UNIVERSITY OF ZIMBABWE

Faculty of Engineering

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ASSESSMENT OF THE QUALITY OF WATER IN URBAN RIVERS – A CASE STUDY OF LILONGWE RIVER IN MALAWI.

BY

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MSc. Thesis in Integrated Water Resources Management

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In collaboration with

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ABSTRACT

Lilongwe the capital city of Malawi has a population of 670,000 and is fast growing at a rate of 4.3% per annum. All streams and runoffs in the city drain in Lilongwe River, hence its water quality for human use appears to be deteriorating.

This research was aimed at identifying the sources of pollution and assessing the quality of the water in Lilongwe River in terms of suitability for domestic purposes of cooking, bathing, washing and drinking. The section of Lilongwe River under study was chosen because there had been reports of water borne diseases occurring every rainy season, there were a lot of waste damping and river bank cultivation along the river despite the river being used for domestic purposes like drinking. The selection of sites for water sampling was done through a physical survey. The grab sampling method was used. Physical identification and interviews were done to identify the major sources of pollution in the study area. Analysis of the 14 chosen physical, chemical and biological parameters was done at the Government Central Water Laboratory in Lilongwe though some were analyzed at the site using portable meters. Analysis of the parameters followed the protocols of the APHA (1989) methods.

The results of the socio-economic survey showed 197 activities that directly or indirectly polluted the water in Lilongwe River. The laboratory analysis results showed that the values of seven out of 14 analysed parameters were above the acceptable limits of the Malawi Bureau of Standards (MBS), concluding the occurrence of pollution in the river. These parameters were Lead (0.07±0.02 mg/l), Cadmium (0.14±0.08 mg/l), Phosphates (0.1±0.01 mg/l), Chemical Oxygen Demand (110±4.2 mg/l), Suspended Solids (81±6.2 mg/l), Turbidity (123±4 NTU), and Faecal Coliforms (3,781±300 counts/100ml). It is therefore concluded that the section of the river under study is polluted and not fit for domestic use. It is recommended that the water of Lilongwe River should not be used directly for domestic purposes of drinking within the study area. It is also recommended that an IWRM approach be used in order to solve the pollution problem of Lilongwe River.

Key Words: *Pollution, analysis, water quality, sampling, acceptable limits, IWRM, temporal and spatial variations*

DECLARATION

I, **Toney Hamilton Nyasulu** hereby do declare that this is my own work and acknowledgement has been duly made where other sources have been used. No part of this work has been submitted previously for a degree at any other University.

Signature: …………………………………………..

Date: ………………………………………………

DEDICATION

I dedicate this work to my late father Noby Guy Nyasulu and my mother Polinah NyaVinkhumbo.

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ACRONYMS AND ABBREVIATIONS

BOD_5	5-day Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
GoM	Government of Malawi
IWRM	Integrated Water Resources Management
KCH	Kamuzu Central Hospital
LWB	Lilongwe Water Board
MBS	Malawi Bureau of Standards
MoIWD	Ministry of Irrigation and Water Development
NSO	National Statistical Office
SADC	Southern Africa Development Community
SS	Suspended Solids
STDEV	Standard Deviation
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids
UNEP	United Nations Environmental Programme
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 Background

Water Quality Assessment is the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself (Chapman, 1996). There is need to have adequate research on fresh water bodies everywhere in the world for the effective and continued sustainable use for human and aquatic life.

It appears that there is little published literature on the quality of water of Lilongwe River apart from the findings of Dryton (1980), Phiri *et al*. (2005) and Mumba *et al*. (2008). There are also routine water quality checks by the Lilongwe Water Board within the radius of its abstraction point. The study by Phiri *et al.*(2005) on the effluents of three industries (textile, soft drink and beer manufacturing companies) in Lilongwe showed that the effluents were discharged into Lilongwe River and had considerable negative effects on the quality of the river water. The findings of Dryton (1980) on the water quality in Lilongwe River showed that faecal coliforms were above the recommended limit of the WHO guidelines for drinking water. While Mumba *et al*. (2008) studied the effluents from the Kaume sewage treatment plant and found that the Biochemical Oxygen Demand, Chemical Oxygen Demand, Phosphates (PO_4^-) and Nitrate values were above the acceptable limits of Malawi Bureau of Standards (MBS). The studies by Phiri *et al*. (2005) and Mumba *et al*. (2008) were done in small portions of the river, while the findings of Dryton (1980) gave a bigger overview of the river that transgresses the city boundaries. Since 1980, there appears to have been no published study across a bigger portion of the river.

1.2 Justification

Lilongwe River was used for domestic purposes like cooking, washing, bathing and drinking by a certain portion of the population of the city (NSO, 2008). However there was a lot of refuse damping along the river in the city (Figure 1). There was also rampart river bank cultivation being practiced along the Lilongwe River (Figure 3). There were reports of occurrence of water borne diseases which were attributed to poor sanitation and use of unsafe drinking water (Lilongwe City Assembly Health Report, 2009). Therefore there was need to monitor and control the levels of pollution of this vital resource (water) by the relevant authorities like the Lilongwe City Assembly, Ministry of Water and Irrigation and the Department of Environmental Affairs. This would help to prevent the occurrence of health problems to people, animals and crops. Such monitoring and control policies can be put in place only if a study (research) was conducted to verify and highlight the sources of pollution and determine the levels of water quality for domestic and other uses in the river.

This research sought to identify the sources and assess the levels of water pollution respectively in Lilongwe River and come up with a possible solution should the water be polluted. The results of the research would be a tool for developing pollution control programs so that the water quality standards are maintained to acceptable levels for domestic, agricultural, ecosystem and recreational use. This is in line with *Section 5.1.4 of the Malawi National Water Policy (2005)* which seeks to promote applied research in water quality and pollution control techniques and technologies.

The overall effect would be improved livelihoods of the people dependent on the river, as water borne diseases will be reduced or eradicated. If water borne diseases are reduced or eradicated, then people can contribute positively and effectively to the general development of the country instead of wasting time and resources on the sick. Therefore the research will contribute positively in achieving the *Millennium Development Goal 7, Target 10* which is to halve the proportion of people without access to clean and potable water by 2015 and ensure environmental sustainability. It would also contribute to achieving *Agenda 21 Chapter 6* which aims at protecting and promoting human health through the prevention and control of common illnesses like water borne diseases.

Figure 1: Waste damping along Lilongwe River

Figure 2: Waste damping a few meters from Lilongwe River

Figure 3: River bank cultivation along Lilongwe River

1.3 Problem Statement

More than half of the world's rivers are seriously polluted, degrading and poisoning the surrounding ecosystems and threatening the health and livelihood of people who depend on them (World Commission on Water, 1999). Lilongwe River runs through a fast developing city and a lot of discharges from industrial, domestic and agricultural activities ended up in this river. Some industries such as oil industries, metal works, automobile garages, and commercial markets had their wastes ending up into this river. Maize and tobacco productions were the major agricultural activities in the rural part of the study area, whose leached fertilizers ended up in the river. There is a sewage treatment plant at Kaume just as the Lilongwe River leaves the city. The sewage in this plant was often poorly treated (Mtethiwa *et al.*, 2007). Poorly treated sewage wastes heavily impact on the quality of the river water (Mayhem and Chapman, 1999).

However there were some urban and rural dwellers along Lilongwe River who due to poverty reasons and lack of adequate piped and borehole water supply, used water from the river for various domestic uses. There were villages along the river, downstream of Kaume Sewage Treatment Plant that relied on the river as well for various uses like domestic, agriculture and animal husbandry. There had also been reports of yearly occurrence of water borne diseases especially cholera within and outside Lilongwe city as evidenced in 2009. Previous studies in Blantyre city had indicated substantial heavy metal pollution in the streams that run through the city (Lakudzala *et al.*, 1999; Sajidu *et al.*, 2007; Kaonga *et al.*, 2008).

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective of the research was to identify the sources of pollution and assess the quality of water in Lilongwe River for its suitability for domestic uses.

1.4.2 Specific Objectives

The specific objectives were:

1. To identify the sources of pollution affecting the water in the part of Lilongwe River under study.
2. To analyze the physical, chemical and biological water quality parameters and compare the results with WHO guidelines and Malawi Bureau of Standards for domestic uses. The parameters analyzed were Temperature, pH, Turbidity, Suspended Solids, Electrical Conductivity, Total Dissolved Solids, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, Nitrates, Phosphates, Lead, Cadmium, Hardness and Faecal coliforms in Lilongwe River.
3. To suggest integrated intervention strategies for reducing the pollution in the section of the river under investigation

1.5 Scope and Limitations

Industrial and economic growth in many parts of the world entails the degradation of the water quality of water bodies in these areas. Lilongwe River experienced industrial growth in its catchment area, making it prone to pollution. Lilongwe River in this research was studied of its water chemical, biological and physical parameters, to assess the suitability of the water for human purposes especially domestic use. The study was concluded only on the state of the water quality within the rainy season due to time limit constraints leaving out the dry season water quality situation. If the dry season was included it could possibly have given different results. Few sampling points were chosen, also due to financial constraints.

1.6 Thesis Outline

This thesis consists of six chapters. Chapter 1 introduces the topic and objectives for the study. Chapter 2 discusses in detail each of the parameters chosen for analysis and also concentrates on previous studies on the same water quality assessment of rivers in different countries across the world. The study area is discussed in Chapter 3. Chapter 4 discuses the methods used to collect data and methods of physical, chemical and biological analysis both in the field and laboratory. The results of the research and discussions are explained in Chapter 5. Chapter 6 concludes on the findings of the research. It also recommends the actions to be taken in reaction to the findings of the research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The UN conference on Human environment 1972 (Principle 2) states that the natural resources of the earth, including the air, water, land flora and fauna and the representative sample of natural ecosystems must be safeguarded for the benefit of present and future generations through careful planning or management as appropriate. In view of this principle the Malawi Government developed an environmental policy with an overall goal of promoting the sustainable social and economic development through the sound management of the environment and natural resources (GoM, 2004). Water is a vital and limited resource, and as such, the effects of damage to it are costly to redress.

Research has shown that human activities, especially in urban settlements, pollute the rivers that pass through them. In 1965, a WHO Expert Committee on Water Pollution Control predicted that water pollution must be expected to increase very much faster in developing countries than in developed countries (Keating, 1994). In urban areas, the careless disposal of industrial effluents and other wastes may contribute greatly to the poor quality of the water in receiving bodies (Chindah *et al*., 2004; Emonger *et al*., 2005; Furtado *et al*., 1998 and Ugochukwu (2004). Malawi, like other African countries, is experiencing rapid industrial growth, and this is making environmental conservation a difficult task (Kadongola, 1997). In Malawi, water resources degradation is the second most critical environmental problem, following deforestation (GoM, 1994). The Malawi Government Environmental Report (2002) stated that the BOD levels in the Mudi River in Blantyre and Lingadzi River in Lilongwe exceeded the acceptable limits of the Malawi Bureau of Standards (MBS).

Furthermore, studies carried out by Mvuma (1999) and Lakudzala *et al.* (1999) in Mudi River in Blantyre found that the industrial activities were contributing to the pollution and degradation of water ecosystems in the city and beyond A similar study of the impact of industrial effluent on the water quality of Alaro River in Ibadan, Nigeria showed that the physical and chemical parameters studied were above the allowable limits and also tended to accumulate downstream (Fakayode, 2005). Moreover it is known that since the industrial Revolution, there have been widespread scarcity, gradual destruction and increased pollution of fresh water resources (Keating, 1994).These effects are due to the discharge of inadequately treated sewage and industrial wastes into water bodies, deforestation and poor agricultural practices which release pesticides and other chemicals into water systems. Another study done in South Lunzu in Blantyre (Malawi) showed that water resources were mainly degraded by poor sanitation practices as people lacked adequate sanitation facilities (Palamuleni, 2002).

In Asia, the Yellow River of China, the Syr Darya River of Central Asia and the Ganges River of India were the world's most highly polluted rivers in the world (World Commission on Water 1999). In Latin America and the Caribbean, the excessive use of fertilizers in agriculture and untreated urban and industrial wastes have caused rising levels of nitrates in rivers, lakes, dams and coastal lagoons (World Commission on Water, 1999). In farming areas, the routine application of agricultural fertilizers is the major source of water pollution (Emongor *et al*., 2005). Similarly in Malawi, studies done in Likudzi river in Ntcheu showed high concentration of organo-chloride pesticides (Mandala, 2002) while studies done in Lunyangwa river also showed high pesticides contamination (Banda, 2002). However, despite the studies highlighted above showing pollution of water resources, there were success stories of water quality management in some countries. For example, in 2000 the rate of industrial wastewater treatment across China increased to 94.7% (SEPA, 2001). In Japan, the government had set environmental quality standards and made remarkable improvements such that in 1991, an estimated 99.8 % of water samples met standards for heavy metals and toxins (RRI, 2000).

Generally, most rivers are being polluted by what is known as anthropogenic activities due to industrial and agricultural development. Specifically urban rivers are much more prone to pollution due to the concentration of industries and the population in urban settlements. Researches on water quality of urban rivers have to be done continuously, especially where the rivers are being used for domestic purpose (which is common in most African countries due to poverty and poor planning). The results of this research would help to avail a plan of action for the health of the people and aquatic life and the sustainable use of the rivers.

2.2 Anthropogenic Activities affecting River Water Resources in Malawi

Anthropogenic activities are human activities that negatively affect the water resources making it polluted and hence unsuitable for normal uses. The anthropogenic activities that mainly affect the river water bodies can be placed into three groups as follows:

2.2.1 Deforestation

This is the clearing of vegetation and cutting down of tress and making the ground bare. Agricultural activities are the major source of deforestation. The ground is then exposed to the impacts of rainfall and wind; this leads to soil particles being loosened and washed away by runoff water when it is raining (GoM, 1994). This fast moving rain water enhances soil erosion, a process through which soil and sediments are transported into surface water bodies. Deforestation along river catchments also robs the ground of its natural cover hence direct sunlight reaches the soil. This increases the evaporation of water from the soil, thereby affecting the amount of water available in the river (Newson, 1992). Where most of the tree covers and vegetation has been removed, the temperature of river water tends to rise, while under good cover, temperature would remain constant for most of the time. This has a direct influence on the biochemical dynamics that can affect the chemical composition of water and aquatic life in the ecosystem (Moss, 2001).

2.2.2 Human Settlements

The rapid urbanization that Malawi is undergoing has resulted in an increase in the demand for shelter and housing in urban areas. There are an increasing number of unauthorized constructions of dwelling structures in unplanned areas using environmentally unsuitable materials. This has led to uncontrolled brick moulding and cutting down of trees for curing the bricks and other constructions, thus creating a great disturbance to the natural environment. An increase in human settlement means an increased need for sanitation facilities for waste disposal for the population (Chindah *et al*., 2004). The habit of defaecating in the bush by some people contaminates surface water through run off. Sanitation facilities such as pit latrine soak ways, poorly constructed rubbish pits and broken sewer lines, are a source of pollutants into the rivers when wastes are washed away by rain water runoff (WHO and UNICEF, 2000). Along the Lilongwe River, there are planned and unplanned housing settlements in Chinsapo, Chigwirizano, Kawale, Nchezi, Area 3, Area 12, and Area 14.

2.2.3 Industrial Activities

Human beings are industrious by nature in a bid to produce products for consumption and for commercial purposes. In most urban settings, industries are the common activities. These industries produce wastes that end up being deposited somewhere (Zembere *et al.,* 1999). Some industries produce toxic and hazardous wastes which when left exposed to the environment do kill plant and animal life (Taylor, 1996). For example Cadmium has been observed in waste waters of industrial sites (Ritter *et al.,* 2002). The main source of cadmium are factories and companies that import or produce cadmium containing products such as Nickel-Cadmium Batteries, PVC products, Cadmium pigmented Plastics and Cadmium containing electronic components (Taylor, 1996). The practice of dipping livestock with chemicals to protect them from ticks and other pests and parasites also leads to the release of some chemicals into the water bodies.

2.3 Water Pollution

Pollution is defined as the introduction into the environment, of substances or energy liable to cause hazards to human health, to cause harm to living organisms and ecological systems, damage to structures or amenities or interference with legitimate uses of the environment (Harrison, 1992).

In most cases, the lack of sanitation and inefficient sewage treatment plants are some of the major causes of pollution of rivers in many cities. The UN World Summit (2002) estimated that roughly 45,000m^3 of waste water were discharged into rivers, lakes and streams around the world. Fresh water resources in Southern Africa are under pressure from pollution and water quality is a growing concern, particularly in urban areas and close to industrial centres (SADC, 2007).

2.3.1 Sources of River Pollution

There are several sources from which potential pollutants may enter water courses, but these can be categorized into two groups as: point sources and non point sources. Point source pollution is from a single defined source discharging pollutants at a specific location such as a pipe discharging into a water body (Harrison, 1992). Point sources possess the property that the total load of pollutants can be determined by sampling and flow measurement at the point of entry to a receiving water body (Jennings and Kahle, 1996). It is easy to identify and control point source pollution because they are specific points. Non Point Sources (Diffuse) are sources of low concentration covering a large area, occurs from a large area as opposed to a small number of well defined points (Davis and Hirji, 2003). These are mainly through runoff where the total flow cannot be measured or sampled directly.

2. 4 Water Quality Parameters and their Impacts on Water Uses

Physical parameters define those characteristics of water that respond to the sense of sight, touch, taste or smell (Cunningham, 2003). These are turbidity, temperature, dissolved and suspended solids .They have a marked effect upon the rate of re-aeration and therefore on the rate of self purification of the river water. Chemical characteristics are those that are to do with the chemical composition of water. Water is dipolar, creating a slightly positive end on the hydrogen end and slight negativity on the oxygen atom. This property makes water a very good universal solvent. Biological characteristics are those that have to do with presence of micro-organisms in water.

2. 4.1 Physical Parameters

i. pH

pH, or the "potential of hydrogen", is a measure of the concentration of hydrogen ions in the water. This measurement indicates the acidity or alkalinity of the water. On the pH scale of 0-14, a reading of 7 is considered to be "neutral". Readings below 7 indicate acidic conditions, while readings above 7 indicate that the water is alkaline, or basic. The scale is negatively logarithmic, so that each whole number (reading downward) is ten times the preceding one (for example, pH 5 is 100 times as acidic as pH 7). The pH of natural waters can be made acidic or basic by human activities such as acid mine drainage and emissions from coal-burning power plants and heavy automobile traffic. Naturally occurring fresh waters have a pH range between 6 and 8. The pH of the water is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms (Chapman, 1996). A three year survey done in Lilongwe river prior to 1980, found that the pH of water from the head of Lilongwe river catchment and where it passes the city, varied between 7.3 and 8.8 (Dryton, 1980).

ii. Temperature

Temperature is a measure of how cold or how hot the water is, expressed in degrees Celsius (^oC). Temperature is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms. The amount of oxygen that will dissolve in water increases as temperature decreases. Water at 0^oC will hold up to 14.6 mg of oxygen per litre, while at 30^oC it will hold only up to 7.6 mg/L. Water temperature that exceeds 18 degrees Celsius (for Class A Waters) has a deleterious effect on several fish species in streams (Canter, 1985). For example, Salmons prefer waters of approximately 12 to 14 degrees Celsius. If the effluents from industrial cooling systems are discharged into a river, they may raise the temperatures of the river water.

iii. Turbidity

The American Public Health Association (APHA) defines turbidity as "the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample." In simple terms, turbidity answers the question, "How cloudy is the water?" Light’s ability to pass through water depends on how much suspended material is present. Any substance that makes water cloudy will cause turbidity. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibres, sawdust, wood ashes, chemicals and coal dust. The most frequent causes of turbidity in lakes and rivers are plankton and soil erosion from logging, mining, and dredging operations. The units of measure for turbidity are Nephelometric Turbidity Units or NTUs (Lutz, 2004).

