A STUDY TO INVESTIGATE POTABILITY OF WATER IN KERICHO MUNICIPALITY

BY
MUTAI NORAH CHEPKEMOI
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DECLARATION

Declaration by the candidate

This thesis is my original work presented to Moi University for Master of Science degree in chemistry. The work has not been presented for a degree in any other university. No part of this thesis may be reproduced without the prior permission of the author and / or Moi University.

Sign________________________________ Date: ___________________

MUTAI CHEPKEMOI NORAH SC/PGC/012/08

Approval by the Supervisors

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

1. Sign ______________________________ Date: _____________________

PROF. P.K. KIPKEMBOI
DEPARTMENT OF CHEMISRTY AND BIOCHEMISTRY
UNIVERSITY OF ELDORET
P.O BOX 1125- 30100
ELDORET

2. Sign ______________________________ Date: _______________________

PROF. L. KITUYI
DEPARTMENT OF CHEMISRTY AND BIOCHEMISTRY
UNIVERSITY OF ELDORET
P.O BOX 1125- 30100
ELDORET

DEDICATION

To my husband and children for their support, understanding and encouragement.

ABSTRACT

Availability of safe and potable water may not be easy due to inadequate control, operation and maintenance of the water distribution system in developing countries. This study was conducted to ascertain whether water supplied by Kericho Water and Sanitation Company (KEWASCO) is safe for human consumption or not. Bacteriological and physico-chemical parameters analysed were: *E. coli*, conductivity, total alkalinity, total hardness, pH, conductivity, Total dissolved solids (TDS), residual chloride, turbidity and heavy metals (Pb, Cd and Cr). Samples were collected from Ngecherock and Timbilil Treatment Plants, Municipal tap water of Kericho prisons staff residence, Kericho main prisons (kitchen tap), Moi estate, Nyagacho estate, dumpsite leachate and river Tiony Soet during the months of January, February and March, 2010. Heavy metal contents were determined using atomic absorption spectrophotometer (AAS), LST-MUG method was employed for detecting *E.coli* while residual chlorine was measured using a commercial Colour Wheel and visual comparator. Total alkalinity and total water hardness were measured by titration method, conductivity and TDS by conductivity meter, turbidity by turbidimeter while the pH was determined by pH meter. The results obtained ranged from: pH 6.2-8.2, conductivity 35-70 µs, turbidity 0.4-3.7 NTU, total alkalinity 18-40 mg/L, total hardness 3-20 mg/L, TDS 16-30 mg/L and residual chloride 0-1.2 mg/L. *E.coli* tested negative in January and February but in March it tested positive in only two stations. Pb, Cr and Cd from water at the treatment plants and consumer points reported values which were within allowable WHO limits. However, not all stations reported appreciable levels heavy metals during the sampling period. In January, the mean levels of the metals in the leachate samples reported Cr having the highest value (2.92 mg/L) followed by Pb (1.70 mg/L) and then Cd (1.48 mg/L). From the mean levels, the concentrations for the metals in river water recorded the highest Cr value of 2.34 mg/L followed by Cd (1.34 mg/L) and then Pb (1.29 mg/L) in the month of January. Generally, all the three metals showed a decrease in trend from January to March. The trend in average metal concentrations in both leachate and river water was Cr > Pb > Cd. Overall, the levels of metal concentrations in various sites and stations followed the order: dumpsite leachate > river water > consumer points > treatment plants. Most of the measured parameters were, however, within the water quality standards for municipal piped water and therefore fit for drinking.

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LIST OF ABBREVIATIONS

A.A.S - Atomic Absorption Spectrophotometer

ATCC- American type culture collection

KEWASCO- Kericho Water and Sanitation Company.

CNS - Central Nervous System

K.M.C. - Kericho Municipal Council

ISO – International Standards Organization

WSP – Water Service Providers

M.S.W. - Municipal Solid Waste

UNEP - United Nations Environmental Program

WHO - World Health Organization

DDT – Dichlorodiphenyltrichloroethane.

LVEMP- Lake Victoria Environmental Management Project

MENR- Ministry of Environment and Natural Resource.

Floc - The chemical alum attracts dirt and silt particles to form larger particles called floc. Floc looks like big snowflakes floating in water which settle in the clarifiers and are later removed as sludge.

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Kericho Water and Sanitation Company (KEWASCO) has two water treatment plants namely: Timbilil with storage tank having the following features: 8 No. storage tanks, underground clear water tank with 4 No. aerators and 1 No. elevated steel tank (capacity not given). Ngecherok treatment works where water supply system is designed to produce 30 m^3/ hr. serving a population of over 15,000. The Company therefore, has a responsibility of ensuring that no health related hazards occur as a result of taking water from the taps.

These are the sources of piped drinking water in Kericho town although there are some people using borehole water and river water from Tiony Soet. Water to be used for human consumption generally undergoes some form of treatment before it is supplied to the consumers. The relevant municipal authorities usually treat piped water in urban and peri-urban areas either directly or via a contracted private company. Treatment at the plant, if done efficiently, usually rids the water of its contaminants. However, this does not necessarily guarantee provision of clean water at the consumer’s end. Further contamination may occur within the distribution network during the supply of the water to the consumers.

Distribution of safe, potable water may not be easy due to inadequate control, operation and maintenance of the water distribution system, especially in developing countries

(Serageldin, 1994).Thus, the quality of drinking water can deteriorate significantly between the treatment plant and the consumers' taps. Water utilities experience microbial problems in their distribution system that cannot be attributed to either operating or disinfection practices. Drinking water distribution systems provide a habitat for microorganisms that are sustained by both organic and inorganic nutrients present in the pipe and/or the conveyed water. Excessive microbial activity can lead to deterioration of the water in the aesthetic terms of colour, taste and odour. It may also interfere with the methods used to monitor such parameters of health significance as faecal coliform (FC) count, viral and helminthic ratio and biochemical oxygen demand percentage. Lack of information on the deterioration of water quality within a distribution system due to contamination intrusion exposes the consumers to effects stemming from these contaminants. This poses a great risk of such water-related diseases as cholera and typhoid to the consumers (Wilson, 1945).

Water distribution systems need to be safeguarded against pollutants, an end that can only be attained by surveillance. These pollutants can be identified using bacteriological and physico-chemical parameters and include organic and inorganic materials. Major organic pollutants majorly found within water distribution systems include bacteria, viruses and parasites. The most useful indicators of faecal contamination are thermotolerant coliforms such as *E. coli*, *Salmonella* spp and *Shigella* spp as they are directly related to the presence of faecal contamination hence to the risk of disease. Bacteriological contamination poses the greatest threat to the health of the consumers. Viral and helminthic parasites may also be present in water, though these are less frequent and more difficult to identify in a given water sample (WHO/UNICE, 2010).

Inorganic matter that may pollute treated water within the pipe work include such metals as iron, manganese and zinc, suspended and dissolved solids and other materials that may infiltrate into the distribution system say via leakages from broken pipes. The objectionable taste of drinking water has been found to be the most common cause of consumer complaints. Inorganic pollutants mainly contribute to the presence of tastes, odours and colour change in the water. Though these may not possess an undesirable effect on the consumers' health, they provide parameters that determine the acceptability of water for human consumption (WHO, 1984).

Control, reduction or total extinction of all these pollutants is meant to be achieved during the process of treatment and distribution of water. Failure to efficiently achieve this target may have wide-ranging effects from consumer complaints, to disease outbreak to mortality. Standards have been set to ensure that water treatment is made to certain specifications that ensure its potability. Locally, treated water must comply with standards set by the Kenya Bureau of Standards (KEBS) and National Environmental Management Authority (NEMA) whilst the World Health Organization (WHO) dictates water quality internationally (WHO, 1984).

This research was meant to determine the effectiveness of Kericho water company treatment plants in providing water fit for human consumption and provide on-site corrective measures or improvements to be undertaken by the Water Service Providers (WSP) to ensure compliance with the Service Provision Agreement, WHO and NEMA water quality standards both at the water supply and at the consumer points (Hart, 1992).

1.2 Statement of the problem

The challenge of how to improve water quality by protection of surface water bodies is a growing global concern (UN-Water, 2006, World Bank, 2009). However, surface water pollution risks, particularly in developing nations, remain relatively widespread. A valuable initial step in identifying the nature and extent of water quality impacts linked to pollution is to distinguish their point sources (PS) and non-point sources (NPS). PS pollution is commonly linked directly to end-of-pipe releases from industrial and municipal wastes. Its control is more direct and quantifiable and in many developed countries its mitigation has been linked to treatment achieving lower contaminant concentrations before discharge (U.S EPA, 2010). The non point sources are widely spread for example, fertilizers among others are swept into water bodies hence enhance pollution. Water being an essential commodity therefore, needs to be protected from the source and up to the consumer point. This will reduce the cases of waterborne diseases hence a healthy nation is a wealthy nation (Schmoll, *et al*., (eds), 2004)

1.3 Justification of the Study

The purpose of water treatment is to convert the water taken from ground or surface source, "the raw water", into water fit for human consumption. Most important is the removal of pathogenic organisms and toxic substances such as heavy metals causing health hazards. Water suitable for domestic use should be wholesome and palatable. Wholesome water should be free from pathogens, poisonous substances, dissolved mineral matter and organic matter. Palatable water should be free from colour, turbidity, taste, and odour and preferably well aerated.

However, records from the Water supplies e.g. Bondo water supply pipeline show deterioration in water quality from the plant to the consumers (WHO and UNICEF, 2012, KWAHO/UNDP Initiative- retrieved 2011). There has also been complaints from the various consumers regarding the turbid water that has been coming out of the taps occasionally (Citizens' report card, 2007). The impact that distribution networks have on reducing water quality has been inadequately addressed due to the limited information available on the magnitude of the public health problem. Existing statistics are often optimistic rather than realistic estimates of the actual conditions of distribution networks. Little research has been conducted to determine whether distribution system inadequacies are a result of sporadic breakdowns or are continually occurring.

Moreover, very few epidemiological studies have been published on disease outbreaks in relation to distribution network deficiencies in developing countries. Hence, there is a vital need for continuous monitoring of contaminants on drinking water distribution systems on river Tiony Soet (Koech, 2003). It must be noted that studies have been carried out on certain systems. However, findings from these studies cannot be deemed to hold true for all distribution networks as each network is unique in its setup, potential contaminants, and existing geological and climatic conditions.

Information obtained from this study will go a long way in assisting to alleviate the debilitating effects of water-related diseases stemming from contamination. KEWASCO will also benefit from this study as they will be knowledgeable regarding the state of water they had treated upon reception by the consumers. This will help ease the monetary losses that could have been faced from ineffective treatment. Despite water treatment by the Water Company, the Municipality residents still prefer boiling their water. This raises questions about the reliability of the treatment plants in providing quality water.

1.4 Objectives of the study

1.4.1 Main objective

To determine the difference in the quality of treated water at the treatment plant and at different locations within the distribution network inclusive of water obtained direct from the river Tiony Soet in Kericho Municipality.

1.4.2 Specific Objectives

The specific objectives of this study were:

1. To determine bacteriological and physico- chemical parameters in treatment plants and consumer points.
2. To determine the levels of heavy metals in leachate dumpsite, treatment plant and consumers' points.
3. To compare the levels of heavy metals in leachate dumpsite, treatment plant and consumers' points

1.5 Scope and limitations

The research was conducted within Kericho municipality and the selected areas were water works, consumer points, the dumpsite leachate and River Tiony Soet. The parameters analysed were total alkalinity, total hardness (calcium and magnesium hardness), *E- coli*, turbidity, conductivity, TDS, residual chlorine, pH, and heavy metals (cadmium, chromium, and lead). The analysis was done in January through March 2010. The limitation experienced during the study was shortage of personnel in going round the selected stations collecting the samples since at times they were busy at their place of work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The earliest precursor of pollution generated by life forms would have been a natural function of existence. The attendant consequences on viability and population levels fell within the sphere of natural selection. These would have included the demise of a population locally or ultimately, species extinction. Processes that were untenable would have resulted in a new balance brought about by changes and adaptations. At the extremes, for any form of life, consideration of pollution is superseded by that of survival (Chatwell, 1989).

For humankind, the factor of technology is a distinguishing and critical consideration, both as an enabler and an additional source of byproducts. Short of survival, human concerns include the range from quality of life to health hazards. Since science holds experimental demonstration to be definitive, modern treatment of toxicity or environmental harm involves defining a level at which an effect is observable (Bartone *et al.,* 1994).

The raw water will go through some processes in water treatment plant such as coagulation or flocculation, sedimentation, filtration, stabilization, fluoridation, chlorination and finally before allowing water to be used in the residential area, water will be tested for a few contaminants again. This is to ensure that the drinking water distributed is safe to be consumed by the public. As discussed in the Congressional

Budget Office Study of 2002, the types of treatment are flocculation/sedimentation, filtration, ion exchange, adsorption, disinfection.

2.2 Types of Treatment

2.2.1 Flocculation/Sedimentation

Flocculation refers to water treatment processes that combine or coagulate small particles into larger particles, which settle out of the water as sediment. Alum and iron salts or synthetic organic polymers (used alone or in combination with metal salts) are generally used to promote coagulation. Settling or sedimentation occurs naturally as flocculated particles settle out of the water (www.epa.gov/safewater).

2.2.2 Filtration

Many water treatment facilities use filtration to remove all particles from water. Those particles include clays and silts, natural organic matter, precipitates from other treatment processes in the facility, iron and manganese, and microorganisms. Filtration clarifies water and enhances the effectiveness of disinfection (www.epa.gov/safewater).

