

An Assessment of water quality along Mukuvisi River, Harare, Zimbabwe

by

BLESSING CHIMURIWO

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DECLARATION

I, Blessing Chimuriwo, hereby declare that this dissertation, which I hereby submit for the degree of Master in Environmental Science at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation does contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source.

I declare that where words from a written source have been used the words have been paraphrased and referenced and where exact words from a source have been placed inside quotation marks and referenced.

I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

____B.C_____ ____November 2016_____

B. Chimuriwo

Date

Dedication

I dedicate my dissertation work to my son Shekinah Chimuriwo. A special feeling of gratitude to my loving wife, Ireen Mangoma Chimuriwo whose words of encouragement and push for tenacity ring in my ears. My Siblings Virginia, Lazarus, Oscar, Abigail, Allen, Emeldah and Richard have never left my side and are very special. I also dedicate this dissertation to my many friends and my Pastors E and A. Chitekedza who have supported me throughout the process. I dedicate this work and give special thanks to Dr T. Madziyire for the encouragement throughout the Masters programme. God bless you all.

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Abbreviations

Ag	Mercury
Cu	Copper
BOD	Biological Oxygen Demand
DO	Dissolved Oxygen
EIA	Environmental Impact Assessment
EMA	Environmental Management Agency
Fe	Iron
Firle STW	Firle Sewage Treatment Works
LEAP	Local Environmental Action Plan
Mn	Manganese
NEP	National Environmental Plan
NEPS	National Environmental Policies and Strategies
Pb	Lead
POPs	Persistent Organic Pollutants
TFCC	Total Faecal Coliform Count
UN	United Nations
UNEP	United Nations Environmental Programme
UNICEF	United Nations International Children Emergency Fund
WHO	World Health Organisation
ZIMPHOS	Zimbabwe Phosphate Industry
ZINWA	Zimbabwe National Water Authority

Abstract

Human activities such as urbanisation, sewage treatment, industrialisation and agriculture represent major human interference in water resources. The water resources are affected both quantitatively as well as qualitatively by these activities. The impact of human interference in the Mukuvisi River catchment hydrology was studied by determining the concentration values of eight selected physico - chemical and biological parameters. These are pH, temperature, total nitrates, total phosphates, Dissolved Oxygen, Biological Oxygen Demand, lead, copper and Total Faecal Coliform Count. Seven sites were sampled along the river, from up the river in Mukuvisi woodlands up to the point where the river discharges into Lake Chivero. Analysis of the results obtained was undertaken using SPSS (paired sample T test) and descriptive graphs were drawn using Microsoft Excel 2010. Nitrates, phosphates, copper, lead and Total Faecal Coliform Counts were found to be higher than the Zimbabwe National Water Authority (ZINWA) maximum and World Health Organisation, 2011 (WHO) permissible standards from site 3 to site 7. Site 6 recorded the highest concentrations of all the measured parameters, except for pH and Dissolved Oxygen. Mean DO and BOD concentrations were 2.53 mg/l and 40 mg/l respectively at site 6. Mean total nitrates were 17.5 mg/l at site 6 above the ZINWA and WHO threshold of 10 mg/l. Site 6 also recorded a mean total phosphate of 5.9 mg/l which was above the ZINWA and WHO threshold of 0.5 mg/l. Mean TFCC was 992.6 mpn100ml⁻¹ higher than the threshold of nil according to ZINWA and WHO threshold. Site 3 recorded the mean DO and TFCC of 2.4 mg/l and 2.80 mpn100ml⁻¹ respectively. Site 2 had the lowest mean TFCC concentrations of 2.80 mpn100ml⁻¹, which did not differ significantly from the WHO and ZINWA threshold of nil at p<0.05. The quality of water in the river varied from site to site in direct relation to the intensity and type of human activities along the river course. Levels of all the water quality indicators increased after discharge from the Firlle sewage treatment plant at site 6 with the

exception of temperature and pH. Sewage effluents, agricultural runoff and industrial effluents were found to be responsible for the high nutrient levels and high metal concentrations in the river which in turn reduced DO levels and increased BOD.

Key Terms

Assessment; Water quality, Mukuvisi River, Harare, Zimbabwe; Challenges to water quality; Anthropogenic sources of pollution; Effects of water pollution; Health impacts of water pollution; point sources of pollution; non-point sources of pollution

CHAPTER 1

1.0 INTRODUCTION

Fresh water has become a scarce and pollution susceptible resource, which is of paramount importance in sustaining life and global development (UNEP, 2012). Fresh water is a critical component in fulfilling the needs of human beings, though it is only a small percentage of the total water available on our planet (Sharip, 2010). Sustainability and thriving of human communities is dependent on freshwater. Globally, lakes cover approximately 1% of land surface area with approximately 90% of this area accounted for by 250 of the world's largest lakes (Lewis, 2000). Statistics by UN - water (2013) reveal that about 2.5 billion people in 2012 were facing challenges in accessing improved sanitation facilities and more than 1.2 billion people live in places without sanitation facilities. Freshwater supply has proved to be the force that drives the growth and development of a country. Limited water supplies show low economic growth levels (Moghadam et al., 2009). There must be a close monitored relationship between sustainable use of water resources that contributes directly to sustainable economic development and maintaining the health of the environment that supports this development. Quality of water as a scarce resource and the quantity in a river system can bring benefits or can be a health hazard to the community (Ballator and Muhaudiki, 2001).

Harare, the capital city of Zimbabwe, draws its water from Lake Chivero which is fed by three rivers Marimba, Mukuvisi and Manyame; Mukuvisi River being the main tributary of Lake Chivero. The study was conducted along one of the major rivers in Harare (Mukuvisi River) to determine the river water quality and the possible impact of human activities prevalent in the catchment. Mukuvisi River, being the main River in Harare, passes through Msasa and Ardbennie industrial areas, and residential areas of Mbare, Parktown, Houghton

Park, Waterfalls, Highfields, Glen Norah and Glen View (Nyamangara et al., 2013). Most of the industries in Southerton area (south of the city) release their effluent in Mukuvisi River through a small canal along Simon Mazorodze Road in Waterfalls.

Lake Chivero is the major source of water supply in Harare and Chitungwiza. Pollution from urban runoff, sediments, industrial effluents and wastewater has been greatly blamed on the higher levels of pollution in the lake. This is due to the fact that the reservoir lies in the same catchment as the city of Harare. Developing countries are facing huge challenges in wastewater and pollution. Urban pressures due to urbanisation and rapid industrialisation with less upgrading of effluent treatment facilities and expansion, has exacerbated these challenges (Nyamangara et al., 2008). According to Urdal and Buhaung (2013), growth and disorders of urban areas in developing countries is primarily associated with corruption, political instability, civil conflicts, overburdening of available infrastructure and rise in standard of living. According to Mangizvo (2009), cities in developing countries such as Harare have been facing sanitation problems due to dilapidated effluent treatment infrastructure resulting in sewage outflows and sewage pipe bursts. Inorganic and organic pollution is exerting pressure on cities in Zimbabwe to produce large quantities and quality freshwater. Over abstraction of the resource in these areas is worsening the situation. This is especially true in the tributaries of hyper eutrophic Lake Chivero.

Organic and inorganic pollutants in water can be anthropogenic or occur naturally and can pose serious health effects to the communities around the water source. Chemicals in water can be both naturally occurring or introduced by human interference and can have serious health effects. Raw sewage has been evident on the streets and open storm drains in cities and towns across the country. In towns like Bindura (Mashonaland Central Province) especially in Chipadze Township, sewage burst is rampant due to population pressure in the town

(UNICEF, 2009). Mukuvisi River, a sub tributary of Lake Chivero and a main source of water for the animals in Mukuvisi Woodlands Nature Reserve Area, is increasingly becoming susceptible to anthropogenic pollution, capturing the attention of the park management because of the important biodiversity held within the park (Mbanje, 2014).

Water pollution has become a World - wide problem affecting most countries, both developed and developing, irrespective of national boundaries. Worldwide assessment (946 rivers) showed that, although most rivers displayed nitrogen export profiles (N fraction distributions) reflecting pristine conditions, nitrate export to rivers that passed through human settlements is related to human population density (Nyamangara et al., 2013; Bilgin, 2015). In most developing countries, especially in Africa, serious environmental and health concerns have been noted in areas close to rivers that pass through municipal, industrial, mining, domestic and agricultural areas as they are polluted (Emeka et al., 2009).

Water pollution is defined as the discharge of any liquid, solid, gaseous, pathogenic organisms or other substances into the water as will or is likely to create a nuisance or to render such water harmful, detrimental or injurious to health, safety or welfare of the public and the environment (Masere et al., 2012). Human activities such as mining, manufacturing industries, agriculture, poor management of urban water has greatly increased the rate at which water is polluted. Water pollution has not only affected aquatic environment but also human health and economic activities for example the nation of Zimbabwe suffered a cholera outbreak in 2009 and 2010, claiming lives of many people (Mangizvo, 2009; Lee, 2013). This was aggravated by poor sanitation and also domestic use of untreated water.

Most industries in Harare, Zimbabwe, have a tendency of illegally discharging untreated or partially treated effluent into the major urban rivers in their proximity such as Mukuvisi, Marimba and Manyame (Mufandaedza and Kamusoko, 2012). High cost of processing

effluent, less monitoring by relevant authorities and unavailability of processing facilities has led to the illegal discharge of effluent. Informal sector industries have mushroomed along some of the main rivers that drain into Lake Chivero, discharging their effluent directly into the water source (Mangizvo, 2009). The cost of dumping effluent is cheaper as compared to effluent treatment cost, promoting formal industries also to dump effluent into rivers (Muchena, 1998; Nyakungu and Mbera, 2013). Physicochemical analyses provide, at best, a fragmented overview of the state of aquatic systems, as sporadic or periodic sampling can reflect fluxes of effluent discharge (Bere, 2011). Total faecal coliform count (TFCC), metals such as lead and copper and physiochemical parameters such as pH, temperature, phosphates, nitrates, dissolved oxygen (DO) and biological oxygen demand (BOD) were tested.

1.1 Statement of the Problem

The water resource of Harare supports several livelihood activities, such as agriculture, bathing, washing, recreational, source of drinking water and is under constrain due to pollution resulting in poor water quality. Weak environmental regulatory institutions and human behaviour and practices in developing and under developed countries contribute to this decline in the river water quality (Blackman, 2010). Mukuvisi River acts as a sink for pollutants from point and non- point sources as it passes through industries and residential settlements. Due to prevalent water shortages, most of the Harare residents eventually consume the water from Mukuvisi River (Ndebele - Murisa, 2012). The water is also used for washing, bathing and agricultural activities.

The scope of the study was to assess the water quality in Mukuvisi River in terms of bacteriological and physicochemical water quality parameters. The water quality evaluations were done against the national and international river water quality standards (EMA, 2011; WHO, 2011) and the likely environmental health impacts discussed.

1.2 Justification

Water quality degradation has been on the rise around the globe and has been classified as a scarce resource. Water is life and has no proven substitute (Luo et al., 2006). The project seeks to contribute to the importance of improved water supply and aid in sanitation provision. A large number of people globally, especially in developing countries, lack access to adequate clean water, sanitation, and solid waste disposal services. Rapid industrialisation and urbanisation, with less of expansion and upgrading of existing treatment facilities has emerged as a huge challenge in developing countries on wastewater management. According to Bose et al. (2012), water quality and quantity have undergone major changes due to human activities. Most of the common sources of pollution and their impacts are related to domestic sewage, agricultural waste, industrial wastes and oil spills.

Higher loads of nutrients in aquatic ecosystem stimulate algal blooms a condition known as eutrophication. Natural processes such as weathering of rocks and soils from the surrounding catchment area of a river lead to an accumulation of nutrients in the water and associated sediments leading to a slower process of eutrophication (Mangizvo, 2009; Masere et al., 2012). Anthropogenic sources can greatly accelerate eutrophication by increasing the rate at which nutrients and organic substances enter aquatic ecosystems. The flow of nutrients and organic substances into aquatic ecosystems has been accelerated by urban runoff, sewage discharges, agricultural runoff and industries effluent discharges. Yuhong et al. (2009), stated that, pollutants from point and non – point sources can accelerate the growth of algae. Algal blooms can interfere with the recreational use of lakes, and the health and diversity of biotic factors such as aquatic plants, fish and animal life. Algae plants can form a layer on water surfaces and block sunlight, resulting in reduction in photosynthesis causing underwater grasses to die, consuming large amounts of oxygen during decomposition depriving aquatic organisms of oxygen.

Freshwater, being a relatively scarce resource and essential to human life, is also greatly affected by climatic change (Chinhanga, 2010). Climate change cannot only change the temperature but affects freshwater quality and quantity. Change in temperature has a great influence on the effects of pollutants. Biochemical reactions and bio magnifications can be speeded up by temperature increase around the globe. According to Bain et al. (2012), Southern African countries are facing drier periods by the year 2025. Predictions are that Lesotho, Mauritius, Tanzania and Zimbabwe will be water stressed, while Malawi and South Africa will face absolute water scarcity (Khedama, 2013). Southern African states, for example Namibia, Mozambique and parts of Zimbabwe and South Africa are currently experiencing low, erratic and unreliable rainfall patterns partly contributed by climate change (Nasimul, 2010). Sustainable utilisation of the aquatic ecosystems is, therefore, of best interest to living organisms, human beings included. Treating polluted water and dealing with unforeseen conflicts over water shortages may be very exorbitant for future generations. Thus the need to evaluate the prevailing water quality of Mukuvisi River.

