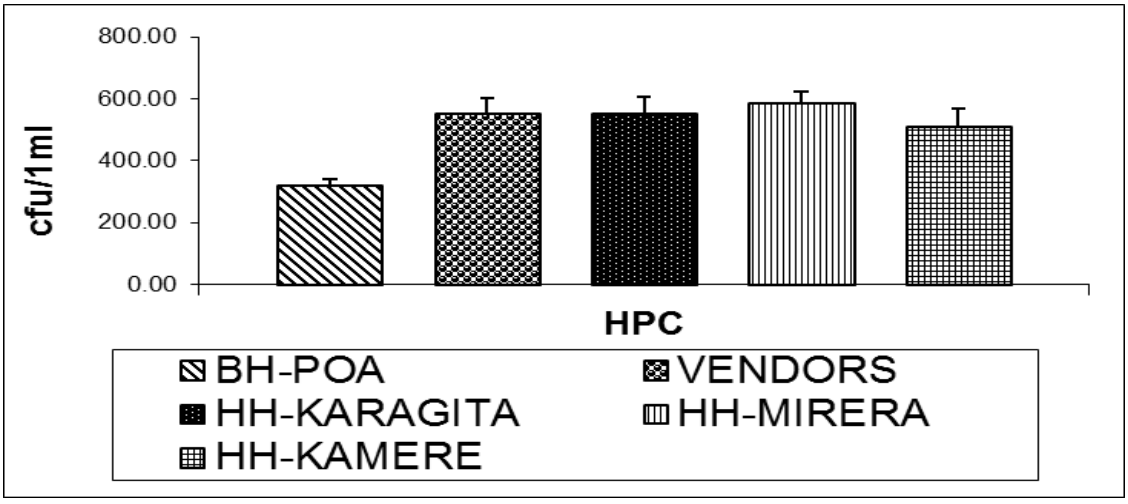




**Figure 11:** Densities of faecal contamination indicators in water at different domains.

**Legend:** Domains are; BH-POA (Borehole Points of Access), vendors and households (HH) from Karagita, Kamere and mirera villages. Vertical bars = +standard deviation, n=25.

**Table 10:** Spatial variation on microbiological quality of water at different domains

| Domains | EC | TC | IE | CP | HPC |
|---|---|---|---|---|---|
| BH-POA | 2.23a | 22.41a | 0.09a | 0.02a | 320.70a |
| VENDORS | 12.73ab | 57.00b | 9.53ac | 5.66ab | 552.00b |
| HH-KARAGITA | 17.92b | 53.40b | 51.60b | 12.80b | 553.00b |
| HH-MIRERA | 24.12b | 71.60b | 34.6bc | 5.48ab | 583.20b |
| HH-KAMERE | 17.76b | 69.48b | 64.36b | 9.16b | 510.4b |

**Legend:** Domains are; borehole points of access (BH-POA), Vendors and Households (HH) in Karagita, Mirera and Kamere villages. Means in a column followed by different letters are significantly different at $p<0.05$ by LSD.

### 4.4 Relationship between faecal contamination indicators and physicochemical parameters

Relationships between parameters measured in different water sources are shown in Tables 11, 12 and 13. From these results, minor significant relationships occurred between parameters in all borehole waters (direct and point of access). Physico-chemical parameters did not show any great influence on microbial parameters. However, it is notable that HPC from direct borehole waters had positive and significant correlation with temperature (Table 11). There were significant correlations between *E. coli* (EC) and all the microbiological faecal contamination indicators in surface water (Table 13).

**Table 11:** Correlation between microbiological and physicochemical parameters in borehole direct sources

| | EC | TC | IE | CP | HPC | TEMP | DO | pH |
|---|---|---|---|---|---|---|---|---|
| **EC** | _ | _ | _ | _ | _ | _ | _ | _ |
| **TC** | 0.300 | _ | _ | _ | _ | _ | _ | _ |
| **IE** | 0.223 | 0.090 | _ | _ | _ | _ | _ | _ |
| **CP** | -0.64 | 0.080 | -0.044 | _ | _ | _ | _ | _ |
| **HPC** | 0.059 | -0.139 | -0.064 | 0.152 | _ | _ | _ | _ |
| **TEMP** | 0.047 | -0.006 | 0.176 | -0.032 | 0.258** | _ | _ | _ |
| **DO** | 0.042 | -0.014 | 0.002 | 0.080 | 0.062 | 0.138 | _ | _ |
| **Ph** | -0.014 | 0.163 | 0.008 | -0.173 | -0.248** | -0.365** | -0.144 | _ |
| **E. COND** | -0.120 | 0.076 | 0.150 | -0.184 | -0.320** | -0.101 | 0.083 | 0.478 |

**Correlation is significant at $P<0.05$, (2 tailed, N=64)

**Table 12:** Correlation between microbiological and physico-chemical parameters in borehole point of access sources

| | EC | TC | IE | CP | HPC | TEMP | DO | pH |
|---|---|---|---|---|---|---|---|---|
| **EC** | _ | _ | _ | _ | _ | _ | _ | _ |
| **TC** | 0.041 | _ | _ | _ | _ | _ | _ | _ |
| **IE** | 0.148 | 0.194 | _ | _ | _ | _ | _ | _ |
| **CP** | 0.099 | 0.311** | 0.215 | _ | _ | _ | _ | _ |
| **HPC** | 0.127 | 0.234 | -0.106 | -0.012 | _ | _ | _ | _ |
| **TEMP** | -0.013 | 0.000 | 0.195 | -0.021 | 0.134 | _ | _ | _ |
| **DO** | 0.084 | 0.364** | -0.003 | -0.079 | -0.169 | -0.74 | _ | _ |
| **Ph** | 0.043 | 0.065 | 0.247** | 0.111 | -0.178 | -0.029 | 0.206 | _ |
| **E. COND** | 0.059 | 0.129 | 0.099 | 0.055 | 0.198 | 0.030 | -0.086 | -0.004 |