Turbidity affects fish and aquatic life by interfering with sunlight penetration. Water plants need light for photosynthesis. If suspended particles block out light, photosynthesis and the production of oxygen for fish and aquatic life will be reduced. If light levels get too low, photosynthesis may stop altogether and algae will die. It is important to realize that reduced photosynthesis in plants result in lower oxygen concentrations and large carbon dioxide concentrations in a water body. Turbidity will also affect the fish negatively in terms of food identification and positively in terms of not being spotted by predators (Cunningham, 2003)

iv. Suspended Solids (SS)

Total Suspended Solids is the amount of material, by weight that is suspended (not dissolved) in a given volume of water and is expressed in mg/l. The solids mainly consist of living and dead phytoplankton and zooplankton, silt, human sewage, animal excrement, portions of decaying plants and animals and a vast range of industrial wastes (Cunningham, 2003). In 1980, a survey on the concentration of suspended solids in Lilongwe River found out that suspended solids varied between 0.2 mg/l and 10 mg/l in the dry season and over 1,000 mg/l in flood flows (Dyson 1980)

Large amounts of suspended matter may clog the gills of fish and shellfish and kill them directly. Suspended particles may provide a place for harmful microorganisms to lodge. Some suspended particles may provide a breeding ground for harmful bacteria (Chapman, 1996).

2.4.2 Chemical Parameters

i Electrical Conductivity (EC)

Electrical Conductivity (EC) is the ability of the water to conduct an electrical current, and is an indirect measure of the ion concentration. The more ions present, the more the electricity that can be conducted by the water. EC is also an indirect measure of Total Dissolved Solids. Electrical conductivity is directly proportional to Total Dissolved Solids. This measurement is done at 25 degrees Celsius and expressed in Micro Siemens per centimetre (μS/cm).

ii Total Dissolved Solids (TDS)

Total dissolved solids (TDS) are a measure of the amount of particulate solids that are in solution. This is an indicator of non point source pollution problems associated with various land use practices though point sources also contribute. The TDS measurement should be obtained with the conductivity meter and is expressed in mg/l (Chapman, 1996)). A study by Dryton (1980) in Lilongwe River recorded between 10 mg/l and 150 mg/l TDS in dry season and between 100 mg/l and 700 mg/l in rainy season.

iii Dissolved Oxygen (DO)

Dissolved oxygen (DO) is the amount of oxygen dissolved in water and is measured in milligrams per litre (mg/l). This component in water is critical for the survival of aquatic life in streams, such as fish. Oxygen gets dissolved in water by diffusion from the surrounding air by aeration of water that has tumbled over falls and rapids, and as a waste product of photosynthesis. The ability of water to hold oxygen in solution is inversely proportional to its temperature. Thus, the cooler the water temperature, the more dissolved oxygen it can hold.

When there is an overpopulation of aquatic life in the water, DO consumption may be high. Oxygen levels also can be reduced through over fertilization of water plants by run-off from farm fields containing phosphates and nitrates (the ingredients in fertilizers). Under these conditions, the numbers and size of water plants increase a great deal. Then, if the weather becomes cloudy for several days, respiring plants will use much of the available DO. When these plants die, they become food for bacteria, which in turn multiply and use large amounts of oxygen (Canter, 1985). Lilongwe River varied between 4.1 mg/l and 11.2 mg/l (Dryton, 1980). The concentrations of DO fell consistently through the dry season, and very low values were measured downstream of Kaume Sewerage Plant (Dryton, 1980).

iv Biochemical Oxygen Demand (BOD_5)

Biological Oxygen Demand (BOD_5) is a measure of how much oxygen is used by microorganisms in aerobic oxidation, or breakdown of organic matter in the streams. The higher the amount of organic material found in the stream, the more the oxygen used for aerobic oxidation. This depletes the amount of dissolved oxygen available to other aquatic life. This measurement is obtained over a period of five days, and is expressed in mg/l. Unpolluted river waters are likely to have BOD_5 values of <3 mg/l and values above 5 mg/l indicate possible pollution (Harrison, 1992). The major point sources which may contribute high levels of BOD include wastewaters treatment facilities, meat and food processing plants. Good examples of non point sources are agricultural run-off, livestock wastes and urban wastes. In a survey conducted in Lilongwe River, the BOD_5 concentration varied between 0.5 mg/l and 8 mg/l. However, very high values of up to 20 mg/l were recorded downstream of the effluent discharge points (Dryton, 1980)

v Chemical Oxygen Demand (COD)

This parameter measures the amount of oxygen consumed for the breakdown of organic matter in a water body under the catalyst of a chemical oxidant. It also measures organic matter that does not decompose in 5 days but nonetheless eventually would decompose and affect water quality (Harrison, 1999).

vi Nitrate (NO_3^-)

Nitrate is a major ingredient of farm fertilizer and is necessary for crop production. When it rains, varying nitrate amounts are washed from farmland into nearby waterways. Nitrates also get into waterways from lawn fertilizer run-off, leaking septic tanks and cesspools, manure from farm livestock, animal wastes (including fish and birds), and discharges from car exhausts (Lutz, 2004). High levels of nitrate, along with phosphate, can over stimulate the growth of aquatic plants and algae, resulting in high dissolved oxygen consumption, causing death of fish and other aquatic organisms. This process is called eutrophication. Nitrates can be reduced to toxic nitrites in the human intestine to produce methemoglobin which causes blue baby disease in children.

vii Phosphates (PO_4^{3-})

The element phosphorus is necessary for plant and animal growth. Phosphates enter waterways from human and animal wastes, phosphate-rich rocks, and wastes from laundries, cleaning and industrial processes, and farm fertilizers. Phosphates stimulate the growth of plankton and water plants that provide food for fish. This may increase the fish population and improve the waterway's quality of life. However if too much phosphate is present, algae and water weeds grow wildly, choke the waterway, and use up large amounts of oxygen. This is called eutrophication and may cause the death of fish and aquatic organisms. The aesthetic values of the river will dwindle; hence, the need to control the amount of phosphates available to a water body. Generally to the humans or animals there are negligible direct effects from phosphates.

viii Hardness

Hardness generally refers to the amount of calcium ions (Ca^{+2}) and magnesium ions (Mg^{+2}) in water. In household use, these cations (ions with a charge greater than +1) can prevent soap from sudsing and leave behind a white scum in bathtubs. In the aquatic environment, calcium and magnesium help keep fish from absorbing metals, such as lead, arsenic, and cadmium, into their bloodstream through their gills. Therefore, the harder the water, the less easy it is for toxic metals to absorb onto gills (Chapman 1996). Sources of calcium are soil leaching, sewage and some industrial wastes. Magnesium arises from weathering of rocks containing ferro-magnesium minerals.

ix Heavy Metals

Heavy metals include metals like Lead, Cadmium, Mercury and others. Many of these metals undergo methylation, as a result of bioaccumulation where bacteria absorb these elements and convert them from a metallic state into a toxic organo-metallic state. By becoming incorporated with an organic component, these metals become readily available to the first trophic level of the food chain and eventually lead to biological magnification throughout the system.

Lead is a toxic heavy metal that has adverse effects on the human health. The common sources of lead are lead wastes, cell batteries; lead solders, lead gasoline and lead based paints. Excess exposure to lead can damage nervous systems and can also cause blood and brain disorders (Gurruswammy, 2000). In pregnant women lead can lead to miscarriages.

Cadmium is another toxic heavy metal. It can be released from car exhaust, metal processing industries, battery and paint manufacturing. Higher levels of cadmium may also be found in soils or water from industrial areas. Extreme high levels of cadmium cause lung damage and thereafter death.

2.4.3 Biological Parameters

Faecal Coliforms

Faecal coliforms are microscopic organisms that live in the intestines of all warm blooded animals, and in animal wastes or faeces eliminated from the intestinal tract (Ritter et. al., 2002). Faecal coliforms may indicate the presence of disease carrying organisms which live in the same environment as the faecal coliform bacteria. The measurement is expressed as the number of organisms per 100 ml sample of water (N/100ml). Dryton (1980) found out that faecal contamination in Lilongwe River was generally high with values in excess of 300 counts/100ml, in all streams that were sampled.

2.5 Quantity Parameters (Flow rate)

Flow rate is the volume of water moving past a point in a unit of time and is measured cummecs (cubic metres per second (m^3/s)). Two things make up flow: the volume of water in the stream, and the velocity of the water moving past a given point. Flow affects the concentration of dissolved oxygen, natural substances, and pollutants in a water body.

2.6 Water Quality and Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is defined as a process that promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems (GWP, 2000). IWRM is of vital importance for ensuring adequate quality and quantity of water within a river system (Rivers-Moore and Jewitt, 2007). IWRM provides a platform for addressing Transboundary issues including those involving water qualities (Huang and Xian, 2001).

The Government of Malawi developed the National Water Policy (2005) to guide the country in the management and development of its water resources based on the IWRM principles which include protection of the environment and conformity with regional and international conventions and agreements in the management of shared water resources (GoM, 2005).

2.7 Climate Change in Context of IWRM

The impacts of climate change need to be tracked through long term monitoring programs, focusing on the variation in water quality in rivers, lakes and wetlands (Kiparrsky and Gleick, 2003). Changes in the water bodies are already evident, such as increases in water temperatures due to increases in atmospheric temperature (Rivers –Moore and Jewitt, 2007).
The effects are also evident in Malawi through the elongated dry spells within the rainy season, which affect the rivers' flow regimes. Concentration of chemical pollution increases with low flow regime of rivers. The Malawi government is emphasizing on incorporation of climate change in natural resources planning. To adapt to the effects of climate change, the Lilongwe Water Board had embarked on a multimillion United States Dollar project of increasing and augmenting raw water storage, capacity of treatment plant and storage of treated water, increasing the transmission system and pumping capacities (LWB Brochure, 2008). This will mitigate some effects of climate change.

CHAPTER THREE: STUDY AREA

3.1 Location

Malawi is in southern part of Africa and is located between latitudes 9^o 22' S and 17^o 03' S and longitudes 33^o 40' E and 35^o 55' E. The country has a total land area of 118,500 km^2. Malawi is divided into three regions namely Northern, Central and Southern region. The capital city is Lilongwe and is in the central region of the country (Figure 1).

The study was conducted on Lilongwe River in Lilongwe District of the central region of Malawi. Lilongwe District lies between 14.5^o and 13.5^o longitude and between 33.5^o and 34.5^o Latitude. Lilongwe River originates in the Dzalanyama Mountain on the border with Mozambique. The length of the river is approximately 100 km. The river has a total catchment area of 1800 km^2. The river drains into Linthipe River, a few kilometres before Lake Malawi, into which the Linthipe River drains. The study was conducted on a 45 km stretch of the Lilongwe River from Malingunde in the remote village area to Kaume waste treatment plant outside the city. Of the 45 km stretch, 30 km is in rural settings while 20 km is in the city. The river passes right through the city of Lilongwe. Lilongwe River is joined by two main tributaries in the study area. These are Likuni River (as Lilongwe River enters the city) and Lingadzi River after Kamuzu Central Hospital Bridge (Figure 1).

There are two dams on the Lilongwe River which are used by the Lilongwe Water Board for supplying water to the city residences. These are Kamuzu Dam 1 with a capacity of 4.5 M (at Malingunde where Site 1 for sampling is located) and Kamuzu Dam 2 with a capacity of 19.8 million cubic meters just below Dam 1.

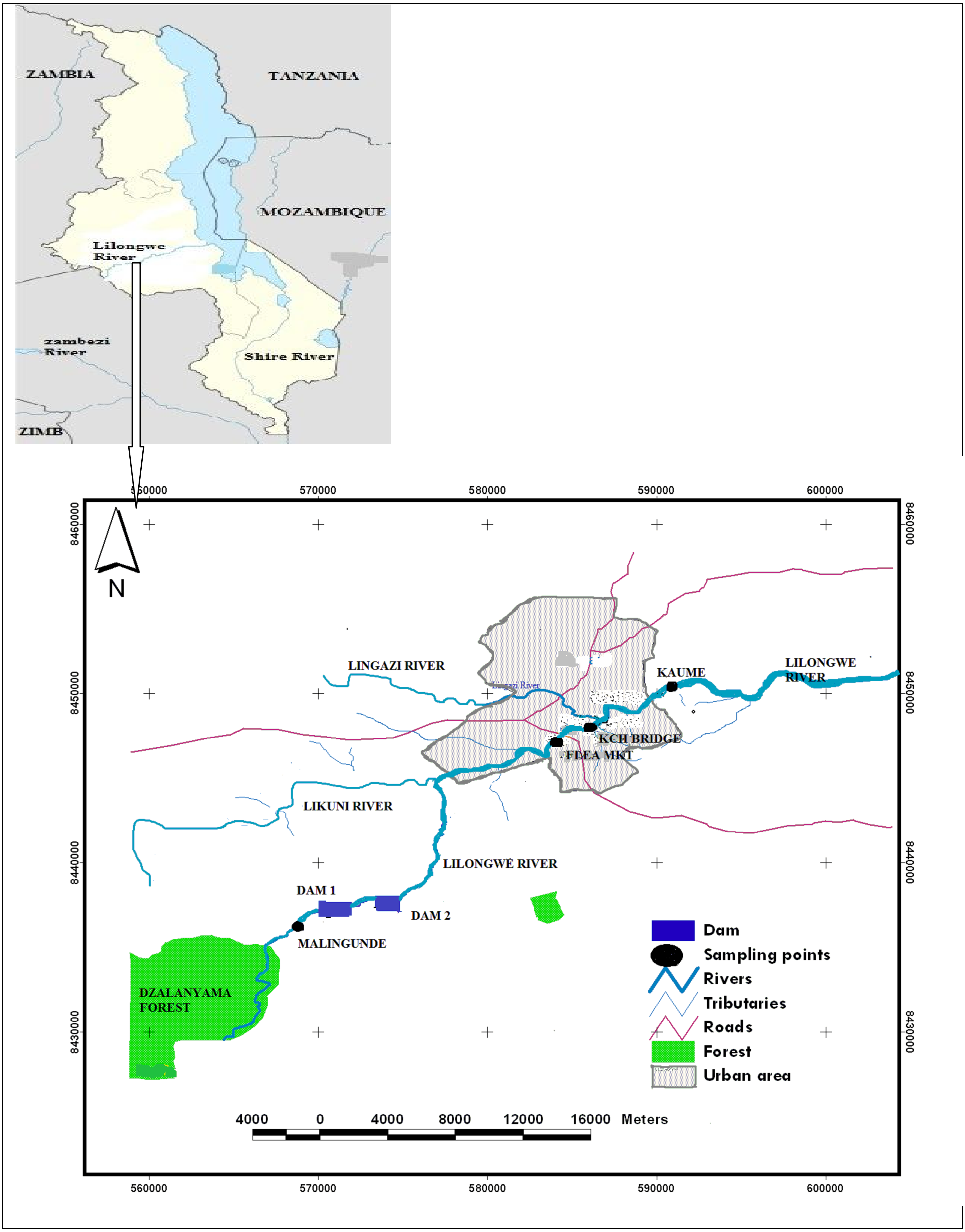


Figure 4: Map of the Study Area

3.2 Geology

The geology of Malawi is dominated by crystalline Precambrian to Lower Palaeozoic rocks that have been affected by the polycyclic Mozambique orogeny (Brown and Young 1970) and are generally referred to as the Basement Complex (Brown and Young 1970). Pelitic to semi-pelitic rocks including banded hornblende-biotite gneisses with intercalations of marbles, calc-silicate gneisses, quartzites and mica schists cover much of the country. Two-pyroxene granulites and gneisses also known as charnockites make a good proportion of the geology in the centre of the country. These rocks have been metamorphosed under amphibolites to granulite facies metamorphism. Granitoid orthogneisses and basic and ultrabasic rocks are scattered throughout the country rocks (Brown and Young 1970). The area under study is composed of metamorphic rocks and igneous rocks which contain relative proportions of quartz feldspar and ferromagnesian minerals (Brown and Young, 1970). These rocks are not easily weathered hence the water quality may not be much affected. Sedimentary and subordinate volcanic rocks such as basalts and dolerites of Permo-Triassic to Quaternary origin overlie unconformably the Basement Complex rocks together with intrusive rocks of Jurassic to Lower Cretaceous which are ascribed to the Chilwa Alkaline Province. Large parts around the major drainage systems such as the Lake Malawi and the Shire River, the Lilongwe, Kasungu and Mzimba plains, are overlain by superficial deposits (Brown and Young 1970).

In terms of topography the area is gently or very gently sloping and is intensively cultivated. The sloping is towards the Lilongwe River. This means that any runoff ends up in Lilongwe River directly or through tributaries.

3.3 Climate

Malawi has a tropical and continental type of climate and so is the area under study. The annual rainfall of the area under study is between 700 mm and 1,200 mm. The study area has two main seasons. The rainy season starts from November to April. The dry season starts from May to October. The temperature ranges from 14^{o}C to 32^{o}C. The altitude ranges from 1,000 m to 1,500 m above sea level. The natural forest in the study area has been cleared for agricultural and industrial activities. This has resulted in soil erosion. The rainfall intensity and duration affect the water quality of the river. The flooding of the river reduces the concentration of chemical water parameters due to the dilution effect.

3.4 Water Supply and Sanitation

It was the mandate and policy of the Malawi government to supply clean and potable water to all the citizens. This was in line with the Millennium Development Goal No.7 Target 10 of reducing the number of people without access to clean potable water by half by 2015. Currently the Malawi government has availed potable water to 71% of its people (GOM, 2008).

The government was itself responsible for the supply of clean potable water to the rural people. While in the cities and towns, the government has mandated Water Boards to supply clean potable water on a commercial basis. The government established the Water Resources Board to manage the water resource bodies through the Catchment Management Authorities (GoM, 2005). However the issue of establishing the catchment authorities was yet to be enacted by the parliament. The Ministry of Natural Resources and Environmental Affairs was partly responsible for improving conservation and protection of catchment areas of all public water bodies, also ensuring that fragile and marginal areas are not used for agricultural activities (GoM, 2004). The local government, through the City Assemblies, had the responsibility to plan and coordinate the implementation of water and sanitation programs at local assembly level.

Within the rural part of the study area, people used gravity fed water supply, wells, boreholes and Lilongwe River for their domestic uses. In the city area, people used wells, boreholes, piped water and the river water, be it Lilongwe River or its tributaries. Lilongwe Water Board (LWB) was responsible for the supply of water to the residence of Lilongwe city. As of 2005, LWB was able to supply only 72% of the water demand for Lilongwe city. The remaining 28% were getting the water from shallow wells, boreholes and rivers. The Board has its intake works on Lilongwe River and treatment plant within the city boundaries about 1 km above the Flea market (2nd Sampling point). The Board takes water samples for analysis at this abstraction point in Lilongwe River on a daily basis. The data collected by the LWB does not give a complete picture of the state of the water quality in the river within the city boundaries and beyond. It was thus, important to have complete data of water quality in the river in both the rural and urban sections of Lilongwe River as this research has done.

Lilongwe city assembly provides the social amenities to the city including city cleaning, refuse collection and waste management. In terms of refuse collection the city was able to collect only 30% of all the refuse in the city due to inadequate resources (Lilongwe City Assembly, 2008). The Lilongwe city assembly manages the solid wastes in the city though only 10% of the city residents were connected to the sewer system. The rest either used septic tanks or use pit latrines. The City operates the Kaume Waste Treatment Plant which treats the sewer from the residents who are connected to the sewer line. The plant was operating at a rate of 15,600 m^3/day, instead of its full design capacity of 61,000 m^3/day. This was due to few users connected to the system.