Mukuvisi River water quality has a major bearing on a number of issues that affect the day to day lives of the citizens that rely on it for various uses. Harare, as a capital city of Zimbabwe, according to the 2012 national census, had a population of 1,468,767 (Central Statistics Office, 2013). In the absence of portable water from council taps, it is ironical that this polluted river has become a “life giver” to families of nearby low income residential flats of Shawasha, Matererini and Majubheki. It is a health hazard, but the only way to survive as Harare’s dire water situation continues unabated. According to Lee, (2013) buckets full of water from Mukuvisi find their way to big, black pots that are used to boil a delicacy called *mazondo* (trotters), which are popular with patrons who frequent unlicensed drinking spots and also cooking mealies. Environmentalists are warning Harare residents to avoid bathing

using water from the river because of fears that it has been contaminated by industrial and chemical wastes likely to cause skin infections (Mbanje, 2014). Residents, not only around Mbare but also other high density suburbs surrounding the river, use it for washing, swimming, agricultural activities such as watering vegetables. Due to economic hardships and high influx of people in Harare, some residents have frame shift accommodation along Mukuvisi River. They use the water for household chores and bathing which might contain pathogens. This increases the risks of water borne diseases such as cholera, dysentery and skin diseases (Mangizvo, 2009; Lee, 2013).

The tourism sector depends on facilities such as Lake Chivero which is fed by Mukuvisi River for drawing in revenue to both the city of Harare and national coffers. Activities such as canoeing, speed boating and fishing are hindered. Flora and fauna is also damaged by high levels of pollution. The current state of Mukuvisi River, and in turn Lake Chivero, will become more deterrent to tourism if unabated.

Car washes have of late sprouted along the Mukuvisi River and also pose a threat to Harare water (Mbanje, 2014). The car washes do not have appropriate structures and equipment that separates the oil sludge and water, so the dirty deposits from the cars flow unchecked into the city's water bodies (Mbanje, 2014). Considering the increase in numbers of ex - Japanese cars that are being imported into Zimbabwe, car washes and street garages now pose a serious health hazard to Harare residents. Drinking water sources of Harare are subjected to heavily polluted effluent that flows into its catchment and there is always need to constantly monitor the water resources quality and ascertain the possible human health and environmental impacts.

1.3 Research Hypothesis

- **H₀**: Water quality in Mukuvisi River is highly polluted and impacted by human activities.
- **H₁**: Mukuvisi River water is not highly polluted by human activities
- **H₀**: Mukuvisi River water quality levels (site means) are above the recommended levels of Zimbabwe National Water Authority (ZINWA) river water guidelines and World Health Organisation (WHO, 2011) aquatic life threshold values rendering it unsuitable for its multiple purposes.
- **H₁**: Mukuvisi River water quality levels (site means) are below the recommended levels of Zimbabwe National Water Authority (ZINWA) river water guidelines and World Health Organisation (WHO, 2011) aquatic life threshold values and is still suitable for its multiple purposes.

1.4 Study aim and Objectives

The aim of the study was to evaluate the water quality in Mukuvisi River using selected physicochemical parameters and evaluate the possible pollution sources and potential environmental impacts.

The study objectives were:

- To evaluate the water quality of Mukuvisi River with respect to selected biological and physicochemical water quality parameters, namely total faecal coliform counts (TFCC), temperature, pH, total phosphates, lead, copper, total nitrates, dissolved oxygen (DO) and biological oxygen demand (BOD).
- To identify point and non-point sources along Mukuvisi River through relating water quality to catchment activities.

- To evaluate the potential environmental impacts of the water pollution in Mukuvisi River based on national and international water guidelines and levels of determined parameters.

CHAPTER 2

2.0 LITERATURE REVIEW

Water is life and key to human life. There is no substitute of water to human, animal or plant life. “Agricultural activities, uncontrolled human populations growth, urbanisation and exponential industrial growth have negatively affected the quality of water World-wide”, says a UN-Water Statement on water quality (UNEP, 2012). This is worsened by climate change that is altering the global hydrological pattern. In most developing countries, water pollution has become a huge challenge (Yavini and Musa, 2013). Lack of adequate resources, rapid industrialization and urbanization, which is not matched by expansion and upgrading of wastewater treatment facilities, has contributed greatly to water pollution in developing countries.

Humans need clean water for healthy living but the resource is being threatened by poor management, over abstraction as well as ecological degradation. Millions of people around the globe cannot have access to clean water; as a result they are deprived of the important resource (Blackman, 2010). Water quality is a growing problem particularly in urban areas and close to industrial centres (Sakai et al., 2013; Vijay et al., 2014). Revision of water resource policies and constant evaluation has become of paramount importance in curbing the global water pollution (Grosse et al., 2012). Higher percentage of deaths and diseases in developing and under developed countries is as a result of water pollution. In India, 580 people die of water pollution related illness everyday (UN-water, 2013). China has the largest population around the globe and in 2007 alone; half of China’s population were facing problems in accessing adequate and safe drinking water (UN-water, 2013). Pollution is very high in most Chinese cities. Problems of water quality in developing countries are exacerbated by high pollution levels. In Italy a study of six rivers was conducted by

Barghigiani et al. (2010), four of the rivers were heavily affected by anthropogenic contamination that causes strong deterioration of the fluvial ecosystems and the environmental conditions necessary for fish life.

2.1 Sources of water pollution

Water quality and quantity have undergone major changes due to point and diffuse sources. Protection of aquatic ecosystem can be ensured by quantification and identification of the pollutants (Mudzori and Kusangaya, 2005). There are point and non-point water pollutant sources. Non – point sources cannot be easily identified and include urban storm water runoff as well as runoff from agricultural activities. Point sources can be attributed to human activities such as industrial effluent discharge and effluent discharge from treatment works. Developing countries face water pollution problems both from non-point and point sources. In most developed countries, there is less pollution from point sources as they have identified and solved point source pollution (Barros et al., 2013; Petersen, 2015). Non - point sources are identified as the major pollution sources in developed countries.

2.1.1 Point source pollution

The U.S. Environmental Protection Agency (EPA) defines point source pollution as any single identifiable source of pollution from which pollutant effluents are discharged, for example factories and sewage works (Hill, 2012). Water point source pollution can easily be identified which includes sewage treatment plants and factories (Yavini and Musa, 2013; Yang et al., 2012). Factories of concern include chemical and electronics manufacturing, oil refineries, leather turning and breweries. Some of these factories discharge their effluents directly into rivers while others treat the effluent before releasing it. Sewage treatment plants mostly discharge their treated effluent into a river or a stream. Point sources include industrial storm water, such as from construction sites as well as municipal storm systems.

Unregulated point source pollution disturbs the aquatic ecosystem and renders river water unsafe for human consumption. Point source pollution is easier to control than non-point source pollution. Most countries (developed) have managed to curb and reduce pollution from point sources (Yuhong et al., 2009; Yang et al., 2012 and Nyamangara et al., 2013). Sewage disposal in cities around Zimbabwe has been on the rise because of rapid urbanisation with less of infrastructural development.

In developing and underdeveloped countries, water quality is still much compromised because of point source pollution. In China, Songhua River, aquatic ecosystems are affected by point sources of pollution such as sewage and industrial effluent from cities along the river (Bilgin, 2015). Sporadic growth of urban areas in developing countries has resulted in high volumes of treated or partially treated effluents from municipal treatment works being discharged into rivers polluting both surface water and ground water (Somaya, 2011). Biological degradation occurs rapidly with the introduction of organic sewage effluents into the water courses resulting in the upset of ecological balance in the river. The aim of treating sewage before it is released into the water system is to remove contaminants from sewage or wastewater and separate sludge and a liquid effluent suitable for disposal to the natural environment.

Discharge of untreated sewage is the single most important source of pollution in surface and ground water in India (Mallapur, 2016). In urban areas of India, less than 30% of the generated sewage by millions of people in the urban setup flows through constructed sewage treatment plants. There is a large gap between generation and treatment of domestic waste water in India (Chand, 2015). India faces a huge problem in treatment of sewage; the treatment plants do not operate normally, treatment plants are not maintained and the treatment infrastructure does not support the numbers in the urban areas. Point source pollution is not only confined in urban areas but is also rampant in rural areas. The main

source of water pollution in rural areas is open defaecation. In developing and under developed countries lack of sanitation facilities has contributed much to water pollution.

2.1.2 Non - point source pollution

Non - point source pollution refers to the introduction into the environment of a substance which has a harmful effect but from a discrete source (Moghadam et al., 2009; Mudgal et al., 2010 and Ngidlo, 2013). Non - point pollution has a tendency of cumulative effect. The pollutants are gathered from a large area to have a huge impact. Main sources of non - point pollution emanate from urban surface runoff and agricultural activities. Agricultural activities include livestock and poultry breeding, cultivation of plants and fungi for food, as well as medicinal plants that do enhance and support human life (International Labour Organisation, 2010). Non - point source water pollution is discrete and widespread, affecting the aquatic ecosystem at any time (Zhang, 2005). Water quality of the aquatic ecosystems has been compromised and even reduced due to complex pollution caused by nonpoint source pollution (USEPA, 2010). Sources of non - point pollution include runoff from agricultural areas, urban runoff and runoff from construction sites. Non - point pollution emanates from different locations. Careless household waste management has also contributed to water pollution in most developing countries (Yalcin et al., 2008).

Reducing pollution from non - point sources has been problematic since the sources are diffuse. Aquatic biodiversity and ecosystem health is threatened by water pollution. Water quality is compromised thus safe guarding water resources is of paramount importance. Ecosystem services that support human livelihoods and aquatic biodiversity at local and global scale are required to curb water pollution. Developed countries such as United States have reduced total amount of water pollution by revamping the sewage treatment plants and controlling pollution from industries (Environmental Protection Agency, 2012). Non - point

source pollution remains the largest source of water quality problems in most developed countries around the globe (Beatley, 2014). Most of the aquatic bodies in developed countries like the United States are not clean enough to meet human basic needs such as consumption, bathing or even swimming (Somaya, 2011). In Nghia Lo village, Vietnam, environmental pollution from non-point source of small scale domestic smelting of automobile is of great concern (Sanders et al., 2014). Heavy metals including lead which are discharged into Red River delta in Vietnam have adverse effects on the health. Eighty percent of children tested had whole blood lead levels of 10 μ g/dL above recommended limits of 5 μ g/dL (Grosse et al., 2012).

2.2 Metal pollution

2.2.1 Heavy Metal Pollution

Heavy metal salts in solution constitute a serious form of pollution and are very harmful to aquatic organisms at very low concentrations (Kwon et al., 2012). Health of the aquatic ecosystem and people who depend on raw river water for consumption are at risk due to heavy metal pollution. Among the various pollutants affecting the aquatic environment, heavy metals constitute an important group of environmentally hazardous substances. A study on lake Yaounde, Cameroon by Kwon et al. (2012) showed that water pollution by heavy metals is one of the main pollution types that were causing stress on the biotic community and also the fish showed presence of heavy metals. Aquatic organisms are more exposed to the effects of high metal pollution since the aquatic environment is their habitat. For example, cadmium affects normal metabolic function of an organism by replacing zinc in many enzymes.

Lead and cadmium are non-essential metals to human health. Ingestion of toxic levels of cadmium may cause renal dysfunction, hypertension, arteriosclerosis, chronic diseases of old age and testicular tumours (Arimoro, 2010). Battery smelting craft practices in rural Vietnamese communities indicate that children are not adequately protected from resultant toxic metal exposures (Sanders et al., 2014). In Vietnam it was realised that most children in communities that had battery recycling had high levels of metals such as lead, manganese and mercury in their system (Zhang et al., 2011). These metals have widespread health effects. Exposure to lead has adverse human effects such as learning disabilities, language impairment and nervous system breakdown. These effects can affect national economic growth and also increase infant mortality rate. The associated economic losses are estimated up to \$319 billion per year in the United States of America (Sanders et al., 2014). Heavy metal pollution in rivers has been largely as a result of mining activities especially in developing countries (Yalcin et al., 2008). According to, Farrington (2000), increase of heavy metals in Tuul River and Selenga River in Northern Mongolia is as a result of gold mining in Zaamar Goldfields. The Selenga River Basin, which drains into Lake Baikal, should be recognised as one of the world's most impacted areas with regards to heavy metal loads, and it contributes 1% and 3% of the world flux of dissolved Fe and Pb, respectively (Farrington, 2000).

2.2.2 Trace elements

These are mineral chemical elements present only in minute quantities in a particular sample or environment needed for physiological functioning. The term “trace element” means smaller quantities though they play a major role in plant and animal physiological (Fairuz et al., 2013). Trace elements, for example the metals iron, molybdenum, fluoride and iodine, are essential to maintain the metabolism and health of the human body. Trace elements are also referred to as micro minerals, which form part of molecules such as enzymes and hormones.

Lack of these micro minerals can cause symptoms of nutritional deficiency. Copper as an essential trace element is recommended in human adults to facilitate the production of energy and neurotransmitters as well as energy production (Fairuz et al., 2013). Common trace elements exhibit toxicity when the conditions in the body reach higher levels. Iron helps in growth, immune functions and is a component of haemoglobin in blood, which helps in transportation of oxygen around the body. Higher iron overloads in humans increase the risks of liver problems and heart attack or heart failure (Grosse et al., 2012). Release of arsenic into the environment can either be natural or man - made. Natural sources of arsenic include volcanoes, ground water, mineral ore and geothermal processes whilst human activities such as mining, agricultural activities and industrial activities (smelting processes) release arsenic into the environment.

High concentrations of arsenic in water can have an adverse effect on health, causing cramping muscles, hair loss and diarrhoea (Awofolu et al., 2005). Trace metals dissolve easily in water and can be absorbed by aquatic organisms such as fish and crabs. Small concentrations of trace metals absorbed pose a higher risk on the physiology of aquatic organisms. Small concentrations can be toxic as trace metals undergo bio-concentration, which means their concentration in an organism is higher than in water (Solomon, 2008). Mercury undergoes bio-magnification in aquatic environments. Each level of food chain carries much higher mercury concentrations than its prey as a result of bio-magnification in aquatic environments. Mercury affects human physiology and nervous system. Muscle weakness, blurred vision, memory and peach loss and also death are some of the effects of mercury on human health. Cadmium also poses higher risks to both humans and aquatic organisms. Cadmium hinders aquatic plant growth, as a result disrupting ecosystem as plants are producers at the initial point of most food chains.

