IMPACT OF WASTEWATER DISCHARGE ON THE BACTERIOLOGICAL QUALITY AND PHYSICO-CHEMICAL PROPERTIES OF THOME RIVER, NAIROBI

BY

AnnCarol Waruguru Karanja (B. Ed Science)

156/7768/2002

A thesis submitted in partial fulfillment of the requirement for the award of the degree of Master of Science (Microbiology) in the School of Pure and Applied Sciences, Kenyatta University

Plant and Microbial Sciences Department

Karanja, Waruguru

Impact of wastewater discharge on the

Plant and Microbial Sciences Department
Declaration

I AnnCarol W. Karanja declare that this thesis is my original work and has not been presented for award of a degree in any other university.

AnnCarol W. Karanja
Plant and Microbial Sciences Department

This thesis has been submitted for examination with our approval as supervisors

Dr. K. Kotut
Senior lecturer, Plant and Microbial Sciences Department, Kenyatta University.

Dr. N. M. Gitonga
Senior lecturer, Plant and Microbial Sciences Department, Kenyatta University.
Dedication

I dedicate this work to my son Ariel
Acknowledgement

This study was made possible by the funding support from the Leibnitz Institute of Freshwater and Fisheries Ecology and the International Foundation for Science. I wish to express my sincere appreciation and recognition to my supervisors for the continued support and guidance during the course of this study. I am also very grateful to my family members for their support, patience and encouragement during the study. Many thanks are due to the technical staff Plant & Microbial and Zoological Sciences departments for the various ways in which they were involved in my research work. Last and not the least, I do acknowledge the great contribution of my fellow students; Josaphine Ngare, Dominic Kiogora, Raphael Mathaka, Enoch Amboga and many others not mentioned here. May God bless you all!
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<tr>
<td>APHA</td>
<td>American Public Health Association</td>
</tr>
<tr>
<td>BOD</td>
<td>Biological oxygen demand</td>
</tr>
<tr>
<td>CDC</td>
<td>Center for Disease Control</td>
</tr>
<tr>
<td>CIDA</td>
<td>Canadian International Development Agency</td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
</tr>
<tr>
<td>EMB</td>
<td>Ethyl Methylene Blue agar</td>
</tr>
<tr>
<td>GTCC</td>
<td>Greater Taree City Council</td>
</tr>
<tr>
<td>MIU</td>
<td>Motility Indole Urease test medium</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Environment Management authority</td>
</tr>
<tr>
<td>NIWA</td>
<td>National Institute of Water and Atmospheric Research</td>
</tr>
<tr>
<td>KBS</td>
<td>Kenya bureau of standards</td>
</tr>
<tr>
<td>MOH</td>
<td>Ministry of Health</td>
</tr>
<tr>
<td>ROK</td>
<td>Republic of Kenya</td>
</tr>
<tr>
<td>SS agar</td>
<td>Salmonella-Shigella agar</td>
</tr>
<tr>
<td>TCBS</td>
<td>Thiosulphate Citrate Bile Salt Sucrose agar</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNESCO</td>
<td>United Nations Educational Scientific and Cultural Organization</td>
</tr>
<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WRI</td>
<td>World Resources Institute</td>
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Water pollution is one of the major problems facing many countries of the world. It may result from the discharge of various substances into water bodies in their catchment areas. Consequently, the world experiences a number of water-related problems including water scarcity and waterborne diseases. The city of Nairobi has experienced rapid industrialization and growth in population in the last 100 years. However, these have not been matched by development of infrastructure to deal with waste disposal. The unplanned disposal of garbage, human and industrial waste has resulted in increased pollution of water bodies. Against this background, a study aimed at determining the water quality of a section of Thome River passing through the city, was carried out between December 2004 and January 2006. The section of the river studied is located about 10 km from Nairobi city along Nairobi-Thika highway. It receives wastewater discharge from various sources. The purpose of this study was to determine whether the river water meets the recommended standards for watering livestock, recreational and irrigation of crops eaten raw. The study focused at determining the bacterial (faecal) status of the river water and measurement of selected physicochemical properties. Water samples for physico-chemical and bacteriological analyses were collected from five stations; Safari Park, Kasarani, Icipe, Sportsview and Warren along the stretch of the river and analyzed. The range in levels of the physico-chemical properties at all sites during the study period were as follows: water temperature, 18.1 to 27.3 °C; pH, 6.6 to 8.1; DO, 0 to 10.8 mg L⁻¹; total alkalinity, 25.0 to 298.0; BOD, 0.1 to 118.9 mg O₂ L⁻¹; and electrical conductivity, 160.0 to 496.0 μS cm⁻¹. One way ANOVA tests revealed significant differences in levels of total alkalinity, electrical conductivity, and DO at different sampling sites (P<0.05, n=20). The water was found to be contaminated with faecal bacteria such as total coliforms, heterotrophic bacteria, *Escherichia coli*, *Salmonella*, *Shigella*, *Vibrio cholera* and faecal *Streptococcus*. There were significant differences in mean total coliform counts at different sampling sites (P<0.05, n=12). *E. coli* counts recorded during the study (6.7 x 10³ to 4.9 x 10⁴) were higher than WHO standards (0/100 ml). *Vibrio cholera* was present in 50.0 % of all water samples analyzed. *Salmonella* spp were detected in 29.0 % of all the water samples analyzed with Safari Park sampling site recording the lowest occurrence frequency (10.0 %). The highest frequency of occurrence for *Shigella* spp (35.0 %) was obtained during the dry season. Icipe sampling site had the highest *E. coli* counts (2.8 x 10⁵ MPN/100 ml). The highest faecal *Streptococcus* density (4.0 x 10 MPN/100 ml) was recorded at Kasarani and Sportsview sampling sites several times during the study period. Based on the levels of bacterial indicators of faecal pollution, BOD concentration and DO levels, the river water at Kasarani, Icipe and Sportsview sampling sites is unfit for drinking, watering animals and irrigation of crops eaten raw. The water at Safari Park and Warren was less impacted. The results indicate that the Thome River water is polluted with domestic and agricultural and/or surface run off effluents. Corrective measures must be taken to stop the pollution of the river.
Chapter 1  Introduction

1.1  Background to the study

1.1.1  Causes of water pollution

Comprising over 70% of the Earth’s surface, water is undoubtedly the most precious natural resource on our planet. Water is essential for life and without it life on earth would be non-existent (Krantz & Kifferstein, 1997). In most parts of the world, getting sufficient and potable water is presently a daily crisis. This is mainly due to pollution of freshwater bodies and poor water distribution systems (GTCC, 2001). While the United Nations recommends a minimum of fifty liters of water per person daily to cater for drinking, sanitation and hygiene, bathing and food preparation, people living in forty of the world’s water stressed countries survive on 7.5 liters of water per day (Ashraf, 2003).

Surface water bodies (rivers, lakes and dams) are the main sources of water for agriculture, human consumption and industry (Zavala & De la Lanza, 2000). Unfortunately, the available water sources are progressively getting polluted (Abiya, 1996). Water pollution results from human activities, which make the water unfit for human use, unsuitable for industrial use and adversely affect aquatic flora and fauna (GTCC, 2001). Two thirds of the world’s population faces both water shortage and problems associated with water pollution (Allison, 2003).

In the past, water pollution in developing countries resulted mainly from the discharge of untreated wastewater. Presently, the problem is more complex as a result of the production of hazardous wastes from industries and the rapidly increasing use of pesticides and fertilizers in agriculture. In fact, water pollution today in some developing
countries; at least in the newly industrializing ones, is worse than in industrialized
countries (Arceivala, 1989). Direct dumping of household and industrial wastewaters into
water bodies without treatment, is a major cause of water pollution especially in
developing countries (Gleick, 1993 and Kupchella & Hyland, 1993). Developing
countries discharge approximately 95 % of their untreated urban sewage directly into
surface waters (WHO, 1993). In urban areas of most developing countries, overflow from
sewers, leaks from illegal sewer connections or broken sewer pipes are common sources
of human faecal contamination of surface waters (GTCC, 2001). In South Africa, sewage
influx is currently a major problem in the Klip River as well as one of its tributaries, the
Riet River in Johannesburg (Wallington, 2006).

Agricultural and surface run-off containing deposits of faecal wastes, nitrogen and
phosphates compounds also greatly contribute to the contamination process (Jackson &
Jackson, 1998). Run-off from riparian settlements and grazing pastures find their way
into streams and rivers where they contribute to elevated nutrient levels, introduce
organic matter and potentially pathogenic microbes especially enteric bacteria (Koning et
al., 2000; Vlok and Engelbrech, 2000; Warrington, 2001). These substances alter the
physico-chemical and biological properties of the water bodies (Warrington, 2001). Changes in the physico-chemical properties and presence of enteric bacteria can render
the water unfit for human consumption, irrigation, livestock watering and recreational
activities (Warrington, 2001).

Worldwide, river pollution is presently very common and very few rivers are free from
foreign and/or man-made substances (Wikimedia Foundation, 2006). In many developing

countries rivers are now little more than open sewers. This is especially the case in tropical Africa where anthropogenic activities are very common along river systems (Mathooko, 2001). In most countries, the rivers are used directly for washing, bathing, watering of livestock, waste disposal and as playing areas for children. This reduces the availability of good quality water (Mathooko, 2001). Data from rivers in Nairobi area suggest that the rivers are heavily contaminated by a combination of raw sewage and industrial effluents (Opala, 2001).

1.1.2 Effects of water pollution

Water pollution is presently a serious threat to public health. Human health problems can result from the consumption of contaminated food or water (Lipp et al., 2001a; WHO, 2002), ingestion of recreational water and through skin exposure to contaminants present in water bodies (Cabelli, 1983; Cheung et al., 1990; and Rees et al., 1998). The environmental effects of discharge of raw or poorly treated sewage include nutrient related water quality problems and bacterial contamination of surface and ground water (Geary 1992; O’Neill et al., 1993; Jelliffie, 1995a, Research Network for Algal Toxins, 2001).

A high concentration of nitrate nitrogen in drinking water can lead to acute toxicity in bottle-fed infants during their first months of life, or in the elderly, a phenomenon called methaemoglobinanaemia (Ivanildo & Helmer, 1989; WQC, 1972). Most drinking water wells in the United States of America are contaminated with sewage effluents exposing 3 million people to nitrate poisoning (Cunte, 1997).

Contaminated water has always been an important agent in the spread of disease
Discharge of raw sewage or inadequately treated sewage in water bodies can lead to outbreak of waterborne diseases as it contains disease causing organisms such as faecal bacteria (Cunté, 1997; Kupchella & Hyland, 1993). Sources of faecal contamination of freshwaters are diverse and vary both spatially and temporally. Contamination arises through the delivery of fecal material in surface (Doran & Linn, 1979) and subsurface (Collins, 2002) flows to a watercourse and through direct access of livestock to a stream or direct deposition of fecal material (Davies-Colley et al., 2002). Wild animals also contribute to fecal contamination of waterways (Niemi & Niemi, 1991).

Sewage pollution, as a cause of illnesses is estimated to affect the health of more than 120 million people at any one time (Vidal, 2002). About 1.8 million people die every year from diarrhea diseases (including cholera) mostly in developing countries, with 88% of the diarrhea diseases being attributed to unsafe water supply, inadequate sanitation and hygiene (Lobster, 1981).