The Lilongwe City Assembly privatized its public toilet facilities in most market areas. This was good but many poor people could not afford the services hence they resort to cheaper but unhygienic means such as open defaecation.

3.5 Demography and Socio- economic Activities

Lilongwe district had a population of 1,200,000 in the rural areas and 670,000 people in the city as of 2008 (NSO 2008). The population density of the city was 1,500 per km^2. The city was divided into 54 areas, both residential and industrial and the number of areas was on the increase as the city expands. The livelihoods of the rural people were dependent on rainfed agriculture and to some extent on irrigation along the river. The major crops grown were maize, tobacco, beans and groundnuts. While in the city, people were either employees or business people.

People were involved in fishing along the river where the river provided conducive environment for fish survival. Therefore if the river was left polluted the fish would disappear and the livelihoods of the people would be negatively affected as their source of protein and income would be terminated. It was important to maintain the good quality of the river water because some people depended on the river for domestic use. Other than fishing there was also irrigation on a small scale along the river where vegetables and maize were produced for commercial purposes. These products were sold to the people in the city.

There was extensive sand mining from the river as well as brick moulding along the banks. It was this brick moulding and sand mining that was making construction work possible in the city. People earned their living out of these two activities. Sand mining was done throughout the year while brick moulding was done in the dry season only. In Malawi, machine brick moulding was still not common.

The river was therefore such an important natural resource to the people of the area under study and any disturbance to it would have adverse effects on the livelihoods of the people. It was important to conduct researches like this one to provide ready information that could be used for environmental protection planning of the Lilongwe River.

CHAPTER FOUR: MATERIALS AND METHODS

This chapter explains the different methods and materials that were used to carry out this research. These were socio-economic surveys, observations, sampling, water sample analysis, data analysis methods and flow measurements as described in the following sections:

4.1 Socio-economic Survey and Observation

In order to identify the anthropogenic sources (pollution sources) in the city, a socio-economic survey was conducted. Written and oral interviews were both used to obtain data on anthropogenic activities. In some cases, mere site observation of the activities or of disposed wastes was used to obtain the information. One questionnaire was used to get data on the types of wastes the institutions were producing in the study area (Appendix B). The data collected could elucidate the types of wastes that were produced by each institution and whether the wastes ended up in Lilongwe River or not. This questionnaire was not done at random but rather targeted those institutions that were observed to be contributing to the pollution of the Lilongwe River. The identification was done by inspecting the vicinity of the institution of whether there were open waste dampings or whether there was an emerging stream of effluents from the institution or company. There were quite a number of movements around the city within the Lilongwe River catchment area, in order to capture real polluting institutions. The next questionnaire was solely used to obtain data on the responsibility and efforts of the Lilongwe City Assembly on the issue of pollution and health related issues (Appendix D).

4. 2 Water Quality Sampling

Grab sampling was the method used to collect samples from the river. Grab water samples were collected from Lilongwe River for biological, chemical and physical analysis. Sampling was done once a week for 8 weeks, though not consecutively, beginning the second week of January 2010. Parameters that had been analyzed were selected considering the activities taking place in the Lilongwe River catchment area and the limitations of available funds. However the chosen parameters were sufficient enough to determine the quality of water. The following physical, chemical and biological parameters were chosen: pH, Temperature, Turbidity, Suspended Solids, Electrical Conductivity, Total Dissolved Solids, Dissolved

Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Nitrates, Phosphates, Hardness ($CaCO_3$), Cadmium, Lead, and Faecal Coliforms.

The sampling campaigns were done in the rainy season, therefore the results could not be considered complete since the dry season was not included. However, the sampling period was varied in accordance to rainfall variability. Sampling continued up to the fourth week and during all this time, there were no rains and the river was in low flow and this could be comparable to the dry season. After the fourth sampling campaign, the sampling was temporarily stopped to await the rains and an increase in the river flows. The rains started again in February and the river had high flows. Following the increase in flows, sampling campaigns resumed for the next four weeks (two weeks each in February and March). The whole exercise took 61 days with breaks in between. The actual day numbers of sampling were Days 1, 4, 9, 15, 40, 47, 54 and 61.

4.2.1 Location of Sampling Sites

The sampling was done at four points along the river (Table 1). Two points were within the city boundaries, while the other two were outside the city boundaries. The first point was at Malingunde outside the city just above Kamuzu Dam 1. At this point, the river is not exposed to the city's anthropogenic activities. This point was chosen to represent some sort of pristine conditions, where natural conditions slightly apply as compared to conditions within the city. The second point was just below the main Flea Market of the Lilongwe City (30 km from Point 1). The third was at Kamuzu Central Hospital Bridge (5 km from Point 2). These two points were chosen to capture the different effects of the activities in the city. The last point was just below Kaume Waste Treatment Plant (10 km from Point 3), where the river leaves the city boundaries. The point was chosen to determine the quality of river water leaving the city after receiving the effluents from the sewage works. The coordinates of the locations of the sampling points were taken using a GPS (Table 1).

Table 1: Coordinates of Sampling Points

POINT	GPS COORDINATES	LOCATION
1) Lilongwe River at Malingunde	E 33°38.5’ S 14°10.5’	Malingunde
2) Lilongwe River at Flea Market	E 33°46.41’ S-13° 59.065’	Opposite the Lilongwe flea market
3) Lilongwe River at Kamuzu Central Hospital Bridge	E 33°47.2’ S 13°59.1’	Just below the bridge
4) Lilongwe River at Kaume Sewage Treatment Plant	E 33°50’ S 13°56.1’	500m after Kauma sewage Treatment

4.2.2 Sampling Procedure

Sampling was done according to the protocols provided by APHA in the Standard Methods for the Examination of Water and Waste Water 1989, 17th Edition. During the water sampling process, one litre polythene sample bottles were used for carrying the water samples. A cooler box with ice blocks was used for carrying and storing the bottles with samples while moving from one sampling point to the other and finally to the laboratory. A two litre polythene bottle attached to a bamboo handle was used to draw water from the river and pour into the sample bottles. Portable testing meters were used for onsite measurements of temperature, pH, electrical conductivity and dissolved oxygen. Nitric acid was used as a reagent for sterilizing the equipments used and Distilled (de-ionised) water was used for rinsing the acidified equipments. Sampling time was between 0900 hours and 1400 hours every sampling day.

Water samples were collected at each sampling site as grab samples and in duplicates. Three bottles of samples were collected at each site, the first two sample bottles were for the determination of physico-chemical parameters, and the third bottle for the biological (bacteriological) analysis. Once collected, the samples were immediately stored in ice (4^oC) in a cooler box and transported to the laboratory later. The samples were analyzed within 24 hours of collection at the Central Government Water Laboratory.

4.2.3 Analysis of Physical, Chemical and Biological Parameters

When carrying out physico-chemical and biological analysis, some parameters were measured at the site and others in the laboratory. Temperature and Dissolved Oxygen were measured onsite using the portable DO meter model HANNA HI 9145. Electrical Conductivity and pH were also measured on site using a portable Multimeter model HANNA HI 9812. The rest of the water parameters were measured at the Central Government Water Laboratory using protocols provided by APHA in the Standard Methods for the Examination of Water and Wastewater (Clesseri *et al.*, 1989) as shown in Table 2.

Table 2: Water Sample Analysis Methods (APHA, 1989)

Parameter	Methods	Method Reference
EC	Portable Multi-meter (Model HANNA HI9812)	APHA 45OO-OG
pH	Portable Multi-meter (Model HANNA HI9812)	APHA 2510 B
DO &Temperature	Membrane Electrode(Model Hanna HI 9145)	APHA 4500-OG
Turbidity	Nephelometric method	APHA 2130 B
BOD_5	5 Day-BOD Test	APHA 5210 B
COD	COD –Closed Reflux Method	APHA5220.C
SS	Gravimetric Glass Fibre Method	APHA 2540 D
Hardness	EDTA Titration Method	APHA 2340 C
Lead	Atomic Absorption Spectrometric (Unicam 969)	APHA 3500-Pb B
Cadmium	Atomic Absorption Spectrometric (Unicam 969)	APHA 3500-Cd B
Nitrate (NO^-_3)	UV Spectrophotometric Method (Model HATCH DR/3000)	APHA 4500-NH_3C
Phosphate (PO_4^{3-})	UV Spectrophotometric Method (Model HATCH DR/3000	APHA 4500-P E
Faecal Coliforms	Membrane Filter Method	APHA 9222 D

4.3 Quality Assurance and Quality Control

Quality Assurance and Quality Control plans were incorporated both in the field and laboratory. As part of the quality assurance and quality control plan, the tools to be used were autoclaved before the analysis started in the laboratory. All sampling bottles were pre-labeled to avoid mixing the samples. Duplicate samples were obtained to verify the accuracy of the results. Measuring equipments were calibrated either in the field or at the laboratory prior to measurements. The final results of a parameter were obtained by taking the mean values of all the data sets for each sampling site. Standard analytical methods and references were used while samples were taken to a reputable laboratory (Central Government Water Laboratory) for analysis.

4.4 River Flow Measurement

The flows were taken from two gauging stations that catered for the three sites apart from site 1 (Malingunde). Gauging station 1 catered for Flea Market and the KCH Bridge while gauging station 2 catered for Kaume Sewage treatment plant. There is a tributary (Lingadzi River) joining Lilongwe River after gauging station at Old Town. This increased the flows at Kaume Sewage Treatment Plant.

The gauging station at Malingunde was after Kamuzu dam1, yet the sampling point was slightly above the dam site. It proved difficult to measure the flows at Malingunde using the floater method because of the nature of the river regime at the point. The flows during the sampling period varied widely. During the first four sampling days the flows were very low. This was in the month of January 2010 and in that month there was a dry spell, rains had completely stopped. There was a break in sampling after the first four sampling days. This was to wait for the rains and see the difference in the results when the flows would be high. The sampling restarted in February for two sampling days and the last two sampling days were done in March. The flow results correlated well with the physical and chemical and biological results. The flow results from the two gauging stations were averaged in order to get the mean flow of the river on a particular day.

4.5 Data Analysis

Results were analyzed using Microsoft Excel to compute the mean values and the standard deviation while the Statistical Package for Social Sciences (SPSS) was used for Analysis of variance (significant tests). The ANOVA was specifically used to test if there were any significant differences between samples amongst the sites. Any chosen correlation between specific parameters was computed using Microsoft Excel to find the relationship between them. The mean values were compared against the MBS (2005) and WHO (1993) Guidelines for drinking water purposes. The following are tables of official standard bodies used for comparison.

Table 3: Malawi Bureau of Standards (MS 619:2005) and WHO (1993) Guidelines for domestic purposes

Parameter	Unit	WHO	MBS
pH units		N/A	6.5
Electrical conductivity	µS/cm	N/A	N/A
Total Dissolved Solids	mg/l	<1000	N/A
Turbidity	NTU	<5	<5
Suspended Solids	mg/l	N/A	<30
Dissolved Oxygen	mg/l	N/A	>5
Biochemical Oxygen Demand	mg/l	N/A	<20
Chemical Oxygen Demand	mg/l	N/A	<70
Faecal Coliform	Counts/100	0	0
Nitrate	mg/l as nitrate	<45	<50
Phosphate (PO_4^-)	mg/l as PO_4^-	<0.05	<0.05
Lead	mg/l	<0.01	<0.01
Cadmium	mg/l	<0.003	<0.003
Hardness	mg/l	60 UK STD	<300

Source T.H.Y Tebutt (1998)

CHAPTER FIVE: RESULTS AND DISCUSSIONS

This chapter presents the results of the findings in the field and the discussions on these findings in accordance to the three specific objects given in Chapter One. The results presented are the sources of pollution, water quality values of the samples and in comparison against the MBS and WHO guidelines. Also presented are the sources of water supply and the types of sanitation used in Lilongwe city.

5.1 Sources of Pollution

The socio-economic survey identified a total of 197 industries /institutions whose activities form the sources of pollution to the water in Lilongwe River. Table 4 presents the polluting industries (activities) in terms of numbers. Of the total number of observed anthropogenic activities, 25.4% were commercial markets and shops, while 23.9% were small scale industries. According to Lilongwe City Assembly, these were the types of activities that generate large amounts of solid wastes that pollute the city of Lilongwe more than any other activities (Lilongwe City Assembly, 2000). Small scale industries include tyre fitting industries, carpentry, welding shops, barber shops and hair salons, bakeries, battery charging shops, tinsmiths shops and under tree motor vehicle works. Commercial markets and shops include flea markets, open markets, groceries and small commodity shops. These anthropogenic activities had their wastes ending up in Lilongwe River directly or through runoff during the rainy season. Wastes from these activities were polluting the water in Lilongwe River

River bank cultivation was rampant along the Lilongwe River, which also contributed to the pollution of the river. River bank cultivation clears the buffer zones which reduce the runoffs into the river. This causes soil erosion, which leads to flooding, siltation, landslides and loss of arable land. River bank cultivation increases the phosphorus and nitrate loading into the river as most crops are applied with chemical fertilizers which leach into the river especially if the field is close to the river (Peters, 2004).

Table 4: Composition of Anthropogenic Activities in the Study Area

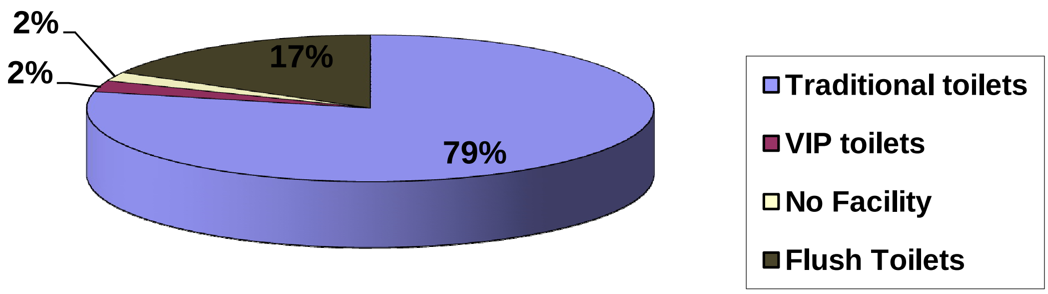
Industry/institutional activity	Number	Percentages of the number
Commercial markets	50	25.4
Small scale industries	47	23.9
Garages	16	8.1
Healthcare service institutions	12	6.1
Crop farms (big farms)	11	5.6
Photographic industries	10	5.1
Boarding education institutions	8	4.1
Urban slam settlements	8	4.1
Chemical laboratories	7	3.6
Produce markets	7	3.6
Poultry farms	5	2.5
Livestock farms	4	2.0
Dairy industries	3	1.5
Abattoir industries	2	1.0
sand mining, brick moulding	7	3.6

There were different sources of water supply in Lilongwe city, depending upon the individual's economic level and the capacity of Lilongwe Water Board to meet the water demand (Table 5). The fraction of the city's population that was using water from the streams including Lilongwe River was 0.9% (Table 5). This might possibly have placed the lives of some people in danger of suffering from waterborne diseases and other infections caused by heavy metal contamination. It was also found that 2% of the people in Lilongwe city were not using toilets (Figure 5), indicating that open defaecation might have been the only available alternative. The faecal matter from the open defaecation ended up in Lilongwe River through runoffs during the rainy season, hence causing pollution and increased the chances of spreading water borne diseases. It was most likely that lack of proper sanitation also contributed to the pollution of Lilongwe River.

Table 5: Sources of Water Supply in Lilongwe City in the year 2008

Source of water	Population	Percent (%)
Piped into dwelling houses	104,327	16.1
Pumped into yard/plot	137,199	21.2
Community stand pipe	267,115	41.3
Borehole	45,778	7.1
Protected well	40,633	6.3
Unprotected well	46,460	7.2
Rivers/stream	5875	0.9

Source: NSO (2008)



Source :(NSO, 2008)

Figure 5: Pie Chart showing types of sanitation and percentage number of people that use them in Lilongwe in the year 2008:

The Kaume Sewage Treatment Plant had operational problems due to limited funds being allocated for its operations by the Lilongwe City Assembly. This led to the ponds not being disludged for long periods, and failure to conduct the laboratory sewage effluents analysis in order to determine the efficiency of the sewage treatment facility. The problem with this was that the quality of the pond's effluents being discharged into the river was not known and it appears that the effluents were being discharged prematurely.

The Lilongwe City Assembly had other shortfalls in its operations as is evidenced by the collection of refuse. The city was generating about 300 tonnes of solid wastes per day. However only 30% of the generated solid wastes were being collected due to lack of adequate resources by the Lilongwe City Assembly (Lilongwe City Assembly, 2009). These uncollected wastes found their way into Lilongwe River. The result of this was the pollution of the water in Lilongwe River even though the river formed the livelihood of many people along it. Therefore the actions of Lilongwe City Assembly were contributing to the pollution of the water of Lilongwe River.

5.2 River Flow Results

Table 6 shows the flow measurements taken at two points along the Lilongwe River under study.

Table 6: River Flow Measurements

Date	Old Town (cummecs)	Kaume STP (cummecs)	Average (cummecs)
11/01/2010	12	20	16
14/01/2010	10.2	17.8	14
19/01/2010	8.97	15.79	12
25/01/2010	9.84	15.05	12
19/02/2010	103.93	186.7	145
26/02/2010	100.8	187.3	144
06/03/2010	71.3	129	100
14/03/2010	82.4	156.4	119

5.3 Physical, Chemical and Biological Results

The physical, chemical and biological laboratory results are shown in the tables of appendix A. The tables show the analyzed mean values, minimum and maximum values (range) and the standard deviations. The ANOVA results are shown in appendix E. The temporal and spatial variations are presented in the graphs within the discussions in this section.

5.3.1 Physical Parameters

i. pH

The spatial mean values varied between 7.6±0.2 and 7.8±0.1 (Figure 6). The spatial trend showed slightly increasing pH values as one moves from upper to lower catchment (from Malingunde to Kaume Sewage Treatment Plant). This trend was due to the industrial effluents which increased the concentration of chemicals in water, thus raising the pH. This concurred with the pH values of 7.4 found by Phiri *et al*. (2005) in the effluents draining into Lilongwe River from three manufacturing companies.

The temporal mean values varied between 7.3±0.3 and 7.8±0.1 (Figure 7). The highest value was in Week 3 (Day 15) when the flows were lowest (12 m^3 /s). The lowest value was in Week 7 (Day 54) when the river was in flood (71 m^3 /s). This lowest value was due to the dilution effect of the floods. The temporal linear trend showed a general decrease of pH mean values with time and this was due to increased flows. The linear trend line shows the trend of pH in general with respect to time in the river. The temporal values were also within the recommended limits of WHO and MBS for drinking water (domestic use). However the pH range found by Dryton (1980), in the same river was 7.7 to 8.8. This range was higher than the current range of 7.0 to 7.9. This implied that the water in Lilongwe River was becoming more acidic. This concurs with the principle that a body of water is generally basic in youthful stage but becomes more acidic with the passing of time (Chiras, 1998). The ANOVA showed significant differences among samples at all sites tested at $p<0.05$ (Appendix E).