**Correlation is significant at P<0.05, (2 tailed, N=64)

**Table 13:** Correlation between microbiological and physico-chemical parameters in surface sources

| | EC | TC | IE | CP | HPC | TEMP | DO | pH |
|---|---|---|---|---|---|---|---|---|
| **EC** | _ | _ | _ | _ | _ | _ | _ | _ |
| **TC** | 0.278** | _ | _ | _ | _ | _ | _ | _ |
| **IE** | 0.384** | 0.112 | _ | _ | _ | _ | _ | _ |
| **CP** | 0.420** | 0.085 | 0.282** | _ | _ | _ | _ | _ |
| **HPC** | 0.560** | 0.056 | 0.447** | 0.538** | _ | _ | _ | _ |
| **TEMP** | -0.085 | -0.147 | 0.132 | -0.242 | -0.035 | _ | _ | _ |
| **DO** | -0.088 | -0.052 | -0.280 | 0.168 | -0.010 | -0.142 | _ | _ |
| **Ph** | -0.234 | -0.059 | -0.122 | 0.037 | -0.176 | 0.023 | 0.143 | _ |
| **E. COND** | 0.078 | 0.005 | 0.272 | 0.085 | 0.100 | 0.241 | -0.312** | 0.049 |

**Correlation is significant at P<0.05, (2 tailed, N=64)

### 4.5 Classification of water sources

Setting a reference of 0-10 cfu/100ml of *E. coli* and enterococci and less than 100 CFU/100ml for total coliforms in classifying water sources based on Kavka *et al.,* (2006) mode of domestic

water classification, and three water source classes were observed within Lake Naivasha basin (Table 14). From these results, sources of water in Naivasha area can be categorised into 3 classes with borehole water as least polluted and surface waters (Lake and Rivers) as most polluted. Boreholes points of access water are moderately polluted and this pollution may be because most residents of Lake Naivasha basin use borehole water and contamination gets into the water as a result of poor handling approaches. Direct borehole water has less risk, indicating its safety.

**Table 14:** Summary of water source classes within Lake Naivasha area based on contamination levels

| CLASSIFICATION | | CLASS I | CLASS II | CLASS III | CLASS IV |
|---|---|---|---|---|---|
| PARAMETER | FAECAL POLLUTION | LITTLE | MODERATE | CRITICAL | STRONG |
| *E. coli* | in 100 ml of water | ≤ 10 | > 10-100 | >100-10000 | > 1000-100000 |
| Intestinal enterococci | in 100 ml of water | ≤ 10 | > 10-100 | > 100-10000 | > 1000-100000 |
| Total coliforms | in 100 ml of water | ≤ 100 | > 50-1000 | > 1000-10000 | > 10000-100000 |

**Class I**- Borehole waters- direct sources.

**Class II**- Borehole waters-POA

**Class III** River Malewa, River Gilgil and Lake Naivasha water

**Class IV-** Nil (No water sourse found to be in this class)

### 4.6 Faecal contamination source tracking

Source tracking for faecal contamination was done through *E. coli* and intestinal enterococci ratio determination. Results are shown in Table 15. The ratios from all the sources were below a value of 4 (Table 15) which is expected for human faecal pollution source. However, all the values were closer to a ratio of 0.7 than 4.

**Table 15:** Mean values and ratios of *E. coli* to intestinal enterococci in borehole and surface sources

| | BH-DIR | BH-POU | KM-BEACH | MAL RVR | GL RVR-UP | GL RVR-DWN |
|---|---|---|---|---|---|---|
| EC | 0.16 | 2.22 | 300.31 | 267.19 | 235.94 | 317.19 |
| IE | 0.09 | 1.68 | 417.81 | 234.06 | 226.84 | 290.94 |
| RATIO | 1.67 | 1.32 | 0.72 | 1.14 | 1.04 | 1.09 |

**Legend:** BH-DIR (borehole direct), BH-POU (Borehole point of use), MAL RVR (river Malewa), GL RVR-UP (River Gilgil upstream), EC (E. coli) and IE (intestinal enterococci).

### 4.7 Solar disinfection

Different water sources (Borehole, Lake and River) of different volumes (1 litre, 2.5 litres and 5 litres) gave different results on solar pasteurization. The water samples were found to pasteurize at a temperature of 65 $^{0}$C which was attained after 50 minutes, this was noted by the melting of WAPI indicator. Different trends of the densities of *E. coli* (EC) and total coliforms (TC) at different levels of treatments; raw and 0, 15 and 30 minutes from pasteurisation point were observed (Table 16 and Figures 12, 13 and 14).