2.3 Effects of water pollution

Water quality of water resources worldwide has undergone major changes that often have far reaching consequences on human and environmental health. Most industrial effluents are toxic, containing pollutants of concern ranging from organics to inorganic pollutants.

Discharge of untreated or partially treated effluent into water bodies could have direct deleterious effects to aquatic life.

2.3.1 Effects on the natural environment

Nutrient compounds in aquatic ecosystem often stimulate excessive plant growth. The two most common nutrients reaching water systems are nitrogen and phosphorus. Phosphorus and nitrogen content in aquatic ecosystem mostly emanates from anthropogenic sources such as runoff from agricultural areas, domestic waste water and effluents discharged by industries. Nutrients increase in aquatic environments results in eutrophication (Abbasi and Abbasi, 2011; Barghigiani et al., 2010 and Emeka et al., 2009). Anthropogenic activities can accelerate the process of eutrophication by increasing the rate at which nutrients find their way into water bodies. Nutrient enrichment (phosphates and nitrates) in aquatic ecosystem stimulate algae blooms. Sources of nitrates mostly include discharge of partially treated and untreated sewage and fertilizers that are applied in the fields close to the water sources. Surface runoff will carry the nitrates to the water bodies. Lowering levels of nitrates in soil using good agricultural practices results in less nitrates reaching and polluting water sources. Excess nutrients running off the land and reaching surface waters can accelerate eutrophication (Ndebele – Murisa, 2012; Zhang et al., 2011 and Nyakungu and Mbera, 2013). A decrease in species diversity, increase of turbidity, reduction of oxygen concentrations, anorexic conditions (low oxygen content) and changes in dominant biota in the aquatic environments is as a result of eutrophication. Algal blooms bring about changes that upset the

natural balance of plant and animal life in an aquatic setup (Utete and Kunhe, 2013). The aquatic ecosystem is also greatly affected. Algal blooms have detrimental effects on uses of water such as recreation, fisheries and tourism (scenic values). When algal blooms decay, they cause an offensive smell and the process of decay uses up most of the oxygen effectively suffocating other aquatic life. Aquatic organisms ranging from crabs, fish and other sedentary animals are affected to the point of death by very low levels of dissolved oxygen in their habitats (Ndebele - Murisa, 2012 and Ngidlo, 2013).

2.3.2 Health impacts of water pollution

Water pollution has been on the rise reaching alarming levels in aquatic bodies. Urban pressures such as industrialisation, urban population increase, slow infrastructural development and higher sewage flow choking treatment works have led to an increase in effluent and waste discharge. Water pollution as a result of waste discharge from industries and sewage treatment plants has contributed greatly to public health problems especially in developing countries (Urdal and Buhaung, 2013; Luzio and Frank, 2013 and Kelishadi, 2012). Pollutants have various adverse health effects from early life such as bacterial, viral and protozoal infectious diseases and mental disorders (Moghadam et al., 2009 and Loux, 2011). Pesticides and heavy metals such as lead and mercury can even damage the central nervous system and cause cancer.

Pollutants such as nitrates restrict amount of oxygen in the brain and cause blue baby syndrome. Untreated sewage high in nutrients and other pollutants has contributed to high deaths rates especially in underdeveloped and developing countries (Mudgal et al., 2010). Organic pollutants such as agricultural pesticides and industrial chemicals pose serious threats to human health. Organic pollutants can easily find their way into water bodies either

accidentally or intentionally discharged into the aquatic systems (Arimoro, 2010). Organic pollutants can affect the aquatic organisms' such as fish and crabs, and this results in compromising the ecological interactions. The pollutants can accumulate in these organisms which become a health hazard to consumers affecting food chains. This process is known as "bio-magnification" (Sanders et al., 2014).

2.4 Challenges to water quality

Water quality can be categorised in reference to its intended purpose (Masere et al., 2012). Polluted water in terms of human consumption could still be used in other areas such as industrial and agricultural activities. Due to high levels of pollution, polluted water is rendered un-usable. In most industrialised countries, river water is so polluted that it cannot be used even in agriculture (Somaya, 2011). Anthropogenic activities such as agriculture, domestic and industrial uses as well as natural processes are affecting water quality (Somaya, 2011). Zimbabwe, due to rapid urbanisation and poor infrastructure maintenance has been experiencing burst sewer in most of its towns and cities. Small mining towns like Bindura in the central of Zimbabwe have experienced a lot of burst sewer (UNICEF, 2009). Dormitory towns such as Norton, Ruwa and Chitungwiza, outside Harare city, have been growing rapidly in terms of population with less infrastructural development in services such as water and sewage reticulation. Sewer systems are under strain, handling about four times more sewage than its designed capacity (Mangizvo, 2009 and Ndebele - Murisa, 2012).

Water-borne pathogen contamination in ambient water bodies and related diseases are a major water quality concern throughout the world (Pandey et al., 2014). Water-borne diseases (i.e., diarrhoea, gastrointestinal illness) caused by various bacteria, viruses, and protozoa have been the causes of many outbreaks. In developing countries, such as those in Africa, water-

borne diseases infect millions. According to World Health Organization (WHO), each year 3.4 million people, mostly children, die from water-related diseases (WHO 2011).

Raw sewage could be a source of diseases. For example, untreated sewage is likely to have been the source of the bacteria *Vibrio Cholerae*, the main cause of Cholera. A total of 4, 282 deaths were recorded in 2009 in cities around Zimbabwe (WHO, 2009). The main cause being burst sewage flow contaminating water. In Maputo (Mozambique), in mid 1980s, there was a cholera epidemic that was linked to raw sewage disposal (Fatoki et al., 2004). Effects of pathogens in rivers can be traced several kilometres away from the point source. This could lead to pollution of water bodies on a large area which in turn can impair the reproduction in fish, retard their growth or even kill them.

2.4.1 Challenges to Mukuvisi River water quality

Urban agriculture is a major source of non-point water pollution in Zimbabwe. In Zimbabwe, during the 2008 to 2009 cropping season, about 50% of households in the capital city (Harare) grew maize to supplement their food requirement (Zimbabwe Vulnerability Assessment Committee, 2009). A wide variety of crops has been grown along the banks of Mukuvisi River for easy irrigation such as maize, tomatoes and vegetables. Mukuvisi River water was discovered to be carrying a lot of pollutants such as heavy metals and nutrients. Water pollution in Mukuvisi River primarily comes from industrial activities in Msasa, Graniteside and Southerton industrial areas, runoff from the city centre area, and treated sewage effluent from Firlle sewage works. Economic challenges in Zimbabwe have resulted in municipalities failing to maintain sewerage infrastructure and waste collections (Nyamangara et al., 2013; Sato, 2013). Industries have a tendency of discharging illegally effluents into the major rivers due to exorbitant prices in effluent processing and lack of standardised processing plants. Lack of prohibitive penalties and inadequate pollution

monitoring programmes results in industries dumping effluent in the river. Polluted water is used for various purposes along the river in activities such as washing, watering vegetables and drinking by those who do not have access to piped clean water increasing risks of diseases (Masere et al., 2012).

Urbanisation and industrial sprawl in Harare, with poor and slow planning to upgrade existing treatment plants, led to overloading and bursting of sewer pipes (Masere et al., 2012). Current treatment capacity of sewage stemming from the main urban areas is insufficient to maintain water quality standards. Nhapi and Tirivarombo, (2004) reported that deterioration of water quality in most rivers around Zimbabwe has been compromised by discharge from sewage treatment plants greatly affecting water treatment resulting in an increase in water treatment cost. There were massive fish deaths in Lake Chivero (March to April 1996), due to high levels of ammonia from sewage, compounded by low levels of oxygen (Masere et al., 2012).

Effluent from sewage treatment plants being discharged into rivers feeding Lake Chivero has caused problems of eutrophication. Water hyacinth is a weed that causes a reduction in Dissolved Oxygen (DO) and light levels in water. Water hyacinth can also increase evaporative water losses from reservoirs and water bodies by as much as 3.5 times (Masere et al., 2012), representing an enormous economic loss, in terms of water available for economic production for example irrigation. Human health, economic activities as well as biotic organisms are all affected greatly by water quality degradation around the globe (Alvarez et al., 2008; Bose et al., 2012). There has been high incidence of water borne diseases in areas of Chitungwiza and Norton as a result of untreated sewage finding its way into drinking water sources (Masere et al., 2012). This was caused by poor effluent management, dilapidated sewage treatment works and a continuous wastewater generated by a drastic

increase in the population of Harare (Moyo and Mtetwa, 2002). This drastic increase is not matched with upgrading of sewage treatment plants.

CHAPTER 3

3.0 METHODOLOGY

3.1 Study Area

The Mukuvisi River study area was described in detail by Nyamangara et al. (2013). The river starts around Mukuvisi woodlands in the city of Harare. Upstream, it is fed by small rivulets which contribute substantially to the inflow. The river passes through industrial areas as well as residential areas. Industrial areas include Msasa, Ardbennie and Southerton before discharging into Lake Chivero. Residential areas include old high density suburbs such as Mbare, Highfields, Glen Norah and Glen View areas as well as medium density areas such as Parktown, Houghton Park and Waterfalls. A lot of human activities characterize the river catchment area. Head water catchment area used to be characterised by wetlands, which are now being transformed into agricultural and settlement area. The transformation of the wetlands into agricultural and residential areas results in decreased flows, erosion and eutrophication in the Mukuvisi River (Utete and Kunhe, 2013).

Mukuvisi River drains through Mukuvisi Woodlands Nature Reserve, a relatively undisturbed area. Industrial effluent from the Msasa industry is discharged after the Mukuvisi woodlands. The main source of Harare water is Lake Chivero which is fed by three rivers Marimba, Manyame and Mukuvisi. Marimba River flows through University of Zimbabwe and northern and western parts of Harare's commercial sector. It also receives effluent from Crowborough sewage treatment plant, Workington industrial site and some residential areas. Manyame River stretches from a dormitory town Chitungwiza through the western side of Harare and discharges into the Lake. Upper Mukuvisi receives effluent from Msasa industries such as Zimbabwe phosphate industries (fertiliser manufacturing plant) and several other 'sundry' industries in the expanding Msasa Industrial Area as well as Msasa residential park

which is close to Mukuvisi River (Ndebele - Murisa, 2012). Around Southerton area, industries release their effluent into Mukuvisi River. It also flows through Houghton Park and Highfields residential areas close in Southerton area. The river flows through Glen Norah and Glen View areas before receiving effluent from Firlle Sewage Works, the major sewage plant in Harare serving the eastern, southern and south western residential locations, city centre and industrial areas. Firlle sewage treatment plant uses an activated sludge process and biological treatment of the waste water it receives from around Harare. Mukuvisi River discharges into Lake Chivero. Harare water for human consumption is primarily drawn from Lake Chivero.

Table 3.1: Description of the study sampling sites.

Site	Designation	Mukuvisi River physical water quality	Coordinates
1.	Close to Mukuvisi Woodlands	Clear flowing water	17°51'50" S 031°01'47" E
2.	Mutare road bridge	Oil films, not clear with debris and flowing slowly	17°50'38" S 031°06'75" E
3.	Discharge point of Zimbabwe Phosphate Industries	Not clear, slightly milkfish and smelly	17°51'14" S 031°07'53" E
4.	Close to Glen Norah High Residential Area	Clear flowing water with debris and flowing	17°54'30" S 030°58'22" E
5.	Before Firlle Effluent treatment plant	Not clear, with a lot of debris, flowing slowly	17°54'28" S 030°56'53" E
6.	After Firlle Effluent treatment plant	algal growth with a slimy appearance, and producing an odour	17°58'47" S 030°50'45" E
7.	Before confluence with Marimba River	algal growth with a slimy appearance, producing an odour and flowing slowly	17°58'52" S 031°50'41" E

Table 3.1: Site description location of activities and the River water quality

3.2 Sampling

Grab sampling method was used for water sample collection. Samples were taken mostly where water was flowing and into sterile sampling bottles. Sampling bottles (500ml) polyethylene were used.

10% nitric acid was used to clean the bottles overnight. The cleaned bottles were rinsed with deionised water in the laboratory before field sampling. Rinsing was also done at the site twice using Mukuvisi River water before sampling. Temperature and pH were recorded immediately at the site. All samples were tightly sealed and immediately taken for laboratory analyses at City of Harare, Cleaverand House (Water Quality Laboratory) for immediate analysis.

Sampling was conducted from December 2014 to April 2015 (5 months). Samples were taken once every month. Two grab samples were taken and analysed per site and the results presented are the mean for the two samples per site.

3.3 Water Quality parameters analysis

3.3.1 In situ measurements

Three parameters were measured *in situ* at the sampling sites and these are DO, pH and temperature. pH meter was used to measure pH, temperature was measured with a thermometer and Dissolved Oxygen (DO) by the OxySense Optical Dissolved Oxygen meter. BOD was determined using the 5 day incubation at 20⁰C (Stankovich et al., 2012).

3.3.2 Total Nitrate Determination

Direct colorimetric method was used to measure total nitrate concentrations in river water as per standard method (American Public Health Association APHA, 2013). Distilled water (50ml) was added to 5ml of sample volume and placed on a hot plate stove to dryness. Freshly prepared Phenol - Disulphonic acid (PDA) (2ml) was allowed to react with the nitrate sample producing a yellow nitro-derivate alkaline solution and 10ml of concentrated ammonium hydroxide (NH_4OH) was gently added. Sample absorbance of samples was measured colorimetrically with the aid of a visible spectrophotometer set as determined at 520nm. Colour intensity produced follows the Beers Law, which was used to compare total nitrate concentration in the sample. The total nitrate concentration is directly proportional to the colour produced and its intensity.