2.2.3 Ion Exchange

Ion exchange processes are used to remove inorganic contaminants if they cannot be removed adequately by filtration or sedimentation. Ion exchange can be used to treat hard water. It can also be used to remove arsenic, chromium, excess fluoride, nitrates, radium, and uranium (www.epa.gov/safewater).

2.2.4Adsorption

The adsorption process uses forces of molecular attraction to bind soluble and gaseous chemicals to a surface. The process retains and accumulates toxic chemicals present in wastes, yet does not chemically alter them. Carbon used for adsorption is usually treated (activated) to make it very porous.

Activated carbon has a large surface area that can adsorb relatively large quantities of material per unit weight of carbon. Activated Organic contaminants, unwanted colouring, and taste-and-odour-causing compounds can stick to the surface of granular or powder activated carbon and are thus removed from the drinking water. (Ecology Fact Sheet, 2002)

2.2.5 Disinfection (chlorination/ozonation)

Water is often disinfected before it enters the distribution system to ensure that potentially dangerous microbes are killed. Chlorine, chloramines, or chlorine dioxide are most often used because they are very effective disinfectants, not only at the treatment plant but also in the pipes that distribute water to homes and businesses. Ozone is a powerful disinfectant, and ultraviolet radiation is an effective disinfectant and treatment for relatively clean source waters, but neither of these is effective in controlling biological contaminants in the distribution pipes.

2.3 Monitoring Water Quality

Monitoring water quality is the last step after all the above-mentioned types of treatments have been undertaken. This will ascertain the purity of water from the source to the end point who is the consumer.

Water systems monitor for a wide variety of contaminants to verify that the water provided to the public meets all federal and state standards (Bailey and Thompson, 1995; WHO, 2008). Currently, the nation's community water systems (CWSs) and non transient non-community water systems (NTNCWSs) must monitor for more than 83 contaminants. The major classes of contaminants include volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganic compounds (IOCs), radionuclides, and microbial organisms (including bacteria). Testing for these contaminants takes place on varying schedules and at different locations throughout the water system (Napacho and Manyele, 2008).

Transient non-community water systems may be monitored less frequently and for fewer contaminants than CWSs. Because these types of systems serve an ever-changing population, it is most important for them to be monitored for contaminants such as microbiological and nitrate that can cause an immediate, acute public health effect.

Water systems also monitor for a number of contaminants that need to be regulated. In a typical municipal water treatment process, water flows through pumps to a rapid mix basin, then to a flocculation basin, to a settling basin, through filters to a clear well, then after disinfection, to storage tanks, and finally to the end users. Water enters the treatment plant at what is called the rapid-mix basin, where aluminum sulphate, polyelectrolytes, polymers, or lime and furic chloride are added as coagulants. The water flows next to the flocculation basins, where the coagulant mixes with the suspended solids. The coagulant is used to form suspended solids into clumps, or floc, which then settle out of the water. Floc forms when the particles from small solids gather to form larger particles. The water then slowly flows through settling basins where the floc settles from the water. Activated carbon is then added to the water to remove colour, radioactivity, taste, and odour. Filtration then removes bacteria and turbidity from the water as it removes any remaining suspended solids and the activated carbon (U.S.EPA, 1990).

The distribution system is the final barrier before delivery to the consumer’s tap. Even when the water leaving the treatment plant is of the highest quality, if precautions are not taken its quality can seriously deteriorate (Bailey and Thompson, 1995). In extreme cases, dangerous contamination can occur. Because it is largely out of sight, distribution infrastructure tends not to be a top priority in the management and financing of water systems. But as populations shift and pipes corrode, substantial ongoing investments are necessary (Doyle, 2002).

Historically in developed countries, the establishment of a distribution system to disseminate potable water has proven critical for public health improvements (Nelson, 2001).

However, in developing countries, many existing systems are operating intermittently and at a fraction of their capacity (WHO, 2003). In addition, many more problems with distribution systems exist, and also occur more frequently, than in developed countries. Therefore, although presence of a public water distribution network is often an indicator of improved water supply in a developing country, it should not be assumed that the resulting water quality is always adequate for human consumption (Lee and Swap, 2005).

In many urban areas, interrupted service, whereby water is provided to residents for a restricted number of hours per day, encourages stagnancy of water and growth of microorganisms. Negative hydraulic pressure can draw pathogens from faecally contaminated material surrounding water pipes into the water supply, through leakages in the network (Agard *et al,* 2002). Similarly, improper disinfection or failure to maintain a sufficient disinfection residual, as well as natural ageing and corrosion of infrastructure can create conditions favourable to bacterial growth. These flaws in the distribution system often work in combination with each other and can seriously compromise both quantity and quality of water reaching the consumer. The decreased microbiological quality of the water may cause public health outbreaks of diarrhoeal disease, a significant disease burden in developing countries today (Napacho and Manyele, 2008).

Clearly, these indirect consequences of poor water supply services are counter-productive to the intended purpose of distribution networks. Typical considerations when selecting piping material include corrosion resistance, internal surface roughness, compatibility with existing materials, susceptibility to chemical leaching or biofilm growth, cost, and use. Materials suitable for transmission may be weakened if tapped for service delivery. Mains tend to be made of cast or ductile iron, wrapped steel or, in recent years, plastic. Service lines into homes are often zinc-coated iron (which may react galvanically with brass, bronze, or copper fittings), copper tubing, or in some older systems, lead pipe. As part of an asset management program, lead service lines should be located and replaced over time with safer materials (Boyd *et al*., 2001).

Information on water retention time in every part of the storage and distribution system needs to be developed and used to schedule additional flushing in slow-flow areas in order to slow biofilm development. Biofilm results from the growth of bacteria that can thrive in water distribution systems (Schock, 1999). Decaying algae from algal growth in insufficiently filtered surface waters is one of many possible sources of dissolved organic matter that may provide a good food source for bacterial growth. Anaerobic groundwater containing soluble iron and sulphur is a food source for two bacterial species that cause a number of aesthetic problems involving odour (LeChevallier, 1989).

Bacteria adhere to pipe walls, and their metabolic products both increase adhesion and protect the bacteria from the residual disinfectant. Furthermore, bacteria that are adapted to low-nutrient conditions, such can occur in distribution systems are less susceptible to disinfectants **(**Besner *et al.*, 2002). Once they are established, they are all but impossible to eradicate with chlorine or chloramines. The regrowth of bacteria may be affected by time, temperature, sediments, and the materials used in the system. There is a direct threat to people from pathogens, and indirect threats from likely interference with coliform detection and even from the transfer of antibiotic resistance factors to pathogenic bacteria. Age, low disinfectant residuals, warm temperatures, relatively high levels of total organic carbon, old iron pipe, and the insufficient flushing of dead ends all contribute to the growth of biofilms, sometimes to the point where bacteria, including coliforms, are released into the water. Biofilm may also support the regrowth of virulent bacteria if treatment failure has occurred at the plant (Ryu *et al.,* 2005).

There are a number of methods for preventing, slowing the growth of, and removing biofilms. Control requires an ongoing, multi-faceted effort that includes monitoring, maintenance, water treatment, and management, and it is not guaranteed by the use of a disinfectant residual alone. There appear to be limits to the efficacy of chlorine as a guarantor of system integrity. In some ways, it may be regarded as little more than an indirect indicator; rapid changes in its measured value signaling that something is wrong and that an investigation is required (Chen and Stewart, 2000).

Addressing problems related to microbial growths in the Baltimore, Md., drinking water supply (Baylis, 1922) observed a wide variety of organisms including algae, diatoms, protozoa, and bacteria in the distribution system. He expressed concern for the lack of attention being given to microbial growths in water systems. Noting a significant increase in bacterial concentrations in winter months, he concluded that decaying algae and diatoms penetrating the distribution system had provided nutrients for "scavenger" bacteria. Even at this early date, Baylis was apparently aware that microbiotic cycling of nutrients between algae, diatom and bacteria took place within water distribution systems. He concluded that taste and odour problems may have been caused by both algal byproducts and subsequent bacterial growth. Similarly, Kofoid (1923) attributed the development of tastes and odours to the growth of algae in reservoirs. He emphasized the maintenance of high quality source water to mitigate distribution system problems.

The principal concern over the observed increases in the number of microorganisms during distribution was related to fear of disease transmission. The fact that organisms in polluted river water were penetrating treatment barriers in the winter underscored concern over the potential for disease transmission (Nygard *et al.*, 2007).

The first experiments to evaluate the control of "bacterial after growths" were conducted by Baylis (1930) utilizing two parallel, continuously flowing taps. Significant after growths were observed where the pipe system received unchlorinated water, while low bacterial plate counts were observed when chlorine residual of 0.5 ppm was maintained. Observing high counts of *E. coli* in the sediments deposited in pipes, Baylis (1930) concluded that pipe sediment accumulations interfere with the destruction of bacteria even though the water may contain high levels of chlorine. Reasoning that there would be regions of chlorine-free water within the sediment in which bacteria could grow abundantly, he recommended that a systematic flushing of dead-end water mains was necessary to control bacterial activity and maintain disinfectant residuals within a distribution system.

Mulder (1964) reviewed the behaviour of slime-forming bacteria and summarized information on the isolation, cultivation and ecology of iron bacteria. Miller and Litsky (1976) classified bacteria found in natural waters and distribution systems as sheathed higher bacteria, stalk or caulobacteria, the spiral forms, the pigmented and non-pigmented rods, the cocci, the nitrogen-fixing and nitrifying bacteria. Tuovinen *et al.*, (1980, 1982) recovered a wide range of organisms from tubercles in the Columbus, Ohio, distribution system. These included sulphate reducers, nitrate reducers, nitrite oxidizers, ammonium ion oxidizers and sulphur oxidizers as well as various unidentified heterotrophic microorganisms. By this time, it was clear that distribution systems routinely serve as hosts to an exceptionally large and diverse population of microorganisms.

Confirming and extending the work of Baylis (1922), Wilson (1945) suggested that bacteria originating in source waters penetrated treatment facilities and, thereafter, became attached to pipe walls. Microbial colonization resulted in the formation of surface slimes and, ultimately, in the formation of encrusting tubercles. Because of extensive microbial growth on pipe surfaces and within tubercles, he concluded that it would be impossible to accurately enumerate all the bacteria present in the distribution system. Wilson was among the first to articulate the concept of microbial ecology within a drinking water distribution system. He suggested that the types and numbers of bacteria that develop in a water distribution system depend on the ecological niches available. He also recognized that many organisms that are unable to flourish in a particular environment may survive in a dormant state for indefinite periods. Subsequently, with a change to a less inhibitory environment, the dormant organisms may again become active, particularly in response to seasonal temperature changes. He suggested that different symbiotic microbial forms become active from season to season and place to place within a single water distribution system. Wilson (1945) also contributed to the early understanding of the microbially mediated transformation of iron, manganese, sulphur, carbon, nitrogen and phosphorus compounds by a mixed population of bacteria, fungi and protozoa. With respect to bacterial growth at distributed water temperature, he reported higher colony counts on plates incubated at 20 °C than on plates incubated at 35 °C. Noting aesthetic concerns resulting from the formation of taste-and-odour-producing compounds during water distribution, Wilson (1945) cited beggiatoa, thiobacillus, crenothrix and sulphate-reducing bacteria among those responsible for aesthetic degradation, corrosion of pipes and the production of tubercles.

The deposition of wastes along roadsides and on riverbanks and on marginal lands and then ‘hoping’ it will go away is both naive and dangerous. It is inevitable that chemical and biological contaminants in wastes will pollute the surrounding natural environment and find their way back to humans to affect health, quality of life and working activities (WHO, 2005).

The traditional thinking in the minds of many waste managers whose municipality’s practices open dumping is that it is acceptable because they cannot do anything else. This attitude is misplaced since there are many small improvements that can be made, often at little or no cost, which can together improve noticeably land disposal operation.

The increase in urban population has strained the sanitary facilities initially meant for less than half the current population. KEWASCO is responsible for the provision of these facilities and is keeping pace with population increase and rural urban migration. In the unplanned development, pit latrines are common human waste disposal facilities. Since residents of the areas affected also draw water from shallow wells, there have been cases of contamination of water by human waste (Draft Final Report, 2005). The central business district as well as a larger part of affluent residential estates such as Nyagacho does not have proper sanitation and hence their entire disposal ended up in the river. Kericho Municipal Council has one main abattoir situated few metres from sewerage treatment plant and a dumpsite that serves all butcheries in town. Since waste from the facility was directed to a soak pit, the effluent ends up polluting the environment (Schuringa, 1999).

Solid waste management is still a major environmental challenge in Kericho town. Solid waste is generated from domestic, commercial, and industrial sources. The waste is a major cause of environmental pollution in Kericho Municipality and its environs (Draft Final Report, 2005). Currently, the town generates lots of tons of waste per day, with market stalls, hotels and restaurants contributing much of the waste. The ever-increasing population worsens the situation. Waste management in Kericho is influenced by people's attitude, especially their pattern of material use and disposal. There is little interest in waste reduction and minimization; this mainly depends on the level of environmental awareness. The attitude, behaviour, and level of environmental awareness contribute immensely to pollution and poor waste management. A large percentage of Kericho residents believe they do not have a stake in waste management and is the sole responsibility of the Municipal Council (Mazingira News Edition, 2008).

The major pollutant in Kericho is plastic paper waste, which have spread to almost everywhere within vicinity of Kericho. Although plastic packaging provides excellent protection for any product, cheap to manufacture and long lasting, waste plastics is a major environmental challenge (Draft Final Report, 2005). The paper plastic is non-biodegradable, eyesore, unhygienic and poses a health risk. Plastic wastes cause sewage and storm water drains blockages, create favourable sites for disease-causing vectors like mosquitoes and deaths of livestock due to ingestion. Although it is the responsibility of Kericho Municipal Council to spearhead the collection, transportation, and disposal of waste, it is hampered by its limited capacity in human resource tools, and financial resources.