**Table 16:** Response of total coliforms and *E. coli* to solar pasteurization at different duration of time and for different water sources and volumes

| | | TC | | | EC | | |
|---|---|---|---|---|---|---|---|
| Water types | Treatments | 1Litre | 2.5 Litres | 5.0 Litres | 1 Litre | 2.5 Litres | 5.0 Litres |
| | RAW | 73 | 73 | 73 | 15 | 15 | 15 |
| | 0 MIN | 0 | 3 | 7 | 0 | 0 | 2 |
| | 15 MIN | 0 | 0 | 0 | 0 | 0 | 0 |
| KRBHV-POA | 30 MIN | 0 | 0 | 0 | 0 | 0 | 0 |
| | RAW | 440 | 440 | 440 | 210 | 210 | 210 |
| | 0 MIN | 26 | 42 | 30 | 14 | 20 | 25 |
| | 15 MIN | 11 | 16 | 24 | 9 | 7 | 13 |
| LAKE (KM-BEACH) | 30 MIN | 0 | 0 | 0 | 0 | 0 | 0 |
| | RAW | 590 | 590 | 590 | 230 | 230 | 230 |
| | 0 MIN | 7 | 20 | 24 | 3 | 13 | 19 |
| | 15 MIN | 4 | 5 | 11 | 2 | 0 | 7 |
| RIVER(GLRVR) | 30 MIN | 0 | 0 | 0 | 0 | 0 | 0 |

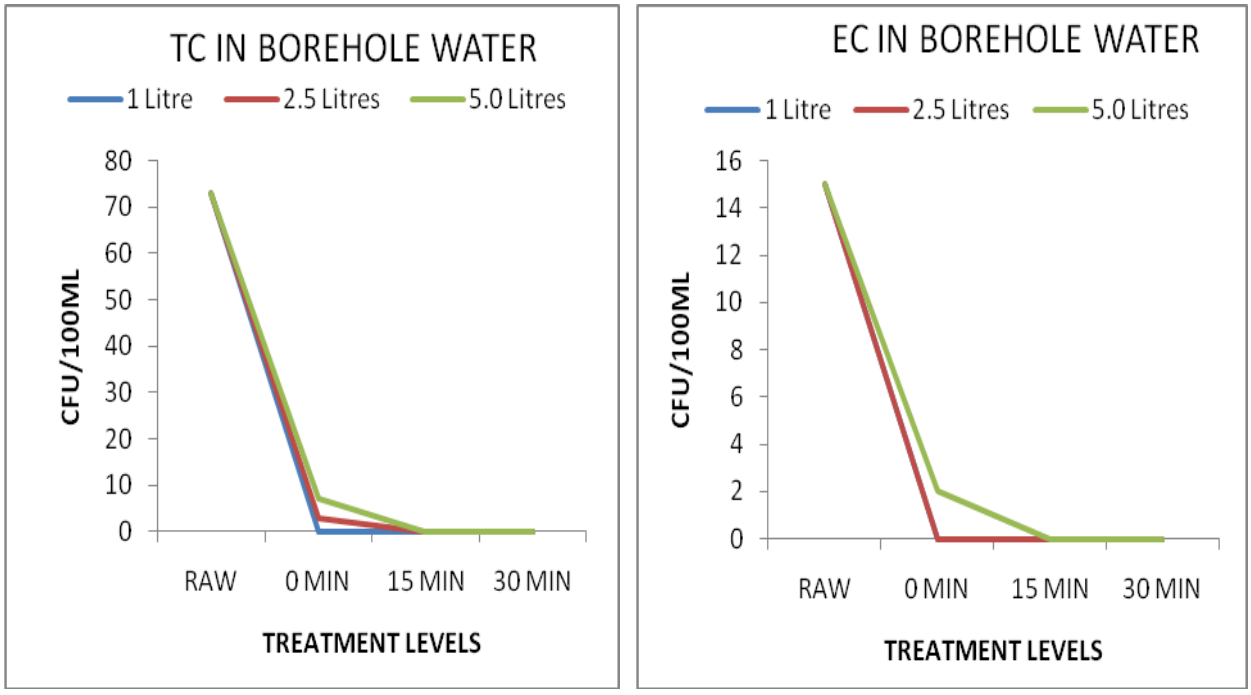



**Figure 12:** Response of faecal indicators to solar pasteurization on water samples from Karagita Borehole V point of access (KRBHV-POA).