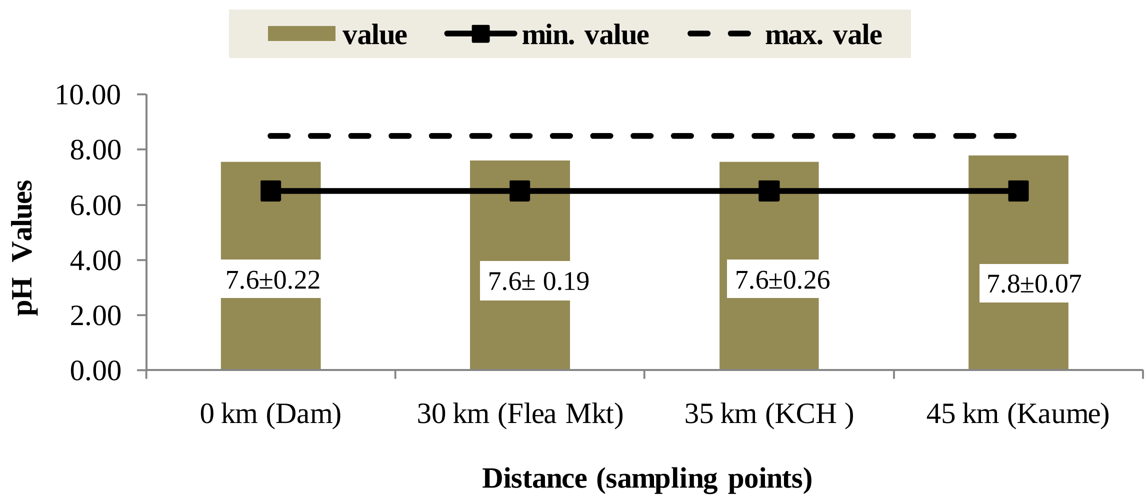


Figure 6: Spatial Variations of pH along Lilongwe River

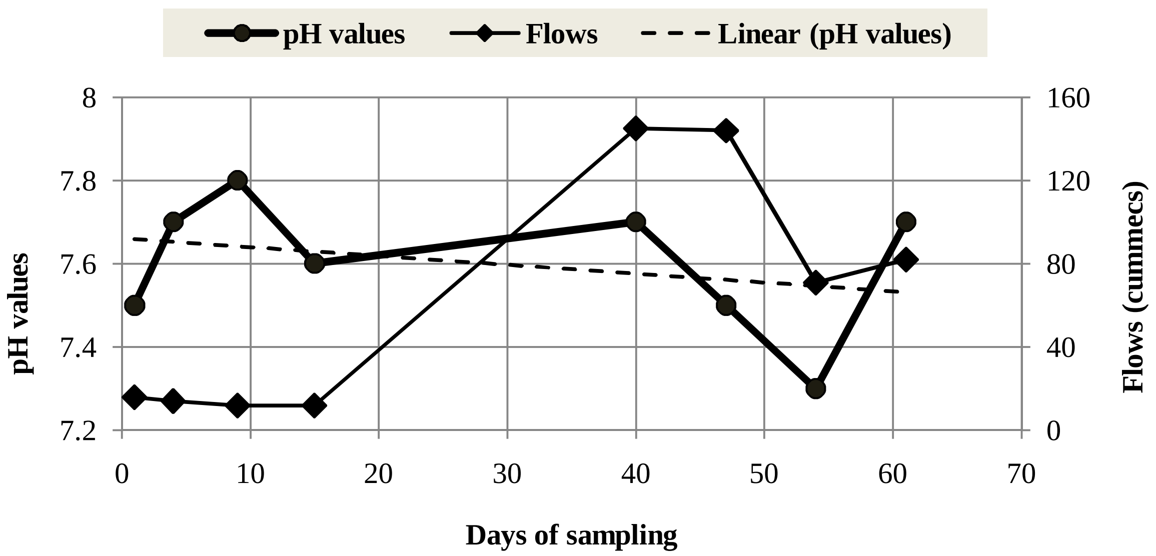


Figure 7: Temporal Variations of pH along Lilongwe River

ii. Suspended Solids (SS)

The results showed that at all sampling points, the values were well above the acceptable limits of the MBS and WHO guidelines of <30 mg/l (Figure 8). The trend also showed lower levels in the upper river catchment and increased downstream. This was due to the higher elemental loads that were washed into the river from the diffuse and point sources prevalent in these segments, mostly from industries and institution. At Malingunde, there were no industries and modernized institutions that could discharge effluents into the river, apart from the natural causes, hence lower values. The results also show that the spatial mean value was highest at the Kaume Sewage Treatment Plant (Figure 8); this was due to tributaries that join the river after the KCH Bridge which increased the suspended loads.

The temporal mean variations showed the highest SS mean value in Week 3 (Day 9), when the discharge was lowest (Figure 9). This was due to loadings from the institutions and industries, especially that the concentrations of city activities are from the Flea Market to the Sewage TP. The linear temporal trend line showed a general increase of SS values with time. This was attributed to the continued rains with time which caused high flows in the river which carried along with eroded silt and other loose materials. The linear trend line explains in general the behaviour of the SS concentration with time as increasing, constant or decreasing. The ANOVA showed significant differences among the samples at all points at $p<0.05$ (Appendix E). According to the MBS, the water in the river with this level of SS values is not suitable for domestic use. High levels of suspended solids also cause problems to aquatic life by blocking light from reaching the submerged vegetation and also can clog the fish gills (Kuyeli *et al.*, 2009).

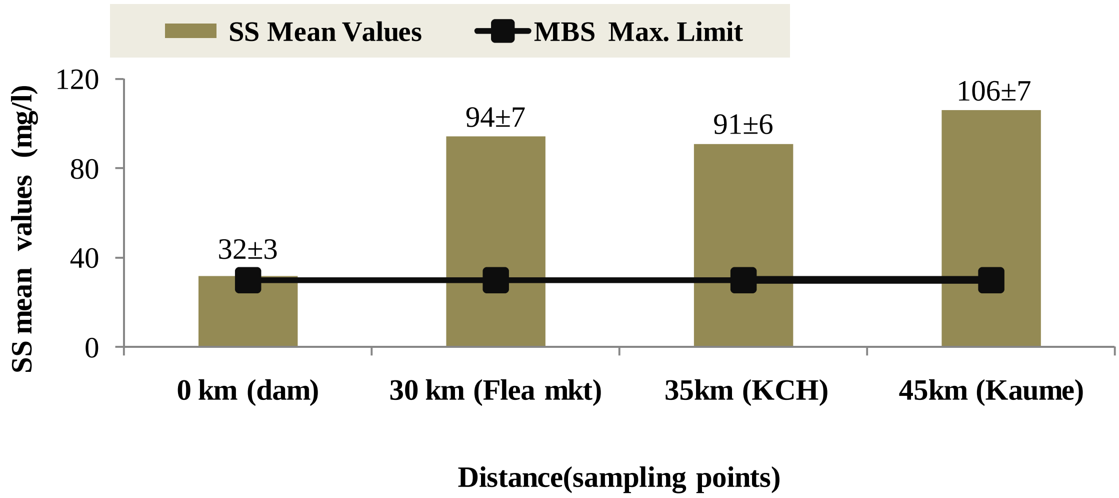


Figure 8: **Spatial Variations of SS along Lilongwe River**

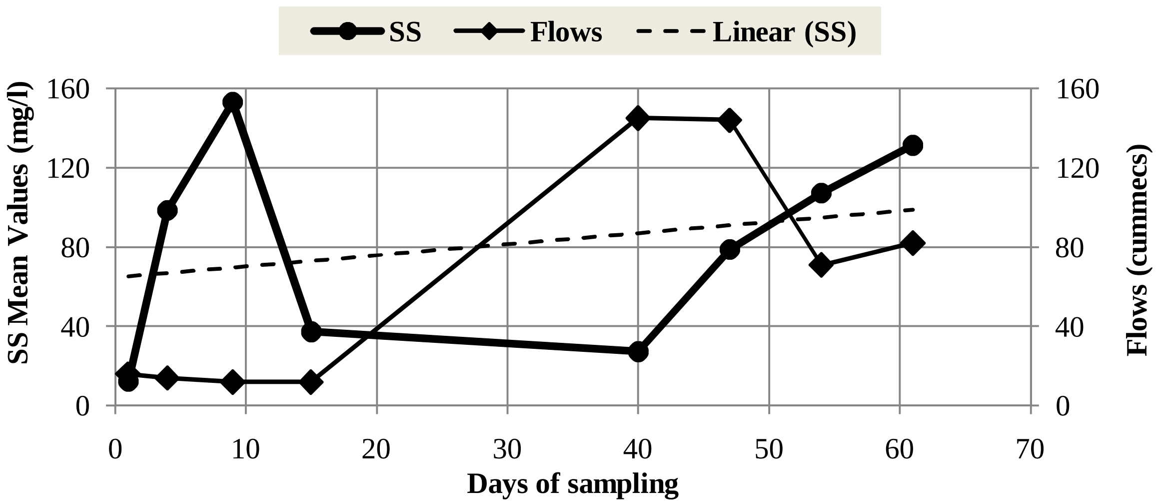


Figure 9: Temporal Variations of SS along Lilongwe River

iii. Turbidity

The results showed very high levels of turbidity at all the sampling points and at all times. The spatial variation of the mean values showed a trend of increasing values downstream, that is less values at Malingunde and higher values as one goes downstream (Figure 10). The lowest value was 61±7 NTU at Malingunde (chosen to represent upstream conditions) which can be attributed only to siltation, plant fibres and presence of phytoplankton. The values at

Flea market and at Kamuzu Central Hospital Bridge were higher than the values at Malingunde. This was due to effluents from the industrial activities that surround these places. Industries that contributed to the increased values at these two places were the diary industries, abattoir industries, and oils from various motor garages, petroleum filling stations, wastes from some hospital ponds, open markets, restaurants, hotels and domestic wastes among others. There were a lot of sand mining activities which also contributed to the high values at these two sampling points. Sand mining stirs the sediments of the river, hence increasing the turbidity. River bank cultivation was another factor that contributed to the high values of turbidity at these two sampling points. River bank cultivation increases siltation (Peters, 2004).

In the temporal variation, there was a linear trend of increasing values with an increase in the rate of flow and with time (Figure 11). Apart from Week 4 (Day 15) and Week 5 (Day 40) results, the rest of the values were in an increasing manner from Week 1 going upwards. This was because of the heavy rains especially from Week 5 (Day 40) to Week 8 (Day 61). The values increased because the river was in flood, which caused a lot of runoff that meant a lot of siltation and debris were carried along from the catchment area of the river under study. All the loose materials carried by the runoff ended up in Lilongwe River, hence an increase in the values of turbidity (Chapman, 1996).

The MBS upper limit of turbidity in water for domestic use is < 5 NTU. The results from all the sampling points were much higher than the recommended value. However some people used this water for domestic use and it meant that their health was at risk. There was a correlation between suspended solids and turbidity as shown in Figure 12. The correlation (R^2) was found to be 0.992 with a relation equation of y=1.413x (Figure 12). This was a very strong correlation indicating that an increase in suspended solids translates into an increase in turbidity (Lutz, 2004).

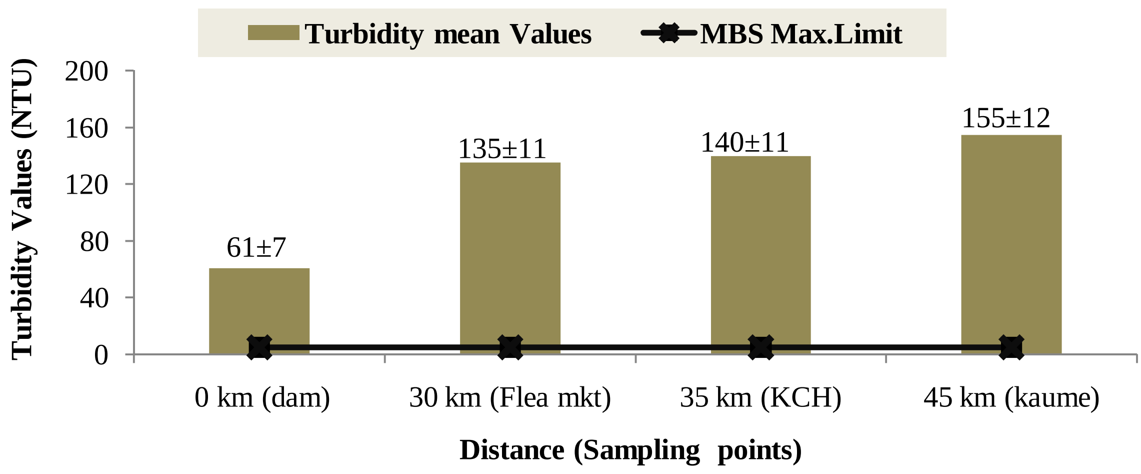


Figure 10: Spatial Variations of Turbidity along Lilongwe River

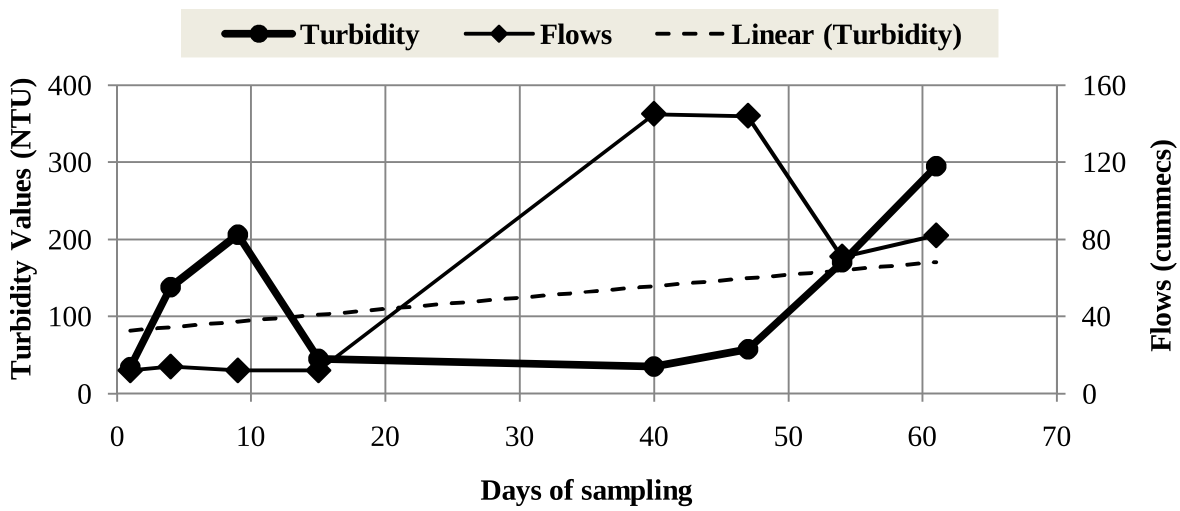


Figure 11: Temporal Variations of Turbidity along Lilongwe River

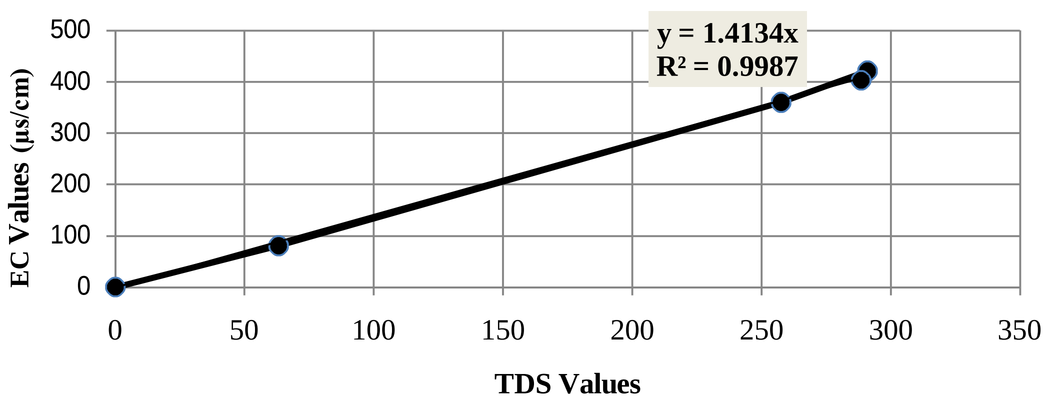


Figure 12: Correlation between Suspended Solids and Turbidity

5.3.2 Chemical Parameters

i. Electrical Conductivity

The spatial results showed a minimum value of 81±2 μS/cm at Malingunde and the maximum value of 421±24 μS/cm at KCH Bridge (Figure 13). The highest value (at KCH) was attributed to the high concentration of chemical constituents from the industries and institutions around this area. Such industries included the hospital laboratories, workshop garages, dairy industries and domestic effluents amongst others. The minimum value at Malingunde was as a result of non industrial activities which could contribute to chemical pollution of the water.

The temporal linear trend showed decreasing values with time (Figure 14). This was due to the subsequent continued flooding which resulted in the dilution effect. The ANOVA showed significant difference at $P<0.05$ among the samples at all the points (Appendix E). Although all these EC values were within the acceptable limits of <1,500 of the MBS for drinking water, the situation was worrisome because the spatial values were increasing, an indication that pollution was taking place along the river. It also shows that with time the values might surpass the acceptable limits. With this increasing trend of EC, it meant that some species both in plant and animal families might be unable to survive and eventually die or disappear.

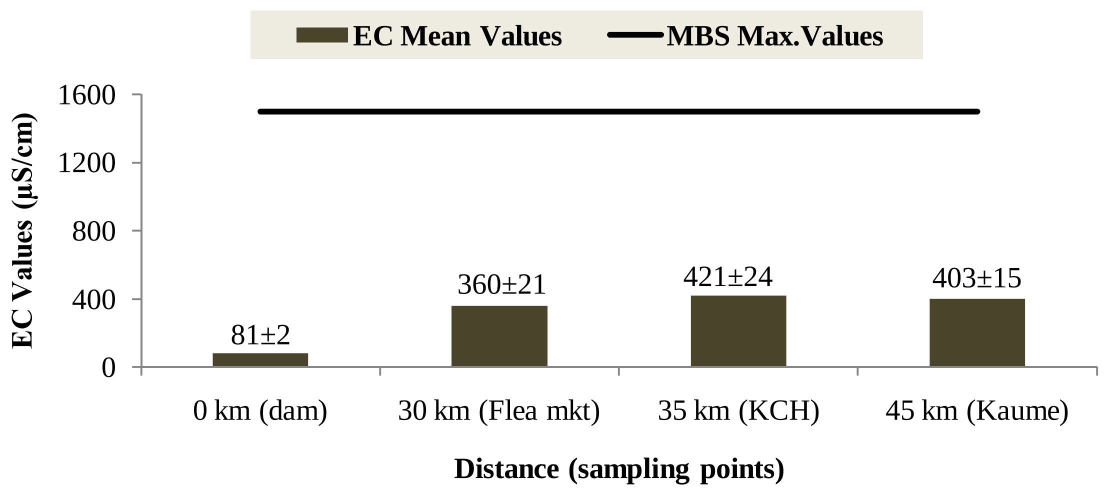


Figure 13: Spatial Variations of EC along Lilongwe River

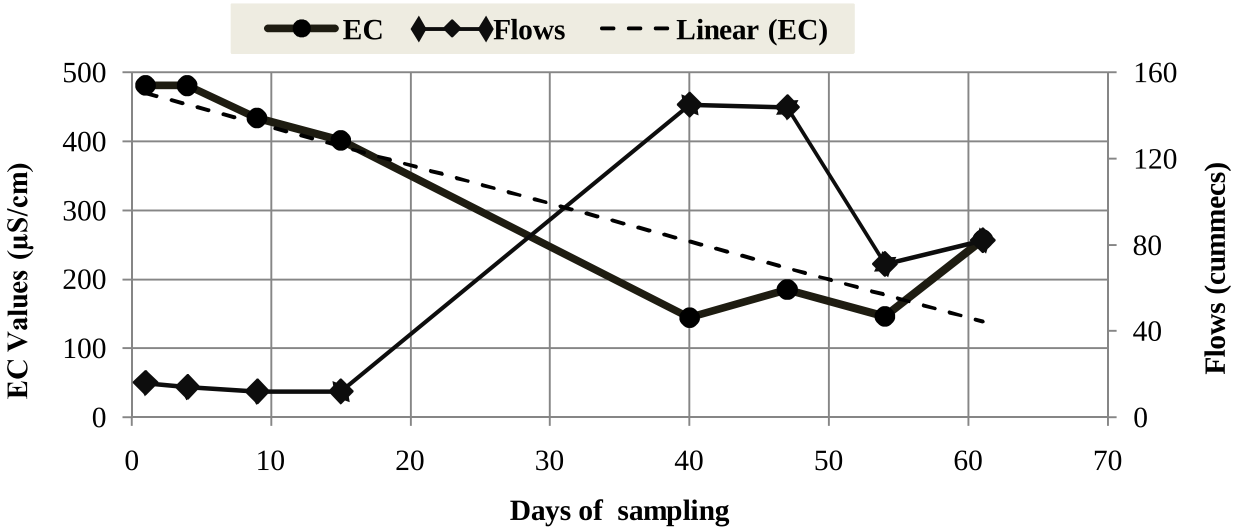


Figure 14: **Temporal Variations of EC along Lilongwe River**

ii. Total Dissolved Solids (TDS)

The mean spatial and temporal variations of EC are presented in Figures 15 and 16. The spatial results showed the highest value of 291±14 mg/l at KCH, the lowest value of 63±2 mg/l at Malingunde (Figure 15). The values were generally increasing downstream. This trend was attributed to the fact that at Malingunde, there were less polluting activities to raise the concentration of the dissolved solids. While from the Flea market there were a lot of commercial activities which resulted in a lot of solid and liquid wastes being discharged into the river and increasing the amount of dissolved solids. In this area there was lot of unmanned solid wastes. This trend of increasing TDS concentration is an indication of chemical pollution caused by the industries of different types in this part of the river catchment area (Mumba *et al*., 2008).