Ill health associated with contaminated water is one of the most significant concerns in many African countries (CIDA et al., 1998). In Zambia, faecal contamination of wells has caused cholera epidemics and other waterborne diseases in peri-urban areas of Lusaka (Taylor et al., 1998). Due to use of contaminated water, there is persistence of water borne diseases in Zambia (CIDA et al., 1998). Contaminated water is the primary cause of many childhood illnesses and poor health in Kenya, Uganda and Tanzania are water-related (Sharma et al., 1996). For example, in June 2005, five people died in Nairobi estates following an outbreak of a waterborne disease. While 9 patients were
admitted to Kenyatta National Hospital, Mbagathi and Eastligh hospitals (Klein, 2005). In Kenya, diarrhea is largely attributed to faecal contamination of water and poor sanitation. Globally, diarrhea is rated the fourth cause of death in children less than five years and accounts for 40% of all outpatient cases (CARE, 2003). Hence the need to determine water quality cannot be over emphasized, as it forms the basis for preventive action.

1.2 Statement of the problem

Unplanned housing projects and other informal settlements are being established in Nairobi city at rates not matched by the rate of provision of waste disposal infrastructure. Consequently, large quantities of raw sewage and household wastewater drain directly into the city's rivers from housing estates and slums located along the banks. Many of Nairobi's rivers are heavily polluted to the extent that their waters are unsuitable for use even in crop irrigation (Hide et al., 2001).

River Thome, which passes through Kasarani division in Nairobi, is a sub-tributary of the Nairobi River. Around the Kasarani area, the river passes through areas characterized by diverse socioeconomic activities that include catering, housing, small-scale dairy and crop farming. Wastewater runoff from these activities is discharged directly into the river. The impact of wastewater discharge on the physico-chemical properties of the river as well as its overall quality has not been investigated.

Downstream, the river is of great importance as it is the main source of water for watering livestock, irrigation and domestic purposes. It is therefore likely that the release of wastewater from these activities into the river is exposing downstream users to health
risks and causing other environmental problems associated with waste discharge into rivers. This study seeks to determine the river water quality. Health risks posed by faecal contamination and the suitability of the water for the various downstream uses will also be established.

1.3 Research questions

In order to focus the study on the problem, the following questions were formulated:

1. What is the magnitude of change in space and over time in the river’s physico-chemical conditions?

2. Is the river water contaminated by faecal bacteria and if so to what level?

3. How do the different sources of wastewater affect the river water quality?

1.4 Hypotheses

i) Levels of selected physico-chemical properties do not vary with sampling sites and time.

ii) The river water is not contaminated by faecal bacteria.

iii) River water quality is not significantly affected by the wastewater discharge from different sources.

1.5 Objectives of the study

The main objective of the study was to assess the impact of wastewater discharge on water quality of a section of Thome River passing through the city.

The specific objectives were as follows:

i) Determine levels and variations in selected physico-chemical properties of the water along the impacted stretch of the river.
ii) Identify and quantify bacteria associated with faecal contamination in the selected stretch of the river.

iii) Assess the influence of wastewater from different sources on the water quality of the river.

1.6 Justification and significance of the study

The first step in prevention and or reduction of river water pollution is an assessment of its physico-chemical properties and its pollutant levels (Behbahaninia, 2006). River Thome has not received any limnological attention; hence little is known about its water quality and the effects of various wastewater effluents. The data generated from this study will provide a valuable insight into pollution levels in the river based on the physico-chemical properties and bacterial quality of its water. The results will be compared with the recommended limits set by WHO and other regulatory agencies. This will help to determine whether the water is safe for its current utilization downstream.

Data on the levels and sources of contaminants will provide a scientific basis for future management and monitoring of the river water quality changes. The data may also provide pollution control agencies with a basis for taking action against the river polluters. The information generated will also create a general awareness on the likely health problems associated with point and non-point wastewater discharge to human beings and the environment in general.
Chapter 2 Literature Review

2.1 Water quality deterioration

2.1.1 Global water quality deterioration

Issues of water quality are most relevant where water is in short supply or altered (WHO, 2004). Dumping of household and industrial wastes directly into rivers and lakes without treatment, has contributed to the rapid increase in waterborne diseases in humans (Gleick, 1993). Discharge of effluent to land surfaces, is considered preferable to direct discharge to a watercourse, however, it leads to contamination of soil and soil water (Trevisan et al., 2002). Ultimately, the contaminated water flows to surface waters (Ministry of Agriculture and Forestry, 2003).

Deteriorating water quality is a major threat in developing countries, where hundreds of millions of people lack access to clean water and the vast majority of sewage is discharged into surface waters without wastewater treatment. In many urban areas of poor countries, people compete for access to polluted water to meet their domestic water needs. River pollution from raw sewage in many developing countries reaches levels thousands of times higher than the recommended safe limits for drinking and bathing (Clarke, 1993). With no sewage disposal system, Bangkok alone discharges an estimated 10,000 metric tons of raw sewage and municipal wastes daily into nearby rivers and canals (WRI, 1993). River Lyari, which runs through Karachi, Pakistan's largest industrial city, is an open drain from a chemical and microbiological point of view as it comprises a mixture of raw sewage and untreated industrial effluents. Most industrial estates with some 300 major industries and almost three times as many smaller industrial
units in Karachi city discharge untreated effluents into the Lyari River (Ivanildo & Helmer, 1989). The Tiete River, which passes through Greater Sao Paulo, one of the world's largest urban agglomerations, receives 300 tonnes of industrial effluents each day. Lead, cadmium and other heavy metals are among the main pollutants. The river also receives 900 tonnes of sewage daily out of which only 12.5 % is treated (Ivanildo & Helmer, 1989). Sewage pollution accounts for more than 75 % of the surface water contamination in India, where bathers, cremated corpses and millions of tons of sewage can all be found in the holy waters of the Ganges (Anderson, 1992; Yodhas, et al., 2003).

2.1.2 Water quality deterioration in Kenya

Water quality deterioration in lakes, rivers, springs, and groundwater, resulting in water resources becoming unfit for human consumption and other purposes is one of the most critical issues in East Africa (Ndege, 1995). The problem of water quality deterioration in Kenya has been known for long but has not been seriously addressed (Akungah, 2003). Two of Athi river’s three tributaries, the Nairobi and Mathare Rivers are polluted 2,000 times above the World Health Organization (WHO) standards for a wholesome water mass. In Nairobi's Industrial Area, various factories discharge wastes directly into Ngong River that traverses this manufacturing belt, rendering it the most polluted river in Kenya (Opala, 2001). A study done in Nairobi River by Budambula-Mong’are (2004) recorded high levels of enteric bacteria. The physico-chemical properties of the river also confirm the highly polluted state of the river.

2.2 Water in relation to disease

Relationship between water and disease has been recognized from the times of Hippocrates following the association of marshy places with fevers (Faechem et al.,
Water in its natural state is not a threat but a life saviour. However, in the developing countries, millions of people continue to suffer from waterborne diseases, like cholera and typhoid (Yodhas, *et al*., 2003). Waterborne diseases are “dirty-water” diseases; mainly attributed to ingestion or contact with water that has been contaminated by human, animal or chemical wastes (Hinrichsen, 1998). Certain serious illnesses result from inhalation of water droplets (aerosols) in which the causative organisms have multiplied because of warm temperatures and the presence of nutrients in the water (WHO, 2004).

The first time that a clear causal linkage between poor water quality and human health problems was established was in 1854, when an outbreak of cholera epidemic in London was traced to a drinking water source (Ivanildo & Helmer, 1989). By the year 1979, an estimated 50 million people a year were dying from diseases related to poor sanitation and half of the world’s hospital beds occupied by patients suffering from water related diseases (WHO, 1979).

Drinking and bathing in polluted water supplies are among the most common routes for the spread of infectious disease, and nearly half the world's population suffers from water-related diseases (Clarke, 1993). Most of those affected are poor, and almost all live in developing countries (WHO, 1992). Waterborne infections account for 80% of all infectious diseases worldwide and 90% of all infectious diseases in developing countries (Epstein *et al*., 1994). Such diseases are the single largest killers of infants in developing countries (Gleick, 1993). During the last decade, the world experienced a child mortality rate of one child every ten seconds due to waterborne diseases (Smith-Stanwell, 1999).
Even in developed countries, waterborne diseases are significant. In the United States, they account for 940,000 infections and approximately 900 deaths each year (Seager, 1995). Diarrhea diseases are the major waterborne illnesses and they result from lack of sanitary conditions. They kill people more than any other disease in the world (WHO, 1999, 1992). Diarrhea alone causes 4 million deaths per year (Gleick, 1993).

Outbreaks of waterborne disease can affect large numbers of people; hence priority should be given to control of such outbreaks (WHO, 2004). Availability of safe drinking water contributes to disease prevention by reducing the need for contact with contaminated water sources (WHO, 2004). To prevent the chance of an outbreak, the presence and levels of indicator organisms and pathogens in natural waters should be assessed continually (Akungah, 2003).

2.3 Bacterial indicators of faecal pollution in freshwaters

Detection of microbial contaminants of faecal origin is a major priority in the control of water contamination. The presence of faecal contamination is most often evaluated through determination of the presence of indicator organisms that are members of the coliform group (Gleeson & Gray, 1997). Indicator bacteria should fulfill a number of criteria to give meaningful results. First, they should be universally present in high numbers in faecal wastes from humans and other warm-blooded animals. Second, they should be readily detectable by simple methods. Third, they should not grow in natural water (WHO, 2004).

Indicator bacteria do not necessarily cause illness but are found in association with pathogenic microorganisms (Myers & Sylvester, 1997). Presence of bacterial indicators of faecal pollution in surface waters provide useful information concerning pollution by
both human and animal faeces and gives a strong indication of the public health hazard associated with such waters (Ellis, 1989). High levels of indicator bacteria usually indicate the possible presence of pathogens that cause waterborne diseases such as gastroenteritis, bacillary dysentery, typhoid fever, and cholera. The presence and levels of pathogens and indicator organisms in surface water sources depends on a number of factors, including intrinsic physical and chemical characteristics of the catchments area and the magnitude and range of human activities and animal sources that release pathogens to the environment (WHO, 2004). Indicator bacteria include *Escherichia coli*, total coliforms and fecal coliforms (WHO, 2004; Meybeck et al., 1989).

### 2.3.1 Coliforms

Coliforms belong to the family *Enterobacteriaceae*, which includes pathogenic bacteria such as typhoid bacilli (*Salmonella typhi*), gastroenteritis bacteria (*Escherichia coli*), and the dysentery bacilli (*Shigella* spp). Others include *Enterococci* and *Aeromonad*. Coliforms are facultative anaerobes, Gram negative, non-spore forming, bile tolerant rods capable of fermenting lactose with production of both acid and gas within 48 hours at 37 °C (Agg et al., 1978). The predominant bacteria in water belong to the coliform group and although harmless, they are used as the test organisms to determine whether water is safe bacteriologically. Coliforms can easily be detected and counted than pathogenic bacteria and if they are not found in water, it’s inferred that the pathogens are absent (Klein, 1972).

Faecal coliforms have traditionally been the indicators of choice, however, their presence does not correlate well with the incidence of disease. This is because some of the bacteria
in this group such as *Klebsiella* are not necessarily of faecal origin. *Klebsiella* may multiply in water containing pulp mill effluent and other organics, which is not contaminated by human sewage and thus gives false positives for faecal contamination (Warrington, 2001). Coliforms are therefore being replaced by more specific indicators such as *E. coli* and *Enterococci*, which are better indicators of gastrointestinal disease causing pathogens (Warrington, 2001).