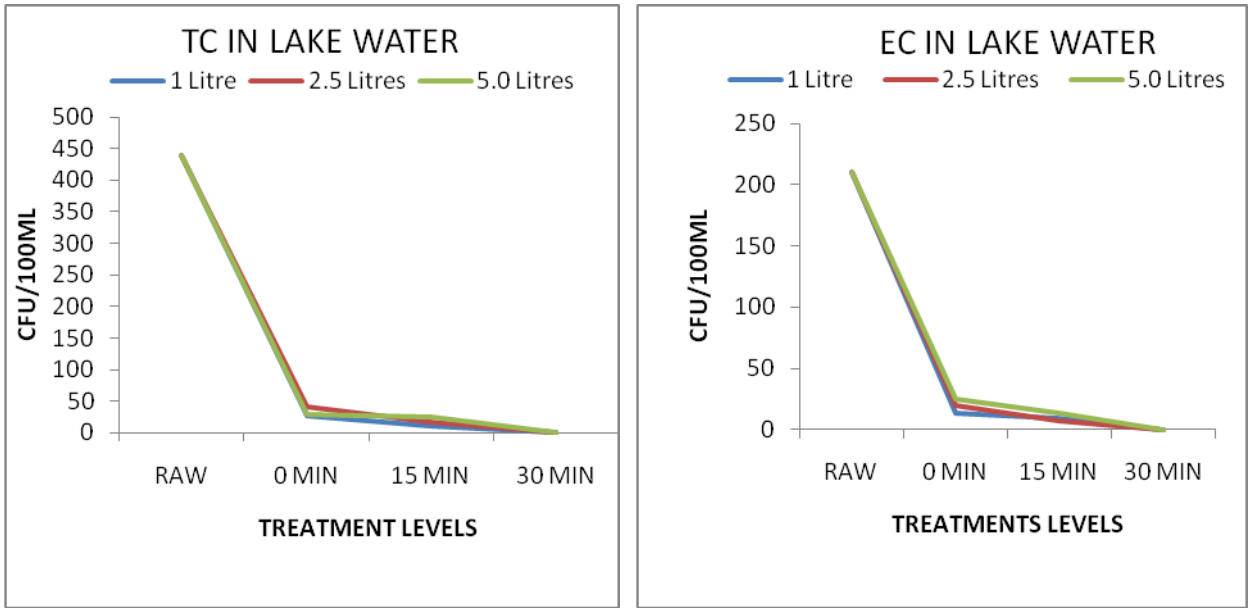



**Figure 13:** Response of faecal indicators to solar pasteurization on water samples from Lake Naivasha

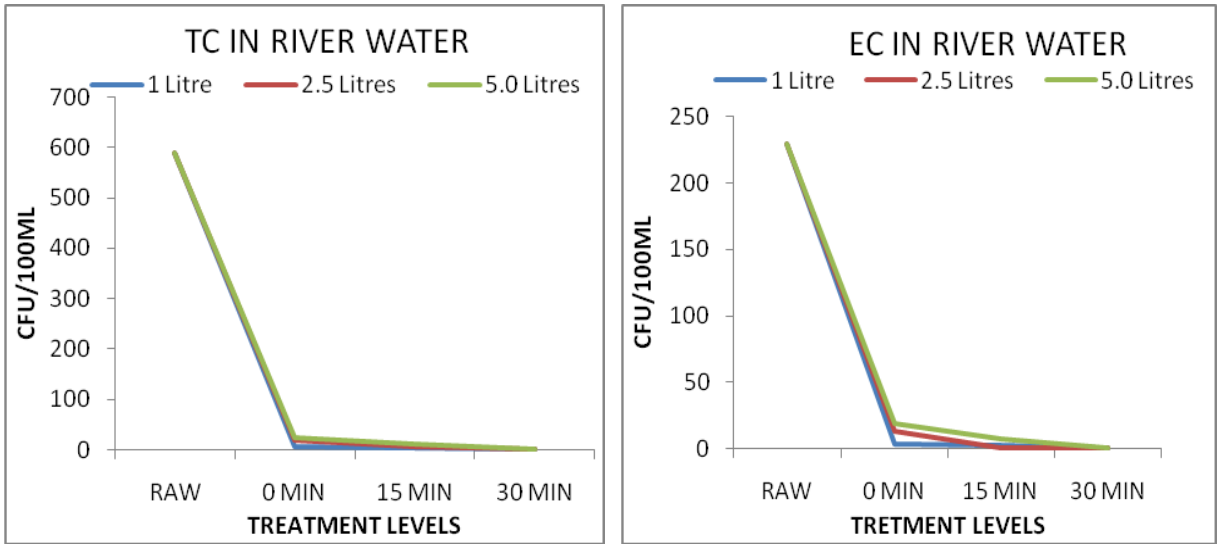



**Figure 14:** Response of faecal indicators to solar pasteurization on water samples from River Gilgil.

The use of solar radiation in water disinfection showed that at a temperature of 65 $^{0}$C attained after 50 minutes, the borehole waters were disinfected of *E. coli* and total coliforms. For rivers and lake waters, a temperature of 75 $^{0}$C attained after an additional 30 minutes was required for complete disinfection of these faecal contamination indicators.

# CHAPTER FIVE

# DISCUSSION

## 5.1 Physicochemical parameters

The results of this study show that all the physicochemical parameters from all the water sources in Lake Naivasha basin were within the recommended standards of WHO, US-EPA and NEMA (appendices 1 and 2) for drinking water. These results are also similar to those obtained in water sources from Aboekuta, Nigeria (Shittu *et al.,* 2008). Higher levels of electrical conductivity were recorded from borehole water than surface water sources as expected. This is attributed to high levels of dissolved minerals found in ground water and in particular fluoride which has been recorded in borehole waters within the region (Matofari, 2006). High values of dissolved oxygen in rivers and borehole waters at the points of access (POA) was due to aeration caused by the flow of water in the rivers and high pressures as the water flows from over-head reservoirs to the lower distribution taps connected with hose pipes (Plate 3a) where sampling was conducted. The values of dissolved oxygen and electrical conductivity varied significantly with respect to sampling sites for all the water sources categories; Borehole Direct sources, Borehole Point of Access (BH-DIR, BH-POA) and Surface sources. This may be attributed to variation in pollution levels, mineral content as well as the volume of the water mass in relation to pollution sources.

For Borehole Points of Acess (BH-POA) sources, temperature did not show significant variation with respect to sampling sites, this could have been due to heating from the sun which tend to warm the water in the reservoir in a more uniformly manner within the entire Lake Naivasha basin. Lower values of dissolved oxygen in samples from vendors and household could have been contributed by the source from which the water was collected. Such samples with low dissolved oxygen may have been collected from the Lake where high organic pollution occurs as evidenced by high levels of Heterotrophic Plate Count (HPC). In addition, further fall in dissolved oxygen levels could have resulted from storage time within the vendors and household domain. Water sampled from vendors were sometimes giving electrical conductivity values lower than expected values from borehole waters, this was an additional evidence that some of the water being sold to the consumers by the vendors could have been collected from the surface sources or was a mixture of borehole and surface sources. Physicochemical parameters obtained

in samples from vendors and households from the three villages did not vary significantly, showing that majority of the water sampled here could have had a common source which was traced to be Borehole Point of Access (BH-POA) sources.