3.3.3 Total Phosphate Determination

Colorimetric method using stannous chloride was used to measure total phosphate concentration (APHA, 2013). Acid persulfate was used to digest the samples. Phenolphthalein indicator (0.05ml) and 1ml of H_2SO_4 were added to 50ml of sample size. The solution was boiled for 30 to 40 minutes until volume of 10ml was reached. During colorimetric development, 4.0ml of molybdate reagent and 0.5ml of stannous chloride reagent was added. Colour intensity was measured photometrically at 690nm using distilled water as blank. A calibration curve was used to determine the concentration of total phosphates. Calibration curve was prepared using 5ppm standard solution and the persulfate digestion and colorimetric development procedures followed.

3.3.4 Total faecal coliform count (TFCC) determination

Total faecal coliform counts (TFCC) were tested by standard plate counts (Feng et al., 2012). Two samples were taken from each sampling site using sterilised bottles of 200ml. Samples were transported on ice to the laboratory and stored at 4⁰C in a refrigerator and was tested within 24 hours. Sample of 100ml was filtered through a 0.45µm. The membrane retains the bacteria (total faecal coliform) on its surface and was transferred to an m-Fc agar plate and incubated for 24 hours at 44⁰C to allow the bacteria to multiply and form colonies. Number of colonies was counted and linked directly to faecal bacteriological content of river water using the formula: Coliform per 100ml = (Number of faecal coliforms counted) / (number of mL of sample filtered) × 100.

3.3.5 Lead and Copper determination

Lead and copper were determined using atomic absorption spectrometry (APHA, 2013). There are various methods that can be used to analyse metal samples. Atomic Absorption Spectroscopy (AAS) was used as it has acceptably higher degree of precision and accuracy. Atomic absorption spectroscopy relies on the Beer-Lambert law to determine the concentration of a particular analyte in a sample. The absorption spectrum and molar absorbance of the desired sample element are known. A known amount of energy is passed through the atomized sample, and by then measuring the quantity of light, it is possible to determine the concentration of the element being measured (Stankovich et al., 2012). Digestion of the samples was done using nitric acid (HNO₃) to bring the metallic compounds in suspension to solution. Digestion removes interfering ions and destroys organic matter in samples. Water samples were treated with nitric acid and perchloric acid and heated until hydrochloric acid (HClO₄) appeared. Digested samples were left to cool down and were

filtered. Distilled water was added to the digested samples. Solution of (HClO_4) was formed and used for the analyses of lead and copper using AAS.

3.4 Statistical Analysis

Paired Sample t test, was used to compare physicochemical variables among sampling sites. The samples were tested for normality and compared to local Zimbabwe National Water Authority (ZINWA) water quality guidelines and World Health Organisation (WHO, 2011) aquatic life threshold values. Data from water sample analysis was entered into Excel spreadsheet. A descriptive graph of each variable was drawn using Microsoft Excel 2010 version. A statistical program known as SPSS was used for statistical analysis. The difference of means was compared on all sampling sites. During analyses, multiple comparisons using the least significant test in which the level of confidence was set at 95%. A paired Sample t Test was used to determine the mean, standard deviation, standard error and the least significance difference.

CHAPTER 4

4.0 RESULTS ANALYSIS

4.1 Sampling sites and observed activities

The seven sites were chosen because of their easy accessibility and that they seemed to be representative of the different human activities profiles or pollution inputs along the stretch of the river channel. Mukuvisi River receives pollutants from both point and non-point sources. Mukuvisi River catchment is spread around the city of Harare. Almost all of the river catchment is covered by the City of Harare. The river flows through Mukuvisi woodlands, an area protected by National Trust of Zimbabwe. Mukuvisi woodlands is close to Mabvuku and Tafara residential areas. Agricultural activities such as crop farming, release agricultural chemicals and fertilizers that runoff into the river. Waste disposal is also rampant close to the river. Some of the anthropogenic activities taking place in this area were washing and bathing.

The water levels in the river were extremely low at site 2 during the April, 2015 visit. Sampling site 2 had visible traces of oil films in the water during sampling. The source of this oil could possibly be non-point sources and most likely from urban runoff containing motor vehicles oil. Oils have huge detrimental effects on the health of the river such as death of marine organisms due to (e.g. poor light penetration and toxicity of petrochemical components). Mukuvisi River, within its upper reaches, receives effluent not only from Zimbabwe phosphate industries a fertilizer manufacturing plant, but from other big and small industries within Msasa Industrial area. The sundry industries include paper mills, abattoirs, textiles, steel and clothes manufacturing. Mukuvisi passes through Coca Cola Company of Zimbabwe and residential areas close by such as Braeside and Hillside. The river meanders down through old high density residential areas of Mbare, Houghton Park, Waterfalls,

Highfields, Parktown and Glen Norah. In Harare's densely populated suburb of Mbare residential area, which is one of the oldest residential areas, a lot of informal industrial activities such as pottery, basketry, leather working as well as shoe repairs have mushroomed. These informal industrial areas release some of their waste products into or close to Mukuvisi River.



Fig 4.1: Illegal dumpsite observed at Mbare (close to Matererini flats and Mukuvisi River)
(Photo taken by Researcher in February 2015)

Rampant illegal waste disposal occurs all along the catchment area. Waste from the dump sites close to the river finds its way into the river, and often is accompanied also with seepage from toxic wastes. These waste materials will be washed into the main source of water in Harare, the Mukuvisi River. Fig 4.1 shows a typical example of how wastes are dumped illegally within the catchment and by the river vicinity. More of illegal dumpsites were noted, not only in Mbare but around the high density suburbs as the city is failing to collect refuse on a daily basis.

In addition to pollution from the Mbare informal industries and wastes disposal, the river banks in most areas are used as latrines and for washing and bathing mostly by homeless people. The river further flows through Southerton Industrial area receiving effluent from industries and residential areas such as Houghton Park and Highfields. Industries sited close to the catchment include abattoirs, textiles, steel and brewing industries (Chibuku breweries). These industrial processes produce large quantities of suspected untreated or partially treated effluent into the environment (Masere et al., 2012). Stream bank cultivation, which is uncontrolled and rampant, was observed in residential areas such as Glen Norah and Highfields. Agricultural activities such as poultry and crop farming were seen close to the river course. Illegal dumping of wastes close to the river was also rampant in these residential areas. These areas were characterised with sewage bursts and surface flow as shown in fig 4.2.



Fig 4.2: Sewage flow observed in Glen Norah (close Mukuvisi River) sampling site 4 (Photo taken by Researcher in March 2015)

The sewage flowing in the streets of the residential areas such as Glen Norah will eventually be washed as surface runoff into storm water drains or flows directly into the river. This has been as a result of pressure on the infrastructure due to higher populations in these suburbs. After Glen Norah and moving into Glen View area, informal industrial activities close to the river were noted. These industries, because of lack of refuse collection system, end up dumping their waste into the river. Firlle Sewage treatment works, which is one of the major sewage treatment plants for the city of Harare discharges partially treated or treated effluent into the river before site 6. Agricultural activities such as crop farming could be seen after sampling site 6 before the confluence with Marimba River. This lower part of Mukuvisi River is characterised by intensive livestock and crop farming especially close to the Pension farm.

4.2 Analysis of water quality parameters

4.2.1: pH and temperature determined at the sampling sites along Mukuvisi River

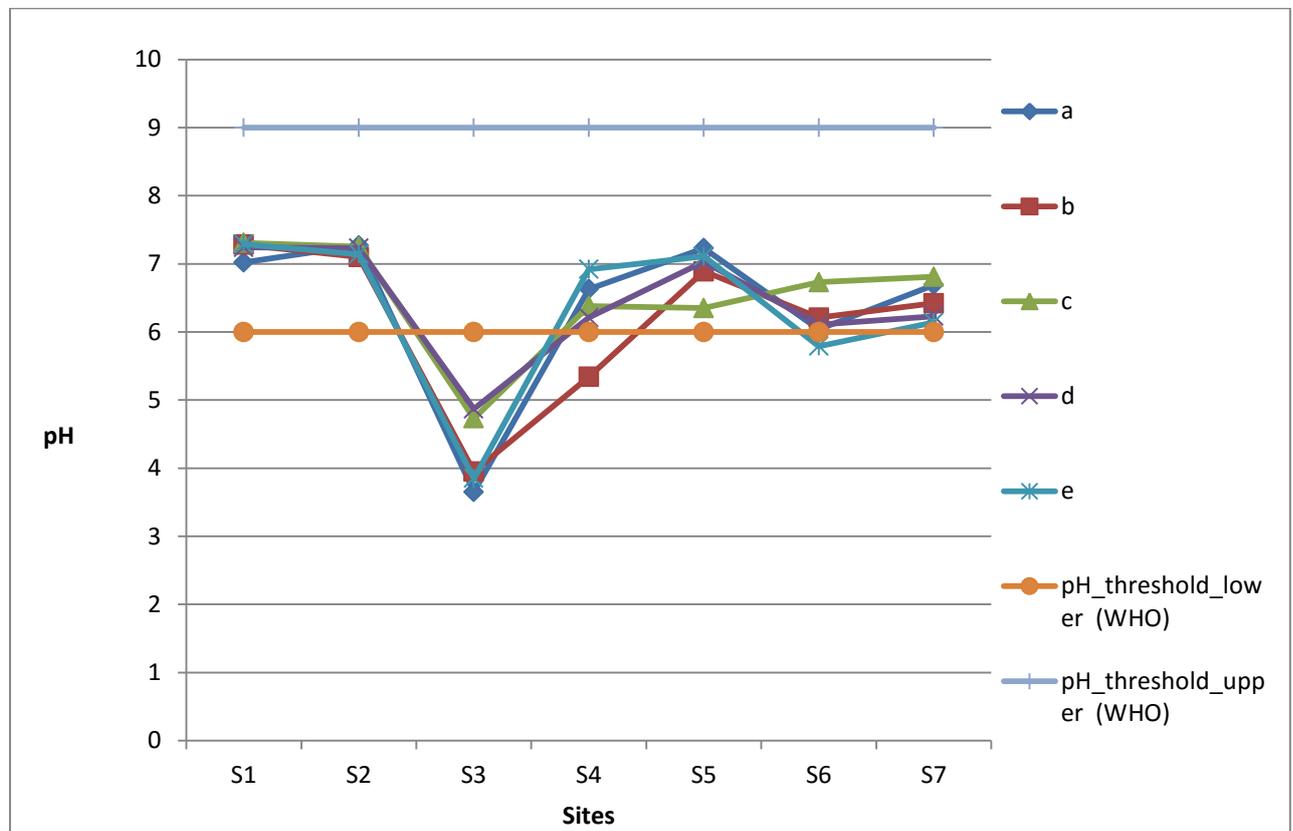


Fig 4.3: Water pH as determined *in situ* over the different sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
b – sampling interval 2 (19/01/15)
c – sampling interval 3 (23/02/15)
d – sampling interval 4 (25/03/15)
e – sampling interval 5 (28/04/15)

The pH results did not show much variation between sites and over time, except at site 3. All the sites had mean pH values within the ZINWA and WHO range of 6 to 9 units except site 3 as shown in fig 4.3. Site 3 consistently, had pH values lower than the WHO and ZINWA thresholds lower limit. The month of February and March recorded pH which was less acidic at site 3. The pH was slightly higher than the site mean of 4.2 units. This might have been aided by the dilution effect of raining water. Site 1 and 2 recorded close means of 7.22 and

7.20 units respectively. The pH ranged from 3.65 to 7.31 along the river. All the sites had values below the WHO and ZINWA threshold upper limit of 9.

Table 4.1: T-test analyses for water pH at selected sampling sites along Mukuvisi River

pH	Site mean	Threshold	Mean	Std. Deviation	95% Confidence Interval of the Difference		Sig. tailed)	(2-
					Lower	Upper		
S1	7.2280	6	1.22800	.11904	1.08020	1.37580	23.067	
S2	7.1980	6	1.19800	.07396	1.10617	1.28983	36.220	
S3	4.210000	6	-1.7900000	.5515433	-2.4748314	-1.1051686	0.003	*
S4	6.2960	6	.29600	.59777	-.44623	1.03823	1.107	
S5	6.9220	6	.92200	.34281	.49634	1.34766	0.064	
S6	6.1760	6	.17600	.34638	-.25409	.60609	0.136	
S7	6.4580	6	.45800	.28822	.10013	.81587	0.553	
S1	7.2280	9	-1.77200	.11904	-1.91980	-1.62420	-33.286	
S2	7.1980	9	-1.80200	.07396	-1.89383	-1.71017	-54.481	
S3	4.210000	9	-4.7900000	.5515433	-5.4748314	-4.1051686	-19.420	
S4	6.2960	9	-2.70400	.59777	-3.44623	-1.96177	-10.115	
S5	6.9220	9	-2.07800	.34281	-2.50366	-1.65234	-13.554	
S6	6.1760	9	-2.82400	.34638	-3.25409	-2.39391	-18.230	
S7	6.4580	9	-2.54200	.28822	-2.89987	-2.18413	-19.721	

Significance level: 5% * (p < 0.05 = significantly different)

From table 4.1, the water was acidic with the pH below 5 and a site mean of 4.21 at site 3. The river pH mean was above 6 (slightly acidic) from site 4 to site 7. Site 1 and site 2 recorded mean pH values above 7 (slightly alkaline). There was a significant statistical difference (p < 0.05) at site 3 (mean) with reference to WHO and ZINWA lower threshold. The pH at site 3 was proved to be lower than the recommended lower threshold of 6 mg/l. The lower pH values might be as a result of acidic effluent discharges emanating from industrial activities surrounding Msasa area. The industrial activities include fertilizer manufacturing, food processing, and abattoirs. However, there was no significant difference (p < 0.05) from all other mean pH on all other sites in Mukuvisi River in relationship to

ZINWA and WHO water quality lower threshold. No significant difference was noted in reference to the upper threshold of pH 9. All sites fell within the upper threshold of pH 9.