### 2.3.2 Faecal *Streptococcus*

The *Enterococci* group including faecal *Streptococcus* is a better indicator of faecal pollution than faecal coliforms and closely approaches the ideal characteristics of an indicator for gastrointestinal diseases. They are the best indicators of bacterial contamination of water meant for recreational uses (Warrington, 2001). Faecal *Streptococcus* is a Gram positive, catalase negative bacterium that is not inhibited by bile salts (Hardwood *et al.*, 2000). The U.S. Environmental Protection Agency (USEPA) recommends the use of *E. coli* or *enterococci*, which it considers to be better indicators of water quality (USEPA, 1986). Faecal *Streptococcus* is a normal inhabitant of the intestines of humans and animals. Their presence has an added value of determining the source of faecal pollution because certain faecal *Streptococcus* species are host specific (CDC, 1985).

### 2.3.3 *Escherichia coli*

*Escherichia coli* is generally regarded as the *sine qua non* of faecal pollution and there is no doubt its presence in rivers is confirmation of fecal pollution (Ampofo, 1997). It is a better indicator than faecal coliforms since *Klebsiella* is not enumerated in the *E. coli* test.
E. coli cannot survive for long outside the host environment owing to its susceptibility to solar radiation (Sieracki, 1980). It is a normal inhabitant of the human digestive tract. However some strains of E. coli cause diarrhea diseases in humans (Orskov et al., 1992). Although pathogenic E. coli have been implicated in foodborne illnesses, several major waterborne outbreaks have also been reported (Feng, 1995). These outbreaks have involved both water supplies (Etienne, et al., 2001) and recreational waters (Brewster et al., 1994).

A disease outbreak in Walkerton, Ontario in May 2000 that resulted in the hospitalization of dozens of people, seven of whom died has been attributed to faecal contamination of a water supply well in a fractured rock aquifer with E. coli (McKay & Layton, 2001). Ill health associated with pathogenic E. coli has not been reported in Kenya. However, in the US, consumption of beef from cattle feeding on pollutants containing E. coli, caused severe gastrointestinal diseases in 1997. Authorities warn that E. coli may not be alien in Kenya; just that it has not been isolated (Opala, 2001).

2.4 Agents of waterborne diseases

In surface waters, potential pathogen sources include point sources, such as municipal sewage and urban storm water overflows, as well as non-point sources, such as contaminated runoff from agricultural areas. Other sources are wildlife and direct access of livestock to surface water bodies (WHO, 2004). Pathogenic microorganisms present in river water vary both in variety and in number depending on the general state of health of the community, the geographical region and the extent of sewage treatment available (Ellis, 1989). Pathogenic bacteria have only a short lifespan in water, are less resistant to
adverse influences such as extreme temperature, hence are more easily destroyed than either the normal intestinal bacteria or ordinary water bacteria (Klein, 1972). Whereas microorganisms like E. coli and Campylobacter can accumulate in sediments and are mobilized when water flow increases, many pathogens in surface water bodies will reduce in concentration due to dilution, settling and die-off due to environmental effects (WHO, 2004).

Pathogenic bacteria have several properties that distinguish them from indicator bacteria. Pathogens are discrete, often clumped or adherent to suspended solids in water. The likelihood of a successful challenge by a pathogen, resulting in infection, depends upon the invasiveness and virulence as well as the immunity of the individual. If infection is established, they multiply in their host. Some pathogenic bacteria such as Salmonella are also able to multiply in food or beverages, thereby perpetuating or even increasing the chances of infection (WHO, 2004). Waterborne pathogenic bacteria include the genera, Leptospira, Brucella, and enteric pathogens; Salmonella, Vibrio cholerae, Shigella, and enteropathogenic E. coli (Ellis, 1989).

2.4.1 Salmonella spp.

Salmonella is a motile rod shaped bacteria with petrichous flagella bearing various antigens. Salmonella typhi is responsible for typhoid fever. The infective dose of Salmonella is $10^6$ to $10^9$ microorganisms (David et al., 1997). A study by McGarry & Bouthiller (1996) indicates that Salmonella spp are better survivors in the environment than E. coli and their survival depends on the presence of nutrients such as phosphates (Hok, 1964; McGarry & Bouthiller, 1996). Salmonella spp are therefore likely to occur in
large numbers than *E. coli*. A frequent outbreak of waterborne disease especially in low-income urban areas of Blantyre, the capital city of Malawi has been attributed to high levels of *Salmonella* in boreholes, wells and standpipes (Lobster, 1981; Wycliffe & Blessing, 2000). In the year 2001, ninety-seven people died in Embu district due to a typhoid outbreak caused by consumption of water contaminated with *Salmonella* (Munene, 2001).

### 2.4.2 *Shigella* spp.

*Shigella* spp are Gram negative, facultative anaerobic, non-sporulating, non-motile rods. They are lactose negative (do no ferment lactose) and glucose positive (ferment glucose) (APHA, 1998). *Shigella* invades the intestine mucosa, producing dysentery characterized by abdominal pain, fever and diarrhea. The infective dose for *shigella* is low (10 to 100 microorganisms) and in most cases results from person to person transmission (APHA, 1998). Presence of *Shigella* spp in the environment is a health hazard to the public as it is highly virulent. Hence its discharge to the environment should be avoided. Four species or serotypes of the genus *Shigella*; *S. dysentriae*, *S. flexneri*, *S. boydii* and *S. sonnei* cause Shigellosis, an acute gastrointestinal disease of humans. In tropical countries, shigellosis is endemic and it has been estimated that some 5 million people die every year from this illness (David *et al.*, 1997). In March 2006, forty-eight people were hospitalized with dysentery following an outbreak of shigellosis in Kaimosi, Western Kenya (Daily Nation Friday, 17th March, 2006). While no specific criteria are set to show the number of cells that are likely to cause health hazards, a health hazard exists if *Shigella* spp are routinely isolated in recreational waters. For drinking water presence of a single cell is a health hazard (Warrington, 2001).
2.4.3 Vibrio cholerae

*Vibrio cholerae* is the causative agent of cholera, a waterborne illness with symptoms ranging from mild to severe and potentially fatal diarrhea disease (Oliver *et al.*, 1997). It has an infective dose of $10^4$ (David *et al.*, 1997) and can reach aquatic environments through sewage effluents (Mara & Pearson, 1986).

Contaminated water with free-living *Vibrio cholerae* cells are probably the main origin of cholera epidemics, followed to a lesser extent by contaminated food, especially seafood products such as oysters, crabs, and shellfish (DePaola, 1981; Kaysner & Hill, 1994). Cholera continues to be a serious global problem due to occurrences of severe outbreaks, which are closely associated with climatic cycles. More severe and frequent outbreaks occur during the wet seasons (Colwell, 1996). The last cholera (seventh) epidemic affected over one hundred countries, including the United States, with over one million reported cases and 10,000 deaths (CDC, 1995). An outbreak of cholera in Chile in April of 1991 resulted from the use of contaminated irrigation water on vegetable crops that are normally eaten raw (Blumental *et al.*, 1989). Frequent water shortages and poor sanitation resulted in about 1,000 cholera cases in various parts of Kenya in June 2000 (MOH, 2000).

2.5 Nutrients

Human activities have profoundly altered nutrient levels in many of the world’s surface waters (Allan, 2004). Faecal wastes of human and animal origin contain high concentrations of both nitrogen and phosphorus (Moss, 1988). High nutrient levels in a water body leads to growth of undesired plants (eutrophication) especially algal blooms,
which may produce toxins lethal to human beings and aquatic life (Jackson & Jackson, 1998). Eutrophic conditions decrease the resource value of rivers, lakes, and estuaries such that recreation, fishing, hunting, and aesthetic enjoyment are hindered (Bartram, et al., 1999). For example, untreated industrial waste, raw sewage and waste from activities and human settlements situated along Nairobi River have turned the once clear water into sludge, causing health hazards, accelerated eutrophication and stress on the aquatic ecosystem (UNEP, 2007). Enteric pathogenic bacteria can survive longer in waters with high nutrient concentration; hence a high nutrient load can increase the incidence of waterborne diseases (James and Keevil, 1999).

2.5.1 Nitrate nitrogen

Nitrogen entering aquatic systems arises from a variety of sources that include point and non-point sources of pollution, biological fixation of gaseous nitrogen and dry deposition of nitrogen oxides (Kotut, 1998). The concentration of nitrate nitrogen (NO$_3$-N) in unpolluted surface waters is usually less than 0.1 mg L$^{-1}$. Nitrate nitrogen levels in excess of 0.1 mg L$^{-1}$ indicate anthropogenic influences such as discharge of municipal wastes and urban and agricultural run-off (Allan, 1995). Presence of high levels of NO$_3$-N often suggests bacterial contamination since their presence is usually a direct result of seepage of surface water from the surrounding fields that are fertilized by either chemical or animal manure. The surface water will in most cases be contaminated with bacteria (Blake, 1994).

The U.S. Public Health Service has established 10 mg L$^{-1}$ of NO$_3$-N as the maximum contamination level allowed in public drinking water. A study by Ngetich (1996)
reported NO$_3$-N concentrations of between 12 mg L$^{-1}$ to 25 mg L$^{-1}$ in River Kipsonoi in Sotik district. A mean concentration of 4.9 mg L$^{-1}$ total nitrogen was obtained in Blue River Kansas City, Missouri between July 1998 and October 2000 (Wilkison et al., 2001).

2.5.2 Phosphate phosphorus (PO$_4$-P)

Phosphorus is often scarce in the well-oxygenated waters (Moss, 1988). However, waste discharge from agricultural runoff can increase the concentration of phosphorus in surface waters. Sewage introduction into a water body can greatly increase its phosphorus concentration to levels above the expected concentrations (Moss, 1988). High PO$_4$-P concentrations of between 0.76 mg L$^{-1}$ and 0.87 mg L$^{-1}$ were recorded near a canning factory along River Njoro, during the dry season (Mokaya, 2000). High PO$_4$-P levels cause eutrophic conditions in water bodies (Jackson & Jackson, 1998).

2.6 Physico-chemical properties

2.6.1 Temperature (°C)

Temperature of a watercourse can vary diurnally as well as seasonally due to weather conditions and can also be markedly affected by the discharge of heated effluents. Watercourses unaffected by heated effluents are usually a little lower in temperature than the mean monthly air temperature. However, a very warm weather can cause a stream to be a little higher in temperature than the ambient air temperature (Klein, 1972). The magnitude of temperature variation varies with elevation, extent of riparian vegetation development and the relative importance of groundwater inputs (Allan, 2004). Water temperatures also vary along the river’s stretch depending on the variation in soil properties. Head water streams, which are fed by ground water, will have a temperature
close to that of the surrounding soil (Townshed, 1980). When heated effluents are dumped into waterways, the effluents raise the temperature of the water (WQC, 1972). Most biochemical reactions within a cell are temperature dependent, showing an exponential increase with temperature to a maximum, which varies for each reaction and is usually between 25 °C to 40 °C (Harper, 1992).

2.6.2 pH

Water pH is an indication of its acidity or alkalinity (Meybeck et al, 1989). In most natural waters, pH is principally controlled by the balance between carbon dioxide, carbonate and bicarbonate ions and is slightly alkaline (Eric, et al., 1994). The pH of freshwaters can vary widely due to the natural causes as well as anthropogenic inputs that include industrial wastes, agricultural runoff or sewage effluents (Wetzel, 1983).