Tiony Soet river is an example of how increasingly polluted Kericho town has become due to increased human activities. The river is polluted with uncollected garbage and human waste from informal settlements; industrial wastes in the form of gaseous emissions, liquid effluents, agro-chemicals, and other wastes especially petro-chemicals and metals from micro- enterprises “Jua-kali” and overflowing sewers (Draft Final Report, 2005). This situation has occasioned the spread of water-borne diseases, loss of livelihoods, loss of biodiversity, reduced availability and reduced potential of the river becoming source of safe usable water, and the insidious effects of toxic substances and heavy metal poisoning which affects human health (American Water Works Association, 1999).

More so, the river has experienced heavy pollution from human activities, the main pollution being dumping of waste papers along the river shores. In developing countries, incorrectly secured and improperly operated Municipal solid waste (MSW) dumpsite poses a serious threat to the environment mainly to the surface and ground waters (WHO, 1999).

MSW dumpsites’ leachate can be considered as highly concentrated complex effluent, which may contain mineral and organic compounds, heavy metals and hazardous chemicals. Depending on the composition and extent of decomposition of refuse and hydrological factors, leachate may become highly contaminated. MSW includes wastes generated in households, commercials and business establishment, institutions and light industries, processing waste and agricultural wastes. These wastes include paper, food waste, glass, ashes, plastics, textiles, rubber, leather, yard trimmings, and wood among others (Ogundiran and Afolabi, 2008).

Sanitary landfill is a land waste disposal site located to minimize water pollution from runoff and leaching. Waste is spread in thin layers, compacted, and covered with a fresh layer of soil or inert material each day to minimize pests, diseases, air and water pollution problems. In Kericho, a sanitary landfill is not there. The council uses a crude dumping method in various dumpsites. This is a case where municipal solid waste is tipped indiscriminately; without considering its impact to the environment. No considerations have been made to the geological or topographical suitability of the site. Most likely, the location of the dumpsite is chosen because it is the cheapest land available that does not interest groups within the municipality. Therefore, there is a high likelihood of the leachate assuming a lateral movement from the Kericho MSW dumpsite. If this is so, then it follows that the river takes in large volumes of leachate along the bank adjacent to the dumpsites (Koech, 2003)

Under monitoring water quality, the following parameters were discussed, analyzed and the results were compared with the standards given by WHO, (2004).

- Heavy metals(Cd, Cr and Pb)
- Total alkalinity
- Total hardness (Ca and Mg hardness)
- *E- coli*
- Turbidity
- Conductivity
- TDS
- Residual chlorine

- pH

2.3.1 Heavy Metals and their health effects

Heavy metal contaminated soils and water can be a long-term environmental concern and hence, the assessment of heavy metal contaminated soil and water had received much attention in the last few decades. For a reliable and cost-efficient investigation, a well-planned sampling strategy, appropriate selection, and implementation of analytical methods and careful interpretation of results are prerequisites. The study presents overview of the sources, uses, and toxicity of the three metals under study.

Chronic low-level intakes of heavy metals have damaging effects on human beings and other animals, since there is no good mechanism for their elimination. Metals such as Pb, Hg, Cd, and Cu are cumulative poisons. These metals cause environmental hazards and are reported to be exceptionally toxic (Ellen *et al.*, 1990; Shitsama, 1999).

Vegetables take up metals by absorbing them from contaminated soils, as well as from deposits on parts of the vegetables exposed to the air from polluted environments (Zurera-Cosano *et al.*, 1989).

Ochieng *et al*. (2002) in their research found out that the concentrations of heavy metals Cd, Cr and Pb (out of the many metals studied) were analysed in water and surface sediments of five Rift Valley lakes Nakuru, Elementaita, Naivasha, Bogoria and Baringo in Kenya. The data indicate that some of the sites analysed, especially in Lake Nakuru, had relatively higher concentration levels of heavy metals like Cd and Pb in the water, which points to anthropogenic addition. This is an indication that most rivers across the country are polluted mostly by heavy metals.

2.3.1.1 Lead

Lead exists in compounds in the +2 and +4 oxidation states. PbO is prepared by exposing molten lead to air. Lead (IV) oxide, PbO_2, is a dark brown powder. This substance forms the cathode of lead storage batteries. The cathode is made by packing a paste of PbO, commercially called litharge into a lead metal grid.

2.3.1.1.1 Uses of lead

Many insoluble lead (II) compounds have been used as paints pigments such as $PbCrO_4$. Pb is used as a construction material for equipment used in sulphuric acid manufacture, petrol refining, halogenations, sulphonation, extraction, and condensation. It is used in storage batteries, alloys, solder, ceramics, and plastics. It is also used in the manufacture of pigments, tetraethyl lead, and other lead compounds, in ammunition, and for atomic radiation and x-ray protection. Lead is used in aircraft manufacture, building construction materials (alloyed with copper, zinc, magnesium, manganese, and silicon), insulated cables and wiring, household utensils, laboratory equipment, packaging materials, reflectors, paper industry, printing inks, glass industry, water purification and waterproofing in the textile industry (Jones, 2008).

2.3.1.1.2 Toxicity of lead

Human exposure to lead, especially where children are involved, has been a public health concern for several decades. Pb was frequently used in the service lines that connect homes with water mains and in the solder used in copper plumbing. As a result, in

Canada, municipalities have been phasing Pb materials out of drinking water systems for a decade, with tin solder is now generally used in plumbing. Ontario's building code requires a lead content of less than 0.2% for plumbing solder used in water systems. Ontario Regulation 459/00 established an upper limit for Pb in drinking water of 0.01 mg/L at the point of consumption. If higher levels remain after pipes have been flushed, the municipality is required to replace any Pb service lines into a house. The risks are posed by a combination of Pb piping and the corrosiveness of water: soft water poses a higher risk than scale-forming hard water (Besner, 2001).

The presence of Pb in drinking water is a significant health risk because even minute quantities are believed to cause neurological problems in infants and children. The U.S. Environmental Protection Agency (EPA), (1990), estimates that, on average, Pb in drinking water accounts for approximately 20% of all human exposure to Pb. In the United States, lead-free solder and piping have been required since 1986, and the 1991 Pb and Cu Rule (LCR), revised in 2000, require the phased replacement of existing Pb pipes. The LCR establishes action levels for example, maximum limits that, if exceeded, require corrective action to be taken) of 0.015 mg/L for lead and 1.3 mg/L for Cu. Maximum Contaminant Level Goals (the standard that will eventually apply in the United States when old Pb pipes have all been replaced) are 0 mg/L for Pd and 1.3 mg/L for Cu. Techniques for addressing concerns about Pb and Cu include minimizing corrosion in pipes, treating source water where appropriate, investing in public education, and replacing Pb service lines if levels in water exceed the action level. People should be informed if the buildings they live or work in are suspected of being serviced by Pb pipes so that they can check their end of the line for Pb pipe as well (Boyd, *et al.*, 2001).

Pb is a toxic element that can be harmful to plants, although plants usually show ability to accumulate large amounts of Pb without visible changes in their appearance or yield. In many plants, Pb accumulation can exceed several hundred times the threshold of maximum level permissible for human **(**Wierzbicka, 1995). The introduction of Pb into the food chain may affect human health, and thus, studies concerning lead accumulation in vegetables have increasing importance (Coultate, 1992). Although a maximum Pb limit for human health has been established for edible parts of crops (0.2 mg/kg) (Chinese Department of Preventive Medicine, 1994), soil Pb thresholds for producing safe vegetables are not available.

Use of Pb in paints is now restricted because Pb compounds are cumulative poisons. Pb (II) ions are retained in the bones, where they replace Ca ions; later the Pb (II) ions may be released to give high concentrations of ions in the blood. Pb (II) ions poisons by reacting with a number of vital enzymes (biochemical catalyst,) in the body (Tyagi and Mehra, 1990).

In humans, toxic levels of Pb damage important body parts such as the liver, kidney, nervous system and reproductive system, or even death. Other health effects of Pb include cot deaths and stillbirths. For pregnant women, elevated Pb concentrations increase the risk of hypertension. There is no evidence though that Pb has carcinogenic or teratogenic effects on human beings (Fergusson, 1990).

2.3.1.2 Cadmium

Cadmium is found in the rare mineral greenockite, CdS and in small amounts in several zinc ores. The two metals are separated by fractional distillation since Cd is more volatile having boiling point of 767 ^{0}C than Zn with boiling point 907 ^{0}C. The amount of Cd released to the environment yearly is 25000 tones, half of which goes to the rivers (WHO, 1989).

2.3.1.2.1 Uses of Cadmium

Cd is used in making a number of alloys. Certain ores are easily fusible; these include Wood's metal (12.5% Cd), melting at 65.5^{0}C, and Lipowitz alloys (10% Cd), melting at 70^{0}C. Some antifriction bearing metals contain Cd. Amalgamated Cd, along with $CdSO_4$, is used in the Weston standard cell for measuring electrical potentials. Rods of Cd are used in nuclear reactors to absorb neutrons and thus control the chain reaction (ATSDR, 2008).

Cd is used in Ni - Cd batteries, PVC plastics, and paint pigments. It can be found in soils because insecticides, fungicides, sludge, and commercial fertilizers that use Cd are used in agriculture. Cd may be found in reservoirs containing shellfish. Cigarettes also contain Cd. Lesser-known sources of exposure are dental alloys, electroplating, motor oil, and exhaust (Bernard, 2008).

2.3.1.2.2 Toxicity of Cadmium

The harmful health effects include diarrhoea, stomach pains and severe vomiting, bone fracture, infertility, damage to the CNS and the immune system, psychological disorders and possible DNA damage and cancer development (ATSDR, 2008).

In small doses, Cd causes vomiting, diarrhoea and colitis. Continuous exposure to Cd causes hypertension, enlargement of the heart and premature death. There is evidence suggesting that Cd can induce chromosome abnormalities and may exert carcinogenic effect on the lungs (Duffus, 1980).

Inhalation accounts for 15-50% of absorption through the respiratory system; 2-7% of ingested Cd is absorbed in the gastrointestinal system. Target organs are the liver, placenta, kidneys, lungs, brain, and bones (Bernard, 2008).

2.3.1.3 Chromium

Chromium occurs in either elemental or trivalent oxidation state, which is less the toxic form. The most toxic form, which is hexavelant Cr, arises from human activities in the environment (Vitale *et al.*, 1997).

2.3.1.3.1 Uses of Chromium

Chromium compounds are used in ferrochrome production, electroplating, pigment production, and tanning. All these uses are sources of pollutants in waterways as they are discharged as effluents by industries (U.S. EPA. 2010).

2.3.1.3.2 Toxicity of chromium

Acute exposure to Cr through ingestion can result in gastrointestinal disorders, hemorrhagic diathesis and convulsions. Death may also occur due to cardiovascular shock. Chronic exposures may lead to chromosomal aberrations (mutagenic) as well cancer of the lung (ISO 9174:1990).

Although some of these health effects may be immediate, most of them are long term and lead to chronic diseases. Chronic toxicity can be observed in several other mammalian species, with hexavelant Cr in concentrations of more than 5mg/L (WHO, 1988).

Among the predictable severe toxicological effects of Cr are mutagenicity, carcinogenicity in chronic exposures and gastrointestinal disorders, hemorrhagic diathesis, convulsions or death following cardiovascular shock during acute exposure. (Blowes, 2002).

2.3.2 Electrical Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity 25 ^{0}C (Trivedy and Goyal, 1986).

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity (Hach Company, 1992).

The basic unit of measurement of conductivity is the mho or siemens. Conductivity is measured in micromhos per centimetre (µmhos/cm) or microsiemens per centimetre (µs/cm). Distilled water has conductivity in the range of 0.5 to 3 µmhos/cm.

2.3.3 Total Alkalinity

Total alkalinity is the total concentration of bases in water expressed as parts per million (ppm) or milligrams per litre (mg/L) of calcium carbonate ($CaCO_3$). These bases are usually bicarbonates (HCO_3^-) and carbonates (CO_3^{2-}), and they act as a buffer system that prevents drastic changes in pH. For example, in waters with low alkalinity, pH might fluctuate from 6 or lower to as high as 10 or above; while in high alkalinity waters, pH might fluctuate from about 7.5 to 8.5 (Almgren *et al.*, 1983).

Greater production in bass-bluegill ponds is attained in high alkalinity waters because this pH buffering capacity makes phosphorus and other essential nutrients more available to the algae bloom (Castelle *et al.*, 1994).

Total alkalinity is not the same as hardness. Calcium (Ca^{++}) and magnesium (Mg^{++}) are primarily responsible for hardness. However, in most waters, alkalinity and hardness have similar values because the carbonates and bicarbonates responsible for total alkalinity are usually brought into the water in the form of $CaCO_3$ or $MgCO_3$ (American Public Health Association, American Water Works Association, and Water Environment Federation, 1998).

2.3.3.1 Environmental Impact of alkalinity

Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes. Living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0. Alkalinity is a measure of how much acid can be added to a liquid without causing a large change in pH. Higher alkalinity levels in surface waters will buffer acid rain and other acid wastes and prevent pH changes that are harmful to aquatic life (Water Quality Criteria, 1972).

For protection of aquatic life, the buffering capacity should be at least 20 mg/L. If alkalinity is naturally low, (less than 20 mg/L) there can be no greater than a 25% reduction in alkalinity (Bhargava, 1982).