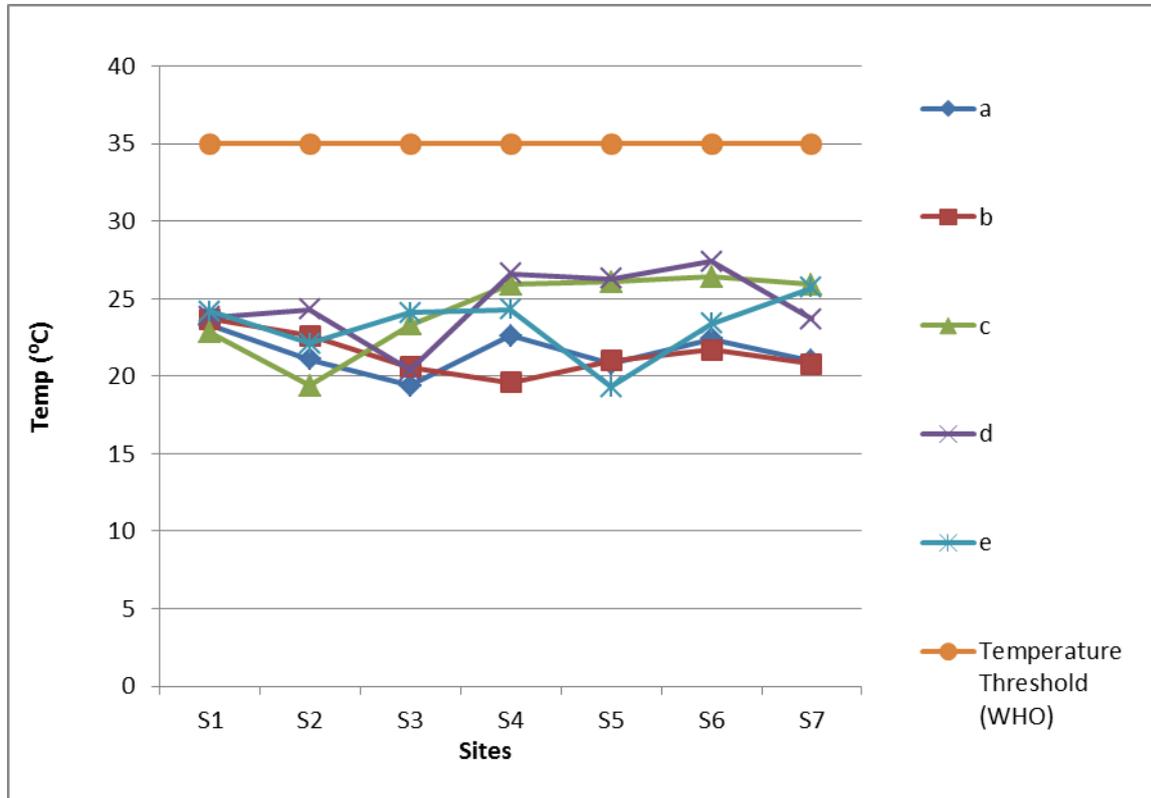


Fig 4.4: Water temperature (°C) as determined over the different sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

The temperature of the river did not show much variation across the river profile. The temperature range was between 19.4°C to 27.4°C. The temperature was within the ZINWA and WHO threshold of 35°C as shown in fig 4.4. This shows that the temperature values were all acceptable, below ZINWA and WHO threshold.

Table 4.2: T-test analyses for water temperature (⁰C) at selected sampling sites along Mukuvi River

	Site	Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
						Lower	Upper		
Temp	S1	25.4666667	35	-9.5333	4.6945	-14.4599	-4.6067	.005	
	S2	24.0833333	35	-10.9166667	5.5890667	-16.7820325	-5.0513009	.005	
	S3	23.800000	35	-11.2000000	5.7782350	-17.2638858	-5.1361142	.005	
	S4	25.6666667	35	-9.3333333	5.2175345	-14.8088000	-3.8578666	.007	
	S5	24.750	35	-10.2500	5.8078	-16.3450	-4.1550	.008	
	S6	26.050	35	-8.9500	4.9257	-14.1193	-3.7807	.007	
	S7	25.35	35	-9.6500	5.2133	-15.1211	-4.1789	.006	

Significance level: 5% * (p< 0.05= significantly different)

From table 4.2, there was no significant difference in temperature across the river system (P<0.05). This shows that the temperature was within the ZINWA and WHO threshold of 35 ⁰C.

4.2.2 Total nitrate and total phosphate concentrations determined during sampling period (December 2014 to April 2015)

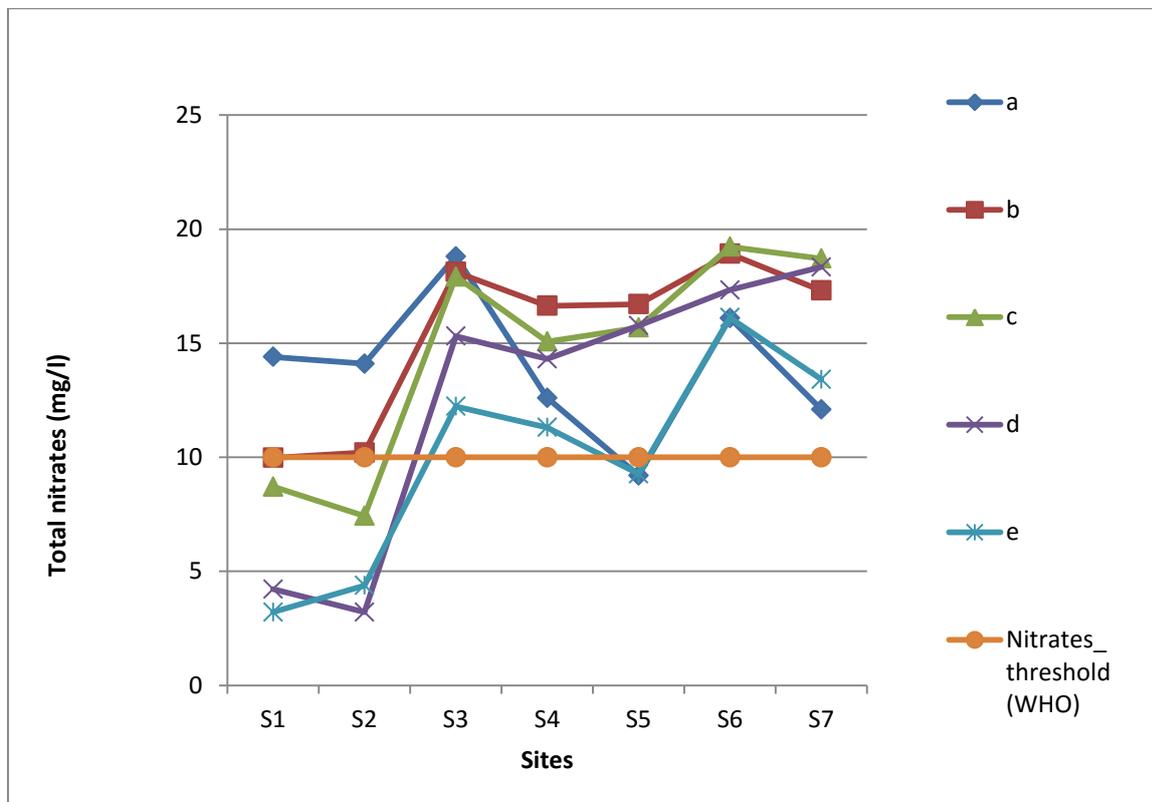


Fig 4.5: Water total nitrate values as determined over the different sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

The total nitrate concentrations increased with sampling points down the river. The concentrations of the total nitrates were low at site 1 and 2 and gradually increased above the threshold values as shown in fig 4.5. The total nitrates ranged between 3.21 mg/l (upper stream) to 19.23 mg/l (downstream). Sampling interval 5 for all sites showed less concentration of total nitrates as compared to the other sampling intervals of sampling across the river system, with site 1 reading as low as 3.21mg/l. Sampling interval 3 recorded the highest average concentration of total nitrates as compared to the other sites. Sites 1 and 2 recorded concentrations below the ZINWA and WHO thresholds of 5mg/l only on sampling

interval 4 and 5 of sampling. This might be due to the dilution effect as it was raining during the sampling period. Sampling intervals 1 and 2 had concentrations of total nitrates which were above the recommended limits on site 1 and site 2. Site 6 recorded the highest mean total nitrate concentration of 17.54 mg/l.

Table 4.3: T-test analyses for water total nitrate levels at selected sampling sites along Mukuvisi River

Total Nitrates		Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
						Lower	Upper		
	S1	8.104000	10	-1.8960000	4.5432070	-7.5371366	3.7451366	.404	
	S2	7.866000	10	-2.1340000	4.4265596	-7.6302997	3.3622997	.342	
	S3	16.476000	10	6.4760000	2.7192333	3.0996258	9.8523742	.006	*
	S4	13.9860	10	3.98600	2.08601	1.39588	6.57612	.013	
	S5	13.328000	10	3.3280000	3.7579276	-1.3380834	7.9940834	.119	
	S6	17.540000	10	7.5400000	1.4911908	5.6884421	9.3915579	.000	*
	S7	15.974000	10	5.9740000	3.0187133	2.2257724	9.7222276	.001	*

Significance level: 5% * (p< 0.05 = significantly different)

The total nitrate concentration was highly significant at (p<0.05) against the ZINWA threshold of 10 mg/l at site 3, 6 and 7. This shows a significant difference in total nitrates from the threshold of 10 mg/l on these three sites. No significant difference in site total nitrate concentrations from the permissible thresholds (WHO and ZINWA) was noted at sites 1, 2, 4 and 5, as shown in table 4.3. However, for site 5, the total nitrates levels were higher than the threshold, though no significant difference was noted at (p< 0.05). Site 1 and site 2 had mean total nitrate concentrations of 8.104 mg/l and 7.866 mg/l respectively. This was below the recommended threshold of 10 mg/l. Site 3 is surrounded by the industries in the Msasa area which might be releasing partially treated or untreated waste into the river. Site 6 is close to the Firlle effluent treatment plant. Partially treated trickling filter effluent from the wastewater treatment plant might be polluting the river with waste rich in total nitrates. Site 7 had total nitrate concentrations higher than the ZINWA permissible threshold. Agricultural

activities in residential areas such as Glen Norah, Highfield's and industrial effluents from the nearby Graniteside industrial areas might be polluting the river.

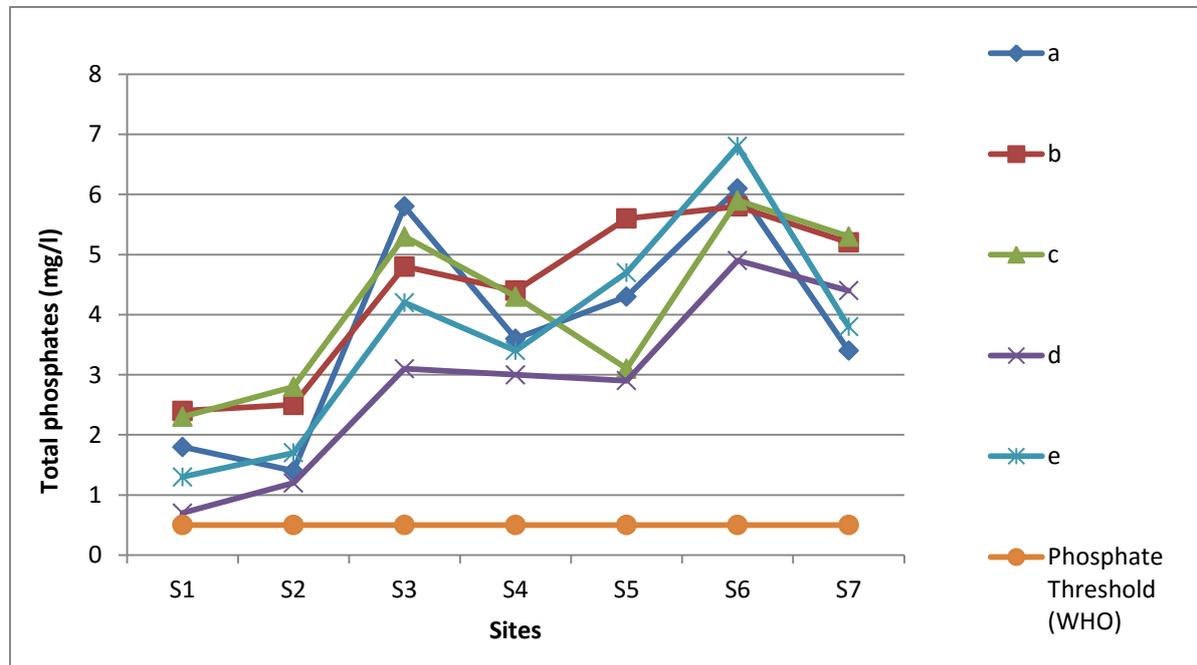


Fig 4.6: Total phosphate concentrations determined over the sampling sites along Mukuvisi River from Dec to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

Total phosphate concentrations increased with sampling sites down the river. There was a gradual total phosphate concentration increase moving from upstream to downstream. Total phosphate concentration in the river was above the ZINWA and WHO standards on all sampling sites. There was a slight drop in the concentrations of total phosphate only at site 4 though it was still above the threshold. Site 1 recorded the least amount of total phosphates. Site 6 recorded the highest concentration of total phosphates on all sampling intervals as shown on fig 4.4. The higher concentrations of total phosphates might be coming from Firle effluent plant, where partially treated filter effluent finds its way into the river. There was an increase in total phosphates as the river was meandering through agricultural, industrial and

residential areas. The total phosphate concentrations increased from 0.7 mg/l (upstream) to 6.8 mg/l (downstream).