Temporal trend line shows decreasing TDS values with time due to the dilution effect of the continued flooding of the river. The ANOVA showed significant differences in samples at $p<0.05$ at all the sites (Appendix E). All the values obtained were within the acceptable limits of MBS and WHO guidelines of 1000 mg/l for drinking water. There was a strong correlation (R^2) between TDS and EC of 0.998 since EC is a measure of TDS. The equation for the relationship was $y = 1.413x$ (Figure 17). This proves that an increase in TDS will result in an increase in EC (Chapman, 1996).

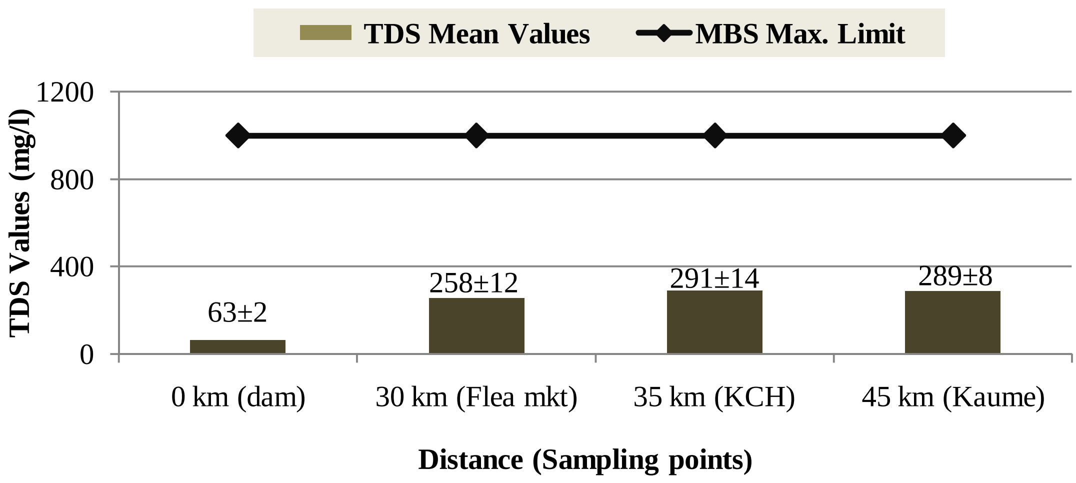


Figure 15: Spatial Variations of TDS along Lilongwe River

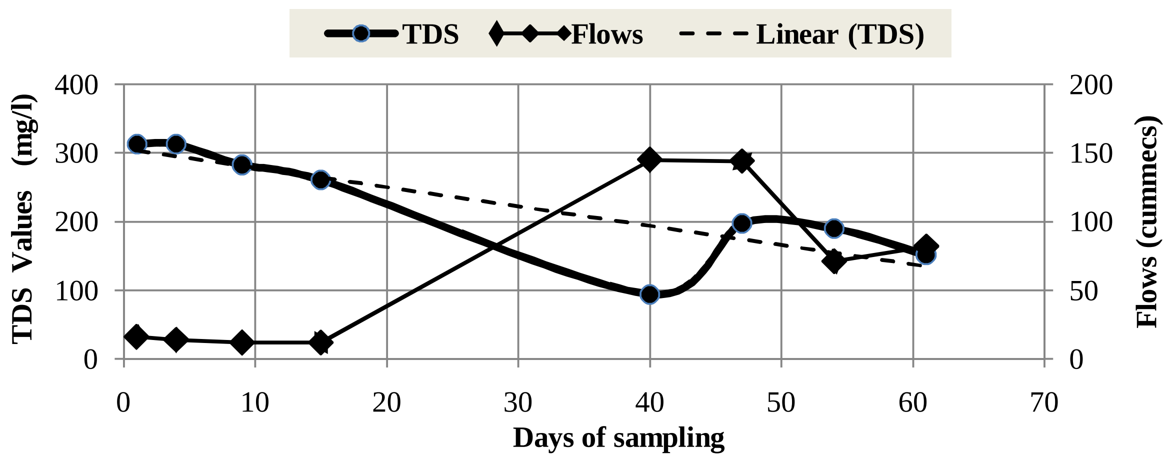


Figure 16: Temporal Variations of TDS along Lilongwe River

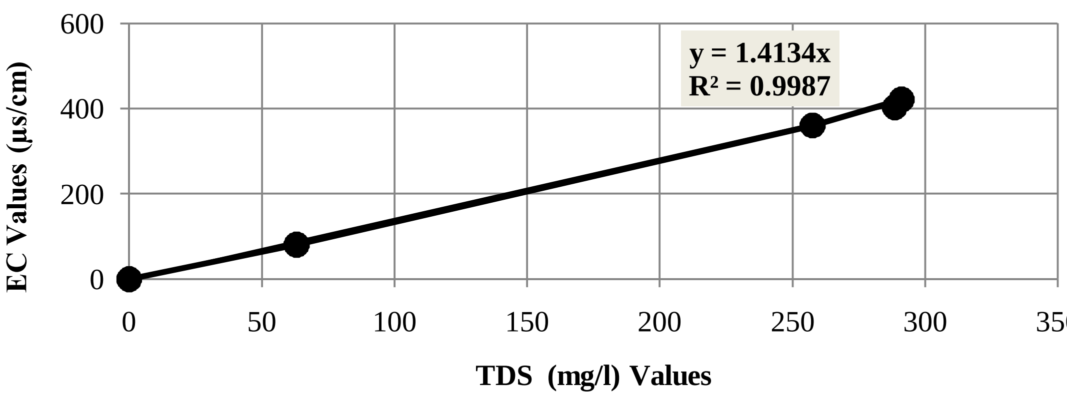


Figure 17: Correlation between EC and TDS

iii. Dissolved Oxygen (DO)

The spatial distribution showed the highest mean value of 6±1.3 mg/l recorded at Malingunde and at the Kaume while the lowest values were at the Flea market and KCH Bridge (Figure 18). The high values at Malingunde and Kaume could be attributed to the abundant vegetation along the river which produced enough oxygen to aerate the water (Chapman, 1996). While the low values at the Flea Market and KCH Bridge were due to commercial and domestic activities surrounding the area which generated a lot of liquid and solid wastes like petroleum products that end up in Lilongwe River, causing pollution which reduced the availability of dissolved oxygen (Sajidu *et al.*, 2007).

The temporal variations showed the highest DO value of 6.8±1.6 mg/l in Week 7 (Day 54) and this was due to high discharges caused by the heavy rains (Figure 19). The minimum value was 4.2±0.3 mg/l in Week 1 (Day 1). In fast moving waters, rushing water is aerated by bubbles as it tumbles over rocks and other barriers thereby falling down hundreds of tiny waterfalls that facilitate mixing with atmospheric oxygen (Cunningham, 2003). The mean concentration values across the studied area was within the MBS recommended limit of >5.0mg/l (Table 3). The variations of DO within the river course were an indication that pollution was taking place. Dissolved oxygen is important in a water body because aquatic life both plants and animals depend on it for survival (Harrison, 1992). This concept assumes other factors of life constant in the right order. The linear trend line on a temporal scale showed a general increase of DO with time. This, as already explained earlier, was because of the gradual rainfall increase with time. At the start of the exercise there were no rains, resulting in low flows. Though, after Day 15 of the start of the exercise, the rains started and the flows increased (Figure 18). The ANOVA showed significant differences in samples at all the sites at $p<0.05$ (Appendix E).

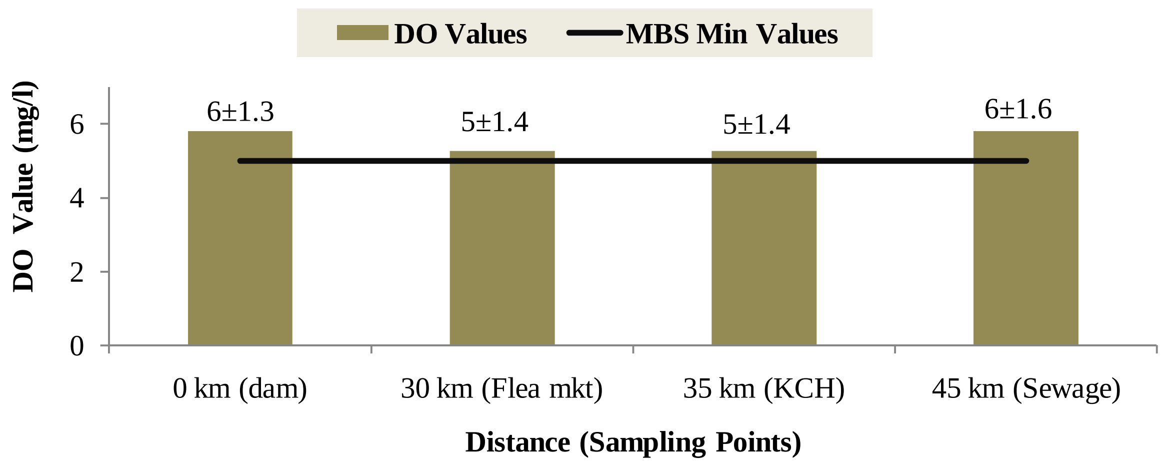


Figure 18: Spatial Variations of DO along Lilongwe River

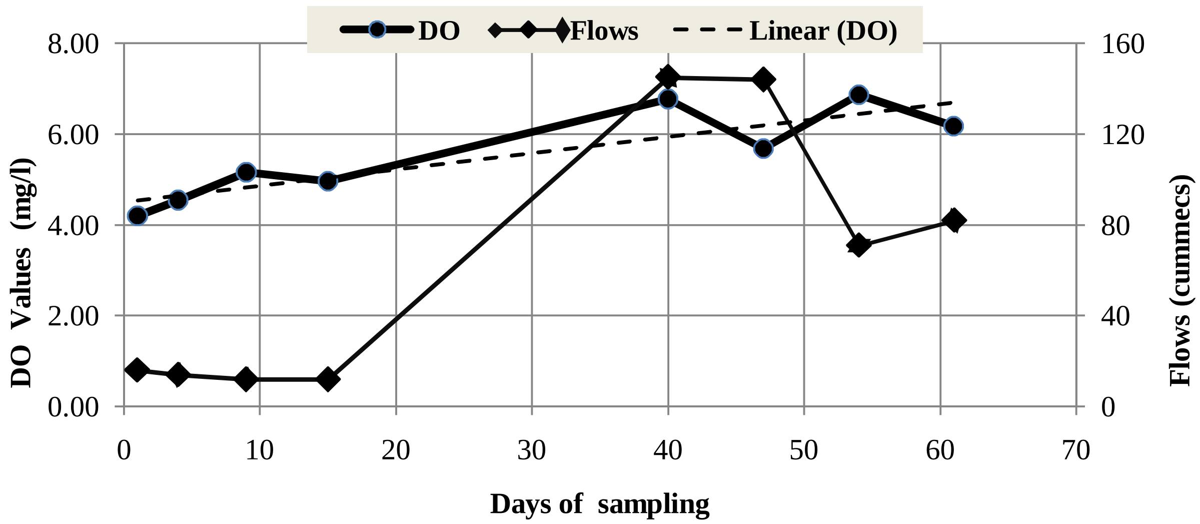


Figure 19: Temporal Variations of DO along Lilongwe River

iv. Biochemical Oxygen Demand (BOD_5)

The temporal and spatial mean values of BOD_5 are shown in Figures 20 and 21. The spatial distributions of the BOD_5 mean values showed the highest values of 25.4±5 mg/l at Kaume Sewage Treatment Plant (Figure 20). This was due to the high concentration of faecal material being discharged at the Kaume Sewage Treatment Plant, since the major source of high BOD_5 is untreated faecal material as more bacteria is required to biodegrade the faecal matter hence more oxygen required for the increased number of bacteria (Tebutt, 1998). The high faecal matter in Lilongwe River at Kaume was due to the inefficiency of the Kaume Sewage Treatment Plant. The lowest value of 13.7±4 mg/l was at Malingunde. In the spatial distribution, it was only at the Kaume STP that the values were above the MBS acceptable limits of <20 mg/l. As explained earlier this was due to poorly treated sewage from the ponds being discharged into the river (Mtethiwa *et al.*, 2008). While at the rest of the points the values were within the acceptable limits of both the MBS and the WHO guidelines.

The temporal distribution showed highest mean values of 22.4 ±7 mg/l in Week 3 (Day 9) and Week 4 (Day 15) with 22±5 mg/l (Figure 21). This was due to low discharge levels and pollution was heavily caused by discharge of domestic and industrial wastes into the river at a time of low river flow. In the temporal distribution, Weeks 3 (Day 9), 4 (Day 15) and 7 (Day 54) had the values which were above the MBS acceptable limits of <20 mg/l while the rest of the weeks were within the acceptable MBS limits. The linear BOD_5 trend line shows decreasing values with time. The linear BOD_5 line explains the general behaviour of BOD with respect to time, as increasing, constant or decreasing. The ANOVA results showed significant differences in all the values at $p<0.05$ (Appendix E).

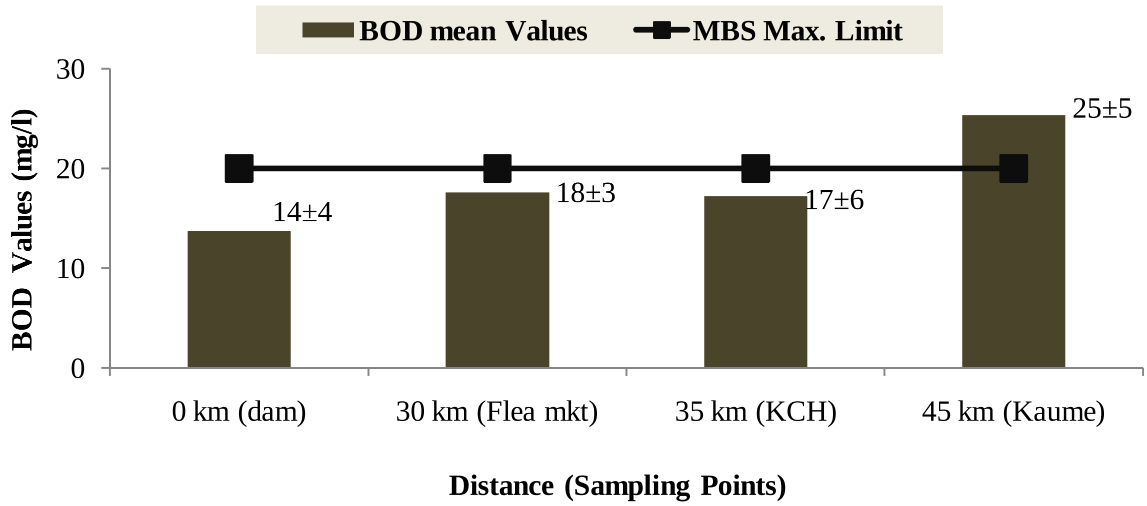


Figure 20: Spatial Variation of BOD_5 along Lilongwe River.

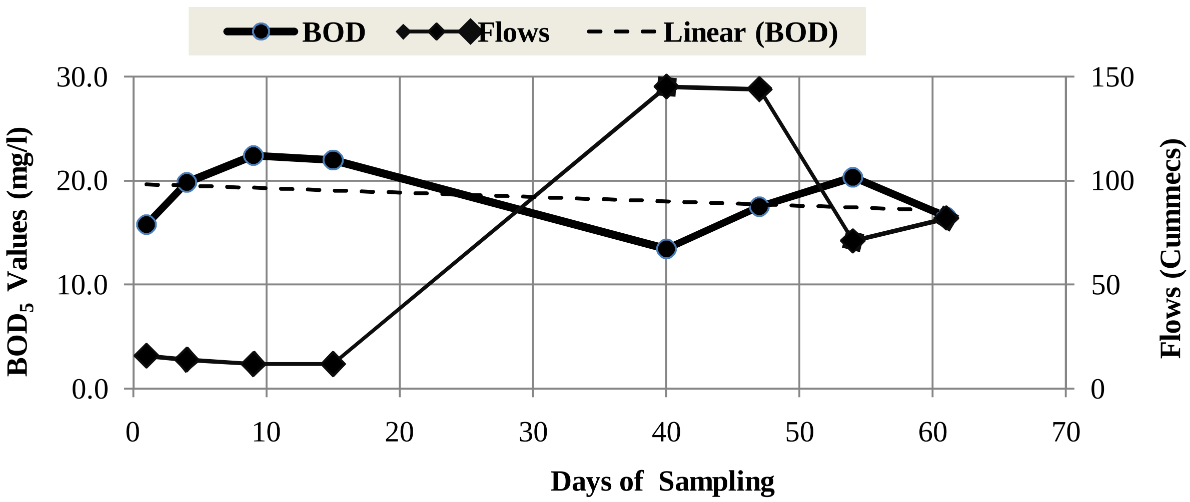


Figure 21: Temporal Variation of BOD_5 along Lilongwe River.

v. Chemical Oxygen Demand (COD)

The spatial variation of COD showed the highest mean value (143.1±3 mg/l) at the Kaume STP seconded by the 109 mg/l at Malingunde, then followed by 96.7±4 mg/l at KCH Bridge and 89.6±5 mg/l at the Flea market (Figure 22). However the expected spatial trend was that the value at Malingunde be the lowest. This could have been due to errors at the laboratory in chemical analysis. However this trend was similar to the spatial trend in the DO analysis and different to the BOD_5 analysis. All these COD values were well above the MBS acceptable limits and WHO guidelines of <70 mg/l.