2.3.4 Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity. Turbidity is considered as a good measure of the quality of water. There are various parameters influencing the cloudiness of the water. Some of these are phytoplankton, sediments from erosion, re-suspended sediments from the bottom (frequently stir up by bottom feeders like carp), waste discharge, algae growth and urban runoff (Suess, 1982).

The WHO establishes that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU (ISO 7027: (1999)).

2.3.4.1 Consequences of high turbidity

The suspended particles absorb heat from the sunlight, making turbid waters become warmer, and so reducing the concentration of oxygen in the water (oxygen dissolves better in colder water). Some organisms also cannot survive in warmer water. The suspended particles scatter the light, thus decreasing the photosynthetic activity of plants and algae, which contributes to lowering the oxygen concentration even more. As a consequence of the particles settling to the bottom, shallow lakes fill in faster, fish eggs and insect larvae are covered and suffocated, gill structures get clogged or damaged. Turbid waters become warmer as suspended particles absorb heat from sunlight, causing oxygen levels to fall (warm water holds less oxygen than cooler water). Photosynthesis decreases with lesser light, resulting in even lower oxygen levels. Suspended solids in turbid water can clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. Settled particles smother eggs of fish and aquatic insects (Sadar, 1996).

2.3.5 Total Dissolved Solids

Water is a good solvent and picks up impurities easily. Pure water is tasteless, colourless, and odourless and is often called the universal solvent. Dissolved solids" refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates) and some small amounts of organic matter that are dissolved in water (Michaud, 1994).

TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water, that is the plumbing. Concentrations of TDS from natural sources have been found to vary from less than 30 mg/L to as much as 6000 mg/L, depending on the solubilities of minerals in different geological regions.
(APHA *et al.*, 2005).

Thus values, expressed as the sum of the constituents, were below 500 mg/L in 36 of 41 rivers monitored in Canada, while, in a survey of the Great Lakes, levels ranged from 65 to 227 mg/L. The levels of TDS in all of the Great Lakes except Lake Superior have increased in the last 70 years, by 50–60 mg/L in Lakes Erie and Ontario. Between 1960 and 1980, a threefold increase in TDS was observed in the Kent River, Australia. Between 1955 and 1970, a tenfold increase in the salinity of the groundwater at Burlington, MA, was noted, resulting from road de-icing. The use of de-icing chemicals was prohibited thereafter (Department of fisheries and environment, Canada, 1977).

2.3.5.1 Potential Health Effects of Total Dissolved Solids

An elevated total dissolved solids (TDS) concentration is not a health hazard. The TDS concentration is a secondary drinking water standard and therefore is regulated because it is more of an aesthetic rather than a health hazard. An elevated TDS indicates the following:

- The concentration of the dissolved ions may cause the water to be corrosive, salty or brackish taste, result in scale formation, and interfere and decrease efficiency of hot water heaters;

- Many contain elevated levels of ions that are above the primary or secondary drinking water standards, such as: an elevated level of nitrate, arsenic, aluminum, copper, lead, etc.

High total dissolved solids may affect the aesthetic quality of the water; interfere with washing of clothes and corroding of plumbing fixtures. For aesthetic reasons, a limit of 500 mg/L has been established by NEMA as part of the secondary drinking water standards.

The total dissolved solids concentration can be related to the conductivity of the water, but the relationship is not a constant. The relationship between total dissolved solids and conductivity is a function of the type and nature of the dissolved cations and anions in the water and the possible nature of any suspended materials. Conductivity is measured through the use of a meter and is usually about 100 times the total cations or anions expressed as equivalents and the TDS in ppm usually ranges from 0.5 to 1.0 times the electrical conductivity (APHA Method 2510A, 1992).

Its effects include the following:

- It causes cancer, coronary heart disease, arteriosclerotic heart disease, and cardiovascular disease.
- Total mortality rates were reported to be inversely correlated with TDS levels in drinking water. It was reported in a summary of a study in Australia that mortality from all categories of ischaemic heart disease and acute myocardial infarction was increased in a community with high levels of soluble solids, calcium, magnesium,

sulphate, chloride, fluoride, alkalinity, total hardness, and pH when compared with one in which levels were lower. No attempts were made to relate mortality from cardiovascular disease to other potential confounding factors. The results of a limited epidemiological study in the former Soviet Union indicated that the average number of "cases" of inflammation of the gall bladder and gallstones over a 5-year period increased with the mean level of dry residue in the groundwater. It should be noted, however, that the number of "cases" varied greatly from year to year in one district, as did the concentration of dry residue in each district, and no attempt was made to consider possible confounding factors (Tyagi and Mehra, 1990).

2.3.6 Total Water Hardness

Water hardness is an expression for the sum of the Ca and Mg cation concentration in a water sample. These cations form insoluble salts with soap, decreasing soap's cleaning effectiveness. They also form hard water deposits in hot water heaters. The standard way to express water hardness is in ppm $CaCO_3$ which has the formula weight of 100.1 g/mole (Harris, 2003). The degree of hardness of drinking water has been classified in terms of the equivalent $CaCO_3$ concentration as follows:

These classification in Table 1 will be used for comparison purposes after analysis of water in various selected stations have been done. On heating, hard waters have a tendency to form scale deposits. Soft water, on the other hand, may result in corrosion of water pipes because it has low buffering capacity. No health-based guideline value is proposed for hardness in drinking-water (WHO, 2008).

Table 1: Classification of Hard Water (Mato, 2002).

S.No	Concentration as $CaCO_3$	Indication
1	0 to 60 mg/L	Soft water
2	60 -120 mg/L	Moderately hard water
3	120 -180 mg/L	Hard water
4	>180 mg/L	Very hard water

2.3.7 *Escherichia coli*

Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in the intestines of man and warm- and cold-blooded animals. They aid in the digestion of food. A specific subgroup of this collection is the faecal coliform bacteria, the most common member being *Escherichia coli (E. coli)*. These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and associated only with the faecal material of warm-blooded animals (Ewing, 1986).

The faecal coliform group includes all of the rod-shaped bacteria that are non-spore forming, *Gram-Negative*, lactose-fermenting in 24 hours at 44.5 ° C, and which can grow with or without oxygen. Faecal coliform by themselves are usually not pathogenic; they are indicator organisms, which means they may indicate the presence of other pathogenic bacteria. Pathogens are typically present in such small amounts it is impractical to monitor them directly (Feng *et al.*, 1982).

Some strains of *Escherichia coli,* which are a type of faecal coliform, can cause intestinal illness. One such strain is E. coli O157:H7, which is found in the digestive tract of cattle (EPA. 2006).

2.3.7.1 Environmental Impact

The presence of faecal coliform bacteria in aquatic environments indicates that the water was contaminated with the faecal material of man or other animals. At the time this occurred, pathogens or disease producing bacteria or viruses may have contaminated the source of water, which can also exist in faecal material (Akunga and Wamicha, 2004). Some waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis, and hepatitis A (Bopp *et al.*, 1999). The presence of faecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. Faecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste (Chandrashekara, 2002).

2.3.8 pH

pH is one of the most common water quality tests performed. pH indicates the sample's acidity, but is actually a measurement of the potential activity of hydrogen ions (H^+) in the sample. pH measurements run on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a $pH < 7.0$ are considered acids while those with a $pH > 7.0$, up to 14.0 are considered bases. All organisms are subject to the amount of acidity of stream water and function best within a given range (EPA 2008).

The pH scale is logarithmic, so every one-unit change in pH actually represents a ten-fold change in acidity. In other words, pH 6.0 is ten times more acidic than pH 7.0; pH 5 is one hundred times more acidic than pH 7.0 (Van Loon, 1982).

2.3.8.1 Environmental impact

Changes in the pH value of water are important to many organisms. Most organisms have adapted to life in water of a specific pH and may die if it changes even slightly. This is especially true of aquatic macro invertebrates and fish eggs and fry.

The pH is a critical factor determining the health of a waterway. The factors that control it are obviously complicated. As with many environmental concerns, we need to be aware of the implications of any impacts we have upon the environment (Elizabeth and Premnath, 2005)

CHAPTER THREE

MATERIALS AND EXPERIMENTAL METHODS

3.1 Study Area

The study area lies over the biggest water catchment area, the Mau Forest with a high altitude of 2093 meters, Longitude (DMS) of 35^0 16’60E and Latitude (DMS) of 0^o 22’0S.(internet: wikipeadia,2010) Kericho as shown in Figure 1 is the centre of Kenya's large tea industry, its town square even known as ‘Chai Square’. Some of the largest tea companies including Unilever Kenya, James Finlay and Williamson tea are based there. It is also home to the popular Ketepa brand. Much of the tea is also exported to overseas with the UK being the largest market. The capital of the county is Kericho town. It has a population of 758,339 and an area of 2,111 km^2 (Population and Household, 2009-Census).

Kericho is located in the western side of the Great Rift Valley in a highland area near Lake Victoria located in a very high potential agricultural zone with soils are red volcanic type suitable for both tea farming and production of food crops such as maize, beans and vegetables. Livestock farming is also practiced in the area. The climate is of equatorial type. The rainfall is between 1200-2000mm per annum with the wettest season occurring in March – June and dry season between December to February.

Temperatures in Kericho range from 12.85 to 28.7^oC. Rainfall varies from 96.0 to 843.0 mm/month). The soils are deep and well drained. The rain is adequate and reliable making the district to produce a surplus of crops (Mazingira News edition, 2008).

The full economic potential of the Kericho region is, however, far from fully exploited and the current growth in population and improved education will hopefully change this in a near future. People are still mostly rural, but urbanization is gradually increasing; new cities and towns contain the rural-urban migration and, provided the right policies are instituted, the district had, emerged as a national economic and cultural hub (Mazingira News edition, 2008).

This involved the collection of water samples for quality analysis. The samples were collected from treatment plants and from the consumption points. Also in the research, dumpsite leachate was studied to ascertain the safety of water obtained directly from the river.

During the research, various water quality tests were carried out. These included bacteriological quality, turbidity, pH, and free chlorine residual tests among others. The results obtained were compared to the water quality standards set by WHO that is, allowable limits for developing countries (Guidelines for Canadian drinking water quality, 1996)