### 5.2 Microbiological Parameters

Groundwater has generally been observed to be of good microbial quality and boreholes are considered to be the cleanest water sources for domestic use. Globally, over 80% of the population relies on ground water for domestic supplies (Cronin *et al.,* 2008). This is because deep aquifers are protected from pathogenic contamination which are effectively removed by soil particles, die offs and predation (Dufour *et al.,* 2003). In the current study, the presence of faecal indicators; *E. coli*, total coliforms, intestinal enterococci, and *C. perfringens* can be attributed to poor handling of water at points of access. As compared to borehole-Poit of Access samples, water samples from boreholes-Direct sources had very low absolute values of the microbiological densities with majority of these parameter values being zero per 100 ml. Direct bore source at Denmark Company in Kenya (DCK) gave poor microbial quality as compared to other direct sources. This could be due to influence from the lake water since the site is in close proximity to the lake than other direct borehole sites. On a general perspective, the quality of water from Borehole-Direct water sources in Lake Naivasha basin was within the recommended standards by WHO, US Environmental Protection Agency and Nationa Environmental protection Agency Kenya (NEMA-Kenya). This is because 88% of the samples analysed were free of faecal contamination and there were no positive results for the presence of faecal contamination noted in any two consecutive sampling occasions. This result showed that Borehole-Direct sources are generally fit for human consumption but due to a few incidences of positive results for faecal contamination, disinfection of these water sources is necessary before consumption for surety of the health safety to the consumer.

In general, Borehole-Point of Access gave higher mean values than the Borehole-Direct sources indicating increased exposure of water to contamination through handling at the water supply points and reservoirs. At the points of use, water samples were obtained without sterilizing the pipes. The reason was to give the actual status in terms of microbial quality of the water being availed to the community from these sources. This is similar to an approach applied by Wright in

2004 in Zambia (Wright *et al* 2004). Sterilization may often result to under estimation of the contamination status especially in supply points where poorly handled hose-pipes are connected to the taps as was the case at the borehole water supply points in Naivasha. In addition, use of hose pipes which are held with dirty hands, dragged on the dumpy grounds and on the back of the donkeys as the supply process contribute further to water contamination at the points of use. This condition is made worse by the dung from the donkeys which were commonly present on the same dumpy grounds within the water selling points. In this regard, sampling of the water without sterilization allowed the capturing of the contribution of all these contamination practices onto the quality of water supplied to the community. With this in mind, most reliable and preventive measure to contamination of water sources could be through protection of all the sources (Figueras and Borrego, 2010). Karagita borehole II at the point of access (KRBHII-POA) and Karagita borehole V at the point of access (KRBHV-POA) gave higher mean values than Karagita borehole I at the point of access (KRBHI-POA) and Karagita borehole III at the point of access (KRBHIII-POA). This together with the significance spatial variation in the mean values of microbial parameters from borehole points of access (BH-POA) could have been caused by the variation in sanitation levels by different borehole owners. This result is in agreement with the study on bacteriological quality of borehole water used by students at the University for Development Studies, Navrongo Campus in Upper-East Region of Ghana, (Adetunde *et al.,* 2010). However, the water quality at the Borehole-Poin of Acess was not within the recommended standards by WHO, US Environmental Protection Agency and NEMA-Kenya. Due to this, disinfection of water from these sources should be a mandatory procedure before its consumption. This is because water of such status are of public health significance considering the possibility of the presence of other bacteria, protozoa and enteric viruses that are implicated in gastro-intestinal waterborne diseases and the low infectious dose for these waterborne pathogens, (Shittu *et al.,* 2008).

During this study, seasonality in the density of faecal contamination indicators was not evidenced in both the Borehole-Direct and Borehole-Point of Access sources. These sources showed no significant variation with respect to time of sampling (April, May, June and July). This was an indication that there was no weather variable that had significant influence on the density of faecal contamination indicators for the entire study period. An additional reason to

support this could have been that, the population of the local community which use/access the borehole throughout the study period remained the same. This consistence in numbers of people who accessed the borehole could have been due to the reason that the intensity of rainfall during that same period was not enough to prevent a significant portion of the population within the Lake Naivasha Basin from visiting Borehole-Point of access sources to collect water. Therefore, on any day when it rained, a few people switched to using rain harvested water and hence the degree of contamination at the Borehole-Point of access did not change greatly with respect to sampling times.

The poor quality of surface water sources (River Malewa and River Gilgil upstream and downstream as well as Lake Water at Kamere beach) could have been contributed by anthropogenic activities in the catchment within the streams and at the beach. These pollution practices noted entailed; in-stream and lake-shore activities such as; laundry, cars and donkeys driven into the river/lake to fetch water by vendors as well as large herds of cattle and wild animals which defecate and urinate in the water when they access these system to drink or even to graze on the riparian vegetation. Similar pollution practices have been reported in other Rift valley Rivers (Mokaya *et al.,* 2004; Yillia *et al.,* 2009). These studies also noted that cows were dominant contributors to faecal contamination in most rivers, raising concern over the health of human and other animals. Therefore, there is need to adopt measures to improve the quality of surface water sources as they were far much above the recommended standards by various drinking water quality monitoring agencies.