Table 4.4: T-test analyses for water total phosphate at selected sampling sites along Mukuvisi River

Total Phosphate		Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)
						Lower	Upper	
	S1	1.70000	0.5	1.200000	.7106335	.3176319	2.0823681	.020
	S2	1.920	0.5	1.4200	.6979	.5535	2.2865	.010
	S3	4.640	0.5	4.1400	1.0455	2.8419	5.4381	.001*
	S4	3.74000	0.5	3.240000	.5983310	2.4970739	3.9829261	.000*
	S5	4.120	0.5	3.6200	1.1278	2.2196	5.0204	.002*
	S6	5.90000	0.5	5.400000	.6819091	4.5532980	6.2467020	.000*
	S7	4.42000	0.5	3.920000	.8378544	2.8796664	4.9603336	.000*

Significance level: 5% * (p< 0.05 = significantly different)

The lowest mean concentration was found upstream (1.7 mg/l at site 1) and the highest mean total phosphate concentration was recorded downstream (5.9 mg/l at site 6). It was evident that mean total phosphate concentrations recorded for all the sites were way above the recommended WHO AND ZINWA concentration guidelines of 0.5 mg/l. Significant differences were noted at site 3 to site 6 on total phosphate levels (p<0.05). Total phosphate levels were significantly higher than the threshold of 0.5 mg/l (ZINWA and WHO) from site 3 to site 7. There was no total phosphate significant difference noted at site 1 and site 2 (p<0.05). Industrial effluent discharge might be responsible for high total phosphate levels at site 3, which is around Msasa industrial area. These industries include Zimbabwe Phosphate Industries, manufacturing industries and leather tanning industries. Agricultural activities, burst sewage overflows and waste dumps might have contributed to the higher levels of total phosphates from site 4 to site 7. Effluent from Firlle sewage treatment plant being discharged

into Mukuvisi River might have higher total phosphates levels, contributing to concentrations recorded at site 6 and site 7.

4.2.3 Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) levels concentrations determined during sampling period (December 2014 to April 2015)

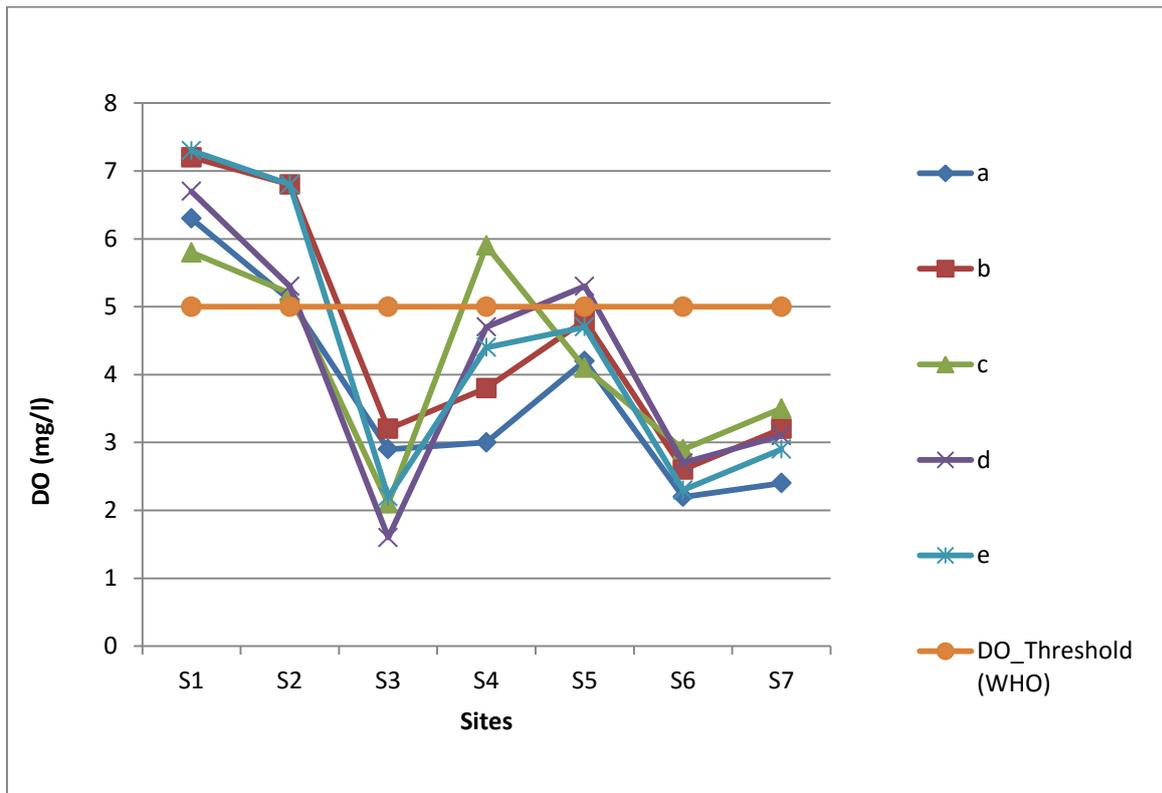


Fig4.7: Water DO as determined over the sampling sites along Mukuvisi River from December 2014 to April 2015

Key:
 a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

The concentrations of DO decreased from upstream to downstream whilst the BOD increased as the river meandered downstream. Site 1 had DO concentrations greater than WHO threshold of 5 mg/l ranging from 6 mg/l to 7 mg/l across the sampling period. High DO levels show less water pollution as high DO means less organic matter is decomposing in the water,

therefore less oxygen is consumed. High DO shows that the river has adequate oxygen that can be used to sustain aquatic organisms. The concentrations dropped down to 1.6 mg/l at site 3 as shown on fig 4.5. Low DO concentrations show high water pollution levels. Low levels of DO show that much of the oxygen is being used by decomposing organic components in the river depriving aquatic organisms of much needed oxygen. Decomposing organic components at site 3 (mean DO of 2.4 mg/l and mean BOD of 33.9 mg/l) might be effluent wastes from fertilizer factories, abattoirs, textiles and clothes manufacturing industries in Msasa industrial area. The organic components maybe from sewage overflows from burst pipes and runoff from agricultural activities. Sites 3, 6 and 7 recorded very low concentrations of DO below the ZINWA limit of 6 mg/l.

Table 4.5: T-test analyses for water DO at selected sampling sites along Mukuvisi River

DO	Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
					Lower	Upper		
S1	6.660	5	1.6600	.6269	.8816	2.4384	.054	
S2	5.840000	5	.8400000	.8792042	-.2516762	1.9316762	.099	
S3	2.400000	5	-2.6000000	.6442049	-3.3998861	-1.8001139	.001	*
S4	4.360000	5	-.6400000	1.0784248	-1.9790412	.6990412	.255	
S5	4.620000	5	-.3800000	.4868265	-.9844749	.2244749	.156	
S6	2.540000	5	-2.4600000	.2880972	-2.8177199	-2.1022801	.000	*
S7	3.020	5	-1.9800	.4087	-2.4874	-1.4726	.000	*

Significance level: 5% * (p< 0.05= significantly different)

From the results in table 4.5, significant differences from ZINWA and WHO permissible thresholds were noted at sites 3, 6 and 7. Effluent discharge from industries around Msasa area (site 3) might be influencing the low DO levels. Effluent discharge from Firle Sewage plant resulted in low DO levels at site 6 and site 7. No DO significant difference was noted at site 1 and site 2 (p< 0.05). These two sites recorded the values which were slightly higher than the recommended threshold of 5mg/l. Site 4 and 5 DO levels were slightly less than 5 mg/l. As shown in table 6, site 4 and 5 recorded mean concentrations of 4.36 mg/l and 4.62

mg/l respectively. Thus no significant difference was noted using the t test on site 4 and site 5 ($p < 0.05$).

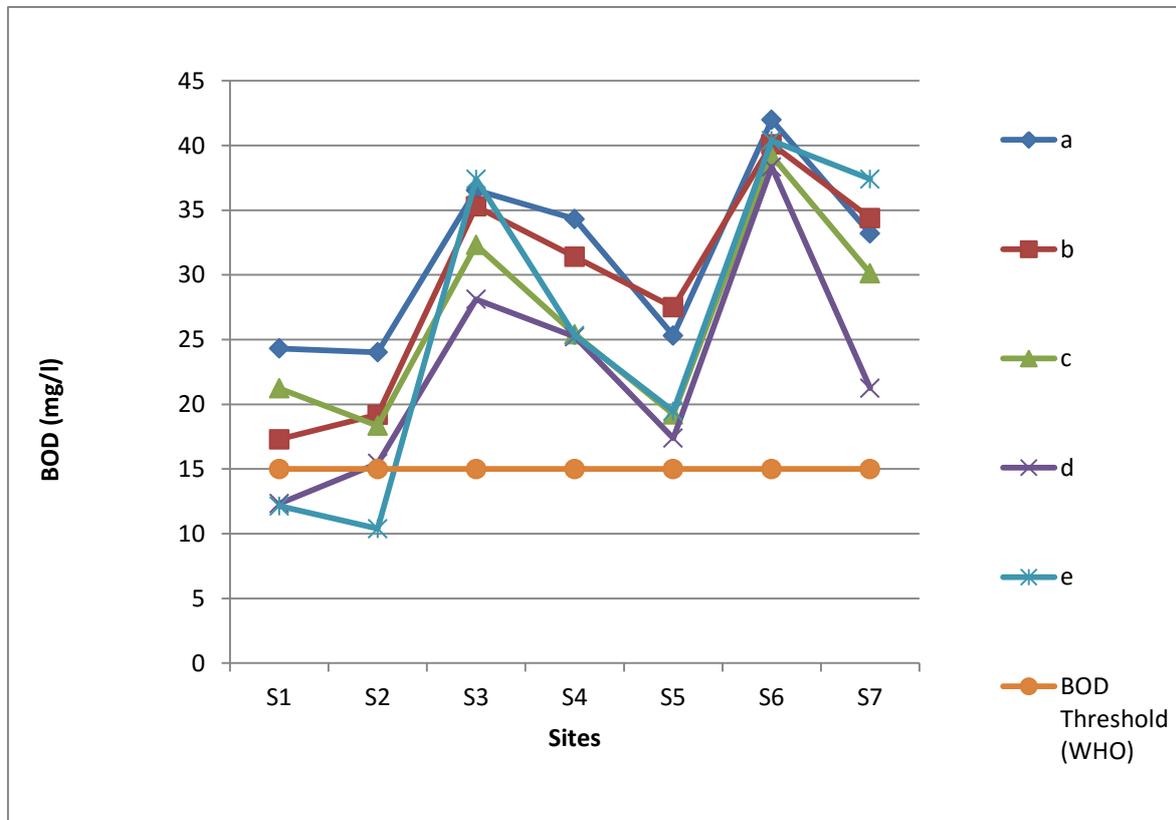


Fig4.8: Water BOD levels as determined over the sampling sites along Mukuvisi River from December 2014 to April 2015

Key:

- a – sampling interval 1 (18/12/14)
- b – sampling interval 2 (19/01/15)
- c – sampling interval 3 (23/02/15)
- d – sampling interval 4 (25/03/15)
- e – sampling interval 5 (28/04/15)

As shown in fig 4.8, BOD levels were low at site 1 and 2 and increased from site 3 to site 7. High BOD levels show high levels of pollution. The river water will be having organic decomposing materials depleting the oxygen concentrations in the water ecosystem. Site 1 and 2 recorded concentrations slightly above the ZINWA and WHO concentrations of 15 mg/l. These sites had an average mean of 17 mg/l across the sampling intervals. Burst sewage effluent from high density residential areas, and illegal rubbish disposal along the river might have contributed to higher BOD mean above the threshold at site 2. At the remaining sites 3,

4, 6 and 7, the BOD concentrations were higher than the threshold of 15 mg/l. Site 6 had the smallest range across all sampling sites ranging from 38.34 mg/l to 41.98 mg/l, with a mean of 17 mg/l which was above the ZINWA and WHO threshold of 15 mg/l. Site 6 recorded the highest BOD concentrations across all the sampling intervals. Partially treated trickling filter effluent from Firlle wastewater treatment plant, burst sewerage pipes overflow, pesticides and fertilizers from agricultural activities as well as illegal waste dumping might be contributing to high BOD levels at site 6. Informal settlements along the banks of Mukuvisi River have also contributed to higher levels of organic pollutants. Disposal of organic wastes in the river is rampant as there is no proper wastes disposal site.