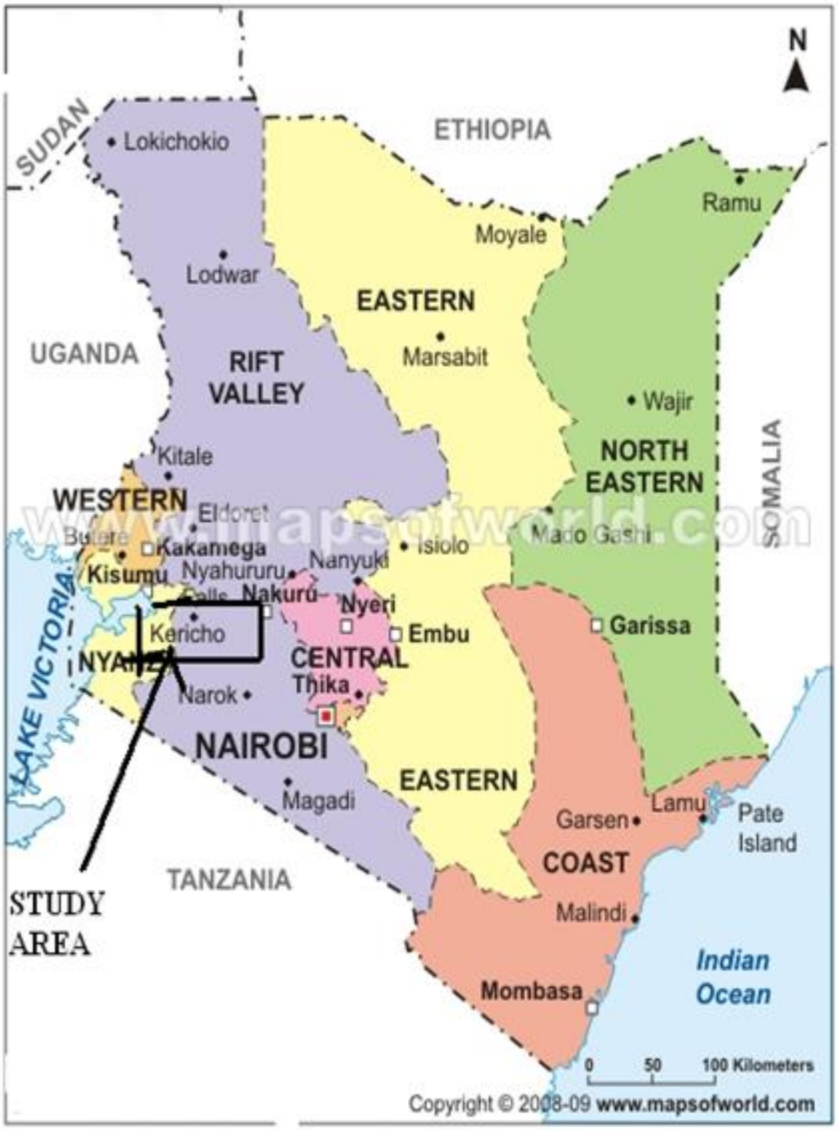

Figure 1: Map of Kenya showing study region **(Source: www.mapsoftworld.com).**

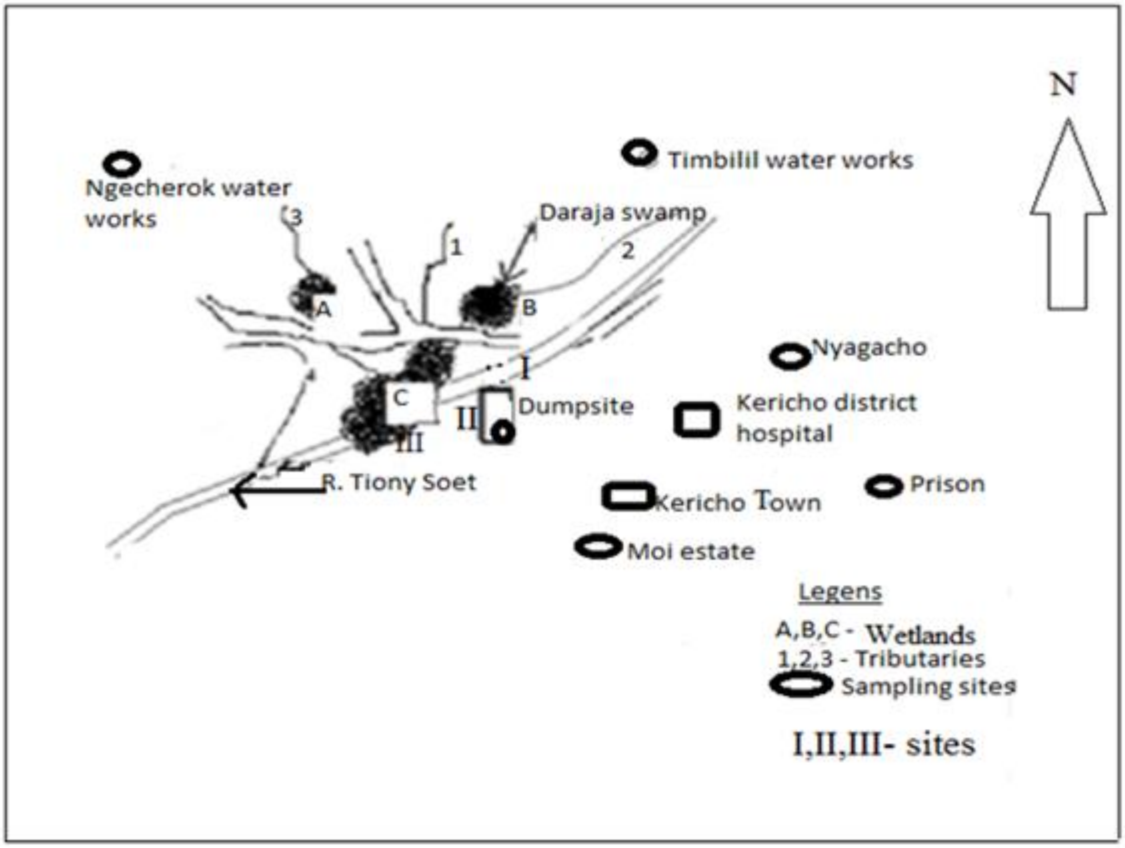

Figure 2: Map showing sampling sites (Source: Author, 2010).

3.2 Reagents and Standards

Analytical grade reagents together with distilled de- ionized water were used in preparation of reagents from Sigma Adrich. Among the reagents and standards used were nitric acid, hydrochloric acid,1+1, standard $H_2SO_{4,}$ 0.02N, 0.1N Na_2CO_3 solution, methyl orange indicator, 16.9 g NH_4Cl, NH_4OH, Mg salt of EDTA (780 g $MgSO_4.7H_2O$), 4.5 g of hydroxylamine hydrochloride, Eriochrome black T indicator, sodium hydroxide, pH butter solutions for calibration, hydrochloric acid for cleaning pH probes and titrators, turbidity standards (StablCal Stabilized Formazin Standards), lab grade dish washing detergent, turbidity-free water, reagents and Bromophenol blue indicator.

3.3 Sample analysis

The dependent variables analyzed were total suspended solids, pH, Total alkalinity, Total hardness (Ca and Mg hardness), *E- coli*, turbidity, conductivity, TDS, residual chlorine, pH, heavy metals (Cd, Cr and Pb). Standard methods were followed in determining the above variables. All probes were calibrated prior to measurements with the appropriate traceable calibration solutions in accordance with manufacturer’s instructions.

3.3.1 Sampling of water

Sampling of water was carried out monthly for three months from January to March 2010. The rain was below 1mm in January. Heavy down pour started in March the same year. Samples were collected from designated sampling points (Figure 2); that is at treatment works, at the consumer points within the distribution network and at the dumpsite leachate then kept in a cooler box filled with ice cubes for preservation before analysis.

A 200 ml of water samples were taken from the identified collection points. Water samples were collected using 250 ml sterile glass stop-cocked containers from the various stations and acidified using nitric acid (1+1) and transported to the laboratory in cold and protected from sunlight. They were processed within 6 hours of their collection.

The sampling bottles were first sterilized in the autoclave in the laboratory and kept in aseptic condition in the field. Other field kits were also calibrated to give accurate results in the field.

In the laboratory, the samples were removed from the cooler box and left to attain room temperature before analysis. The samples were then analyzed for the following water quality parameters;

- Total alkalinity
- Total hardness (Ca and Mg hardness)
- *E- coli*
- Turbidity
- Conductivity
- TDS
- residual chlorine
- pH
- Heavy metals(Cd, Cr and Pb),

3.3.2 Dumpsite's Leachate Analysis

The analyses were done for three months during low and high rains that was on January, February, and March 2010.

3.3.2.1 Sampling technique

3.3.2.1.1 Leachate sample

A1m deep trial holes of diameter 0.3 m were dug at the intervals of 60 m along the stretch of the dumpsite. The stretch was 5 m from the edge of the dumpsite. Leachate samples were collected from all points located within the perimeter of the dumpsite and points where wastewaters get into the river. A 5 L Plastic buckets, perforated halfway from the top, were placed in the five trial holes and their lids replaced and covered with soil to avoid interference from surface runoff and undue attraction by passersby. Monitoring of the trial holes was done for a month after which the leachate in the buckets was lifted and taken for analysis. In the laboratory, blank solutions de- ionized water without reagent (0.00 mL) were analysed to evaluate the general performance of the analytical procedure in all the three metals.

3.3.2.1.2 Water sample

250 mL of Water samples were collected at about 100 m before the dumpsite along the river, along the mid-length of the dumpsite in the river and finally at a point after the dumpsite.

The samples from the respective trial holes and wastewater from the sampling sites were then transferred into 500 mL bottles. The bottles were covered with foil paper at the top to prevent the sun rays from interfering with composition of the leachate. The bottles were then placed in a cool box and transported to the laboratory on the same day for analysis. Standard solutions were also prepared for comparison purposes for all the parameters selected.

3.4 Measurements

Measurements of the samples were categorized into two as field and laboratory measurements. This depends on availability and nature of reagents and standards, devices and their portability

3.4.1 Field measurements

Parameters such as pH and turbidity, were analyzed at the time of sampling that is *in situ* sampling technique was employed.

3.4.1.1 Determination of pH

The efficacy of disinfection with chlorine is highly pH-dependent with disinfection being less effective where the pH exceeds 8.0. pH meter Hannas model H1 9025 was used. To check the accuracy of the pH meter, buffer tablets were used where one tablet was dissolved in distilled water and made up to 100 ml produces a solution of pH 7.00+-0.02 at room temperature (Hanna® Instruments, 2000).

3.4.1.2 Measurement of turbidity (Turbidimeter)

Turbidimeter Hach Model FT660 Sc was used. The water sample was put in the instrument and the values read. Turbidimeter was properly calibrated with a primary standard which is StablCal Stabilized Hach Formazin Turbidity stand 4000NTU 508. (Black and Hannah, 1965).

3.4.2 Laboratory measurements

3.4.2.1 Sampling procedure for bacteriological analysis

The taps were cleaned and the tap attachments that could cause splashing were removed. The taps were turned on for maximum flow and the water was left to run for 1-2 minutes to ensure that stagnant water was flushed from the pipes before the samples were taken.

The sampling bottles were taken and carefully the caps were unscrewed. Sodium thiosulphate solution had been added to the bottles before sterilization to neutralize chlorine. While holding the cap and protective cover face downward (to prevent entry of dust, which could contaminate the sample) immediately the bottles were held under the water jet, and filled. A small air space was left to make shaking easier before analysis. The bottles were capped and covered with aluminium foil.

3.4.2.2 Analytical Procedure for bacteriological analysis

The method employed LST-MUG method for detecting *E.coli*. The LST-MUG assay is based on the enzymatic activity of β- glucuronidase (GUD), which cleaves the substrate 4 - methylumbelliferyl β-D glucuronide (MUG), to release 4-methylumbelliferone (MU). When exposed to long wave (365 nm) UV light, MU exhibit a bluish fluorescence that is easily visualized in the medium or around the colonies (Doyle and Schoeni, 1987). Cerium oxide, which is added to glass as a control measure, fluoresces under UV light and interferes with the MUG test (Hartman, 1989). One tube was inoculated having LST-MUG with a known GUT- positive *E. coli* isolate as positive control, ATCC standard reference Materials™ (ATCC 25922). In addition, another tube inoculated with a culture of *Enterobacter aerogenes* (ATCC 13048) as negative control, to facilitate differentiation of sample tubes that show only growth from those showing both growth and fluorescence. Both tubes were incubated for 48 h at 35 ^{0}C and were examined for growth (turbidity, gas) then again examined in the dark under long wave UV lamp (365 nm) and a bluish fluorescence was a positive presumptive test for *E.coli.*

3.4.3 Analysis of Heavy Metals

The technique employed was Atomic Absorption Spectroscopy (AAS) Varian, Model Spectra- AA-100/200 was used in determining the levels of Pb, Cd, and Cr found in both leachate and water. In direct aspiration atomic absorption spectroscopy, a sample was aspirated and atomized in a flame. A light beam from a hollow cathode lamp whose cathode was made of the element to be determined was directed through the flame into a monochromator, and onto a detector that measures the amount of light absorbed. Since the wavelength of the light beam was characteristic of only the metal being determined, the light energy absorbed by the flame measured the concentration of that metal in the sample. This principle was the basis of AAS filtration and acid digestion of the suspended material of metallic constituents. The acid digest were subsequently determined and the sum of the dissolved plus suspended concentrations then provided the total concentrations present. The sample was filtered as soon as possible after collection and the filtrate acidified immediately (Paus, 1973).

The characteristic concentration check value is the concentration of element (in mg/L) that produces a signal of approximately 0.2 absorbance units under optimum conditions at the wavelength listed in Table 2. The use of characteristic concentration check was to determine whether instrumental parameters were optimized and whether the instrument was performing up to specifications. Optimum conditions for instrument settings for analysis of the three metals were observed as indicated in Table 2 below.

Table 2: AAS optimized conditions for determination of Pb, Cd and Cr.

Metal	Wavelength (nm)	Slit width (nm)	Flame	Gas flow (L/min)	Instrument mode
Pb	217.0	1.0	Air-Acetylene	2.00	Absorbance
Cd	228.8	0.5	Air-Acetylene	2.00	Absorbance
Cr	357.9	0.2	Air-Acetylene	2.90	Absorbance

(Alloway, 1995)

3.4.3.1 Preparation of stock and working solutions

Sample solution for analysis of the three metals was prepared following manufacturer's instructions. High purity metal salts dissolved in high purity acids were used to make the stock solution. Working standards were diluted as indicated below for each metal and the values were recorded as shown in Table 3.

Digestion was done using concentrated nitric acid and concentrated hydrochloric acid for leachate sample and the procedure was done as follows:

The samples were collected in acid – cleaned plastic or glass bottles and preserved by adjusting to pH 2 or less by Nitric acid about 2 mL per litre). Before analysis the pH was adjusted to 4-5 with 5.0N sodium hydroxide. Then 5 mL of Conc. HNO_3 was added to one litre of sample. The acidified sample was transferred to 250 mL flask (Erlenmeyer flask). A 5mL of 1:1 HCl. was added and the sample was heated on hot plate for 15 minutes at 95°C thereafter, cooled, filtered through a membrane filter and adjusted the volume to 1000 mL with deionized water.

Table 3: Concentrations of the various standard solutions used.

Standards	Values in mg/L		
	Pb	Cd	Cr
Blank standard	0.00	0.00	0.00
STD I	2.00	0.05	5.00
STD II	4.00	1.00	10.00
STD III	6.00	3.00	15.00

3.4.3.2 Preparation of calibrations solutions

A stock solution of 100 ppm was prepared by pipetting 10.0 mL from 1000-ppm stock solution transferring into a volumetric flask of 100 mL and topping to the mark by deionized water. Standard solutions were obtained as 2.00, 4.00 and 6.00 ppm for Pb, 0.00, 0.5, 1.00 and 3.00 ppm for Cd and 5.00, 10.00 and 15.00 ppm for Cr. The absorbance of each solution was then measured and a curve relating the experimentally determined absorbance and the concentration of the standard was prepared. The relationship between absorbance and concentration is linear to indicate that Beer-Lambert’s law was obeyed as shown in Figure 3 and Appendix 3. Blank solutions (0.00 mL) as indicated in the Table 3 were analysed to evaluate the general performance of the analytical procedure in all the three metals.