Within River Gilgil, down-stream water sampling point was found to have higher microbiological density values than up-stream water sampling points. This indicated an increase in faecal pollution loading as the river flows across the animal grazing field, residential places as well as flower farms. This result is in agreement with that of Shawky *et al.,* (2007) who showed that there was gradual increase in the bacterial counts from up-stream to down-stream from El-Qanater to Damietta of river Nile. They attributed this observation to domestic, sewage and agricultural effluents discharge. In addition, a study on the quality of River Nile Water at Cairo Region in Egypt also attributed its poor water quality to anthropogenic influences (Hala, 2007). The higher mean density of microbiological parameters reported in samples from River Gilgil

than River Malewa despite both rivers draining through flower farms and residential areas could be due to difference in water mass. River Malewa is bigger than River Gilgil and this could have resulted in dilution effects which lowered the microbial density levels. The water quality of the surface sources was not within the recommended standards by WHO, US Environmental Protection Agency and NEMA-Kenya as it was observed that 100% of the samples were positive for faecal contamination. The result on surface water sources is the same as the finding on assessment of the microbial quality of river water sources in rural Venda communities in South Africa, (Obi *et al*., 2002). As a remedial measure, there is need to disinfect water from these sources before its consumption by human beings to eliminate disease causing organisms (Shittu *et al.*, 2008). The significant variation in mean density of faecal contamination indicators with respect to time of sampling (April, May, June and July) was an indication that unlike the borehole sources, surface sources based on their microbiological quality were more susceptible to influence of weather variables e.g. rainfall. The few incidences of rain that occurred during the duration of this study were noted to have an influence on the microbiological quality of surface water which is in agreement with results of a similar study in United States by Hatfield and Prueger, (2004).

Household water security comprise of water availability, good quality, easier accessibility and availability for consumption at household level (Asare, 2004). Water at the household and vendors domain was noted to be of poorer quality as compared to the Borehole-Point of Access sources. This was generally due to poor water handling practices at both the house hold and vendors domain. Insignificant difference in the means of microbial parameters between Borehole Point of Access, vendors and household from the three villages (Karagita, Mirera and Kamere) indicated that majority of the households and vendors had their water contaminated through poor handling in a more or less the same degree. The positive and significant correlation between Heterotrophic Plate Count and temperature in borehole direct sources indicates that temperature could be one of the factors influencing microbial growth in borehole water. The fact that there was no significant correlation between temperatures with faecal indicator micro-organisms means that faecal contamination in direct borehole water was of minor consequence in causing public health concerns. The significant correlations between *E. coli* and all microbial faecal indicators of pollution apart from total coliforms in surface water sources could probably

be an indicator that contamination with organic matter is of faecal origin. Lack of significant correlations between *E. coli* and total coliforms in surface water could indicate that total coliforms could have proliferated in the environment and there was no direct relationship with *E. coli* of recent origin. This low correlation between microbiological indicator organisms has also been a major issue for discussion in a study within the wooded watersheds of the Southern Piedmont (Dwight and Dinku, 1999).

The ratios of *E. coli* to intestinal enterococci of different water sources were closer to 0.7 than 4.0. This showed that the major source of pollution into the water sources within Lake Naivasha basin were most probably of non-human warm blooded animals' origin. Indeed, domestic and wild animals were a common occurrence at the precincts of water sources. Vendors were also using donkeys for transportation of water to the consumers. In addition, domestic and wild animals were also noted to be visiting the lake and rivers for drinking purposes. This result was the same as what was reported for a river in North Area of Wigry National Park where it was found that source of faecal contamination was majorly coming from flows arising from other arable-forestry-pasture-meadow catchments as expressed by a larger number of streptococci than *E. coli*, (Niewolak, 1999).

### 5.3 Solar radiation disinfection

Solar disinfection was able to eliminate *E. coli* and total coliforms from all the water sources (rivers, lake and borehole) and hence proved to be a small scale cost-effective method of disinfecting water for domestic consumption and reducing incidences of waterborne diseases. The duration of time needed for complete eradication of *E. coli* and total coliforms through solar pasteurization was probably due to the density of these microbes in the water/class of the water. More time of exposure to radiation for disinfection was required for highly polluted water than for less polluted ones. Similar studies in Kavaraipettai, Tamil Nadu, and India on water quality improvement also confirmed that there was a reduction of coliforms in the waste water after subjecting it to solar disinfection (Negar and Metcalf, 1999). In these areas, like in many parts of Africa, maximum temperature occurs around 1 p.m. and this therefore increases the efficiency of the solar pasteurization kit in disinfection of water. The solar disinfection kit used for domestic water purification in Lake Naivasha basin eliminated 99.99% of coliforms after an additional 30

minutes from pasteurization point. This innovative solar disinfection system has additional advantages; the kit being portable, it is cost-effective and it can be fabricated in Africa for US$ 8 (approximately Kenya Shillings 640). The unit incorporates the principle of reflection to increase solar intensity and large units can also be manufactured for large scale use. Since all the materials are available locally, the unit can be manufactured locally by the local people. The most valid and reinforcing reason to the use of this kit is the fact that day temperatures above 25 $^0$C occur at the tropics for more than 10 months in a year and as such this innovative solar disinfection unit can be of much benefit in Lake Naivasha Basin.