Most organisms have adapted to life in water of a specific pH range and may die if the range is exceeded (Wetzel, 1983). Neutral pH is suitable for bacteria such as Pseudomonas spp, Caulobacter spp and Acinetobacter spp. However, with an increase or decrease in pH levels, these bacteria tend to die (Mwachiro & Durve, 1997). Extreme pH values such as below 5 or above 9 are harmful to most organisms. Hence the buffering capacity of water is critical to the maintenance of life (Wetzel, 1983). Shallow waters that hold considerable organic matter often vary from pH 9.5 during the day to pH 7.3 at night. Organisms living in these waters are able to tolerate these extremes or may move to more neutral waters when the level exceeds their tolerance limit (WQC, 1972).
2.6.4 Biochemical oxygen demand (BOD₅ mg O₂ L⁻¹)

Biochemical oxygen demand is a measure of dissolved oxygen used by aerobic microorganisms as they metabolize complex molecules such as proteins, carbohydrates and lipids present in sewage and other wastewater (Ellis, 1989). Biochemical oxygen demand test is not a measure of the level of a specific pollutant, but it is an indicator of the general level of pollution with reducing organic matter. A very low BOD rate can indicate that the water is either clean, organisms present are not using the oxygen or they are dead.

The BOD of a water body can vary with changes in environment conditions. For example, an increase in temperature increases the overall metabolic rate of the water and consequently its BOD (Opala, 2001). Introduction of wastewater with a high BOD can cause anaerobic conditions in receiving streams (Vesilind et al., 1990). River Athi has BOD values that are seven times higher than the set standards of 3 mg L⁻¹ for natural river systems. The BOD of the Nairobi City Rivers most of which are tributaries of the Athi is in the range of between 40 and 4400 mg L⁻¹ (Opala, 2001). This is much higher than the normal levels, hence the rivers are said to be highly polluted.

2.6.3 Dissolved oxygen (DO mg L⁻¹)

Dissolved oxygen is the most essential for survival of fish, and other aerobic aquatic organisms (Vesilind et al., 1990). The solubility of oxygen in water at sea level is about 9 mg L⁻¹. The solubility decreases with increasing temperature and increases with increasing atmospheric pressure (Ellis, 1989). Oxygen levels can be reduced through introduction of organic wastes. Under this condition, if the weather becomes cloudy for
several days, respiring plants will use much of the available DO. When these plants die and decompose, they are broken-down by bacteria, which in turn multiply and use large amounts of oxygen (Michaud, 1991).

Enteric bacteria including coliforms are generally adapted to relatively low oxygen concentrations due to the nature of their natural habitat, i.e. the lower intestine of warm-blooded animals. It is therefore possible to isolate these bacteria in water with very low concentrations of oxygen. *Escherichia coli* O157 expresses different phenotypes including stronger adhesion to human epithelial cells when grown under anaerobic conditions (James & Keevil, 1999).
Chapter 3. Materials and methods

3.1 The study area

The section of the river studied is located at Kasarani, about 10 kilometers from Nairobi city along the Nairobi-Thika highway. The surrounding area is characterized by upcoming residential estates, small-scale farming and hotels such as Safari Park and Sportsview. Kasarani Estate is a fast growing residential area inhabited mostly by civil servants and young professionals. Housing is a mixture of smart new two storey houses and low rise apartment blocks, some of which are still under construction. There is some limited small scale arable farming along the river’s banks. The river, which is a sub-tributary of the Nairobi River rises from Kiambu district. Sampling was carried out in five sites spread across the study area (Fig. 1). Their geographical locations (UTM coordinates) are as follows: Safari Park (N0264297, E9864486), Kasarani (N0264819, E9864372), Icipe (N0265848, E9864708), Sportsview (N0266516, E9864354) and Warren (N0267099, E9864382).

3.2 Selection of sampling sites

The five sampling sites were chosen during a reconnaissance sampling trip to the study area (Fig. 1). The sites were selected on the basis of the physical appearance of the water, land use patterns, presence of point sources of pollution and accessibility. The first sampling station (Safari Park) was located upstream of Safari Park a few meters upstream of the bridge on the private road leading to Thome Estate (UTM coordinates; N0264297, E9864486). This site is characterized by comparatively clean water suggesting low human impact. The second sampling site (Kasarani) was located downstream of Safari
Park, below the bridge on the road to Kasarani Sports Centre. Water at this site was usually grey to black in colour due to direct wastewater discharge. Sections of the river’s banks were covered by a dense growth of *Cyperus altenifolia*. The next two sampling sites were chosen in such a way that each site was downstream of a major point of wastewater discharge into the river. Site three (Icipe) was located upstream of the bridge on the road after Icipe. One side of the river bank at this site was swampy with the common vegetation being *Papyrus* spp. Site four was located approximately 500 meters downstream of a point of wastewater discharge from Sportsview Hotel. Upcoming residential houses and dairy farms characterized this site. The final sampling station (Warren) was established about 1 km downstream of the fourth sampling point. The site was characterized by a mass development of macrophytes and vegetable growing along the river bank. The distance between the study sites ranged from between 800 meters to 1.2 kilometers. Water sampling for physico-chemical and bacteriological analyses were carried out twice each month for a period between December 2004 to January 2006

### 3.3 Sampling techniques

Water samples for laboratory analyses were obtained in duplicates from each of the five sampling sites. The samples were drawn from as close to the middle of the river as possible using a water scooper with a 3-meter extension pole. Plastic sample bottles with a capacity of 1.0 liter were used to transport water samples to the laboratory for physico-chemical analyses. Samples for bacteriological analyses were collected directly in duplicates in sterile 250 ml glass bottles.
Fig. 1. Map of the study area showing the study sites.

Key: $S_1$- Safari Park Sampling site, $S_2$- Kasarani sampling site, $S_3$- Icipe sampling site, $S_4$- Sportsview sampling site & $S_5$- Warren sampling site.
3.4 Field measurements of temperature, dissolved oxygen, pH and electrical conductivity

Temperature, dissolved oxygen, pH and electrical conductivity were measured by their respective electrodes contained in a universal digital multiline P4 WTW (Weilheim Germany) meter. The multiline meter uses Cell Ox325, Sentix 41-3 and Tetra Con 325 probes to measure dissolved oxygen, pH and electrical conductivity respectively. Each probe was lowered in turn into the middle section of the river and measurements taken after the readings stabilized (APHA, 1998). The conductivity meter has an in-built temperature probe which gives a direct reading of the water temperature in degrees Celsius to one decimal point.

3.5 Laboratory determination

3.5.1 Biochemical oxygen demand (BOD5 mg O₂ L⁻¹)

Biochemical oxygen demand was estimated using a modification of the method outlined in APHA (1998). Fresh reagents (phosphate buffer, magnesium sulfate, calcium chloride, and ferric chloride) for constitution of dilution water used for the biochemical oxygen demand test were prepared in the laboratory. The dilution water was prepared by first saturating distilled water with air followed by addition 1 ml per litre of each of magnesium sulfate, calcium chloride, phosphate buffer and ferric chloride solutions. Each water sample was first diluted with the dilution water. Dilution factor for the samples varied from site to site and from time to time depending on an estimate of the level of pollution. Pollution level was estimated based on DO measurements in the field, water colour and smell. The diluted water samples were transferred into three 250 ml reagent bottles. One bottle was used to determine the initial DO by Winkler titration and the
remaining two samples incubated. Final dissolved oxygen was determined after 5-day incubation of water samples in water bath at a constant temperature (APHA, 1998). BOD was calculated as the difference between the two values.

3.5.2 Total alkalinity (CaCO₃ mg L⁻¹)

Total alkalinity was determined by titrating 100 ml water samples with 0.02 N standard HCl. Mixed bromocresol green-methyl red indicator was used to determine the titration end point (APHA, 1998). The volume of acid used was recorded and total alkalinity value calculated using the equation provided in APHA (1998).

3.5.3 Soluble reactive phosphorus (PO₄-P µg L⁻¹)

Glassware for phosphorus analyses were washed with 10 % hydrochloric acid, rinsed with tap water and finally rinsed with copious amount of freshly prepared distilled water. Samples for orthophosphate analyses were filtered through pre-washed Whatman glass fiber filters (Whatman GF/C, Whatman International Ltd., Maidstone England) and analyzed following the procedure outlined in APHA (1998). Under acidic conditions, the molybdate ions react with phosphate ions to form molybdophosphoric acid, which is reduced by ascorbic acid to intensely coloured molybdenum blue. The colour intensity was measured with a digital grating spectrophotometer (CE 23434 Series 2) and the phosphate concentrations determined based on the absorbance values of standards with known PO₄-P concentration.

3.5.4 Total phosphorus (TP µg L⁻¹)

Samples for TP analyses were first oxidized to PO₄-P (APHA, 1998). This was achieved through autoclaving a 25 ml unfiltered water sample at 140 °C, for 40 minutes in
presence of 0.2 g potassium persulfate oxidizing agent. The amount of orthophosphate phosphorus present was then determined spectrophotometrically by the ascorbic acid reduction procedure as outlined in Section 3.5.3 above.

3.5.5 Nitrate nitrogen (N\textsubscript{03}-N \(\mu\)g L\(^{-1}\))

Samples for N\textsubscript{03}-N determination were filtered through pre-washed Whatman glass fiber filters (Whatman GF/C, Whatman International Ltd., Maidstone England). Five milliliters of water samples were taken into 12 ml nessler tubes in duplicates and 2 ml of sodium salicylate solution added (Kalff \textit{et al.}, 1984). The samples were then dried in an oven overnight. After drying one milliliter of concentrated sulphuric acid was added and swirled several times to dissolve the residue. An amount of 25 ml distilled water was added to the acid solution followed by 5 ml of Rochelle solution. Colour intensity was measured with a spectrophotometer and the nitrate nitrogen concentration determined based on the absorbance values of standards with known N\textsubscript{03}-N concentration that were subjected to the same treatment as the samples.

3.5.6 Total nitrogen (TN \(\mu\)g L\(^{-1}\))

Total nitrogen was determined by oxidation of all forms of nitrogen in unfiltered water samples to NO\textsubscript{3}-N through autoclaving water samples at 121 °C for 40 minutes in presence of 0.1 g potassium persulfate. Levels of NO\textsubscript{3}-N in samples were then analyzed by modified sodium salicylate procedure as in the case of NO\textsubscript{3}-N above (Kalff \textit{et al.}, 1984).
3.6 Microbial analysis of water samples

Reagent bottles for the collection of microbial water samples were sterilized in an autoclave at 121 °C for 15 minutes and kept closed and wrapped in aluminium foil until the time for sample collection at various sampling sites (APHA, 1998). Bacteriological examination of water samples commenced on arrival at the laboratory. Delay in examination was limited to 6 hours with samples being kept at 4 °C (APHA, 1998).

3.6.1 Total coliforms - Most Probable Number (MPN)/100 ml

Analysis of water for the presence of total coliforms was carried out using the multiple tube fermentation technique (Cheesbrough, 1985). This technique has two steps, the presumptive and the confirmed tests. Laury tryptose broth medium was prepared, dispensed into tubes with Durham tubes and sterilized in an autoclave for 15 minutes at 121 °C. Dilution water was prepared and appropriate dilutions of each sample prepared. The diluted samples were then used to inoculate the sterilize laury tryptose broth using sterile pipettes (sterilized at 160 °C for 1 hour). In the presumptive test, three sets of five tubes containing different portions of water samples was inoculated in the broth and incubated at 37 °C for 48±3 hours.