The temporal variations showed the highest value in Week 4 (Day 15) seconded by Week 8 (Day 61), third Week 7 (Day 54) and least in Week1 (Day 1). The temporal mean values were also above the MBS and WHO guidelines of <70mg/l. This was an indication that the river was polluted. The COD values correlated well with the values of both BOD and DO because the COD values were higher than the values of these two. This should be so because the COD gives the total sum of biodegradable organic matter that would normally be decomposed by the microorganisms during a 5-day BOD plus biodegradable organic matter that would decompose with the use of a chemical catalyst (Harrison, 1999). It was worth noting that the temporal COD linear trend was of slight increase with time. The slope of this trend was very small (Figure 23). This indicated that the COD was not changing much with time. There are significant differences in the samples at all the sites as shown by the ANOVA at $p<0.05$. It was concluded from the results and explanation above that the COD values made the water in the river not suitable for domestic purposes.

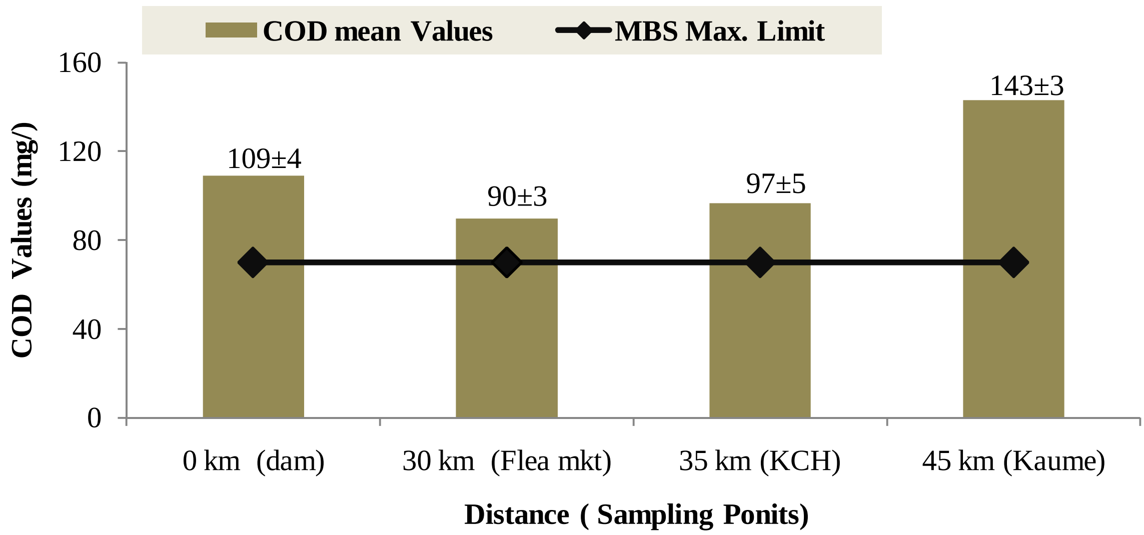


Figure 22: Spatial Variation of COD along Lilongwe River.

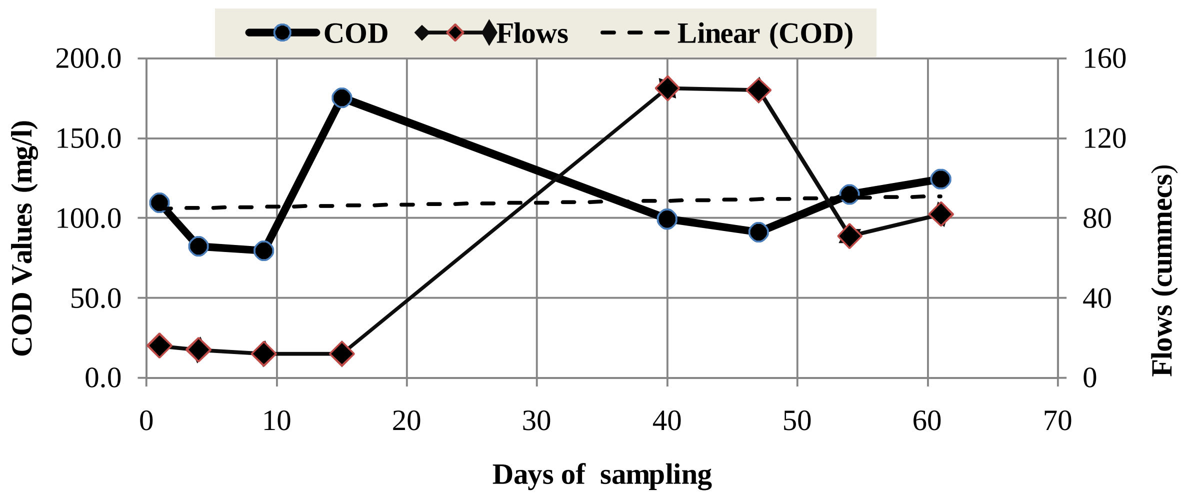


Figure 23: Temporal Variations of COD along Lilongwe River

vi. Nitrate (NO^-_3)

The spatial variations mean values of Nitrate showed the highest value (0.18±0.01 mg/l) at the Flea market. This was due to the effluents from the surrounding industries, as well as the fertilizers from fields above this point and gardens of some residential compounds. It was also due to the garbage that was deposited around the river in this area which got decomposed or filtered depending upon the type of materials in the garbage. For the possible sources of increased nitrates concentration are the natural decay of dead plants and animals, industrial effluents and animal excreta (Gower, 1980). Spatially, the lowest value of 0.03±0.01 mg/l was at Malingunde. There were less or no industrial activities at Malingunde to raise the concentration of nitrates apart from the natural causes of geology, fertilizers carried by run offs from fields and domesticated animal excreta. It should be noted that Malingunde was in typical rural area where fertilizer application was also limited due to economic reasons.

Figure 24 shows the temporal variation with the highest Nitrate value of 0.32±0.04 mg/l in Week 8 (Day 61). This was due to the fact that the river during this week was going through flooding as it was raining continuously, increasing runoffs carrying with it mineral rich substances especially field fertilizers, domestic wastes and others ended up into the river and this increased the nitrate concentrations. It should be noted that the highest value was in the same week at the Flea market. The temporal linear trend showed a general increase of nitrate concentration in the river with time. Anthropogenic activities are also mainly concentrated around this area. The nitrate values in the river were within the MBS acceptable limits of <45 mg/l, but the fact that they were changing in an increasing manner downstream, it meant that the river was being polluted as one went downstream. The ANOVA at $p<0.05$ showed no significant difference in the samples at all the sites except at the KCH.

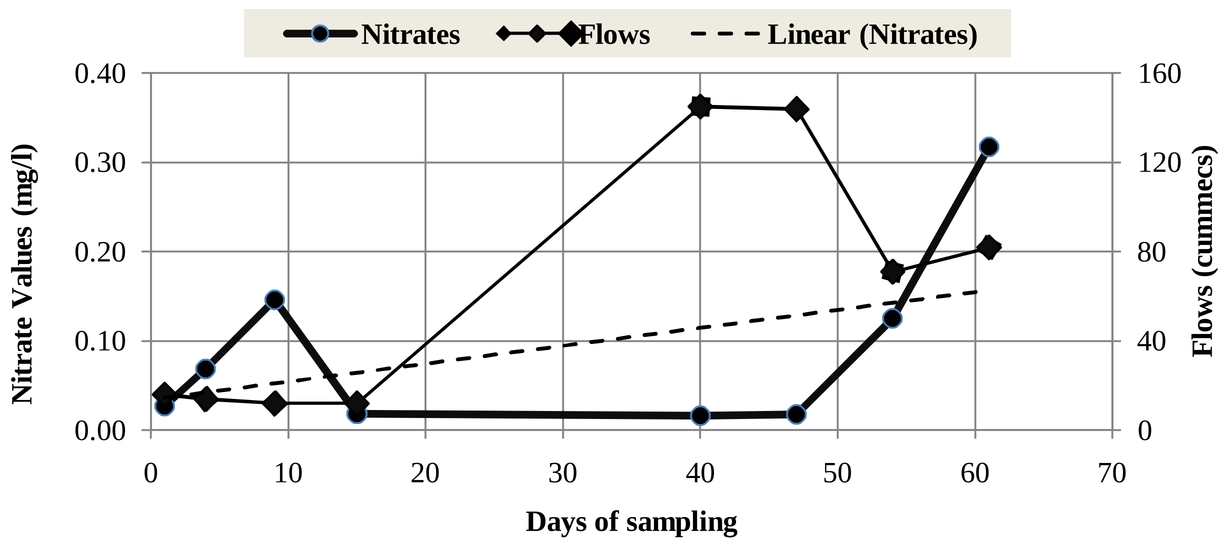


Figure 24: Temporal Variation of Nitrate along Lilongwe River

vii. Phosphate (PO_4^{3-})

The spatial variation of phosphates showed the highest mean value of 0.16±0.15 mg/l and this occurred at the Flea market (Figure 25). This was due to industrial effluents around this area. There were a number of laundry plants, plastic industries and photographic industries which utilised high levels of industrial phosphates because they use phosphate detergents and diluted phosphoric acid for cleaning production lines (Sajidu *et al.*, 2007). The effluents from these industries most probably ended up into the river, increasing the phosphate concentrations. Additionally, as stated earlier there was a leaking sewer pipe point whose sewage ended up into the river, hence increasing the concentration of the phosphates. Kaume STP recorded 0.11±0.09 mg/l. This high value was also due to the effluents from the Kaume treatment plant which is not functioning efficiently. The ponds were discharging poorly treated faecal material into Lilongwe River. This contributed to the high concentration of phosphates at the sampling point below the Kaume STP. The principal sources of phosphates are inorganic chemical fertilizers from fields, diffuse sources and sewage effluents from point sources and detergents from laundry industries or domestic waste waters (Mvungi *et al.*, 2003). The lowest value of 0.02±0.01 mg/l was from Malingunde, as earlier indicated that there were no industrial activities. The spatial mean values except that of Malingunde were well above the acceptable limits of MBS and WHO guidelines of <0.05 mg/l.

The phosphates temporal variations (Figure 26) showed the highest value of 0.21±0.13 mg/l in Week 8 (Day 61). This was attributed to the fact that the river was going through flooding, increased runoffs carried with it mineral rich substances especially field fertilizers, domestic wastes and others which ended up into the river that increased the phosphate concentrations. There was rampart river bank cultivation along the Lilongwe River which increased the passage for the runoff into the river as earlier stated**.** The temporal linear trend showed a general increase in phosphate concentration with time. In general, the phosphate concentrations in the river made the water not suitable for domestic purposes. Measures are required to be taken to prevent further damage to the Lilongwe River.

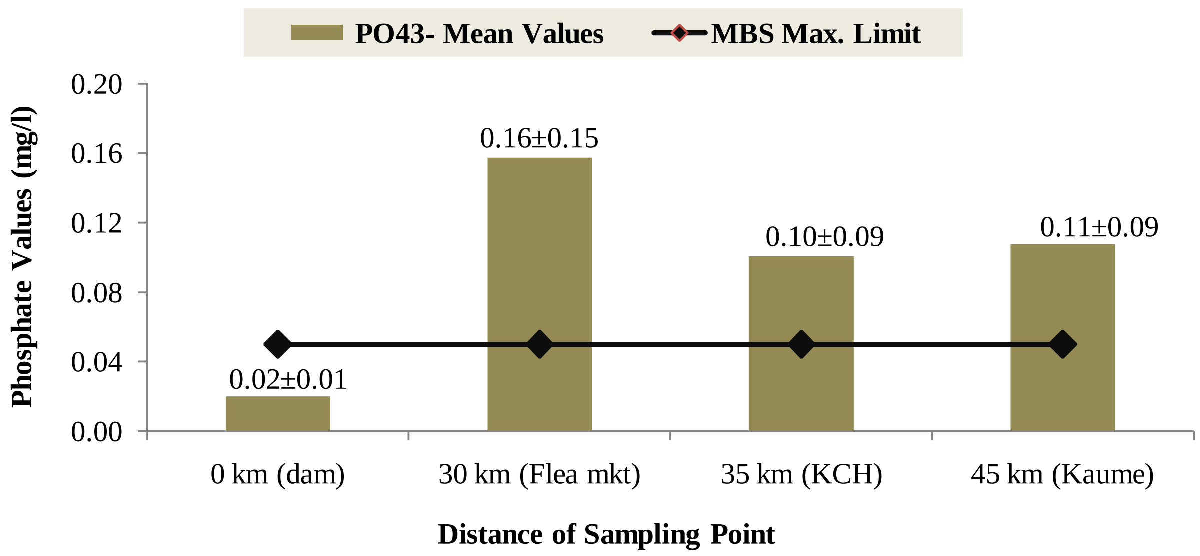


Figure 25: Spatial Variation of Phosphate along Lilongwe River

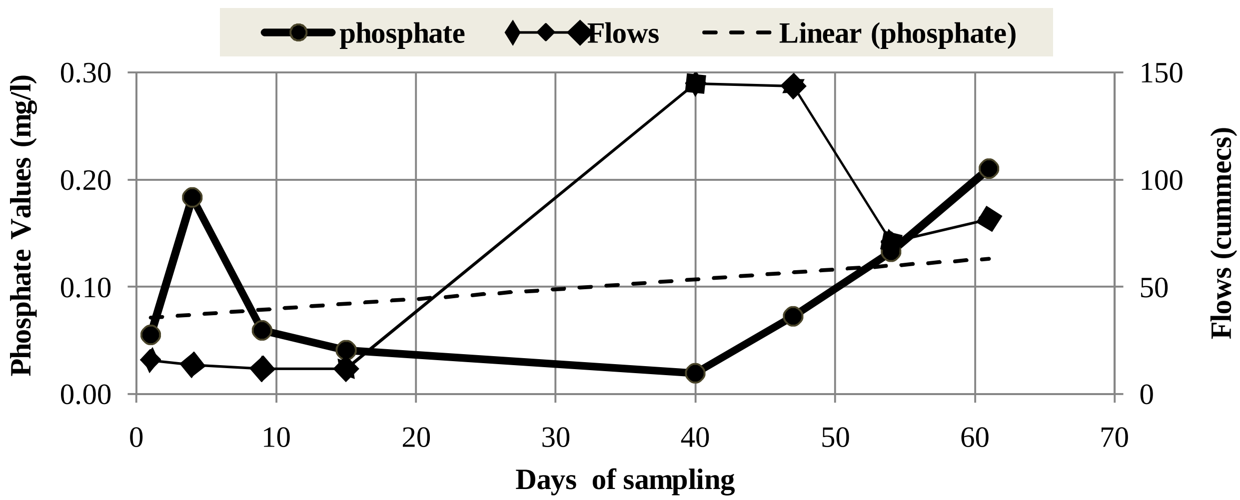


Figure 26: Temporal Variations of Phosphate along Lilongwe River

viii. Hardness Levels Analysis (CaO_3)

The spatial and temporal mean values of hardness along the river are shown in Figures 27 and 28. The spatial variation showed high values at Kaume and KCH Bridge while lowest values were at Malingunde. This explains that at Malingunde, there were no anthropogenic activities to raise the hardness where as at the KCH Bridge there were many industrial activities taking place like poultry, battery and photographic industries, hence the increased value of hardness. Spatially the values were increasing as one goes downstream. This was because the industries were downstream of Malingunde. The ANOVA showed significant differences in the samples among all the sites at $p<0.05$ (Appendix E).

The temporal linear trend line showed a general decrease of hardness values with time (Figure 28). This was due to the increasing rainfall and increasing flows which resulted in the dilution effects. All the values of hardness were within the acceptable limits of all the controlling bodies of MBS and WHO guidelines. The extents of variation in the mean values from 47.9±14 mg/l at Malingunde to 184.8±75 mg/l at the Flea market and then to 217.7±63 mg/l at the Kaume SWTP, showed that the river was being polluted. Hence it was important that the quality assessment of the river be done frequently inorder to detect any change that might be harmful to human and aquatic life.

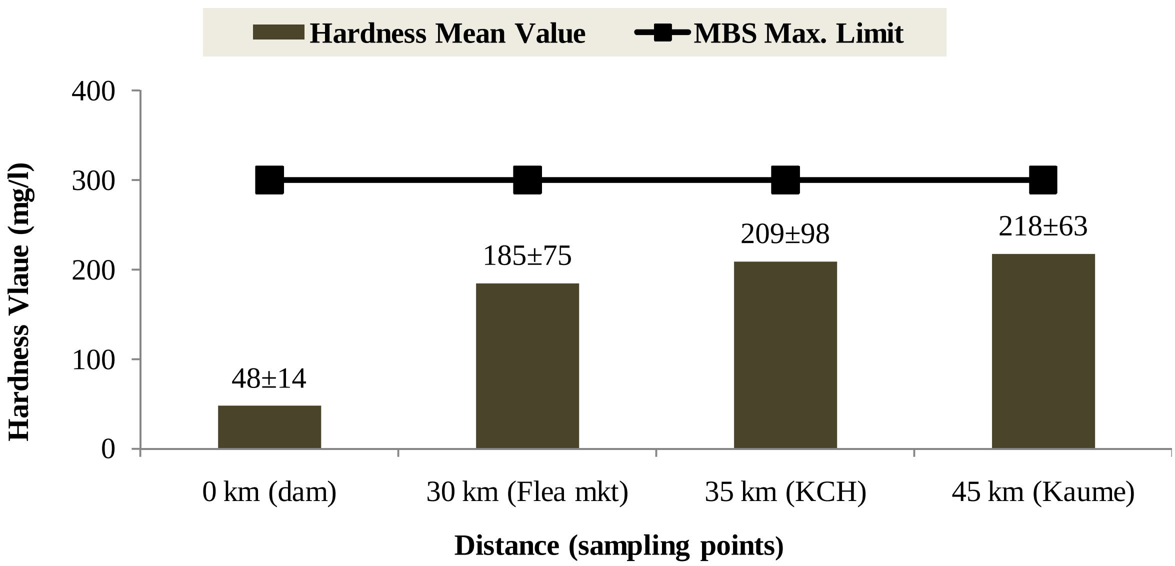


Figure 27: Spatial Variation of Hardness along Lilongwe River

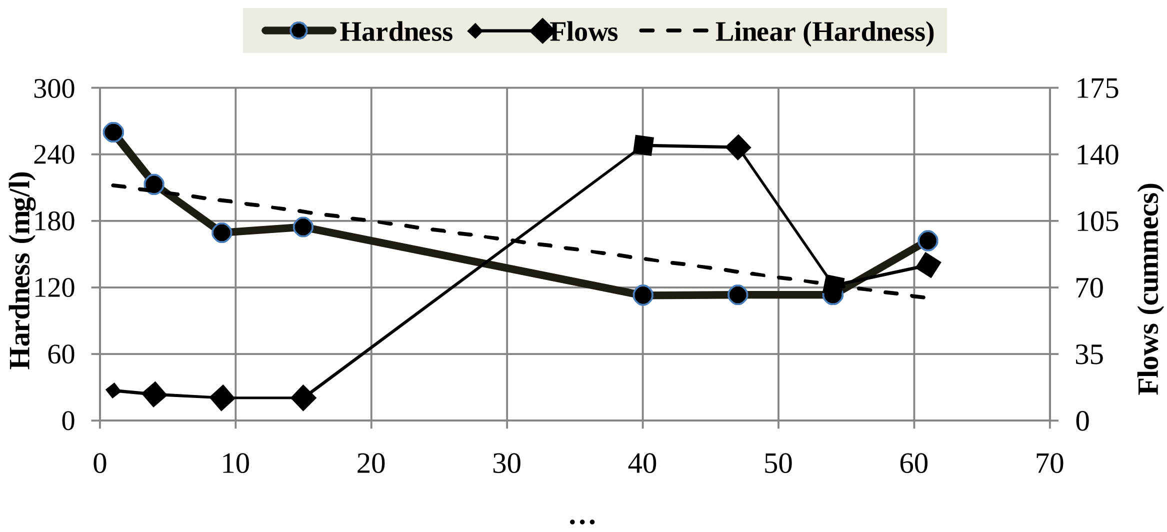


Figure 28: **Temporal Variation of Hardness along Lilongwe River**

ix. Lead

Lead is a heavy metal, which has carcinogenic effects on human life if consumed in excess through water. It can damage the nervous system if taken in excess. It causes disorder of the blood and brain (Gurruswammy, 2000).