This solar pasteurization technology can be a better approach in water quality improvement. Indeed, microbial contamination of drinking water is associated with incidences of gastrointestinal illnesses in many studies. In addition, 88% of such reported cases occur as a result of contaminated water, poor hygiene, and poor sanitation (WHO, 2002). The technology can be of paramount benefit to human health in Naivasha Lake basin where rampant cases of diarrhea have been reported. Based on this, WHO guideline which restricts water services providers to have water safety plans to ensure consistent supply of safe drinking water is of great importance as far as the quality of water is concerned. The approach manages the risks associated with consumption of contaminated drinking water from the catchment level to the treatment plant and then to the household level at consumers' taps (Figueras and Borrego, 2010). It aims at ensuring catchment conservation and protection, protection of water at the sources, during and after treatment through proper storage and distribution and awareness creation to the distributors and consumers about their responsibilities in maintenance of the good water quality. This would be a major achievement to Naivasha Water and Sanitation Company (NAWASCO) especially in line with their goals of upgrading water and sanitation services within Naivasha region. Due to variety of risk factors, in the spread, transmission and acquisition of waterborne and water related illnesses, interventions for their prevention not only enhance water availability but also tries to improve the proper disposal of human faeces, improve water quality and quantity as well as personal and environmental hygiene.

Microbiological assessment of drinking water at source and point of use has also become a major issue due to realization of the impact of poor water quality with microbiological contamination at

household level on public health. This health risk is caused by various factors among which water quality plays a significant role. Assessment of drinking water quality at public and private domains aims at ensuring that consumers use water that is free from disease causing organisms and protects them from water related diseases (Jensen *et al.,* 2002). The contamination may arise from transportation of bacteria laden water that is rich in organic matter and suspended particles through overland flow into surface water, while in ground water it is through sub-surface flow into aquifers, especially when the aquifer is shallow and unconfined. Due to open access to surface water ecosystems, bacteria density are often high in rivers ranging between 4-5 log units compared to ground waters with zero *E. coli* densities in deep wells and up to 3 log units in polluted shallow wells (Cronin *et al.,* 2008). This is of particular interest in many developing countries where a large number of the population still depends on surface water sources use as their source of domestic water.

Based on reference adapted from Kavka *et al.,* (2006), the water in Lake Naivasha basin can be categorized into classes I and II for Borehole-Direct and Borehole-Point of Access sources respectively. Surface sources on the other hand fall under class III. This classification was in agreement with the classification made on the study on bacteriological monitoring of River Water Quality in the North Area of Wigry National Park. In that study, the density of the examined indicator bacteria found put the river into (class III of purity), (Niewolak 1999).

# CHAPTER SIX
# CONCLUSION AND RECOMMENDATION

## 6.1 Conclusion

Based on the findings of this study, the following conclusions can be drawn;

I. Water from all Borehole direct sources within Lake Naivasha basin is of good bacterial quality and the good quality does not change over time. Water from all the borehole point of access sources within the basin are of poor quality and this poor quality does change over time. Water from surface sources within the basin is also of poor quality, these sources are exposed to numerous contaminants hence their poor microbial quality levels undergo variation over time.

II. Poor human water handling practices within Lake Naivasha basin result to degradation of the bacterial quality of domestic water.

III. The *E. coli* to intestinal enterococci ratios were noted to be closer to 0.7 than to 4.0 this indicates that the major contributor of faecal contamination into various water sources with Lake Naivasha basin is non-human warm blooded animals.

IV. Solar pasteurization kit has the potential of disinfecting domestic water based on the prevailing solar radiation conditions within Lake Naivasha basin.

## 6.2 Recommendations

Several recommendations can be drawn from the result of this study. They are necessary in improving the quality of water available for human consumption and reducing the incidences of waterborne disease outbreaks. They are;

I. Awareness creation on personal and environmental hygiene including maintenance of high sanitation standards in water distribution points as well as in water storage and distribution containers.

II. Need to put in place proper sewage disposal and treatment measures to reduce the amount of raw sewage that finds its way into the water sources.

III. Need to supply the communities with clean piped water at their households to keep the population away from the surface sources (rivers and lake). This can assist in protecting these water sources from further quality degradation and pollution.

IV. An urgent need to focus on the means and ways of controlling pollution of these community water sources by other organic and inorganic materials through proper solid and liquid waste disposal and regular water monitoring programmes to be established for all water sources in Lake Naivasha basin.

V. Recommending the use of other faecal contamination source tracking approaches like molecular techniques to increase the reliability and accuracy in tracking the sources of faecal contamination in controlling faecal pollution.

VI. Availing and emphasizing the use of affordable, cheap and locally available and environmentally friendly point of use/household water treatment approaches. These include solar radiation disinfection using water pasteurization kits. This is required in rural and informal urban settlement (slams) as it is the case in Lake Naivasha basin where water is obtained from public standpoints, rivers, lake or from resellers (vendors).

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# APPENDICES

## Appendix 1: Summary of drinking water guidelines by different authorities

| | | AUTHORITY | | | |
|---|---|---|---|---|---|
| **PARAMETERS** | **UNITS** | **WHO** | **NEMA-KENYA** | **US-EPA** | **EU-FRAMEWORK** |
| **PHYSICO-CHEMICAL** | | | | | |
| Colour | True colour units | Colourless | | | |
| Odour and taste | | | Not offensive to consumers | | |
| Suspended matter | | | | nil | |
| pH | pH units | 6.5-8.5 | | 6.5-8.5 | ≤ 6.5≥9.5 |
| Conductivity | µs/cm at $20^0$C | | | | 2500 |
| TDS | mg/l | | 1500 | 500 | |
| **MICROBIAL PARAMETERS** | | | | | |
| Total viable counts at 37°C/ml | CFU | | 100 | 500 | 20/ml |
| Total coliforms | CFU | not detected/100ml | shall be absent | <1/100ml | 0/100ml |
| E. coli | CFU | not detected/100ml | shall be absent | <1/100ml | 0/100ml |
| Enterococci | CFU | not detected/100ml | shall be absent | | 0/100ml |
| Sulphite reducing anaerobes | CFU | not detected/100ml | shall be absent | | 0/100ml |
| Salmonella in 250ml | CFU | not detected/100ml | shall be absent | | |