After a 24-hour period, the inoculated tubes was removed and checked for gas production indicative of possible presence of coliforms. The negative tubes were incubated for another 24 hours and then checked for gas production. Confirmatory tests involved the transfer of inocula from all positive presumptive test tubes into sterile brilliant green broth and incubating at 37 °C for 48±3 hours. The production of gas constitutes a positive confirmatory reaction while absence of gas within this period is indicative of
absence of total coliform group of bacteria (APHA, 1998). The combination of positive tubes was read and the MPN of the total coliforms determined from MPN coliform statistical tables or calculated as described in APHA (1998).

3.6.2 *Escherichia coli*

Careful streaking of each of the tubes showing gas production in brilliant green medium on eosin methylene blue (EMB) agar plates was carried out. The plates were then incubated at 37 °C for 18 to 24 ± 2 hours. Appearance of dark blue colonies with a green metallic sheen on the EMB agar indicated the possible presence of *E. coli*. The suspect colonies were subjected to Indole production, Methyl-red, Voges-proskauer and Citrate utilization ”IMViC” tests to confirm the presence of *E. coli*. Gram staining was also performed to study the morphology of the microorganisms. Further confirmation by the use of definite substrate EC methylumbelliferyl–β-D-glucorinide (EC-MUG) medium was also done to test for presence of known enzymes produced by *E. coli*. The bacteria cleave the fluorogenic substrate which fluorescence after being exposed to light by a long wave UV lamp. A bright blue fluorescence confirms presence of *E. coli* (APHA, 1998).

3.6.3 *Salmonella* and *Shigella*

A one-millilitre water sample was enriched with selenite F broth followed by careful streaking on salmonella-shigella agar. Typical *Salmonella* colonies are colourless with black centers while those of *Shigella* are colourless and shiny with no black centers. Presence of *Salmonella* and *Shigella* spp was confirmed by transferring the suspect colonies onto Triple Sugar Iron (TSI) agar. A pink-red slant and a yellow butt are typical for both *Salmonella* and *Shigella*. Production of hydrogen sulphide gas, shown by
blackening of the medium and gas bubbles is specific for *Salmonella* (Cheesbrough, 1985). Further confirmation was also conducted by inoculating the colonies onto motility indole urease agar. This is necessary because some *Proteus* spp also produce hydrogen sulphide but are urease positive while *Salmonella* are urease negative. This also differentiates between motile *Salmonella* from non-motile *Shigella*. Defined substrate technique (explained in 3.6.2 above) was used to confirm suspicious colonies of *Shigella*.

### 3.6.4 Vibrio cholerae

Screening for *Vibrio cholerae* involved enrichment of the water sample with peptone water, incubation for 6-8 hours followed by subsequent streaking onto thiosulphate citrate bile salts (TCBS) agar. The TCBS plates were then incubated aerobically at 35 °C for 24±3 hours. Yellow colonies (due to fermentation of sucrose), 2-3 mm in diameter, shiny and surrounded by yellow zone in the medium were sub-cultured on nutrient agar and incubated at 35 °C for 24 hours (Cheesbrough, 1985). Colonies formed were subjected to various identity confirmation tests. These included microscopy and oxidase test using oxidase discs. The oxidase discs were placed on young cultures for a period of 10 seconds. If the disc turned from white to dark purple, it indicated a positive oxidase test (oxidase enzymes have been produced). Gram staining was also performed to study the morphology of the microorganisms (APHA, 1998).

### 3.6.5 Faecal Streptococcus

Tests for faecal *Streptococcus* were carried out in two steps: presumptive and confirmatory. Presumptive test involved inoculation of a series of tubes of azide dextrose broth with appropriate graduated dilutions of 0.5 ml water sample and then incubating at
35± 0.5 °C for 48±3 hours. Definite turbidity indicates a positive reaction. All the positive presumptive tubes were subjected to the confirmatory test by inoculating a portion of the growth from azide dextrose tubes into KF streptococcal broth and incubating at the same temperature. A bright yellow colour constitutes a positive reaction.
Chapter 4 Results

4.1 Rainfall (mm)

Monthly total rainfall ranged from 1 to 242 (mm) during the study period. The highest rainfall was received during the long rains season (March – June) (Fig. 2). A total rainfall of 663 mm was received in the year 2005.

4.2 Physico-chemical properties

4.2.1 River discharge (m$^3$ sec$^{-1}$)

The river discharge of Thome River ranged from 0.032 to 0.342 m$^3$ sec$^{-1}$ in the three sites studied depending on weather and/or the volume of effluents being discharged at the particular sites. The lowest river discharge was recorded in February 2005 while the highest was in May. A lower discharge was characteristic of dry season months (January – March) while a higher discharge characterized the wet season months (April – June) (Fig. 3).

4.2.2 Temperature (°C)

The lowest temperature (18.1 °C) was recorded at Icipe sampling station in June 2005, while the highest (27.3 °C) was recorded at Sportsview sampling site in March 2005. High water temperatures were characteristic of the dry season while comparatively lower values were characteristic of the wet season (Fig. 4). Mean water temperature varied narrowly amongst the five sampling sites with a mean range of 22.2 °C to 23.4 °C (Table 1). Using a one way analysis of variance (ANOVA) test, a significant difference in mean water temperatures of the sampling sites was recorded (P<0.05, n=20).
Fig. 2 Rainfall (mm) recorded during the study period - December 2004 to March 2006

Fig. 3 Temporal changes in discharge of Thome River from January 2005 to January 2006.
Based on Turkey's mean separation procedure, mean temperature at Safari Park sampling site was found to be significantly higher than that at Icipe sampling site.

4.2.3 Dissolved oxygen (DO mg L\(^{-1}\))

A wide range (below the limit of detection to 10.8 mg L\(^{-1}\)) of DO concentrations was observed at the study area (Fig. 5). The highest reading was made at Safari Park sampling station in January 2005. A number of sites recorded undetectable levels of dissolved oxygen including Sportsview and Kasarani sampling sites on diverse dates of the study period. Low DO levels were recorded in Sportsview and Icipe during the dry season and elevated levels during the wet season months. Temporal changes in DO varied with sampling site. There were higher DO levels during the dry season months (January and February) and a general decline to the lowest level during the wet season (Fig. 5). Using a one-way ANOVA test, a significant difference in the mean concentration of dissolved
oxygen in the different sampling sites was recorded ($P<0.05$, $n=20$). Based on Turkey's mean separation procedure, mean dissolved oxygen concentration at the Safari Park sampling site was found to be significantly higher than that of the other sites.

![Dissolved oxygen (mg L$^{-1}$)](image)

**Fig. 5** Temporal changes in dissolved oxygen at different sampling sites of Thome River during the study period - December 2004 to January 2006

### 4.2.4 pH

The highest river water pH (8.1) was recorded at Kasarani sampling station while the lowest value (6.6) was recorded at Sportsview Hotel. Median pH values at all sampling sites were generally neutral (Table 1) without major changes even after addition of sewage effluent into the river. There was a wide range in pH during the dry season and narrow range during the wet season (Fig. 6). Less polluted sites such as Safari Park (based on DO concentration) had low pH during the wet season and high pH during dry season.
4.2.5 Electrical conductivity (µS cm⁻¹)

Electrical conductivity (µS cm⁻¹) recorded in the present study ranged from 160.0 to 496.0 recorded at Safari Park and Kasarani sampling sites respectively. Safari Park sampling site had consistently low conductivity values throughout the sampling period with a mean of 202.4 µS cm⁻¹ (Fig. 7). The same site had the least fluctuation in conductivity as compared to all other sites. The other sampling sites had comparatively high conductivity values with wide fluctuations from time to time especially during the first seven months of the study period. Low electrical conductivity recorded in May 2005 (160.0 µS cm⁻¹ to 179.0 µS cm⁻¹) coincided with the period with the highest rainfall (Fig. 7). Nearly similar conductivity values were recorded during the wet season in all the sampling sites. Overall conductivity values obtained during the wet season were lower than during the dry season. Using a one-way ANOVA test, a significant difference in the
mean values of electrical conductivity at the different sampling sites was recorded (P<0.05, n=20). Based on Turkey's mean separation procedure, the mean conductivity at Safari Park was found to be significantly lower than that of the other sites except at Icipe.

![Electrical conductivity graph]

**Fig. 7** Temporal changes in electrical conductivity at different sampling sites of Thome River during the study period - December 2004 to January 2006.

### 4.2.6 Total alkalinity (mg CaCO$_3$ L$^{-1}$)

A wide range in total alkalinity (25.0 to 289.5 mg CaCO$_3$ L$^{-1}$) was recorded during the study. The lowest value was recorded at Safari Park sampling site while the highest was recorded at Kasarani sampling site (Fig. 8). A pronounced seasonality pattern with lower levels during the wet season and high levels during the dry season was observed during the study period (Fig. 8). Safari Park sampling station had the least fluctuation in total alkalinity as compared to all the other sites. A one-way ANOVA test, revealed a significant difference in the mean values of total alkalinity at the different sampling sites (P<0.05, n=20). Based on Turkey's mean separation procedure. The mean alkalinity value
recorded at the Safari Park sampling site was found to be significantly lower than at the other sites except at Icipe. Total alkalinity values obtained in May at all the sites varied narrowly from between 45.5 to 50.0 mg CaCO$_3$ L$^{-1}$.

![Total alkalinity (mg CaCO$_3$ L$^{-1}$)](image)

**Fig. 8 Temporal changes in total alkalinity at different sampling sites of Thome River during the study period - December 2004 to January 2006.**

4.2.7 Biochemical oxygen demand (BOD$_5$ mg O$_2$ L$^{-1}$)

A wide range (0.1 mg O$_2$ L$^{-1}$ to 118.9 mg O$_2$ L$^{-1}$) in BOD$_5$ was recorded during the study (Fig. 9). The highest reading was made in April at Kasarani sampling site while the lowest value was made at Safari Park sampling site in September. Kasarani constantly recorded high BOD values on most occasions during the study period. The least fluctuation in BOD values was recorded at Safari Park. Nearly similar BOD values were recorded in all sampling sites during the wet season (Fig. 9). High BOD values were characteristic of the dry season while comparatively lower values were recorded during the wet season. A one-way ANOVA test revealed significant difference in mean BOD
values among sampling sites (P<0.05, n=20). Based on Turkey’s mean separation procedure, mean BOD at Safari Park sampling site was significantly lower than at Kasarani and Sportsview (Table 1).