The lead spatial variations showed the mean values ranging from 0.003±0.00 mg/l to 0.21±0.01 mg/l (Figure 29). The highest was observed at the Kaume STP and the lowest at the KCH Bridge. The values at Kaume STP (0.21±0.01 mg/l) and Flea market (0.067±0.01 mg/l) were above the acceptable limits of the MBS and WHO guidelines of 0.05 mg/l and 0.01 mg/l for surface waters. Previous water quality studies conducted in some streams in Blantyre city have revealed heavy lead contamination. The lead concentration in Mudi stream was 0.08 mg/l while Shire River registered 0.96 mg/l (Lakudzala *et al.*, 1999). The high value at the Flea market was due to the presence of many industries in this part of the river catchment such as the motor vehicle garages, automotive industries, paint manufacturing industries, printing and packaging industries and lead acid battery industries. For these are the major sources of lead (Guruswamy, 2000). While the high value at Kaume STP was due to the poorly treated effluents from the ponds. Probably the values might have been much higher, were it not for the Malawi Government order to phase out the use of leaded petrol in 2006. Elimination of lead from gasoline has resulted in a significant decrease in the amount of lead in water bodies in United States of America (Cunningham, 2003). The temporal linear trend line showed a general decrease in concentration of lead with time. This was due to the continued rainfall that kept increasing the flows that resulted in the dilution effects. The ANOVA shows significant differences at $p<0.05$ in the samples at all the points except at the Flea Market.

The changing of lead concentration values along the course of Lilongwe River shows that the river was being contaminated. Lilongwe River passes through the commercial areas and the presence of lead in its water indicated that the industries are contributing to lead in the river which was later transported along the river downstream. Specifically, the contamination was higher at Flea market and Kaume STP. It is recommended that action be taken to prevent further lead contamination of the water in Lilongwe River. Otherwise people depending on river for domestic uses are prone to face the carcinogenic consequences of lead.

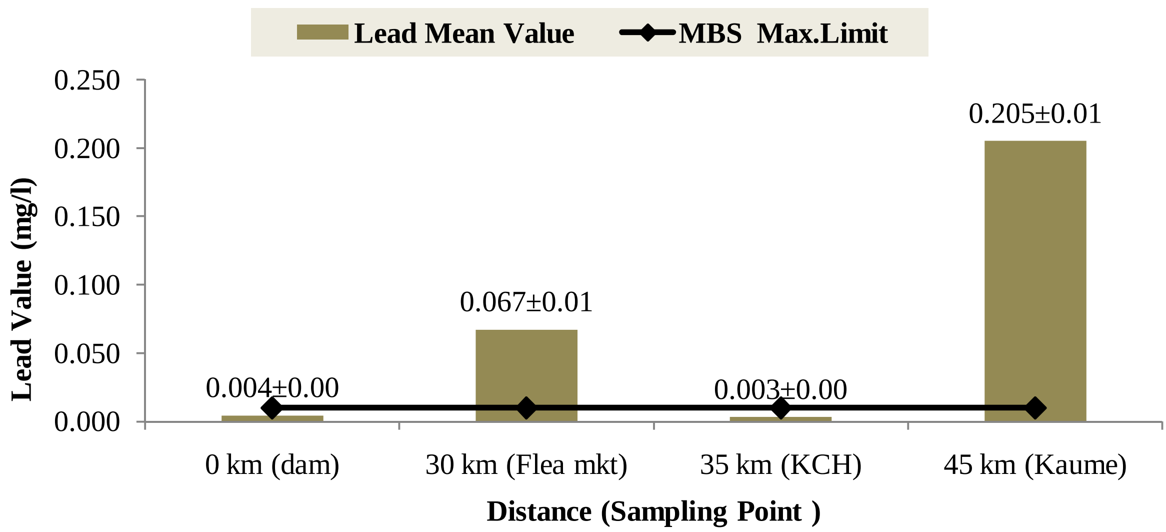


Figure 29: Spatial Variation of Lead along Lilongwe River

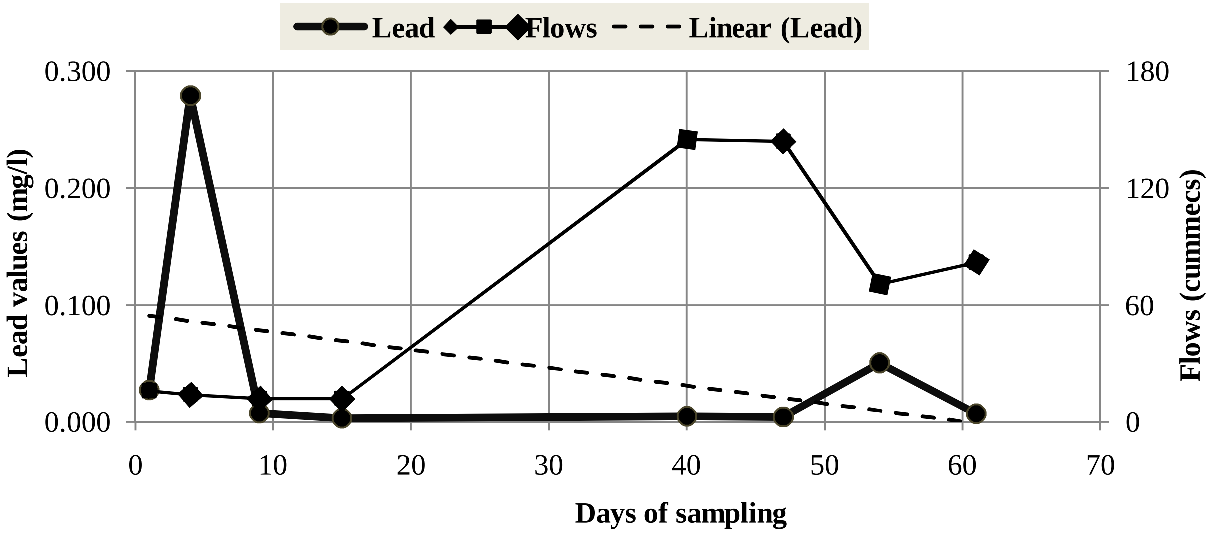


Figure 30 : Temporal Variation of Lead along Lilongwe River

x. Cadmium

Cadmium is a toxic heavy metal which has adverse effects on human health. It causes lung damage and death if taken in excess of the recommended values. Its known quantity state in water is very vital for remedial purposes in case the quantities surpass the acceptable limits. The spatial values showed that the Lilongwe River was heavily contaminated with cadmium (Figure 31). The spatial variation show high values at Malingunde (0.16±0.08 mg/l). This was attributed to the natural cause of deposition and chemical weathering of base rocks like the granite which is the dominant parent rock of the area. The temporal linear trend line shows a general increase of cadmium concentration with time in the river. The ANOVA at $p<0.05$ also shows significant differences in the samples at all points except at the KCH Bridge.

The MBS acceptable standards of cadmium for drinking water is <0.01. With this standard, the values obtained in Lilongwe River were still far above. This concluded that the river experiences heavy metal contamination both in time and in space (Figures 31 and 32).

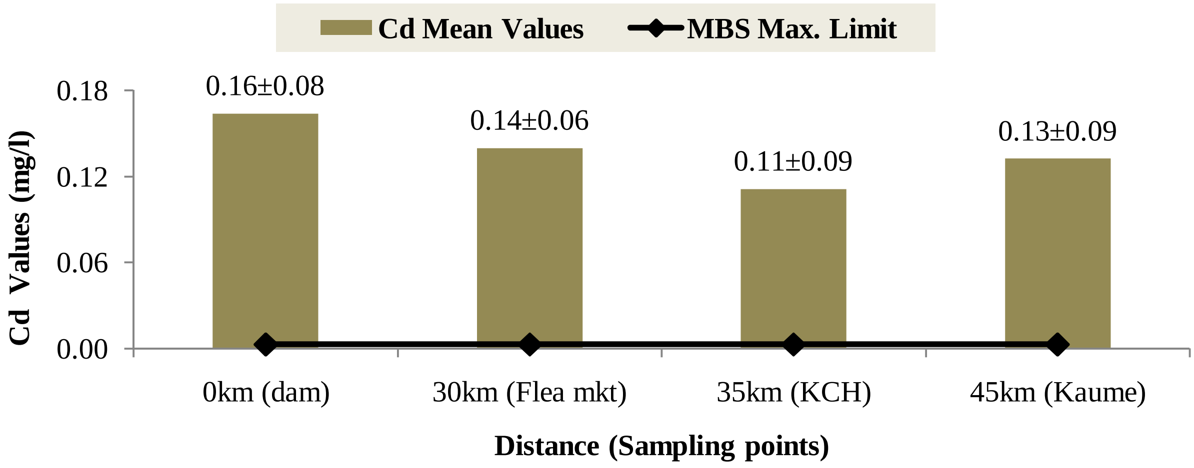


Figure 31: **Spatial Variation of Cadmium along Lilongwe River**

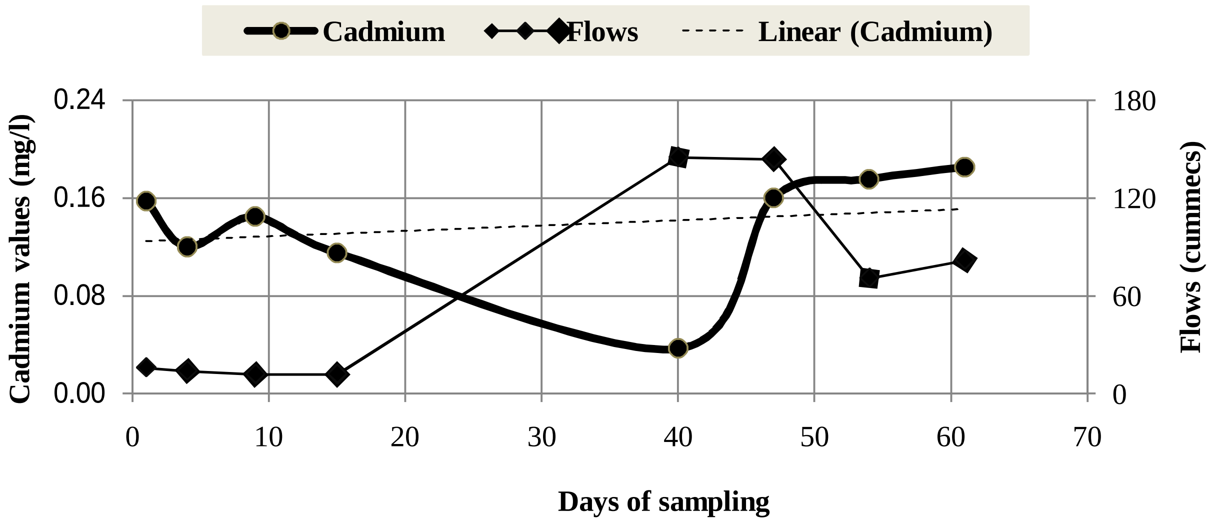


Figure 32: Temporal Variation of Cadmium along Lilongwe River.

5.3.3 Biological Parameters

Faecal Coliforms

The mean spatial variations showed a general trend of increasing values of faecal coliforms from upstream to downstream (Figure 33). The values at the Malingunde, though less than the values of other sites, were still high above MBS and WHO guidelines acceptable limits. This was due to contamination of run-offs with human faeces which is caused by lack of proper sanitation in the villages around. Also domestic animals contributed to this faecal coliforms contamination of water since the villagers kept domestic animals like goats and cattle. There was a high increase in the faecal coliforms mean of values between Malingunde (1,938±657 counts/100 ml) and the flea market (4,894±703 counts/100 ml). The high values at the Flea market were most likely due to open defaecation and shallow temporally toilets at the market and the squatter settlements above the flea market. While the highest figure at the Kaume STP were as a result of the poorly treated effluents from the plant (Mtethiwa *et al.*, 2007). It was reported that the sludge in the ponds at the Kaume sewerage plant had not been disludged for a long period of time. This affected the volumetric efficiency of the ponds. During all the 8 weeks time of data collection, the personnel at the STP indicated lack of adequate chemicals to carry out tests for the quality of effluents from the ponds. Therefore there was no measurement of the efficiency of the ponds.

The faecal coliforms temporal variation showed a linear trend of constant high values of 3,750±1500 counts /100 ml (Figure 34). The ANOVA showed significant differences among all the sites at $p<0.05$. With the high faecal coliforms, it meant that the likelihood of occurrence of waterborne diseases like cholera was very high.

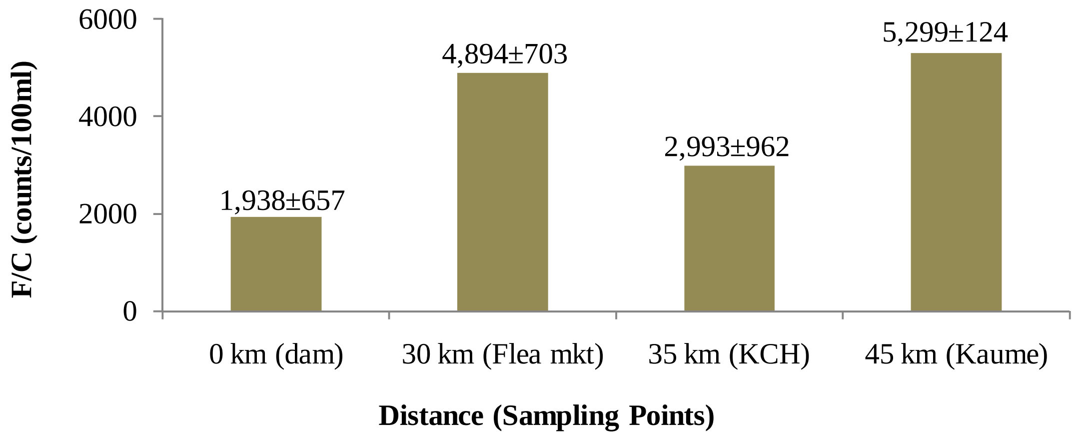


Figure 33: Spatial Variation of Feacal Coliforms along Lilongwe River

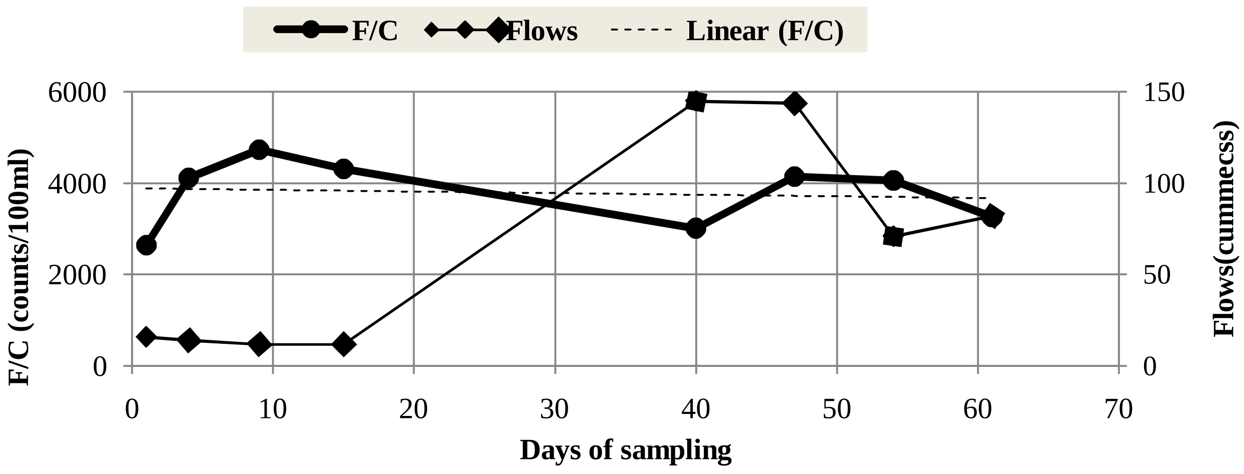


Figure 34: Temporal Variation of Faecal Coliforms in Lilongwe River

5. 4 Summary of the Water Quality Analysis Results

The results analyzed in the preceding chapter showed that the values of some water quality parameters were above the acceptable limits of MBS for drinking water while others were below it. Seven out of the 14 parameters analyzed, were above the MBS acceptable limits. These were phosphates, lead, cadmium, COD, suspended solids, turbidity and faecal coliforms (Figures 35 and 36). The faecal coliforms value (3780±300 counts/100) across the section of the river was exceedingly above the acceptable limits of MBS.

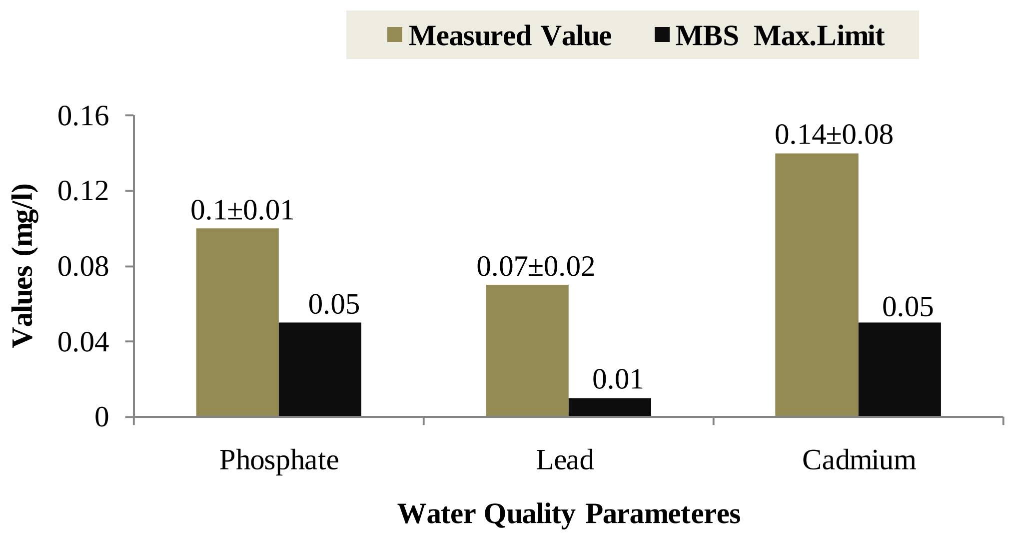


Figure 35: Phosphate, Lead & Cadmium status against MBS limit

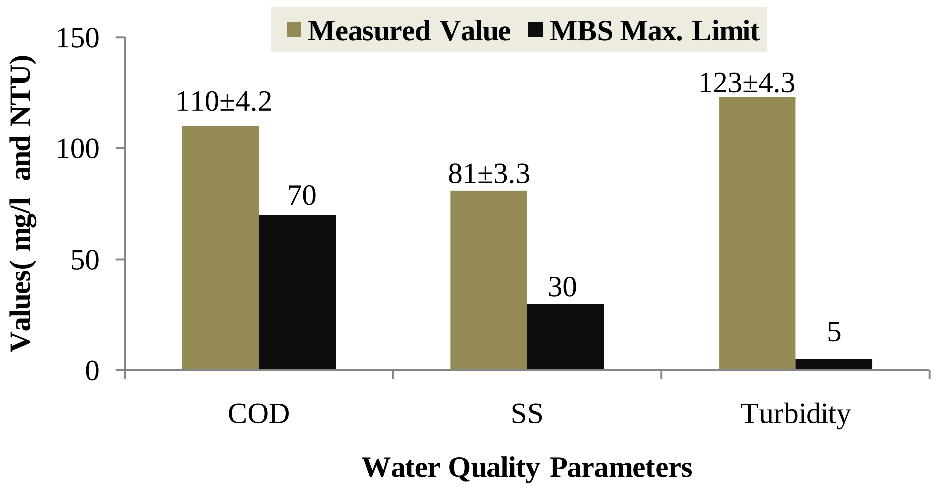


Figure 36: COD, SS & Turbidity status against MBS limits

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CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study of the assessment of the quality of water in Lilongwe River drew the following conclusions:

1. There were 197 identified sources of pollution that contributed to the pollution of water in the part of Lilongwe River under study. River bank cultivation was another source identified, contributing to the pollution of the water in Lilongwe River.