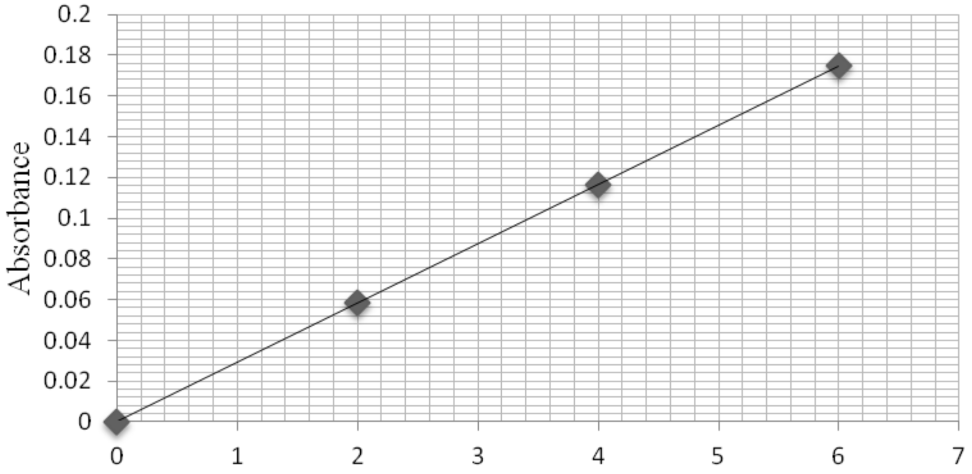

Figure 3: Calibration curve for Lead (mg/L)

3.5 Determination of free residual chlorine

Residual chlorine in a water sample was measured using a commercial Hach mode CN 66 Colour Wheel and visual comparator that consisted of a box with an eyepiece in front and two cells, the whole arranged so that both cells were in the field of vision of the eyepiece. The comparator used was the disc type, containing a wheel of small coloured glasses. The reagent used in the analysis was N, N-diethylparaphenylenediamine (DPD).

One cell, containing a water sample without the reagents, was placed in line with the rotating colour glasses or the ampoules containing the standards. The water sample containing the reagent was placed in another cell. If free chlorine was present, a colour would develop. The concentration of chlorine was estimated by matching the colours in both cells, as seen through the eyepiece. Each colour of the disc or ampoule corresponded to a certain quantity of chlorine in the water and different calibration discs or ampoules were needed for each of the reagents specified (Hach Company, 2002).

3.6 Total alkalinity

Alkalinity was measured by titration. A 0.02N sulphuric acid (the titrant) was added to a 200 mL volume of a treated sample of water in which the methyl orange indicator had been added. The volume of acid required to bring the sample to a specific pH level reflects the alkalinity of the sample. The end point indicated by a colour change from orange to pink. To check the accuracy of the sulphuric acid used, fresh 0.02N sodium hydroxide was prepared. Alkalinity is expressed in units of milligrams per liter (mg/L) of $CaCO_3$ (calcium carbonate) (American society for testing and materials, 1982).

3.7 Total water hardness

A 100 ml water sample is measured into a plastic beaker containing a stirring bar. The water was at room temperature. A 1 ml volume of buffer solution was added to the stirred water before titration in which the quantity of “hardness ions” was determined by measuring the concentrations of Ca and Mg in water samples by titration. 0.01M EDTA, a weak acid, was used as the titrant. In its ionized form, it is able to form soluble complexes with Ca and Mg cations (Harris, 2003). One packet of the indicator added to the buffered sample was Eriochrome Black T. Initially, the indicator formed a complex with the cations. When complexed it is red in colour. As the EDTA was added drop wise to the sample, it replaced the Eriochrome Black T and formed more stable complexes with Ca and Mg. When the indicator was released by the metal ions, it had a distinct blue colour. Therefore, the endpoint of the titration was marked by the colour change from red to blue. A blank titration was run using distilled water (Clesceri and Greenberg, 1998).

The total water hardness of the sample was calculated by the following equation,

$$\text{Total hardness (mg)} = \frac{(A - B) \times 1000}{L - \text{Volume of sample (ml)}}$$

Where, A= volume of EDTA consumed for sample, ml

B= volume of EDTA consumed for blank, ml

$CaCO_3$ 10 mg/L Standard EDTA titrant was used during analysis to check the accuracy throughout the process was prepared from the 1000 mg/L standard by diluting 50 ml in a 500 ml volumetric flask.

3.8 Conductivity and Total Dissolved Solids

Hach conductivity meter, model 3084 was used to measure the conductance generated by various ions in the water. Conductivity/TDS standard (1413 µs/cm) was used to correct the accuracy of the meter. The Hach Conductivity Probe was equipped with a thermostat to allow automatic temperature compensation when attached to the sension5 Conductivity Meter. The probe was inserted into the 100 mL water sample solution making sure the slot in the tip was fully immersed. The probe was agitated vertically and the readings was allowed to stabilize, then recorded and stored it in the meter memory. Conductivity readings were converted to TDS readings by multiplication with a known mathematical factor by placing the Conductivity Probe into the 500 mg/L TDS standard solution. Total Dissolved Solids (TDS) Model 3084 automatically calculates the TDS from the conductivity reading by multiplying the preset factor [.625] and Set keys. Manual Range (A – F) and Auto Range displays TDS in Parts per Million (PPM) as a function of conductivity and the TDS multiplier. The TDS multiplier was adjustable from 40% to 90%. (Annual Book of ASTM Standards, 2000).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Variations in values of pH and turbidity during the study period on the selected stations

Selected parameters analyzed at the field were the pH and turbidity levels. These were carried out at selected stations in the months of January, February, and March. The values of pH and turbidity are shown in Figure 4.

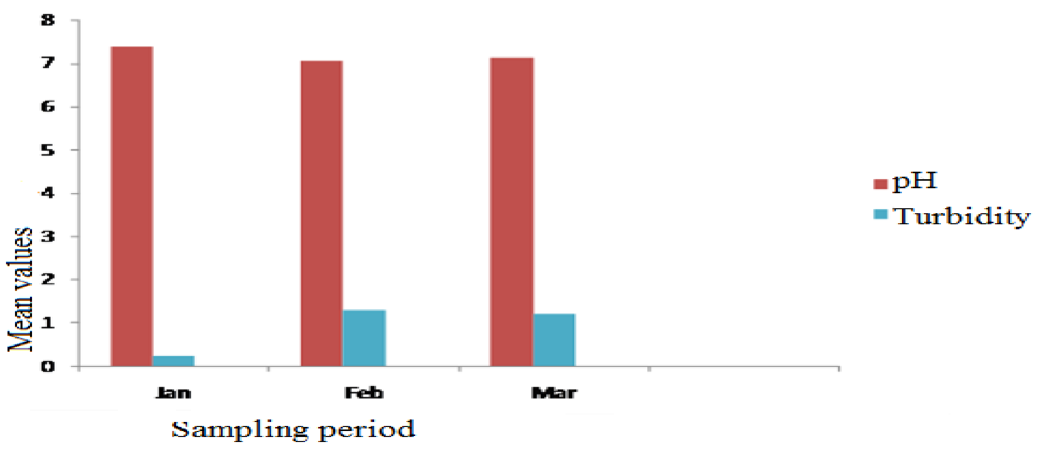

Figure 4: Mean concentrations of pH and turbidity (NTU) for the three months during study period

From Figure 4 and Appendix 5 show that turbidity increased in trend from January to February but the levels dropped in March while pH decreased slightly then increased again in the month of March. The heavy rain in March could have brought about dilution effect. In February, turbidity reached 1.30 mg/L, which could be due to influx of several materials as the amount of rain received was higher as compared to the amount received in January. However, the turbidities of all the water samples were within permissible criteria (WHO, 1984).

The pH levels recorded in the study for all the stations were within the acceptable limits for drinking water. There were no exceeding acidity or basicity levels in the water in any of the samples within the sampling months except in Nyagacho where the highest pH value recorded during the month of March was 8.20 as shown in Appendix 5.The reason for the difference could be due to leakage of water pipes could have led to seepage of bicarbonate since the area is highly populated as compared to other areas in Kericho municipality (Draft Final Report, 2005).

Turbidity level recorded a lower value instead as depicted in Appendix 5 with Moi estate having a value of 0.01 in March and 1.18 and 3.00 in January and February, respectively. Turbidity was expected to increase considerably in March because sediments could have been washed into the river from the catchment area. The deposited sediment could have been re-suspended (Cosser, 1989). However, in Kericho, since water is obtained from protected springs, no influence of runoffs water was expected (Ngecherok Water project, 2013).

In a related study, Mwangi *et al*. (2010) reported mean pH for most samples to be neutral (7.10) which is within the range associated with most natural waters (6.0 to 8.5) as is stipulated for drinking and domestic purposes (Chapman, 1992). These values were in agreement with those reported in the current study ranging between 6.2 and 8.2.

Mwangi *et al*. (2010) further found that the turbidity of the water ranged from 2.0 to 142.0 NTU during the wet period, which is the most critical time when most run offs occur carrying a lot of silt. These values were, however, much higher than those obtained this study that ranged from 0.4-3.7 NTU.

4.2 Variations in concentration of the bacteriological and physicochemical parameters

Table 4 show physicochemical parameters analysed during the sampling period

Table 4: Mean values of bacteriological and physicochemical parameters analysed in January, February, and March from the selected stations

Stations	Parameters																	
	TDS (mg/L) **(Max 1200)**			Residual chloride (mg/L) **(0.2 -0.9)**			conductivity (µs) **(Max 2000)**			Total alkalinity (mg/L) **(Max 500)**			Total hardness(mg/L) **(Max 500)**			*E.coli* **(-VE)**		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Ngecherok	28	24	20	1.2	0.4	0.9	56	52	40	36	32	27	18	17	14	-VE	-VE	-VE
Timbilil	23	20	21	0.7	0.4	0.3	48	47	35	40	35	32	20	15	12	-VE	-VE	-VE
Prison staff resident	26	22	16	0.1	0.5	ND	57	50	45	30	25	20	16	14	09	-VE	-VE	-VE
Main prison tap	25	21	17	0.1	0.7	ND	50	48	43	24	20	18.2	06	05	03	-VE	-VE	-VE
Moi estate	29	24	20	0.1	0.3	ND	59	54	46	25	23	18	13	11	14	-VE	-VE	**+VE**
Nyagacho	30	27	19	0.2	0.6	1.0	70	65	55	25	26	40	12	14	20	-VE	-VE	**+VE**

NB: bolded and in the brackets are WHO, (2004) standards.

Key: -VE – Nil, +VE - Presence

From the Table 4, the results show that parameters were within the WHO standards in nearly all the sampled stations except a few like residual chloride and E. coli where the levels were above the recommended standards. The highest parameter viewed was, however, residual chlorine at Ngecherok (1.2 in January) and this could be due to the presence of a dosing point that was quite close to the draw point at which the samples were taken from. The rest of the stations recorded values between 0.1-0.7, which is an acceptable range for assurance of safety of drinking water.

The *E.coli* detected at Moi estate and Nyagacho during the month of March could be due to mineral content and pH that brought about the corrosion of the water pipes and growth of bacteria in the distribution network (Wagner, 1994). In addition, the presence of thermo tolerant coliforms in the samples suggests contamination of the water by faecal matter. Since these changes were only observed in samples from consumer collection points and not from treatment plants, it implies contamination along the reticulation system or at the collection points. This could be attributed to the regular bursting of water pipes along the distribution system. Another contributing factor could be contamination at the collection site and in the laboratory during analysis or possibly due to microbial resistance to chlorine. The water from other stations did not record any bacteriological activity since all the tests for *E. coli* turned out to be nil. Thus the chlorine levels were adequate to disinfect the water throughout the distribution system and this guaranteed that the water quality was suitable for drinking.

Mwangi *et al*. (2010) found out that *E. coli* MPN index per 100 ml ranged between 43- > 1100 against WHO standards. These were comparable to the results obtained in the current study since it was an indication that water was not fit for consumption. The bacteriological quality of the water as indicated by the total and *faecal coliform* counts exceeded the standard (0 cfu per 100 ml) for portable water. In general, the bacteriological quality of the water was unacceptable as it may pose risk to consumers if not treated. The poor quality indicated possible contamination with human or animal waste that could have been contributed by inadequate physical infrastructure, especially heavy reliance on pit latrines and weak solid waste management mechanisms. Lack of functioning solid and liquid waste management system in the rapidly growing urban centre represents a possible and significant source of pollutants, which may find their way into water resources.

Although the WHO guidelines placed a lot of emphasis first and foremost on the microbiological safety of drinking water supplies, more than half of the world's population is still exposed to water that is not free from pathogenic organisms. This has resulted in infectious diseases that ultimately lead to increased mortality rates in the population (WHO, 2003).

The current study recorded a general decrease in TDS, conductivity, and total alkalinity from January to March for all sampling points possibly because of dilution effect as a result of heavy rain experienced in March. Mwangi *et al*. (2010) noted that conductivity ranged between 0.07 to 0.85 and 0- 180 EC mS/cm during wet and dry seasons, respectively. These values were, however, not in agreement with the results reported in the current study that ranged from 35 – 70 µs.

The corresponding TDS ranged between 21- 62.40 and 0-123 mg/L during wet and dry seasons as observed by Mwangi *et al*. (2010) which again were higher than the values obtained in the present study that ranged from 16- 30 mg/L. This could be due to as a result of inorganic fertilizers used by farmers. In another study, Akunga (2004) reported mean measurements for electrical conductivity to be 39.95µS for four private man-made reservoirs in the central part of Kericho count conducted between November 2001 and March 2002. This value was in close agreement with the values obtained in the present research.

The conductivity of rivers in the United States generally ranges from 50 to 1500 µmhos/cm. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 µhos/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macro invertebrates. Industrial waters can range as high as 10,000 µmhos/cm (APHA, 1992). The values reported in most rivers in USA were comparable to the values reported in this current study which ranged from 35-70 µs. This means majority of the stations recorded values which were 50 µs and above.