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**Fig. 9** Temporal changes in BOD at different sampling sites of Thome River during the study period - December 2004 to January 2006

**Table 1** Mean values of selected physico-chemical properties (median in the case of pH) recorded at different sampling stations at Thome River for the year 2005

<table>
<thead>
<tr>
<th>Site</th>
<th>pH</th>
<th>DO (mg L⁻¹)</th>
<th>Alkalinity (mg CaCO₃ L⁻¹)</th>
<th>Conductivity (µS cm⁻¹)</th>
<th>Temperature (°C)</th>
<th>BOD (mg O₂ L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safari Park</td>
<td>7.22±0.06ᵇ</td>
<td>6.44±0.40ᵈ</td>
<td>69.32±5.66ᵃ</td>
<td>203.3±17.52ᵃ</td>
<td>23.35±0.50ᶜ</td>
<td>11.56±1.58ᵃ</td>
</tr>
<tr>
<td>Kasarani</td>
<td>7.11±0.05ᵇ</td>
<td>2.81±0.26ᵇ</td>
<td>126.97±16.23ᵇ</td>
<td>313.40±9.83ᶜ</td>
<td>22.72±0.42ᵇ</td>
<td>33.69±6.50ᶜ</td>
</tr>
<tr>
<td>Icipe</td>
<td>7.23±0.06ᶜ</td>
<td>3.19±0.26ᶜ</td>
<td>112.08±11.21ᵇ</td>
<td>286.53±15.05ᵇ</td>
<td>21.96±0.54ᵃ</td>
<td>34.40±3.63ᵇ</td>
</tr>
<tr>
<td>Sportsview</td>
<td>6.98±0.04ᵃ</td>
<td>1.64±0.24ᵃ</td>
<td>124.85±12.11ᵇ</td>
<td>327.40±15.02ᵈ</td>
<td>23.51±0.50ᶜ</td>
<td>28.15±4.31ᵇ</td>
</tr>
<tr>
<td>Warren</td>
<td>7.05±0.05ᵇ</td>
<td>3.15±0.18ᶜ</td>
<td>122.11±12.61ᵇ</td>
<td>312.20±10.65ᶜ</td>
<td>22.68±0.40ᵇ</td>
<td>23.52±3.53ᵇ</td>
</tr>
</tbody>
</table>

Means flanked by the same letter are not significantly different (P<0.05, n=20)
Fig. 10 Spatial changes in mean water temperature at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE

Fig. 11 Spatial changes in mean DO at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE

Fig. 12 Spatial changes in median pH at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE
Fig. 13 Spatial changes in mean total alkalinity at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.

Fig. 14 Spatial changes in mean electrical conductivity at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.

Fig. 15 Spatial changes in mean BOD concentrations at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.
4.2.8 Phosphate phosphorus (PO$_4$-P µg L$^{-1}$)

Phosphate phosphorus concentration (µg L$^{-1}$) ranged from 46.5 to 1101.7 recorded at Kasarani and Sportsview sampling sites respectively. A distinct seasonal pattern of change in PO$_4$-P concentration was observed during the study period, with high concentrations in the wet season months of April and May while low levels were recorded during the dry season months of July-September (Fig. 16). A one way ANOVA test revealed a significant difference in the mean PO$_4$-P concentration at different sampling sites (P<0.05, n=20). Using Turkey’s mean separation procedure, mean PO$_4$-P concentrations at Kasarani sampling site was significantly higher than at Safari Park and Icipe (Table 2).

4.2.9 Total phosphorus (TP µg L$^{-1}$)

Total phosphorus concentration ranged from 38.0 to 1748.0 µg L$^{-1}$. The highest concentration was recorded at Sportsview sampling site in December 2004 while the lowest was recorded in January 2006 at the same site (Fig. 17). Safari Park sampling site generally had low TP concentrations throughout the sampling period (Fig. 17). A wide-range in TP concentration was recorded during the wet season and a narrow range during the dry season. A pronounced spatial pattern was noted with Kasarani and Sportsview having comparatively higher concentrations during most of the study period. Using the one-way ANOVA test, a significant difference in the mean concentration of total phosphates in the different sampling sites was observed (P<0.05, n=20). Based on Turkey's mean separation procedure, the mean concentration values obtained at
Sportsview and Kasarani sampling sites were found to be significantly higher than in other sites.

![Graph showing temporal changes in phosphate phosphorus concentrations at different sampling sites of Thome River during the study period - December 2004 to January 2006.](image)

**Fig. 16** Temporal changes in phosphate phosphorus concentrations at different sampling sites of Thome River during the study period - December 2004 to January 2006.

4.2.10 Nitrate nitrogen (NO$_3$-N µg L$^{-1}$)

The highest NO$_3$-N concentration (1801.1 µg L$^{-1}$) was recorded at Warren sampling site in June 2005 while the lowest (38.0 µg L$^{-1}$) was recorded at the Safari Park in January 2005. A wide temporal fluctuation in NO$_3$-N concentration, with the wet season months recording comparatively higher concentrations than the dry season months was observed (Fig. 18). There were no significant differences among the sampling sites (P=0.657, n=20), as revealed by a one-way ANOVA test.
Fig. 17 Temporal changes in total phosphorus concentrations at different sampling sites of Thome River during the study period - December 2004 to January 2006.

4.2.11 Total nitrogen (TN µg L⁻¹)

A wide variation in TN concentrations (34.3 to 6971.5 µg L⁻¹) was recorded during the study period. The lowest concentration was obtained at Safari Park sampling site in January 2005 while the highest was recorded at Sportsview sampling site in December 2004. No distinct pattern in seasonal changes was observed (Fig. 19). Using one-way ANOVA test, a significant difference in the mean concentration of total nitrogen in the different sampling sites was observed (P<0.05, n=20). Based on Turkey's mean separation procedure, the mean concentration values obtained at Safari Park sampling site were significantly lower than those obtained in the other sites.
Fig. 18 Temporal changes in nitrate nitrogen concentrations at different sampling sites of Thome River during the study period - December 2004 to January 2006.
Fig. 19 Temporal changes in total nitrogen concentrations at different sampling sites of Thome River during the study period - December 2004 to January 2006.

Fig. 20 Spatial changes in mean phosphate phosphorus concentration at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE
Fig. 21 Spatial changes in mean total phosphorus concentration at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.

Fig. 22 Spatial changes in mean nitrate nitrogen concentration at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.

Fig. 23 Spatial changes in mean total nitrogen concentration at different sampling sites of Thome River in the year 2005. Vertical bars represent ±SE.
Table 2  Mean values of selected nutrients concentrations obtained at different sampling sites at Thome River for the year 2005 (µg L⁻¹)

<table>
<thead>
<tr>
<th>Site</th>
<th>PO₄-P</th>
<th>TP</th>
<th>NO₃-N</th>
<th>TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safari Park</td>
<td>194.63±46.84ᵃ</td>
<td>213.93±32.39ᵃ</td>
<td>657.59±97.62ᵇ</td>
<td>1221.10±421.50ᵃ</td>
</tr>
<tr>
<td>Kasarani</td>
<td>477.58±91.04ᵈ</td>
<td>639.93±85.45ᵈ</td>
<td>527.28±85.19ᵃ</td>
<td>1997.34±404.40ᵇ</td>
</tr>
<tr>
<td>Icipe</td>
<td>195.99±32.27ᵃ</td>
<td>270.07±23.02ᵇ</td>
<td>635.24±82.93ᵇ</td>
<td>1478.81±314.26ᵃ</td>
</tr>
<tr>
<td>Sportsview</td>
<td>375.81±41.28ᶜ</td>
<td>587.15±60.76ᵈ</td>
<td>673.46±89.04ᵇ</td>
<td>2174.33±389.55ᵇ</td>
</tr>
<tr>
<td>Warren</td>
<td>251.30±25.88ᵇ</td>
<td>451.43±39.85ᶜ</td>
<td>776.28±90.63ᶜ</td>
<td>2042.28±355.05ᵇ</td>
</tr>
</tbody>
</table>

Means flanked by the same letter are not significantly different (P<0.05, n=20)

4.3  Bacterial properties

4.3.1  Heterotrophic plate count (HT CFU ml⁻¹)

Heterotrophic bacteria counts varied from between 1.5 x 10² CFU ml⁻¹ to 3.6 x 10⁵ CFU ml⁻¹ (Fig. 24). The lowest HT counts were recorded at Safari Park sampling site while the highest were made at Icipe. Heterotrophic counts were nearly similar in all sites during the dry season (Fig. 24). HT bacterial counts at Icipe increased drastically from 5.0 x 10⁴ to 3.6 x 10⁵ during the last month of the study. The counts recorded at Safari Park revealed a maximum level of 4.7 x 10⁴ CFU/ ml in January 2006. There was no significant difference in HT counts among the sampling stations (P=0.05, n=12).
4.3.2 Total coliforms (TC MPN/100 ml)

Total coliform counts ranged from below the limit of detection to \(3.5 \times 10^5\) MPN/100 ml. The lowest counts were obtained at the Safari Park sampling site while the highest were made at Kasarani (Fig. 25). Using the one-way ANOVA test, a significant difference in the mean total coliform counts at the different sampling stations was recorded \((P<0.05, n=12)\). Based on Turkey’s mean separation procedure, mean total coliforms levels recorded at Safari Park were significantly lower than those observed at Kasarani, Icipe and Warren Sampling sites (Table 3). Total coliform bacteria found positively correlated with heterotrophic counts \((R=0.690, P=0.01, n=12)\).
4.3.3 E. coli (MPN/100 ml)

The highest E. coli counts ($2.8 \times 10^5$ MPN/100 ml) recorded during the study was obtained at Icipe sampling station. E. coli counts below detection limit were obtained at Safari Park, Icipe, and Warren sampling sites on diverse dates during the study period (Fig. 26). A wide fluctuation in levels of E. coli was observed at Icipe sampling site compared to a narrow fluctuation at Sportsview sampling station. Using the one-way ANOVA test, no significant difference in the mean E. coli counts at the different sampling stations was recorded ($P>0.05$, n=12). Mean E. coli counts showed a positive correlation with heterotrophic counts ($R=0.747$, $P=0.05$, n=12) and total coliforms ($R=0.867$, $P=0.05$, n=12).
Fig. 26 Temporal changes in *E. coli* at different sampling sites of Thome River during the study period - December 2004 to January 2006.

### 4.3.4 Faecal *Streptococcus* (MPN/ 100 ml)

Levels of faecal *Streptococcus* were recorded during the study (Table 3) ranged from below limit of detection to 8.0 MPN/ 100 ml. Counts below detection limit were obtained at all sampling sites on diverse dates during the study period while the highest counts were recorded at Kasarani sampling site. There was no significant difference in the mean faecal *Streptococcus* levels among the sampling sites and seasons (Fig. 3).

### 4.3.5 *Salmonella* spp

The lowest occurrence frequency (15.0 %) was recorded at Safari Park sampling site while the highest 45.0 % was recorded at Kasarani (Table 4). *Salmonella* spp were actually absent in most of the water samples analyzed with an occurrence frequency of
29.0 % for all the sampling stations. The frequency of occurrence was higher during the dry season months compared to the wet season months.

**Table 3**  Mean levels of selected bacterial indicators of faecal pollution obtained at different sampling stations (MPN/ 100 ml)

<table>
<thead>
<tr>
<th>Site</th>
<th>Heterotrophic counts</th>
<th>Total coliforms</th>
<th>E. coli</th>
<th>Faecal Streptococcus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safari Park</td>
<td>1.33 x 10^4</td>
<td>2.16 x 10^4</td>
<td>1.24 x 10^4</td>
<td>0.4 x10</td>
</tr>
<tr>
<td>Kasaani</td>
<td>4.94 x 10^4</td>
<td>7.2 x 10^4</td>
<td>4.87 x 10^4</td>
<td>0.8 x10</td>
</tr>
<tr>
<td>Icipe</td>
<td>5.6 x 10^4</td>
<td>5.1 x 10^4</td>
<td>3.92 x 10^4</td>
<td>0.5 x10</td>
</tr>
<tr>
<td>Sportsview</td>
<td>2.44 x 10^4</td>
<td>2.0 x 10^4</td>
<td>1.65 x 10^4</td>
<td>0.4 x10</td>
</tr>
<tr>
<td>Warren</td>
<td>1.96 x 10^4</td>
<td>1.59 x 10^4</td>
<td>6.67 x 10^3</td>
<td>0.4 x10</td>
</tr>
</tbody>
</table>

Means flanked by the same letter are not significantly different (P<0.05, n=12)

**4.3.6 Shigella spp**

The highest occurrence frequency (35.0 %) of *Shigella* spp was recorded at Kasaarani sampling site while the lowest (15.0 %) was recorded at Safari Park (Table 4). Each of the sites studied recorded *Shigella* spp of levels below the limit of detection on diverse dates during the study period. Occurrence frequencies were higher during the dry season as compared to the wet season.