## Appendix 2: Summary of bathing water guidelines by different authorities

| | | AUTHORITY | | |
|---|---|---|---|---|
| **PARAMETERS** | **UNITS** | **WHO** | **US-EPA** | **EU-FRAMEWORK** |
| **PHYSICO-CHEMICAL** | | | | |
| pH | pH units | 7.2-8.0 | 6.5-8.5 | ≥6.5≤9.5 |
| Temperature | °C | 26-40 | | |
| **MICROBIAL PARAMETERS** | | | | |
| Total viable counts at 370C | Cfu | <200 | | |
| Thermotolerant coliforms/100ml | Cfu | <1 | 33 | 100 |
| E. coli/100ml | Cfu | <1 | 126 | 100 |
| Pseudomonas aereginosa/100ml | Cfu | <10 | | |

**Appendix 3:** Means± Standard deviation (SD) and range of faecal contamination indicators (EC, TC, IE, CP) per 100ml and HPC per 1ml on samples from borehole direct (DIR) sources

| WATER | *E. coli* | | TOTAL COLIFORMS | | I. ENTEROCOCCI | | *C. perfringens* | | HPC | |
|---|---|---|---|---|---|---|---|---|---|---|
| SOURCES | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE |
| KRBH I-DIR | 0.06±0.3 | 0.0-1.0 | 14.80±3.5 | 8-20.0 | 0.06±0.3 | 0-1.0 | 0.0±0.0 | 0.0-0.0 | 256.8±50.5 | 185.0-335.0 |
| KRBH III-DIR | 0.06±0.2 | 0.0-0.5 | 16.00±3.9 | 10-25.5 | 0.10±0.5 | 0-2.0 | 0.0±0.0 | 0.0-0.0 | 278.7±78.1 | 60.0-370.0 |
| KRBH IV-DIR | 0.31±0.7 | 0.0-2.0 | 15.20±3.4 | 6-21.5 | 0.06±0.3 | 0-1.0 | 0.0±0.0 | 0.0-0.0 | 280.3±64.4 | 195.0-425.0 |
| DCKBH-DIR | 0.18±0.5 | 0.0-2.0 | 13.50±4.2 | 4-20.0 | 0.10±0.5 | 0-2.0 | 0.1±0.3 | 0.0-1.0 | 334.6±71.1 | 235.0-460.0 |

**Appendix 4:** Means± Standard deviation (SD) and range of faecal contamination indicators (EC, TC, IE, CP) per 100ml and HPC per 1ml on samples from borehole points of access (POA) sources

| WATER | *E. coli* | | TOTAL COLIFORMS | | I. ENTEROCOCCI | | *C. perfringens* | | HPC | |
|---|---|---|---|---|---|---|---|---|---|---|
| SOURCES | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE |
| KRBH I-POA | 2.18±2.7 | 0.0-7.0 | 19.3±4.8 | 9.0-24.5 | 1.4±1.9 | 0-6.0 | 0.2±0.6 | 0.0-0.0 | 262.8±96.2 | 70.0-465.0 |
| KRBH II-POA | 2.31±2.1 | 0.0-5.0 | 24.2±4.9 | 14.0-32.0 | 2.1±2.5 | 0-6.0 | 1.3±1.9 | 0.0-0.0 | 340.0±50.9 | 250.0-430.0 |
| KRBH III-POA | 1.75±2.4 | 0.0-7.0 | 22.1±4.0 | 13-29.5 | 0.8±1.4 | 0-4.0 | 0.4±1.0 | 0.0-0.0 | 324.6±105.8 | 210.0-645.0 |
| KRBH V-POA | 2.62±2.8 | 0.0-7.0 | 23.9±6.0 | 8-34.0 | 2.2±2.9 | 0-9.0 | 1.2±2.9 | 0.0-11.0 | 355.3±53.1 | 270.0-445.0 |

**Appendix 5:** Means± Standard deviation (SD) and range of faecal contamination indicators (EC, TC, IE, CP) per 100ml and HPC per 1ml on samples from surface sources

| WATER | *E. coli* | | TOTAL COLIFORMS | | I. ENTEROCOCCI | | *C. perfringens* | | HPC | |
|---|---|---|---|---|---|---|---|---|---|---|
| SOURCES | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE | MEAN±SD | RANGE |
| KM-BEACH | 300.3±82.2 | 185.0-535 | 512.8±84.0 | 360-695.0 | 417.8±87.4 | 270-570 | 198.1±65.6 | 105.0-325.0 | 22701.5±5711.2 | 9000.0-31000 |
| MAL RVR | 267.1±79.0 | 185.0-430 | 475.9±89.0 | 380-690.0 | 234.0±48.1 | 155-320 | 164.0±45.8 | 100.0-265.0 | 17940.6±4446.5 | 8550.0-22150 |
| GL RVR-UP | 235.9±52.6 | 150.0-300 | 537.1±120.0 | 385-835.0 | 226.8±50.0 | 100-305 | 168.2±56.0 | 85.0-295.0 | 17671.8±3437.5 | 11000.0-22050 |
| GL RVR-DWN | 317.1±42.2 | 255.0-365 | 639.3±91.0 | 475-865.0 | 290.9±47.9 | 205-390 | 221.5±75.6 | 130.0-390.0 | 23118.7±5639.9 | 9400.0-29550 |