Table 4.6: T-test analyses for water BOD at selected sampling sites along Mukuvisi River

BOD		Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
						Lower	Upper		
	S1	17.4600	15	2.46000	5.38245	-4.22319	9.14319	.365	
	S2	17.4740	15	2.47400	5.02698	-3.76781	8.71581	.333	
	S3	33.936000	15	18.9360000	3.7808637	14.2414377	23.6305623	.000	*
	S4	28.3320	15	13.33200	4.26098	8.04129	18.62271	.002	*
	S5	21.7760	15	6.77600	4.37118	1.34846	12.20354	.026	
	S6	40.002000	15	25.0020000	1.3651447	23.3069490	26.6970510	.000	*
	S7	31.274000	15	16.2740000	6.1875827	8.5911013	23.9568987	.004	*

Significance level: 5% * (p< 0.05 = significantly different)

High BOD levels show high pollution levels, with decomposing organic compounds. No significant difference from the threshold of 15 mg/l was noted on site 1 and site 2 (p<0.05). According to fig 4.6 BOD values at site 1 and 2 were higher than the threshold. The difference was not significant according to table 4.6. Significant differences were noted at site 3, 4, 6 and 7 mean BOD levels. These sites reflected high levels of organic wastes requiring more dissolved oxygen. These organic compounds maybe coming from illegal dumping of rubbish that occurs along the river bank, pesticides and fertilizers from

agricultural activities close to the river as well as sewage effluent from sewage plants. There was no significant difference from the threshold of BOD at site 5 ($p < 0.05$). Site 6 had the highest mean of 40 mg/l with lowest mean recorded at site 1 (17.46mg/l) as shown in table 4.6. Effluent rich in organic compounds from Firle effluent treatment plant might be responsible for high BOD levels at site 6.

4.2.4 Lead and copper concentrations determined during sampling period (December 2014 to April 2015)

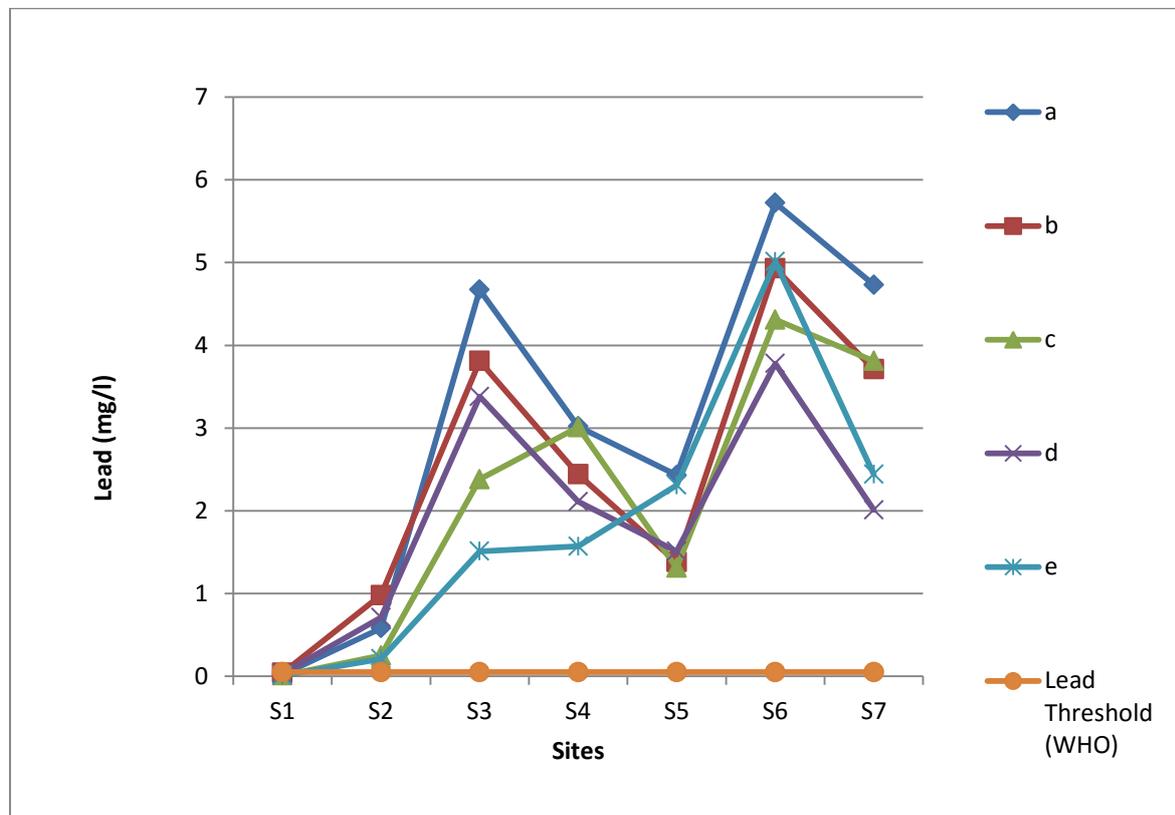


Fig 4.9: Lead concentration in the water as determined over the sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

Lead levels at all sites were higher than the ZINWA and WHO threshold of 0.05 mg/l, except for site 1. Low lead concentrations were recorded at site 1. There was a gradual lead increase

as from site 2 to site 4. Site 3 had higher lead values that are attributed to industrial effluents discharged into the river from Msasa industrial sites. Site 3, site 6 and site 7 recorded the highest values during the sampling period as shown in fig 4.9. These sites recorded a mean of 3.15 mg/l, 4.75 mg/l and 3.34 mg/l respectively. Storm water might be contributing to high lead levels in the river. Surface runoff that is channelled into storm water contains untreated effluent from car washes that have mushroomed in the capital and industrial areas. From the results in fig 4.9, the lead concentration decreased at site 4 and 5 though they were above the threshold. Site 6 was after the discharge from the Firlle effluent treatment plant. Partially treated effluent maybe containing heavy traces of lead.

Table 4.7: T-test analyses for water Lead levels at selected sampling sites along Mukuvisi River

Lead	Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
					Lower	Upper		
S1	.0220	0.05	-.02800	.01304	-.04419	-.01181	.009	
S2	.546000	0.05	.4960000	.3228467	.0951329	.8968671	.026	
S3	3.1500	0.05	3.10000	1.23302	1.56900	4.63100	.005	
S4	2.4300	0.05	2.38000	.61778	1.61293	3.14707	.001	*
S5	1.788000	0.05	1.7380000	.5377918	1.0702433	2.4057567	.002	*
S6	4.750000	0.05	4.7000000	.7374619	3.7843202	5.6156798	.000	*
S7	3.340000	0.05	3.2900000	1.1032679	1.9201120	4.6598880	.003	*

Significance level: 5% * (p< 0.05 = significantly different)

Results in table 4.7 show that site 6 had the highest mean value of 4.75 mg/l. Site 1 recorded the least mean of 0.22 mg/l. Sites 1, 2 and 3 showed no significant difference from the ZINWA and WHO threshold of 0.05 mg/l (p<0.05). Significant difference between the Lead concentrations and ZINWA and WHO permissible threshold were noted as from site 4 to site 7 (p<0.05). Rapid industrialisation and urbanisation compounded by stagnant economic development can be attributed to be the causative to the sharp rise in lead levels in Mukuvisi River. Lead in river water can occur naturally but can be increased by human activities such as industrial wastes, vehicular effluents and effluent from sewage treatment plants.

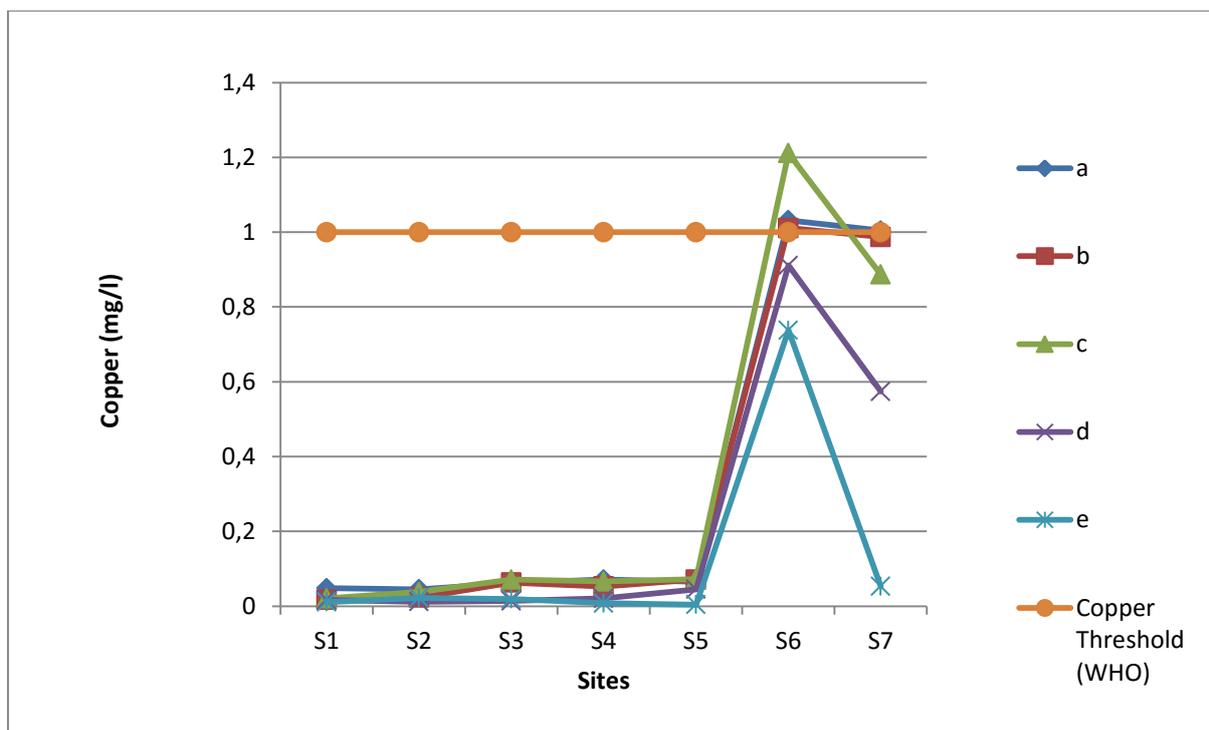


Fig 4.10: Water copper values as determined over the sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

Copper results do not show much variation as the river meanders along its channel. Sites 1 to 5 were within the recommended thresholds of ZINWA and WHO of 1 mg/l. Copper concentration along the river showed a range of 0.01 mg/l to 1.2 mg/l. Site 6 recorded the highest concentration of copper of 1.2 mg/l as shown in fig 4.10. Site 6 had a range of 0.7 mg/l to 1.2 mg/l due to the discharge from Firle effluent treatment plant. Trace elements of copper can easily flow into the river from the sewage treatment plant and the pesticides used in agricultural activities around the area. The highest concentration of copper was during sampling interval 3 (in February) and at site 6. Site 6 also had values for other parameters greater than ZINWA and WHO threshold. Household waste emanating from residential areas close to site 6 in addition to sewage effluent might be carrying large amounts of copper.

Table 4.8: T-test analyses for water Copper levels at selected sampling sites along Mukuvisi River

Copper		Site mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig. (2-tailed)	
						Lower	Upper		
	S1	.022800	1	-.9772000	.0145327	-.9952448	-.9591552	.002	*
	S2	.028000	1	-.9720000	.0132853	-.9884959	-.9555041	.000	*
	S3	.045800	1	-.9542000	.0270315	-.9877640	-.9206360	.000	*
	S4	.043800	1	-.9562000	.0279231	-.9908711	-.9215289	.000	*
	S5	.051400	1	-.9486000	.0286409	-.9841623	-.9130377	.000	*
	S6	.980600	1	-.0194000	.1734569	-.2347752	.1959752	.815	
	S7	.701000	1	-.2990000	.4013209	-.7973058	.1993058	.171	

Significance level: 5% * (p< 0.05 = significantly different)

According to table 4.8, highest mean was 0.98 mg/l (site 6) and the lowest was recorded at site 1 with a copper value of 0.0228 mg/l. Significant difference of copper concentrations was noted at the following sites, 1, 2, 3, 4 and 5 (p<0.05). These sites had mean concentrations lower than the ZINWA and WHO recommended threshold of 1 mg/l. This showed that they fell within the threshold limit. Site 6 and 7 had copper levels of 0.98 mg/l and 0.70 mg/l, respectively as shown in table 4.8. No significant difference was noted at site 6 and 7. The traces of copper at site 6 and site 7 might have been as a result of effluent from Firle sewage treatment plant that is close to site 6. Domestic waste water and industrial effluents might be the main sources of copper.