Fafioye and Adebanjo (2013) in their study reported several mean physico-chemical parameters of Azikwe River water samples in Nigeria were: pH-7.75 ± 0.3, alkalinity (mg/L) - 80.00 ± 3.74, hardness (mg/L) - 140.00 ± 6.15, conductivity (SC/m) - 480 ± 4.21 and turbidity (TU) - 8.60 ± 0.64. These values were within permissible criteria set by WHO but were much higher than the values obtained during the present study. They also reported TDS (mg/L) value of 510.00 ± 3.54, which was higher than the values indicated in the current research.

All natural waters contain some dissolved solids due to the dissolution and weathering of rocks and soil. It is the general indicator of ionic concentration. In another study Holmbeck-pelham *et al.* (1997) reported the TDS of the river water sample to be 10 mg/L higher than that of the federal US drinking water standards of 500 mg/L which can pose a health effect. It had been observed that water with high total dissolved solids is unpalatable and potentially unhealthy and this may affect the taste of the river water.

In the current study, the residual chloride recorded at main prison, prison staff residence and Moi estate were below the WHO maximum allowable limits and this could be attributed to water flow velocity, residence time, age and material of the pipe and water pressure (Egorov, 2002).

It was also observed that during the third month most of the samples had no chlorine residual as sampling was carried out in the month when there were heavy rains and this could have led to increased level of suspended matter in the raw water hence need for higher dosages of chlorine for effective treatment. The source of KEWASCO raw water is springs which lie in an agricultural area thus suspended matter is washed into the treatment works. According to the WHO standards, the minimum Free Residual Chloride (FCR) should be 0.2 mg/L (WHO, 1998).

The total alkalinity of the water samples were below the permissible and desirable criteria for domestic water supply. The observed alkalinity was due to methyl orange alkalinity. Consequently, the water samples were not polluted with respect to alkalinity. Also, water hardness for Kericho Municipality as indicated by the results show that it is soft water as classified in Table 1.

4.3 Analysis of heavy metals in water samples

A few drops of concentrated nitric acid were added to water samples to reduce the pH to less than 2. This was done in different sampling sites of the study, the results of the analysis are given in three sections according to where the water sample was taken from, and the results of the outcome are indicated in Figure 5 and Table 5.

Table 5: Values of heavy metals in the water samples from the three sampling sites analysed in the three subsequent months

	Heavy Metals (mg/L)								
	Pb			Cd			Cr		
Sampling sites	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Site I	1.342	0.210	0.17	1.778	0.157	0.015	1.675	0.982	0.773
Site II	1.270	0.224	0.18	1.170	0.134	0.013	2.501	1.120	0.858
Site III	1.245	1.314	0.21	1.06	0.109	0.060	2.850	1.187	1.351
Mean	**1.29**	**0.58**	**0.19**	**1.34**	**0.13**	**0.03**	**2.34**	**1.10**	**0.99**

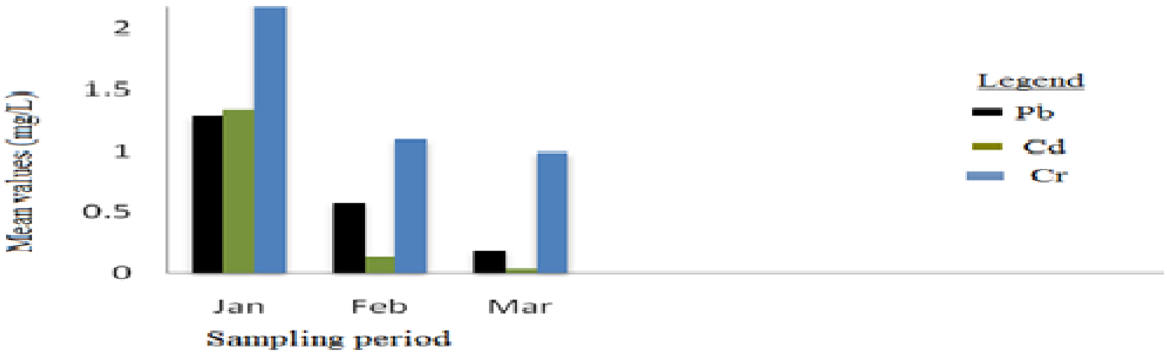

Figure 5: Mean concentration of the three heavy metals in water from the three sites analysed in January, February and March.

Figure 5 shows a decreased trend for each of the metals studied in water samples over the sampling period from January to March. From Table 5, Pb levels decreased in trend in January but increased in both February and March downstream. Cd showed a general increase in January and March but decreased in February while Cr generally increased in all the months from sites I-III. Pb levels in water samples were by far higher than the recommended maximum WHO (1999) standards for drinking water (0.05 mg/L). Pb concentration was higher in January and lowest in March possibly due to lack of dilution effect. This could imply that water pollution is contributed mostly from the surrounding runoffs rather than solid waste dumpsite's leachate. However, in most contaminated aquatic systems, almost all the Pb is tightly bound to sediments and only a small fraction of it is dissolved in the water.

Decreased trend in Cd levels could be due to its presence in phosphatic fertilizers and the phosphatic rock (WHO, 1998). Also, the bedrock in the area could be of Cd related residues. Other sources could be volcanic activities in the Rift Valley where water passes through to the receiving river, runoffs from waste batteries, paints and forest fires that could lead to release of Cd related oxide to the environment (Ongulu, 2008).

The mean concentration of Cr was higher for the three months as compared to those for Pb and Cd which were, however, much higher than the WHO (1999) standards (0.05 mg/L). Chromium is found chiefly in chome-iron ore. Chromium is used in alloys, in electroplating and in pigment. Chromium salts are used extensively in industrial processes and may enter a water supply through the discharge of wastes. Chromate compounds are frequently added to cooling water for corrosion control (Vitale *et al.*, 1997).

The general trend of the mean concentration of the three metals was January$_{>}$ February$_{>}$ March could possibly be due to dilution effect brought about heavy rains that occurred in March. This could have led to an increase in volume of water which was higher than the increase in the amount of mobilised pollutants, consequently, slight decreased concentration (Draft Final Report, 2005).

In a similar study conducted by Koech (2003) on water quality of the Dionsoyiet River, it was reported that Pb concentration at a station downstream was much higher (2.22 ppm) than upstream with a much lower value of 0.74 ppm. These values were much higher than the values obtained in the present research and this leads to a conclusion that urban runoff and effluent from the sewage treatment plant could be the main contributors to the observed trend.

In another related study, Ochieng' *et al.* (2002) conducted analysis of water and surface sediments of five Rift Valley lakes Nakuru, Elementaita, Naivasha, Bogoria and Baringo and observed that the dissolved mean levels (mug/L) of metals in water ranged within 2.0-43.0 (Cd), 25.0-188.0 (Cr), and 25.0-563.0 (Pb). These values were, however, not in agreement with the values obtained in the current study because they were much higher implying anthropogenic factors in addition to the fact that lakes receive a lot of drainage from rivers, most of which pass through areas where several human activities involved.

In a similar study, Moore *et al*. (2009) analysed total concentrations of a number of metals including Cr, Cd, and Pb in lake water. The respective mean concentrations for dissolved metals Cd and Pb were 0.28 μg/L and 5.17 μg/L while Cr was not detected.

These values, however, showed a great variation with what has been reported in the present study indicating lake pollution could be resulting mainly from anthropogenic sources and rivers draining into it.

Macdonald and Christopher (2011) reported mean concentration of the heavy metals in surface water samples from Warri river in Delta State, Nigeria to be: Cr: 0.0 mg/L - 0.06 mg/L; Cd: 0.0 mg/L - 0.05 mg/L and Pb: 0.0 mg/L - 0.001 mg/L. The heavy metals concentrations in the surface water samples from this river decreased in the order: Cr > Cd > Pb (among other metals). These values, however, were lower and did not agree with the trend observed in the present research which was Cr > Pb > Cd. The difference in the results and trend could be due to the fact that river Warri receives a lot of wastes from industrial, agricultural and domestic sources. This river serves as the main source of drinking water, fish and irrigation for the various communities settling along its banks and catchment area. Therefore, with more industries discharging their effluents into the river, the prospects of a greater pollution is high, so also is an increased risk to public health

Among the three metals studied, Cr had the highest level and this implies that the metal is likely to affect human health (Ongulu, 2008).

4.4 Analysis of heavy metals in the leachate samples from the dumpsite

The mean concentration of heavy metals found in leachate samples from three sampling sites: I, II and III are presented in Figure 6 and Table 6. This was done in the laboratory for three months and the values in mg/L were recorded.

Table 6: Mean concentration (mg/L) of the three heavy metals in leachate from the three sites analysed in January, February and March

	Heavy metals (mg/L)								
	Pb**(WHO-0.05)**			Cd(**WHO-0.05)**			Cr(**WHO-0.05**)		
Sampling sites	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Site I	1.36	0.27	0.26	2.75	1.25	1.66	2.98	1.34	1.29
Site II	1.45	0.34	0.34	1.23	0.16	0.05	2.87	1.50	1.50
Site III	1.49	0.40	0.36	1.56	0.12	0.05	1.93	1.67	1.60
Mean	**1.70**	**0.69**	**0.32**	**1.48**	**0.50**	**0.55**	**2.92**	**1.50**	**1.46**

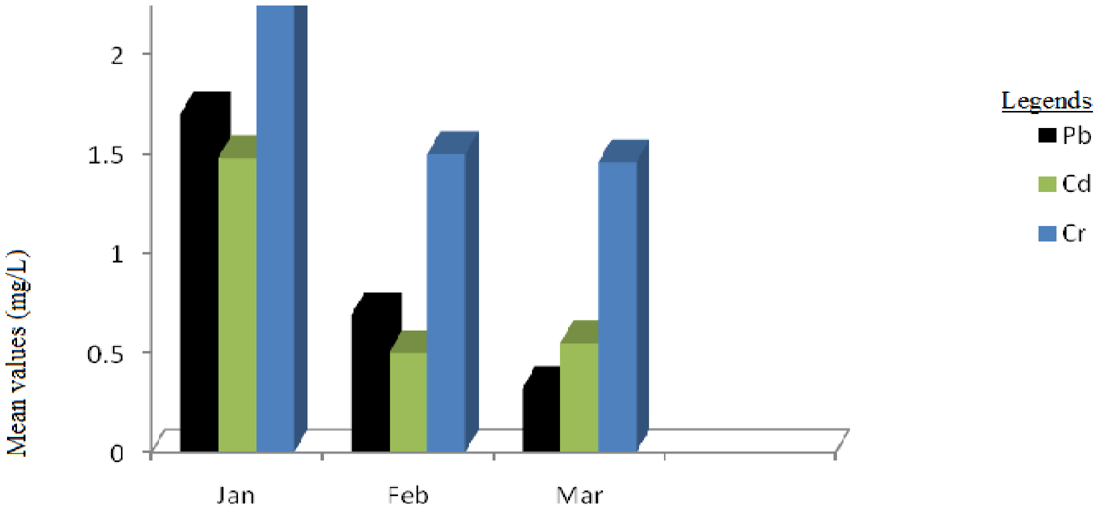

Figure 6: Mean concentration (mg/L) of the three heavy metals in leachate from the

three sites analysed in January, February and March

From Figure 6 all the three metals showed a general decreasing trend downstream. Pb contents in leachate samples from the three sites were, however, higher than in water samples, as depicted in and Table 6. Pb levels showed a general increase from sites I - III over the three months from January to March while Cd showed a general decrease over the same period. Moreover, Cr level decreased in January and increased in both February and March from sites I – III. There was no rainfall, in February there was light showers while in March, there was heavy rainfall. These differences in rain patterns could have contributed to the differences in results obtained during the study. Among the three heavy metals analyzed, Cr had the highest deviations from the WHO (1999) standards. The high levels of the element could be attributed to the use of phosphate fertilizers in farms, which end up being washed into the water bodies, leading to Cr enriched water.

The Cd values in leachate samples were far higher than WHO (1999) standards for drinking water (0.05 mg/L). This shows that municipal effluents could have been the major source of pollution to the environment. These values were, however, higher compared to those found in water. Other factors such as use of phosphate fertilizers, insecticides, fungicides, Ni - Cd batteries, PVC plastics, cigarettes and paint pigments which when disposed of are washed into the water bodies, consequently, leading to Cd enriched water. Also Cd may enter into water as a result of industrial discharges or the deterioration of galvanized pipe (Ganotes et al., 1962).

Generally, the level of metals decreased from January to March in all the three Sites (I-III). Analogous to filtration or screening, the presence of plant matter within a wetland provides a physical barrier that prevents sediment and sediment attached pollutants from being swept downstream by the flow (Waters, 2004). The very dense vegetation that is present within the wetland causes high flow resistance and thereby severely moderates flows. Most of the flow is transmitted by through a dendritic open water stream network within the wetland that comprises of five streams arising from each of the inlets, which merge within the first few hundred metres of the length of wetland into a single stream that flows through the centre of the wetland to the outlet. Apart from these limited number of fast flowing streams, water in the vegetated sections of the wetland is near stagnant (Draft Final Report, 2005).

4.5 Analysis of heavy metals in the water samples from the selected stations

Table 7 shows the analysis of heavy metals in mg/L in water samples from the selected stations for the three months.