2. The water within the study area was not fit for domestic use like drinking, cooking and bathing. The water parameters suspended solids, turbidity, chemical oxygen demand, phosphorus, cadmium, lead and faecal coliforms had values exceeding the acceptable limits of the MBS and WHO guidelines, resulting to the poor water quality.

3. There was a problem of proper sanitation within the study area as evidenced by the extreme high values of faecal coliforms obtained at all the sampling points and at all the sampling times in the Lilongwe River under study

6.2 Recommendations

The research therefore recommended the following:

1. The water from Lilongwe River under study should not be used for domestic purposes.

2. The population of the people that rely on river water for domestic use within the study area should be provided with boreholes or wells as a matter of urgency, as they are a waiting for the expansion of the services of the Lilongwe Water Board.

3. The Lilongwe City Assembly should seriously and quickly find means of increasing the rate of refuse collection from 30% in the city to 100%. The city can either privatize the refuse collection or revisit the act on damping and collection of wastes in the city.

4. An IWRM approach should be used to tackle issues of water pollution. All the stakeholders including the public, communities, interest groups, individuals as well as

the government must have the will to participate in tackling the water pollution problem in a curative but also in a preventive manner. Women and children should be fully involved at all levels of environmental management process.

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A P E N D I C E S

Appendix A. Tables of Physical, chemical & Biological Water Analysis Results

Table 7: pH Results

POINT	Wk 1	Wk 2	Wk3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	7.63	7.68	7.71	7.39	7.57	7.35	7.2	7.9	7.55
Flea Mkt	7.29	7.79	7.83	7.69	7.75	7.5	7.4	7.5	7.59
KCH	7.32	7.63	7.75	7.7	7.7	7.6	7	7.74	7.55
Sewage	7.92	7.78	7.78	7.74	7.8	7.7	7.7	7.84	7.78
Mean	7.5	7.7	7.8	7.6	7.7	7.5	7.3	7.7	
Min	7								
Max	7.92								

Table 8: Electrical Conductivity Results (µS/cm)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	76	84	89	85	55	66	91	101	80.9
Flea Mkt	595	573	583	468	162	180	102	218	360
KCH	710	700	577	530	152	195	191	315	421
Sewage	544	566	486	522	209	300	202	396	403
Mean	481.2	480.8	434	401.2	144.5	185.3	146.5	258	
Min.	55								
Max.	710								

NB: wk= week; Min. =Minimum value; Max. =Maximum value;

Table 9: Total Dissolved Solids Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	49	55	61	55	36	95	80	74	63.1
Flea Mkt	387	372	378	304	105	188	177	149	258
KCH	462	455	375	344	99	210	201	183	291
Sewage	354	368	316	339	136	295	301	199	289
Mean	313	312.5	283	260.5	94	197	189.8	151	
min	36								

Table 10: Suspended Solids Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	12.0	20.0	23.0	12.0	12.0	16.0	91.0	67.0	31.6
Flea Mkt	6.0	102.0	213.8	53.0	37.0	98.0	102.0	142.0	94.2
KCH	6.0	122.0	186.0	48.0	24.0	105.0	99.0	137.0	90.9
Sewage	25.0	150.0	189.0	36.0	36.0	96.0	137.0	179.0	106.0
Mean	12.3	98.5	153.0	37.3	27.3	78.8	107.3	131.3	
Min	6.0								
Max	213.8								

Table 11: Turbidity Results (NTU)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	18.0	52.0	64.0	20.0	20.0	130.0	105.0	240.0	81.1
Flea Mkt	20.0	160.0	240.0	60.0	40.0	240.0	266.0	310.0	167.0
KCH	20.0	160.0	260.0	60.0	40.0	195.0	275.0	316.0	165.8
Sewage	80.0	180.0	260.0	40.0	40.0	210.0	290.0	313.0	176.6
Mean	34.5	138.0	206.0	45.0	35.0	193.8	234.0	294.8	
Min	18.0								
Max	316.0								
STDEV	103								

NB: wk= week; Min=Minimum value; Max=Maximum value;

Table 12: Dissolved Oxygen Results (mg/l)

Point	Wk 1	Wk 2	Wk3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	4.26	4.99	5.1	5.73	5.2	6.1	6.9	8.2	5.81
Flea Mkt	3.82	4.89	4.84	4.84	6.7	5.1	6.1	5.88	5.27
KCH	4.2	3.4	5.11	4.24	7.8	6.1	5.34	6	5.27
Sewage	4.49	4.89	5.58	5.04	7.39	5.4	9.1	4.6	5.81
Mean	4.19	4.54	5.16	4.96	6.77	5.68	6.86	6.17	
Min	3.4								
Max	9.1								
STDEV	1								

Table 13: BOD_5 Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	14.2	20.5	16.5	15.8	8.5	9.2	14	11	13.71
Flea Mkt	16.5	17.4	23.2	16.8	13.3	16.4	21.1	16	17.59
KCH	13.4	16.9	16.8	29.1	10.9	14.2	19.2	17	17.19
Sewage	19	24.5	33	26.2	21	30.2	27	22	25.36
Mean	15.775	19.83	22.38	21.975	13.43	17.5	20.325	16.5	
Min	8.5								
Max	33								
STDEV	6								

Table 14: COD Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	128.6	79.2	82.1	151.3	66.6	77	99	188.1	109
Flea Mkt	88.6	58.8	61.2	143.5	82.3	84	101	97.1	89.6
KCH	73.3	53.3	63.5	206.9	114.5	98	89	75	96.7
Sewage	148	138	111.3	200	134.1	106	170	137	143.1
Mean	109.6	82.3	79.5	175.4	99.4	91.3	114.8	124.3	
Min	53.3								
Max	206.9								
STDEV	42								

NB: wk= week; Min=Minimum value; Max=Maximum value; STDEV=Standard Deviation

Table 15: Faecal Coliforms Results (counts/100ml)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	1300	2700	3100	1820	1930	1850	1600	1200	1938
Flea Mkt	3800	4900	5900	4950	5320	5402	4880	3997	4894
KCH	1250	3500	4100	3600	900	3400	4170	3020	2993
Sewage	4200	5350	5800	6855	3900	5890	5600	4795	5299
Mean	2637	4113	4725	4306	3013	4136	4062	3253	
Min	900								
max	6855								
STDEV	1650								

Table 16: Results of Nitrates (mg/l)

Point	Wk 1	Wk 2	Wk3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	0.03	0.01	0.01	0.01	0.01	0.01	0.09	0.08	0.03
Flea Mkt	0.01	0.06	0.2	0.04	0.03	0.03	0.11	0.97	0.18
KCH	0.02	0.08	0.19	0.02	0.02	0.02	0.13	0.1	0.07
Sewage	0.05	0.13	0.19	0.01	0.01	0.01	0.17	0.12	0.09
Mean	0.03	0.07	0.15	0.02	0.01	0.02	0.13	0.32	
Min	0.01								
Max	0.97								
STDEV	0.17								

Table 17: Results of Phosphates (mg/l)

Point	Wk 1	Wk 2	Wk3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	0.02	0.02	0.02	0.01	0.02	0.03	0.03	0.02	0.02
Flea Mkt	0.03	0.25	0.19	0.05	0.02	0.02	0.39	0.31	0.16
KCH	0.02	0.22	0.01	0.05	0.02	0.11	0.1	0.28	0.1
Sewage	0.15	0.24	0.02	0.06	0.02	0.13	0.01	0.23	0.11
Mean	0.06	0.18	0.06	0.04	0.02	0.07	0.13	0.21	
Min	0.01								
Max	0.39								
STDEV	0.11								

NB: wk= week; Min=Minimum value; Max=Maximum value; STDEV=Standard Deviation

Table 18: Lead Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	0.005	0.001	0.01	0.001	0.015	0.001	0.001	0.003	0.004
Flea Mkt	0.103	0.305	0.01	0.001	0.001	0.008	0.1	0.009	0.067
KCH	0.001	0.01	0.001	0.001	0.002	0.007	0.1	0.011	0.003
Sewage	0.001	0.8	0.01	0.01	0.001	0.001	0.001	0.005	0.205
Mean	0.028	0.279	0.008	0.003	0.005	0.004	0.051	0.007	
Min	0.001								
Max	0.8								
STDEV	0.15								

Table 19: Cadmium Results (mg/l)

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	0.17	0.27	0.2	0.25	0.02	0.19	0.11	0.1	0.16
Flea Mkt	0.15	0.14	0.17	0.16	0.02	0.2	0.17	0.11	0.14
KCH	0.11	0.01	0.12	0.01	0.02	0.17	0.18	0.27	0.11
Sewage	0.2	0.06	0.09	0.04	0.09	0.08	0.24	0.26	0.13
Mean	0.16	0.12	0.15	0.12	0.04	0.16	0.18	0.19	0.14
Min	0.01								
Max	0.27								
STDEV	0.08								

Table 20: **Hardness Results (mg/l)**

Point	Wk 1	Wk 2	Wk 3	Wk 4	Wk5	Wk6	Wk7	Wk8	Mean
Dam	40	40	42	68	48	38	71	36	47.88
Flea Mkt	300	272	223	186	160	122	102	113	184.8
KCH	400	228	218	224	92	132	121	257	209
Sewage	300	312	194	220	152	162	159	242.5	217.7
Mean	260	213	169.3	174.5	113	113.5	113.25	162.1	
Min	36								
Max	400								
STDEV	96								

NB: wk= week; Min=Minimum value; Max=Maximum value; STDEV=Standard Deviation

Appendix B: Questionnaire for Industries and Institutions

This questionnaire was used to get the information on the type of wastes that were being produced by an institution or industry (public or private) in the area under study. It was also meant to find out if the institutions were aware of the importance of proper waste disposal by asking mechanisms in place for waste disposal. The information collected would be used by Toney Nyasulu for the purpose of the study of Msc. in IWRM at the University of Zimbabwe. The information would be divulged to nobody else. The respondent was to fill or answer orally.

1. Name of Industry/Institution………………………………………………………............

2. What activities are carried out in this industry?……………………………….....................
3. What type of wastes do you generate in your industry?…………………………………….
4. State the kinds of raw materials that are used in this industry……………………………..
5. How is the waste disposed of?.....…………………………………………………………….
6. Do the wastes end up in a nearby water body? Explain the channel………………………..
7. What measures do you take to avoid the entry of wastes into the river?......……………….....
8. Any toxic substances used or produced in your industry?………………………………...
9. Any technology in place to avoid or reduce the production of toxic/harmful substances in your industry? …………………………………………………………………………………
10. Are women involved in the issue of Health, Safety, Security and Environment (HSSE) in your organization?......…………………………………………………………………

Appendix C: Types of Anthropogenic Activities and wastes type produced that were polluting the water of Lilongwe River in the study area

Table 21: Anthropogenic Types

Anthropogenic Activity type	**Type of waste**	**Distribution**
Peri-urban settlements	Domestic	8
Hospital/clinical services	Health care wastes	12
Boarding schools	Solid wastes	8
Agricultural farms(big &small holder)	Agricultural field wastes and field run offs	11
Abattoir industry	Factory wastes waters	2
Dairy industries	Factory wastes and waste waters	3
Livestock farms	Animal dung	4
Poultry farms	Chicken manure and wastes	5
Produce markets	Solid waste and wastewater	7
Commercial markets	Solid wastes and waste waters	50
Chemical Laboratories	Toxic chemical wastes and solid wastes	7
Photography and plastic Plastic industries	Toxic chemical wastes and solid wastes	10
Motor vehicle Garage works	Oils and chemical spills	16
Small scale industries	Industrial solid and liquid wastes	47
Sand mining, brick moulding	silt	7
TOTAL		**197**

Appendix D: Questionnaire for Lilongwe City Assembly

This questionnaire was used to get the information of the responsibility of the Lilongwe city Assembly on river pollution concerns. The respondent would fill in the spaces or answer orally. The information would be used by Toney Nyasulu for the Msc. IWRM thesis Zimbabwe University). Acknowledgement of use would be made in the thesis and not treated as confidential

1. Any work or concern about the rivers within the city's boundaries?
   …………………………………………………………………………………………...........
2. Any health related concern emanating from the use of waters from Lilongwe river by the people within the city?……………………………………………………..........................
3. Who are more victims (women, men and children) of the health hazards emanating from the use of Lilongwe River?...
4. Any data available to the above question if yes, in terms of disease types occurred, when, and how many?………………………………………………………………………...
5. Any statistical data on the population within the city that rely on Lilongwe river as an alternative source of water supply?………………………...
6. Pollution is likely occurring in the Lilongwe River, what are the major causes of pollution in the Lilongwe River that are of a concern to the city Assembly?
7. …………………………………………………………………………………………
   ………………………………………………………………………………………..
8. What steps have been taken or are in the pipeline to prevent the pollution causes in Lilongwe?
   …………………………………………………………………………………………
9. Any link with the industries, ministry of health, ministry of environmental affairs in relation to the health hazards caused by the rivers within Lilongwe city?
   …………………………………………………………………………………………
10. How effective is the Kaume Sewage treatment in terms of its operation and in terms of its capacity to meet the demand of the city?...
11. Any other information that may be relevant to my topic of concern?..................................

Appendix E: Analysis of Variance (ANOVA)

One Sample Test **Test Value=0.05**

					95% Confidence of the Difference		
	t	**df**	**Sig.(2-tailed)**	**Mean Difference**	**Lower**	**Upper**	**Significance**
Turb_Sewage	3.774	7.000	0.007	154.700	57.762	251.638	
Turb_KCH	3.655	7.000	0.008	139.950	49.404	230.496	
Turb_Flea Mkt	3.655	7.000	0.008	135.075	47.683	222.467	
Turb_Dam	2.304	7.000	0.055	60.575	-1.588	122.738	Not sig.
Temp_Sewage	27.660	7.000	0.000	30.063	27.493	32.632	
Temp_KCH	34.180	7.000	0.000	29.888	27.820	31.955	
Temp_Flea Mkt	26.829	7.000	0.000	29.775	27.151	32.399	
Temp_Dam	15.428	7.000	0.000	30.938	26.196	35.679	
Susp_Soli.Sewage	4.462	7.000	0.003	105.950	49.800	162.100	
susp_Soli.KCH	4.221	7.000	0.004	90.825	39.947	141.703	
SuspSoli.FleaMkt	4.105	7.000	0.005	94.175	39.927	148.423	
Susp_Soli.Dam	2.957	7.000	0.021	31.575	6.324	56.826	
PO4_Sewage	1.662	7.000	0.140	0.057	-0.024	0.137	Not sig.
PO_4_Flea Mkt	1.133	7.000	0.294	0.130	-0.141	0.402	Not Sig.
PO_4_Dam	-11.076	7.000	0.000	-0.029	-0.036	-0.023	
PO_4_KCH	1.424	7.000	0.197	0.051	-0.033	0.134	Not Sig.
NO_3_Dam	-1.614	7.000	0.151	-0.020	-0.048	0.009	Not sig.
NO_3_Flea Mkt	2.056	7.000	0.079	0.108	-0.016	0.231	
NO_3_KCH	0.964	7.000	0.367	0.022	-0.032	0.076	Not sig.
NO_3_Sewage	1.323	7.000	0.227	0.035	-0.028	0.098	Not sig.
pH_Sewage	297.035	7.000	0.000	7.733	7.671	7.794	
pH_KCH	80.628	7.000	0.000	7.505	7.285	7.725	
pH_Flea Mkt	107.574	7.000	0.000	7.544	7.378	7.710	
pH_Dam	93.616	7.000	0.000	7.504	7.314	7.693	

One-SampleTest

Test value =0.5

	t	df	Sig (2-tailed)	Mean Difference	95% Confidence of the Difference		
					Lower	Upper	Significance
Pb_Sewage	-3.862	7.000	0.006	-0.060	-0.038	-0.015	
Pb_KCH	-2.841	7.000	0.025	-0.035	-0.063	-0.006	
Pb_flea Mkt	0.459	7.000	0.660	0.017	-0.071	0.105	Not Sig.
Pb_Dam	24.513	7.000	0.000	-0.045	-0.050	-0.041	
Faecal_Sewage	15.513	7.000	0.000	5298.700	4491.008	6106.39	
Faecal_KCH	6.807	7.000	0.000	2992.450	1952.987	4031.91	
Faecal_Flea	19.697	7.000	0.000	4893.575	4306.114	5481.04	
Faecal_Dam	8.345	7.000	0.000	1937.450	1388.456	2486.44	
Dis.Soli_Sewage	10.133	7.000	0.000	288.450	221.135	355.765	
Dis.Soli_KCH	6.060	7.000	0.001	291.075	177.500	404.650	
Dis.Soli_Flea	6.321	7.000	0.000	257.450	161.138	353.762	
Dis.Soli_Dam	9.457	7.000	0.000	63.075	47.305	78.845	
Dis.Oxyg_Sewage	10.109	7.000	0.000	5.761	4.414	7.109	
Dis.Oxyg_KCH	10.696	7.000	0.000	5.224	4.069	6.379	
Dis.Oxyg_Flea	16.292	7.000	0.000	5.221	4.463	5.979	
Dis.oxyg_Dam	13.031	7.000	0.000	5.760	4.715	6.805	
EC_Sewage	7.632	7.000	0.000	403.075	278.193	527.957	
EC_KCH	5.079	7.000	0.001	421.200	225.097	617.303	
EC_Flea Mkt	4.761	7.000	0.002	360.075	181.237	538.913	
EC_Dam	15.540	7.000	0.000	80.825	68.526	93.124	
COD_Sewage	13.256	7.000	0.000	143.000	117.491	168.509	
COD_KCH	5.625	7.000	0.001	96.638	56.016	137.259	
COD_Flea Mkt	9.538	7.000	0.000	89.513	67.321	111.704	
COD_Dam	7.160	7.000	0.000	108.938	72.960	144.915	
Cd_Sewage	2.693	7.000	0.031	0.083	0.010	0.155	

	t	df	Sig.(2-tailed)	Mean difference	Lower	Upper	Significance
Cd_KCH	1.832	7.000	0.110	0.061	-0.018	0.140	Not Sig.
Cd_Flea Mkt	4.561	7.000	0.003	0.090	0.043		0.136
Cd__Dam	3.418	7.000	0.011	0.103	0.032	0.174	
$CaCO_3$_Sewage	9.783	7.000	0.000	217.638	165.035	270.240	
CaCO3_KCH	6.049	7.000	0.001	208.950	127.273	290.627	
CaCO3_Flea Mkt	7.007	7.000	0.000	184.700	122.373	247.027	
CaCO3_Dam	9.788	7.000	0.000	47.825	36.272	59.378	
BOD_Sewage	15.13	7.000	0.000	25.313	21.357	29.268	
BOD_KCH	8.870	7.000	0.000	17.138	12.569	21.706	
BOD_Flea Mkt	15.96	7.000	0.000	17.538	14.932	20.143	
BOD_Dam	9.601	7.000	0.000	13.663	10.297	17.028	