**4.3.6 Vibrio cholerae**

A high occurrence frequency (75.0 %) in *Vibrio cholerae* was recorded at Sportsview while the lowest (10.0 %) was obtained at Safari Park sampling station (Table 4). Half of all the water samples analyzed were positive for *Vibrio cholerae*. The highest occurrence frequency was recorded during the dry season.
Table 4 Presence/absence table of selected pathogenic bacteria recorded at different sampling stations in Thome River

<table>
<thead>
<tr>
<th>Site</th>
<th>Safari Park</th>
<th>Kasarani</th>
<th>Icipe</th>
<th>Sportsview</th>
<th>Warren</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Sal</td>
<td>Sh.</td>
<td>V.c</td>
<td>Sal</td>
<td>Sh.</td>
</tr>
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<tr>
<td>22/12/2004</td>
<td>A</td>
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<td>5/01/2005</td>
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<td>A</td>
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<td>% frequency</td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>45</td>
<td>35</td>
</tr>
</tbody>
</table>

Key: Sal-Salmonella, Sh-Shigella, V.c-Vibrio cholerae.
A- Absence
P- Presence
Chapter 5  Discussion

5.1  Physico-chemical properties

5.1.1  River discharge (m$^3$ sec$^{-1}$)

The low river discharge observed most of the time during the study period was due to generally low total annual rainfall (663 mm), for the year 2005. The changes in the river discharge were therefore as a result of changes in weather. The high river discharge recorded in May (0.342 m$^3$ sec$^{-1}$) was quite outstanding as compared to other times; during this month the river occasionally broke its banks due to high rainfall.

5.1.2  Temperature (°C)

Data from the present study indicate that the water temperature of the river was a little lower than the ambient air temperature during most of the sampling period. Mean water temperature readings during the present study (Table 1) varied narrowly among the five sampling sites primarily because the water temperature changes were largely influenced by the prevailing weather conditions. The temperature values recorded at various sampling points fall within a suitable range for mesophilic microorganisms (20 - 40 °C). A water temperature range of between 18.1 to 27.3 °C is lower than a range of 13.8 to 24 °C for Ruwenzori Rivers, Uganda (Busulwa & Bailey, 2004). The difference is possibly due to the cooler climate and high altitude of the Ruwenzori Rivers. A water temperature range of between 16 to 30.5 °C was obtained in Tana River in November 2003 (Kenya Rowing and Canoe Association, 2006).
5.1.3 Dissolved oxygen (DO mg L$^{-1}$)

The low DO concentrations recorded at Kasarani and Sportsview (below the limit of detection in some months) was caused by addition of wastewater with a low concentration of DO. The addition of wastewater with low DO levels or constituents with high oxygen demand has been shown to reduce river water DO (Metro, 1990). Relatively lower levels of DO experienced at Sportsview (below the limit of detection) were caused by a higher load of organic matter. A case of reduced DO with an increase load of organic has been reported for the Nairobi River (Budambula, 2004).

The consistently high dissolved oxygen levels at Safari Park can be attributed to the relatively low human activities upstream leading to low microbial activity as compared to other sites. Introduction of organic matter into a water body causes the depletion of dissolved oxygen (Metro, 1990). Low mean dissolved oxygen at Kasarani and Sportsview possibly resulted from the inflow of wastewater from Safari Park and Sportsview hotels respectively into the river at points upstream of the sampling site. Bacterial decomposition of organic wastes, utilize most of the oxygen in the water resulting in anaerobic conditions. Residential houses and dairy farms along the riverbanks are also possible sources of wastewater whose organic matter load may have also contributed to depletion of dissolved oxygen during their decomposition. A significant increase in mean DO concentration from Sportsview (1.64 mg L$^{-1}$) to Warren (3.15 mg L$^{-1}$) can be attributed to self purification aided by presence of many macrophytes along the riverbank in between the two points and absence of further addition of organic matter. Macrophytes help in self-purification of the water bodies by using up the nutrients in the organic matter (Whitehead, 1982).
Low DO levels in Kasarani, Icipe and Sportsview sampling sites during the dry season can be linked to changes in the loading of organic matter into the river. This was however far much higher than (0.38 mg L\(^{-1}\)) reported by Ochieng (1983) in Rivers Kasat area Kisumu. Dissolved oxygen concentration in Blue River, Kansas City, in July 1998 and October 2000 (8.9 mg L\(^{-1}\)) was lower than the highest DO concentration (10.8 mg L\(^{-1}\)) measured in the present study (Wilkison et al., 2001).

5.1.4 pH

River Thome water pH range (6.6 - 8.1) was within the range for freshwaters, which usually have pH values between 6.5 and 8.2 (Cambers et al., 2002). A water pH above 7 is important for the growth of mesophilic bacteria involved in biodegradation of organic matter (Boone, 1987). Absence of a significant change in pH following the introduction of wastewater to the lower sections of the river can be attributed to the influence of domestic sewage that was part of the wastewater flowing into the river. Domestic sewage mainly contains fats, proteins, carbohydrates, amino sugars, amides and detergents that are neutral (Guo et al., 1995). A wide range in pH during the dry season months may have been due to the influence evaporation during the dry weather resulting to high concentration of hydrogen ions. A narrow range of pH during the wet season months was due to the increased river discharge leading to dilution in all the sites.

5.1.5 Electrical conductivity (µS cm\(^{-1}\))

The consistently low conductivity readings at Safari Park confirm the limited human activities at the site. Visually, the water at this site was clearer than in the other sites indicating a low input of organic matter. The electrical conductivity range (160.0 - 496.0
μS cm⁻¹) recorded in the present study for the whole river is much higher than that obtained by Busulwa & Bailey in 2004 at Rivers Mubuku and Nyamugasani, Uganda (78.0 – 91.0 μS cm⁻¹ and 89.0 – 110.0 μS cm⁻¹ respectively). This may be due to the effect of wastewater on electrical conductivity in Thome River versus these unpolluted rivers. The low conductivity range (160.0 to 179.0 μS cm⁻¹) recorded on 27th May resulted from an increase in river discharge caused by a heavy downpour the night before the sampling date. A new source of wastewater effluent upstream of Icipe sampling site may have contributed to a drastic increase in electrical conductivity levels towards the end of the study period.

Nearly similar conductivity values during the wet season are attributable to an increased river discharge without a change in effluent load. Dilution effect due to increased river discharge also contributed to lower levels of electrical conductivity during the wet season as compared to the dry season.

5.1.6 Total alkalinity (mg CaCO₃ L⁻¹)

A wide range (25.0 - 289.5 mg O₂ L⁻¹) of total alkalinity recorded can be explained by a reduction in river discharge without a change in effluent load. A reduction in discharge volume in sections receiving wastewater resulted in high TA values while the least impacted sites (e.g. Safari Park) only showed a small increase in TA. Consistently low total alkalinity recorded at Safari Park can be explained by low levels of wastewater discharge into the river upstream of this site. A narrow range in total alkalinity recorded on 27th May 2005 in all the five sampling stations resulted from the dilution effect of the high rainfall that led to the complete flooding of the river channel.
The total alkalinity range (25.0 - 298.5 mg CaCO$_3$ L$^{-1}$) obtained in this study is close to the range recorded for Nairobi River of between 35.0 – 220.0 mg CaCO$_3$ L$^{-1}$ (Budambula, 2004). The two rivers have similar catchments and receive similar wastewater effluents.

5.1.7 Biochemical oxygen demand (BOD$_5$ mg O$_2$ L$^{-1}$)

A high biochemical oxygen demand of sewage effluent is known to cause anaerobic conditions in recipient stream (Vesilind et al., 1990). BOD values obtained during the study (0.1 to 118.9 mg O$_2$ L$^{-1}$) indicate that the river is highly polluted as unpolluted waters usually have biochemical oxygen demand (BOD) values of less than 2 mg O$_2$ L$^{-1}$ (Wikipedia, 2006). It was, however, below that of raw sewage (600.0 mg O$_2$ L$^{-1}$) as recorded by Opala, 2001. A mean BOD value of 11.6 mg O$_2$ L$^{-1}$ recorded at Safari Park confirms that the site is less polluted as compared to other sites with mean BOD values ranging from 23.5 to 33.7 mg O$_2$ L$^{-1}$. Based on the BOD data obtained, it is evident that the most polluted section of the river is at Kasarani (33.7 mg O$_2$ L$^{-1}$). BOD levels recorded from the present study constantly exceed the limit for drinking water (2.0 mg O$_2$ L$^{-1}$) (WHO, 1985b) except once at Safari Park (0.1 mg O$_2$ L$^{-1}$). The levels were also higher than the acceptable values (10.0 mg O$_2$ L$^{-1}$) for river waters. Based on BOD values obtained, the river water can be classified as unsuitable for human consumption unless treated at all sites. Minimal fluctuations at Safari Park site confirms the comparatively low human impact while consistently high values at Kasarani can be attributed to discharge of effluents with high load of organic matter from Safari Park Hotel.

Low BOD levels recorded during the wet season and high levels during the dry season can be attributed to the influence of river dilution caused by increased discharge Mean
BOD values in the five sampling sites (11.6 - 33.7 mg O₂ L⁻¹) were far much less compared to 115 mg O₂ L⁻¹ obtained in Ruaraka River, Nairobi. High values at Ruaraka River have been attributed to the discharge of untreated wastewater from Kenya Breweries. Untreated industrial effluents are known to have higher BOD levels than domestic effluents (Kilani, 1993). BOD values of up to 226.4 mg O₂ L⁻¹ have been reported for Nairobi River (Budambula, 2004).

5.1.8 Phosphate phosphorus (PO₄-P) and total phosphorus (TP) (μg L⁻¹)

An increase in nutrients in water, particularly phosphates, has been shown to favour bacterial development (Canosa & Pinilla, 1999). Low PO₄-P and TP at Safari Park sampling site as compared to the other sites could be attributed to the comparatively low human activities upstream of this area. High concentration at other sites indicates that the river receives domestic effluents or agricultural runoff which are known to be rich in phosphorus (Golterman, 1975; Madhusudan et al., 1984).

Livestock access to Thome River at various sections especially near Sportsvie Hotel also enriches the water with phosphorus rich organic wastes while the introduction of wastewater also raises the phosphorus load. This explains the high concentrations of PO₄-P and P recorded at Kasarani and Sportsvie sampling sites. High PO₄-P and TP concentrations recorded during the warmer months of February and March 2005 (Fig. 9 and Fig. 10) can be attributed to reduced river flow (0.034 m³ - 0.016 m³) without change in effluent load.
The significantly higher phosphate and total phosphorus concentrations at Sportsview than at Warren (Table 2) might have been due to biological self-purification as it results in reduction of nutrients in water including total phosphates (Whitehead, 1982). Extensive zones of macrophytes (like the one present between the two sites) are known to assist rivers in the self-purification process (Whitehead, 1982).