Table 7: Mean concentration of heavy metals in the water samples from the selected stations in January, February, and March

	Heavy metals (mg/L)								
	Pb			Cr			Cd		
Stations	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Ngecherok	ND	ND	ND	ND	0.001	0.001	ND	0.001	0.003
Timbilil	ND	ND	ND	ND	0.005	0.002	0.001	0.003	0.001
Prison staff Resident	0.003	0.004	0.007	0.001	0.004	0.002	ND	0.001	ND
Main prison tap	0.002	0.003	0.005	0.002	0.002	0.001	0.004	0.005	ND
Moi estate	0.001	0.015	0.003	0.007	0.005	ND	0.003	0.004	ND
Nyagacho	0.005	0.006	0.009	0.005	0.005	ND	0.006	0.008	0.010

From the results indicated in the Table 7 heavy metal levels in drinking water were within the recommended WHO standards. However, only in some few instances were the metals in trace amounts therefore not detected. The reason could be due to alkalinity, which not only helps regulate the pH of a water body, but also the metal content. Bicarbonate and carbonate ions in water can remove toxic metals such as Pb, As, and Cd leading to precipitation. The levels of the metals observed could also be due to seepage of pollutants from the surroundings into the broken water pipes for example, Pb being naturally available in the soil as a result of weathering of rock fragments on which soils develop (Omoga and Kagwanja, 1999).

The Draft Final Report (2005) gave Pb levels that were relatively high and therefore industries upstream of both wetlands and rivers should be encouraged to dispose of their wastes more diligently and careful attention is required to check on activities that may directly add heavy metals to the wetlands such as car washing. Pb in a water supply may result from smelter discharges and from the dissolution of plumbing and plumbing fixture. Tap water is inherently not corrosive but if not suitably treated may contain Pb resulting from an attack on Pb service pipes, Pb interior plumbing, brass fixtures and fittings on solder pipe joints chiefly from galena (PbS). Pb is used in batteries, solder, piping, pigments, insecticides and alloys. Pb also was used in gasoline for many years as an anti-knock agent in the form of tetraethyl lead. The Food and drug administration regulates lead content in food and in house paints (American Society For Testing And Materials, 1977).

The presence of Cr in drinking water could be due to use of Cr related products such as seed protectants and wood preservatives (Ongulu, 2008). Afiukwa (2013) observed that mean concentrations (mg/L) of elevated metals in drinking water (surface water) in Ebonyi State, Nigeria ranged from: Cd- 0.004 – 0.011, Cr - 0.16 – 1.65 and Pb - 0.02 – 2.5 This study showed that some metal concentrations exceeded the WHO guideline limits for drinking water in the order: Pb > Cr > Cd in surface water. These levels were, however, higher than those reported in the present study. A non-point source of pollution which included indiscriminate waste dumps in water bodies, poor sanitation and other uncontrolled anthropogenic sources of pollution could be the cause for the observed trend. Also high amounts of nutrients such as nitrates and sulphates arising from fertilizer applications could be a contributing factor.

4.6 Comparison of levels of heavy metals in treatment plants, consumer points, and Dumpsite

The levels of Pb in the two water works were not detected over the sampling period of three months. At the consumer points, however, the metals were detected but with higher levels in the leachate samples which resulted from the dumpsite. In January, Cd was not detected in the Ngecherok treatment plant but was detected in the Timbilil treatment sample. The highest level was recorded at the dumpsite leachate followed by water sample from the river adopting the general concentration trend of: Leachate sample > water sample from the river > consumer points > treatment plants.

For Cr, the general trend of concentration was leachate sample > river water > consumer points > treatment plants. The reason for could be because the water which is obtained from protected springs goes through two treatment works, therefore, reducing pollutants levels. At the consumer points, water pollutant levels were within permissible criteria set by WHO and KEBS except when the pollutants entered the pipes through leakage, bursting of pipes and when the river water gets pollutants from the immediate dumpsite and municipal waste water runoffs.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the findings,the water supplied by KEWASCO is far much safer for drinking purposes as compared to other untreated water. The water, which tested positive with *E.coli* from the consumer points, was an indication that the water systems should be inspected to determine the cause and sampling should continue until consecutive samples comply with the standards in the guidelines. Other physico- chemical parameters tested in the treatment plants and consumer points were within the acceptable standards and thus do not need any further treatment once it reaches the consumer points.

From the three metals analysed, the highest levels were recorded in the dumpsite leachate and this could be a possible source of water pollution to the river water that were concurrently analysed for comparison purposes.

The levels of heavy metals in the treatment plant and consumers' points were within the acceptable limits as compared to WHO standards. Therefore water from treatment plant is far much safer for human consumption and frequent users of untreated water are at risk of contracting any disease brought about by polluted water.

5.2 Recommendations

Since not all parameters were analyzed and therefore recommended more research to be done especially to include the impact of nutrients and other heavy metals not covered during the study on the quality of drinking water.

E. coli provides conclusive evidence of recent faecal pollution and should not be present in drinking water. In practice, testing for thermo tolerant coliform bacteria can be an acceptable alternative in many circumstances. While *E. coli* is a useful indicator, it has limitations. Enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of *E. coli* will not necessarily indicate freedom from these organisms. Under certain circumstances, it may be desirable to include more resistant microorganisms, such as bacteriophages and/or bacterial spores in future research. Such circumstances could include the use of source water known to be contaminated with enteric viruses and parasites or high levels of viral and parasitic diseases in the community.

In addition, the analysis of the raw water is recommended to be analysed in the future for comparison purposes, as this was not covered during this study.

The KMC dumpsite has not met any of the recommended WHO guidelines. Important issues such as topography and walkover site surveys that are required to address the following design issues-topography of the surrounding landscape, preliminary inspection of actual or offsite pollution that causes a distinct threat to local communities need a further study of its own.

The dumpsite is not far away from the River Tiony Soet thus a possible source of water pollution and not far away from the Nyagacho slum and therefore a threat to the local community. Moreover, there are no proper laid down plan or mechanism for the draining and subsequent treatment of the leachate from the dumpsite. Hence, there is a need for a study to be done on this.

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APPENDICES

Appendix I: Table of laboratory analysis analysed for the three months from various selected stations in comparison with WHO standards

Parameters	**WHO stand**	**Ngecherock plant**			**Timbilil plant**			**Prison staff resident**			**Main prisons -Kitchen tap**			**Moi Estate**			**Nyagacho Estate**		
		Jan	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**
PH	6.5-8.5	6.83	6.6	6.2	7.52	7.5	6.00	7.5	7.0	6.85	7.36	7.25	7.0	7.2	6.78	7.5	8.2	7.36	8.2
Conductivity (µs)	Max 2000	56	52	40	48	47	35	57	50	45	50	48	43	59	54	46	70	65	55
Turbidity (ntu)	5	1.49	1.47	1.40	0.55	0.56	0.4	0.7	0.68	1.67	0.18	0.17	2.00	0.6	1.78	0.1	2.0	1.92	3.7
Total alkalinity(mg/l)	Max 500	36	32	27	40	35	32	30	25	20	24	20	18.2	25	23	18	25	26	40
Total hardness(mg/l)	Max 500	18	17	14	20	15	12	16	14	09	6	5	3	13	11	14	12	14	20
TDS(mg/l/)	Max 1200	28	24	20	23	20	21	26	22	16	25	21	17	29	24	20	30	27	19
RC(ppm	0.2-0.9	1.2	0.4	0.9	0.7	0.4	0.3	0.1	0.5	0.00	0.1	0.7	0.00	0.1	0.3	0.00	0.2	0.6	1.00

E.coli (No/100ml)	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve	-ve	-ve	+ve
Lead	0.05	ND	ND	ND	ND	ND	ND	0.003	0.004	0.007	.002	0.003	0.005	0.001	0.015	0.003	0.005	0.006	0.009
Chromium	0.05	ND	.001	0.001	ND	0.005	0.002	0.001	.004	0.002	.002	0.004	0.001	0.007	0.005	ND	0.005	.005	ND
Cadmium	0.05	ND	0.001	0.003	0.001	0.003	0.001	ND	.001	ND	.004	0.001	ND	0.003	0.004	ND	0.006	.008	0.010

Appendix II: Absorption data from standard solution for lead, cadmium, and chromium respectively

Concentration of standard solution of lead	Absorbance, A= log (I_0/I)
0.00	0.00
2.00	0.0583
4.00	0.1166
6.00	0.1749

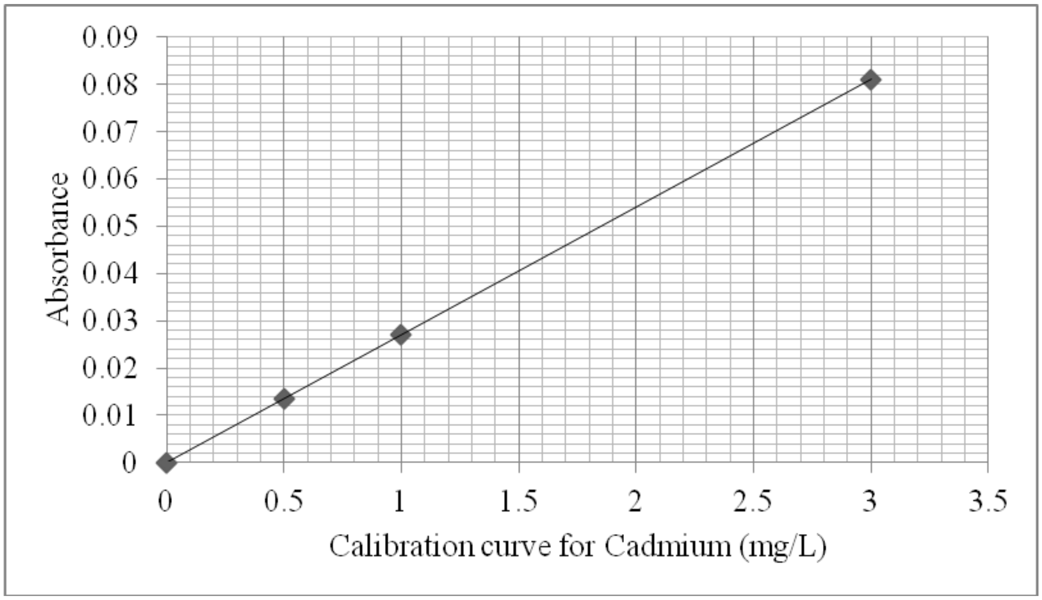
Concentration of standard solution of Cadmium	Absorbance, A= log (I_0/I)
0.00	0.00
0.5	0.0135
1.00	0.027
3.00	0.081

Concentration of standard solution of Chromium	Absorbance, A= log (I_0/I)
0.00	0.00
5.00	0.0413
10.00	0.0826
15.00	0.1239

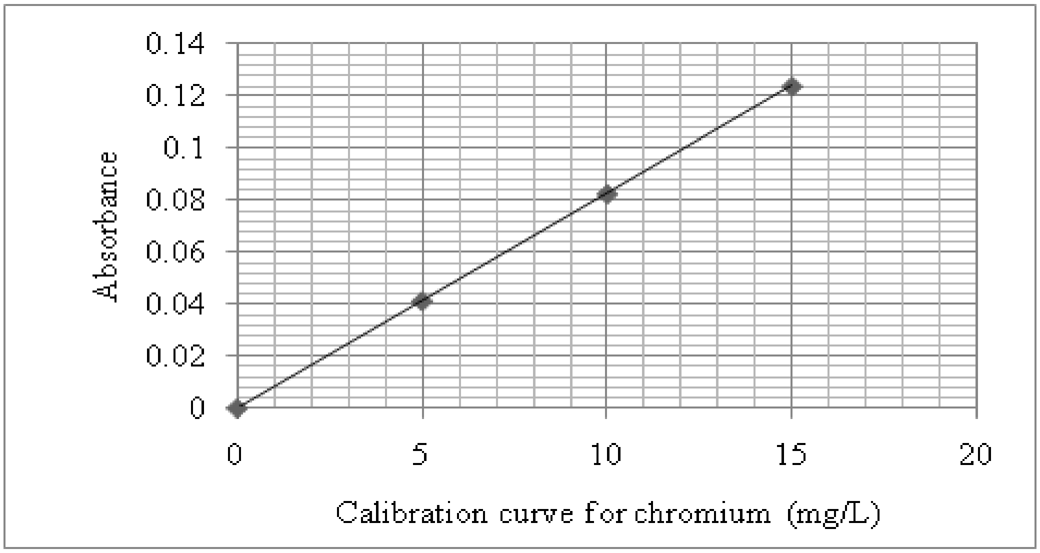
0.0 is blank solution

Appendix III: Calibration curve for Cadmium and chromium respectively.

(a)



(b)



Appendix IV: Required number of tests for physiochemical parameters

Number of samples per year per parameter*	Groundwater		Surface water	
	Water production per year		Water production per year	
	<240,000 m3	>240,000 m3	<240,000 m3	>240,000 m3
Turbidity,pH, colour	4	6	12	12 + 1 for each additional 60,000 m3 above 240,000m3
Others**	Every six months***	1	2	4

* The required number of tests per parameter applies to both the network and each source

** Others refer to parameters such as heavy metals and pesticides.

*** More frequent sampling might be required where there is known or suspected contamination e.g. from industry, agriculture or human settlements

Adopted from Water Services Regulatory Board – Drinking Water Quality and Effluent Monitoring Guideline

Appendix V: Values of pH and turbidity analysed during the study period from the selected stations

Stations	Parameters					
	pH **(WHO standard – 6.5 -8.5)**			Turbidity (NTU) **(WHO standard -Max 5)**		
	Jan	Feb	Mar	Jan	Feb	Mar
Ngecherok	6.83	6.57	6.20	1.49	1.47	1.40
Timbilil	7.52	7.5	6.00	0.56	0.56	0.40
Prison staff resident	7.5	7.0	6.85	0.70	0.68	1.67
Main prison kitchen tap	7.36	7.25	7.00	0.18	0.17	2.00
Moi estate	7.2	6.78	7.50	1.18	3.00	0.10
Nyagacho	8.0	7.36	8.20	2.00	1.92	3.70
Mean	7.4	7.07	7.13	0.23	1.30	1.21

Legend Jan- January, Feb – February, Mar – March