Phosphate phosphorus concentrations recorded during the study (46.46 to 1101.67 μg L$^{-1}$) on most occasions exceeded the maximum concentration (100.0 μg L$^{-1}$), recommended for rivers and streams (WQC, 1972). The maximum concentration is lower than 5120.0 μg L$^{-1}$ reported for the Nairobi River (Njuguna, 1979). High PO$_4$-P concentration during the dry season months has also been reported for the Nairobi River (Budambula, 2004).

5.1.9 Nitrogen (μg L$^{-1}$)
High levels of nitrates nitrogen and total nitrogen concentrations recorded in this study can be attributed to the influence of wastewater disposal from such sources as livestock and arable farms. It has been shown that human activities can increase nitrate nitrogen concentration up to between 1.0 to 5.0 mg L$^{-1}$ while values greater than 5.0 mg L$^{-1}$ usually indicate pollution by human or animal wastes (Chapman, 1996).

Increased levels of total nitrogen during the wet season can be attributed to surface run-off water bringing in nitrogen from the surrounding area. In absence of pollutant introduction to rivers, increased discharge usually results in a rapid decrease in nutrient concentration (Hassan et al., 2005). This indicates that nitrate-nitrogen concentration may
not be subject to dilution as its concentration in the river increased with increase in river volume.

The maximum NO$_3$-N concentration measured (1.801 mg L$^{-1}$) was lower than the toxic level (50 mg L$^{-1}$) and the upper limit of 13.4 mg L$^{-1}$ for drinking water (WHO, 1985b). However, the concentration range 0.038 to 1.801 mg L$^{-1}$ measured exceeded the typical concentration range of 0.0 to 0.1 mg L$^{-1}$ for unpolluted rivers (Weltz, 1983). A NO$_3$-N concentration range of 7.0 to 38.0 mg L$^{-1}$ is lower than a range of 520.6 to 1,200.0 mg L$^{-1}$ recorded for Nairobi River by Budambula (2004). This suggests that organic matter rich in nitrogen is less in Thome River than in Nairobi River.

5.2 Bacteriological properties

5.2.1 Heterotrophic bacteria (HT CFU ml$^{-1}$)

Low HT mean counts at Safari Park sampling site is further confirmation of the low input of domestic organic wastes to this site as compared to others. A huge increase in levels of heterotrophic bacteria from $5.0 \times 10^4$ CFU ml$^{-1}$ to $3.6 \times 10^5$ CFU ml$^{-1}$ in January 2006 (Fig. 14) at Icipe was possibly as a result of a new source of wastewater discharge, upstream of this site. A new school had just been opened upstream of this site, right at the riverbank. The river discharge (0.068 m$^3$ sec$^{-1}$) was also low during the study period.

A very low discharge recorded in January 2006 (0.015 m$^3$ sec$^{-1}$) without subsequent reduction in organic load may partly be responsible for the highest number ($4.7 \times 10^4$ CFU ml$^{-1}$) of heterotrophic bacteria recorded at this site. Highest HT counts ($3.6 \times 10^5$ CFU ml$^{-1}$) recorded in the present study is lower than $9.0 \times 10^5$ CFU ml$^{-1}$ obtained in
Nairobi River (Budambula, 2004). This further confirms that Thome River is less polluted as compared to Nairobi River.

5.2.2 Total coliforms (MPN/ 100 ml)

High coliform counts obtained at Kasarani sampling site confirms that the site receives a higher load of organic matter than all other sites, a position further supported by the higher BOD values. Significantly lower coliform counts at Warren as compared to Kasarani can be explained by the limited sewage pollution at Warren. River water at Kasarani usually appeared grey with a rich growth of sewage fungus, possibly as a result of the introduction of raw sewage from Safari Park Hotel. On several occasions, the site recorded dissolved oxygen levels below the limit of detection indicating a high loading of organic matter. In the absence of further introduction of organic matter, the process of river self purification led to reduced coliform levels at Warren sampling station.

Total coliforms range (0 to 3.5 x 10^5 MPN/ 100) ml recorded in River Thome exceed the World Health Organization (WHO, 1985a) and Kenya Bureau of Standards (KBS, 1996) recommendations that total coliforms of drinking water should not exceed 10/ 100 ml of water. The river water is therefore polluted and unfit for human consumption.

5.2.3 E. coli (MPN/ 100 ml)

A continuous presence of E. coli at Sportsview and Kasarani sampling sites throughout the sampling period was because the two sites were constantly receiving wastewater discharge from the Sportsview and Safari Park hotels respectively. A wide range of E. coli counts at Icipe sampling site can be explained by variation in waste discharge into
the river around this site. In the early months of the study, there was evidently lower waste discharge, which increased during the last months of the study period.

A positive correlation between *E. coli* and total coliforms (R=0.867, P=0.05, n=12) suggests that the bacterial load in the water was due to organic waste discharge into the river leading to increase in levels of these bacteria.

*E. coli* counts obtained in this study exceed the limits set by WHO for drinking, irrigation and recreational water indicating that the water is unsuitable for such uses. For all water directly intended for drinking, *E. coli* or thermotolerant coliform bacteria must not be detectable in any 100 ml sample. This also applies to treated water entering or in distribution system while the set limit for irrigation of crops eaten raw is 77/100 ml of water (WHO, 2004).

5.2.4 Faecal *Streptococcus* (MPN/100 ml)

Faecal *Streptococcus* counts range (0 to 4.0 MPN/100 ml) recorded during the study can be attributed to varying pollution events. Low counts on most occasions during the study can be explained by the fact that faecal *Streptococcus* are indicators of present pollution events, which die fairly quickly once they get into receiving waters (Fujioka *et al.*, 1981). The data suggests that Thome River receives wastewater contaminated with faecal wastes at irregular intervals resulting in a wide fluctuation in water quality over time at each site. The recommended limit for faecal *Streptococcus* in raw drinking water is 0/100 ml and 20/100 ml of water for recreational and irrigation of crops eaten raw (Fujioka *et al.*, 1981).
5.2.5 Pathogenic bacteria

The high frequency of occurrence of *Shigella* spp, *Vibrio cholerae*, and *Salmonella* spp (35.0 %, 75 %, 45 %) recorded at Kasarani sampling site as compared to the other sites suggests that this site was the most contaminated with faecal waste containing these pathogens. This was also the case with Sportsview sampling site also with a high frequency of occurrence of 75.0 % for *Vibrio cholerae*. The organisms may therefore have been introduced into the river through wastewater discharge.

The lower frequency of occurrence of pathogenic bacteria at Safari Park sampling site (10 %) for all the pathogenic microorganisms, during the study period further confirms the low impact of human activities upstream of this site. Pathogenic bacteria detected at Warren were possibly those carried down from upstream sites as Warren had comparatively lower human activities. Low occurrence frequency at Warren (20 %) for both *Salmonella* and *Shigella* suggests that the site is less frequently contaminated with faecal wastes containing these bacteria. The lower occurrence frequency may also have been contributed by the self-purification of the river as it passed through a mass development of macrophytes (Whitehead, 1982).

Absence of pathogenic bacteria in more than half of all the water samples analyzed suggests that there are low incidences of the diseases caused by these pathogens among the people living around the study area (Ellis, 1989). However, this may also be probably because pathogenic bacteria have only a short life span in water, are less resistant to adverse influence and are more easily destroyed than either the normal intestinal bacteria or ordinary water bacteria (Klein, 1972). A low occurrence frequency recorded during the
wet season months can be explained by the increased river discharge that may have limited their detection due to dilution.

A high overall frequency of occurrence (50.0 %) for *Vibrio cholerae* recorded during the study as compared to other pathogens can be attributed to the fact that *Vibrio cholerae* are normal inhabitants of aquatic habitats (APHA, 1998).

Absence of *Shigella* spp on 27th May 2005, in all the sites was probably due to the dilution effect of a high flow in the river after a heavy downpour the previous night that limited the detection of these microorganisms. A lower frequency of occurrence of *Shigella* spp (24.2 %) during the study compared to that of *Salmonella* spp (31.6 %) might have been due to *Shigella* spp being rare in tropical areas unlike *Salmonella* spp (APHA, 1998).
6.1 Conclusion

The results obtained in this study indicate that wastewater discharge into Thome River has led to the deterioration of the river water quality. The temporal and spatial variations in the physico-chemical and bacterial properties studied indicate that the river is polluted due to wastewater discharge into the river.

River Thome water is polluted by raw domestic sewage as suggested by the neutral pH. Sources of this sewage appear to be Safari Park and Sportsview hotels and some residential houses along the riverbank at Sportsview sampling site.

High levels of some physico-chemical properties investigated such as BOD, total alkalinity and electrical conductivity especially at Kasarani and Sportsview sampling sites indicate that Thome River receives wastewater with a high organic load from various sources along its course.

The study established that the river water is contaminated with bacteria of faecal origin, which may have either been from human or livestock sources. The presence of high levels of indicator organisms such as \textit{E. coli} and total coliforms and the pathogens (\textit{Salmonella} spp, \textit{Shigella} spp and \textit{Vibrio cholerae}) in the water indicates the possible presence of other potentially pathogenic organisms commonly found in the gut of warm blooded animals such as enteric viruses and nematodes that are known to cause ecological and health problems.
Differences in the concentrations of microbial faecal indicators between the sites with low human activities (Safari Park and Warren) and the highly impacted sites suggest that varying levels and types of human activities were the cause of the spatial variability of bacterial loads.

In general human activities at Kasarani area had the highest impact on the river water quality. This is because the site recorded the highest levels of bacteria, high nutrient levels and high BOD concentrations among other factors. The site at Sportsview closely followed Kasarani with Safari Park sampling site being least impacted. Kasarani and Sportsview sampling sites are hence the most polluted sections of the river. Icipe sampling site experienced varying situations having very low human impact at times and very high impacts at other times.

Based on the levels of the bacterial indicators of faecal pollution, BOD concentrations, and DO, the river water is unfit for drinking, watering animals and irrigation. Variations in presence and absence of the pathogenic bacteria analyzed in the study supports the fact that pathogenic bacteria do not survive for long in the environment.

Thome River water is therefore heavily impacted by wastewater discharge. It is contaminated with human and animal wastes but is still used on daily basis for washing, drinking, watering animals and irrigating vegetables. This implies that there is danger posed to humans and livestock who use the water.
6.2 Recommendations

Since the need for water conservation through pollution reduction cannot be over emphasized, the following actions should be taken to control the contamination in Thome River:

1) Ensure that the people involved in the various activities along the river follow the proper procedure in disposal of wastewater. The main sources of wastewater, i.e. Safari Park and Sportsview Hotels must adhere to the provisions of the Water Act and NEMA.

2) Limit livestock access to the river as they might be contributing to the contamination of the river water.

3) Educate farmers along the river about the possible risks associated with use of untreated sewage in irrigation of crops especially vegetable that are eaten raw.

4) Discourage people from the use of the water for drinking and bathing without treatment.

5) Further research to identify presence of other potential pathogens is necessary.

6) Regular monitoring of the water quality to ensure that the contamination does not occur.
References