4.2.5 Total Faecal Coliform Count levels determined during sampling period (December 2014 to April 2015)

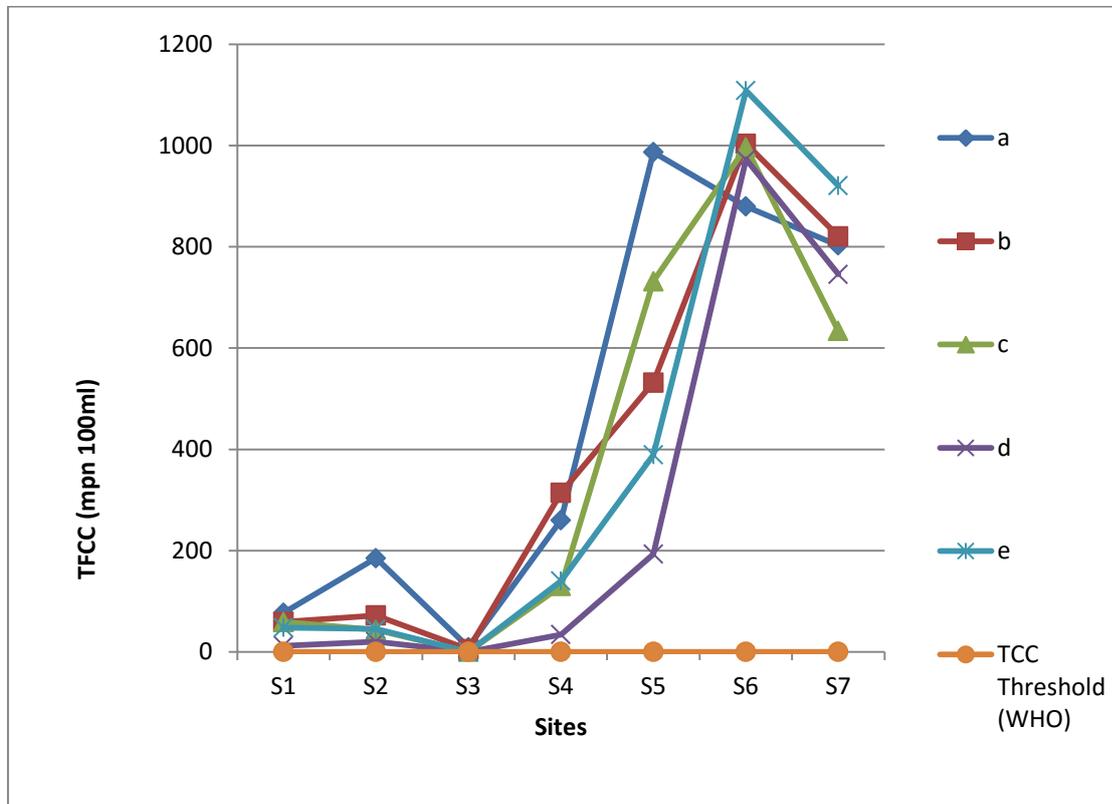


Fig4.11: Total Faecal Coliform Count in the water as determined over the sampling sites along Mukuvisi River from December 2014 to April 2015

Key: a – sampling interval 1 (18/12/14)
 b – sampling interval 2 (19/01/15)
 c – sampling interval 3 (23/02/15)
 d – sampling interval 4 (25/03/15)
 e – sampling interval 5 (28/04/15)

From the results in fig 4.11, the TFCC levels were higher than the threshold of ZINWA and WHO of nil at all sites. The highest TFCC was recorded at site 6 on sampling interval 5, with a recording of 1109mpn100ml⁻¹. High levels of TFCC might be from the spillage of millions of cubic metres of raw sewage into the river from Firle effluent treatment plant (Beatly, 2014). Other sources of TFCC might be from illegal dumpsites that are along the river course. Site 3 had the lowest mean of 2.80mpn100ml⁻¹. Sewage bursts are common in locations surrounding the river. The untreated sewage will flow into the storm water drains or directly into the river increasing the concentrations of TFCC. There was a gradual increase in

TCC concentrations along the stream from site 4. Site 3 had concentrations mean above the threshold though the difference was not significant. Site 6 had the highest mean concentration of 992.6mpn100ml⁻¹.

Table 4.9: T-test analyses for water TFCC levels at selected sampling sites along Mukuvisi River

	Site	Site Mean	Threshold	Differences	Std. Deviation	95% Confidence Interval of the Difference		Sig (2 tailed)	
						Lower	Upper		
TCC	S1	51.00	0	51.000	24.156	21.007	80.993	.059	
	S2	73.00	0	73.000	65.265	-8.037	154.037	.047	
	S3	2.80	0	2.800	4.087	-2.274	7.874	.200	
	S4	175.60	0	175.600	111.440	37.229	313.971	.024	
	S5	566.60	0	566.600	306.761	185.706	947.494	.004	*
	S6	992.60	0	992.600	81.794	891.039	1094.161	.000	*
	S7	785.00	0	785.000	105.402	654.127	915.873	.000	*

Significance level: 5% * (p< 0.05= significantly different)

The highest mean was recorded at site 6 (992.6mpn100ml⁻¹) and the lowest was recorded at site 3 (2.80mpn100ml⁻¹). No significant difference from the threshold of 0 mpn100ml⁻¹ was noted (p< 0.05) at site 1 to site 4. TFCC levels were significantly higher than the threshold at sites 5, 6 and 7 as shown in table 4.9. TFCC is an indicator of poor sanitary quality of river water. The river shows higher levels of pollution downstream compared to the upstream. The effect of human activities along the river course can be seen especially downstream (site 6), which has the highest total coliform count. Illegal dumping of wastes by textile, abattoirs and food processing industries in Graniteside might have contributed to higher TFCC levels at site 4 and 5. Highfields, Glen Norah and Glen View residential areas might have contributed to higher levels of coliform at site 4. Effluent discharge from Firlle sewage treatment before site 6 might be the major contributor of higher TFCC levels at site 6 and site 7. These two site mean difference were highly significant at 95% significance level above the threshold.

CHAPTER 5

5.0 DISCUSSION

5.1 River Water Quality

Water quality is a big problem in most African cities and Harare is no exception. Based on water chemistry; water quality of Mukuvisi River one of the major rivers in Harare is severely compromised by anthropogenic activities. A wide range of human activities ranging from domestic to industrial activities are occurring along the river course. Water quality of Mukuvisi River decreases as the river meanders through the city's industrial, residential areas and town centre of Harare before discharging into the lake. There has been a drastic increase in Harare population growth as most people are moving from rural areas to urban centres as the country is facing difficult economic meltdown and unreliable annual rainfall (Utete and Kunhe, 2013). Water quantity is becoming limited in Zimbabwe and its quality is deteriorating rapidly affecting human and environmental health (Sato et al., 2013; Utete and Kunhe, 2013). This means constant monitoring and management is of paramount importance. Rural to urban migration has an adverse effect on water quality as it results in overloading basic infrastructure, uncontrolled sewage discharge, urban agricultural activities, industrial discharge and informal settlements. This has also been a problem to all Southern African countries. Southern Africa is already a water stressed region and by 2025, it is projected to be a water deficit region (Chirisa and Chanza, 2012).

Problems of environmental management in Africa have their origins in historical, economical, sociological and political factors (Alberti, 2010). The infrastructure of many cities in Africa was designed for small urban expatriate communities. Some of it has aged considerably (Chirisa and Chanza, 2012). However, the post-independence Africa has seen a

surge of urban drift, primarily due to rural poverty. Magadza, (2010), noted that the mean doubling period of many African cities is close to the project development, funding and implementation cycle for such projects as wastewater treatment works. Thus many urban settlements are caught in a spiral of growing services demands and diminishing resources. Lack of resources has been the prime source of lack of infrastructural development. This is because the states are not promoting citizens involvement in environmental management. Successful environmental monitoring requires legal and institutional frameworks that ensure sustainability at both policy and operational level. Nevertheless, perhaps the most important issue in water quality monitoring is lack of resources. Limited state funds are channelled to activities that appear to need urgent attention such as health services and poverty alleviation programmes. Environmental monitoring is viewed as of no immediate benefit. However, the situation leads to unmonitored environmental deterioration, which leads to higher health risks, and more costly remedial measures.

5.1.1 pH and Temperature at sampling sites

The mean pH of Mukuvisi River water for the sampling period was within the WHO guideline range of 6.0 – 9.0 units except at site 3. Site 3 recorded acidic pH. pH affects the quality of water directly. The possible reason for very low pH may be acidic process wastewaters from industrial activities. For example, Zimbabwe Phosphate, a fertilizer manufacturing company situated close to sampling site 3, discharges process wastewater containing sulphuric acid that may result in reduction of pH in the river. Extremes of pH of water and wastewater are generally not acceptable as they pose problems to survival of aquatic life (Kavitha et al., 2012). Air pollution by industries in Msasa area might also be contributing to a decrease in pH of river water. Sulphates released into the atmosphere often combines with water to form acidified precipitation. The acid rain will reach the aquatic

ecosystems lowering the water pH. There are therefore a number of reasons that possibly contributed to the decrease in pH at site 3. Organic matter has a tendency of releasing humic acid when decomposing which might also increase the acidity of river water at site 3 (Kashy, 2008). Low pH values at site 3 could be an indicator of leaching of soils rich in organic elements through run-off and acidic effluents being discharged into the river, an indication of effluent discharge from industries close to sampling site.

The pH of river ecosystem generally fluctuate since most natural waters contain weak acids and these perhaps were responsible for the fluctuations in pH recorded at others sites. Water pH levels can also be controlled by the rate at which aquatic organisms photosynthesise. Aquatic plants such as phytoplankton help increase the pH levels during photosynthesis at site 4, 5 and site 7 as there was increased nutrient discharge which influences phytoplankton growth. Photosynthesis elevates pH in proportion to the removal of free carbon dioxide (Masere et al., 2012; Sakai, 2013). When more carbon dioxide is removed the water becomes less acidic or more alkaline. This supports arguments by Vijay et al., (2014), that during photosynthesis more carbon dioxide is absorbed which results in increased pH levels. This means that the higher the removal rate of carbon dioxide in aquatic ecosystems, the higher the pH or more alkaline it is. Extremes in pH can make a river inhabitable by aquatic life (Utete et al., 2013). Low pH is harmful to most aquatic organisms. Physical and biological processes in aquatic water are greatly affected by pH changes. Most living organisms in aquatic ecosystems survive in water with a pH range of 6.5 - 8.0 (Petersen, 2015). pH lower or above this range will automatically affect life activities of the organisms' such as metabolism and reproduction, resulting in extinction of organisms.

Acidic conditions in water are detrimental to organisms in that most toxic elements will become mobile and can easily be absorbed. However, at sampling point 6 (after Firl

discharge), there was a slight mean pH decrease. The drop in pH was mostly due to partially treated or treated effluent being discharged by Firlle sewage treatment plant. Fig 4.1 shows that site 6 recorded pH which was slightly lower than all sites (below pH 7). Effluent from Firlle sewage treatment plant which was discharged into the river may have lowered the river water pH. Water bodies receiving untreated or partially treated sewage elsewhere have been reported to be highly acidic, sometimes with pH as low as 2.6 (Agbozu and Rim-Rukeh, 2013). Lower pH reduces the chances of survival for aquatic organisms such as fish and some invertebrates that prefer fresh water as a habitat. Aquatic water having acidic conditions falls below the recommended levels for good quality water (WHO, 2011).

The temperature profile of the Mukuvisi River did not show a great variation. The temperature range was 19.4⁰C to 27⁰C. Temperature was below the threshold (ZINWA of 35⁰C). Change in temperature and weather conditions of the atmosphere during the period of study might have caused the slight variation between sites. Processes such as reaction rates and biological processes as well as dissolved oxygen are either increased or decreased based on temperature changes (Vijay et al., 2014). River water temperature can be affected by human activities such as discharging effluent that is either cool or hot from industries, or activities such as urban development and agriculture (deforestation). Deforestation removes tree shades close to the river banks and also causes global warming, increasing global temperatures as a result affecting water temperature. Discharge of industrial effluents around Msasa areas might have some cooling effects at site 3 with a mean of 23.8⁰C as shown in table 3. Based on ZINWA guidelines, Mukuvisi River water temperature falls within the threshold, meaning temperature cannot pose any threat to the homeostatic balance of the river ecosystem.

5.1.2 Total nitrates and Total phosphates

The nutrient content of a river is an indication of the degree of pollution. Eutrophication in water bodies can be triggered by high concentration of nutrients such as total phosphates and nitrogen. The ranges of total phosphate and total nitrates in the study of Mukuvisi River water ranged between 0.7 – 6.8 mg/l and 3.21 – 19.23 mg/l respectively. Zimbabwe National Water Authority (ZINWA) water quality guidelines and World Health Organisation (WHO, 2011) aquatic life threshold values were used as a bench mark to compare total phosphate and total nitrate concentrations in Mukuvisi river water. Only the upstream (site 1 and site 2) total nitrate mean concentrations were below the ZINWA and WHO threshold concentration of 10 mg/l (Table 4.3). Total nitrate concentrations from Site 3 to site 7 were above the threshold limits. These concentrations can easily pose an environmental and health hazard to organisms relying on water from the river for consumption or as a habitat. Aquatic life and the general populace of Harare and satellite towns will be affected. Human activities such as agriculture and discharge of industrial effluent from industrial activities (fertilizer manufacturing) taking place along the river from site 3 downstream have increased the concentration of nitrates in the river. Kamudyariwa (2000) stated that water quality in Mukuvisi River was significantly affected by anthropogenic activities such as effluent discharge from sewage plants and storm water which disturbs aquatic ecosystem.

The impact of effluent discharged in Msasa and Southerton Industrial area and partially treated wastewater from Firle treatment plant on the quality of Mukuvisi can be seen by an increase in water quality variables from site 3 to site 7. Magadza (2010), highlighted areas such as Kuwadzana, Marimba, Budiro, Epworth and Glenview as low income suburbs' and poorly serviced with high levels of storm water nutrient export to the river course. These areas contributed about 10.28 mg/l and 39.98 mg/l of total phosphorus and total nitrogen

respectively, into Mukuvisi River per annum. These concentrations are increasing eutrophication in the river. These values of phosphates were attributed to the use of fertilizer in the urban cultivation and some industries such as the fertilizer factory on Mukuvisi catchment which releases effluent high in phosphorus. There are many tributaries feeding Lake Chivero. Some of the tributaries flow through industrial areas and residential areas. Between site 6 and 7, there is a tributary feeding the river that flows through Msasa industrial area and Prospect residential areas before discharging into Mukuvisi River. The highest site mean total nitrate and total phosphate concentrations were found to be 7.54 mg/l and 5.5 mg/l higher than the recommended concentration, respectively. Nyamangara et al. (2013) noted that the concentrations of nitrates actually doubled during wet season than the dry season. Dilution effect could not reduce nitrate concentration. This shows the effect of surface runoff, bringing higher loads of nutrients from agricultural areas and industrial areas in close proximity to the river. A sudden increase in total nitrate and total phosphate concentrations from Site 3 to Site 7 (fig 4.5 and fig 4.6) implies that sources of pollution are close to the river. Sites 3 to Site 5 fall within residential areas and industrial areas.

Site 6 was located downstream after discharge from Firle Sewage Processing Plant. Firle sewage treatment plant receives large quantities of effluent from industries, storm water and residential areas. The high phosphate concentrations in the Mukuvisi river is a major cause for concern as Phosphorus is generally the most limiting nutrient to growth of aquatic vegetation under natural conditions in most freshwater bodies (Nyamangara et al., 2013). High phosphate concentration in river water causes eutrophication (algal blooms) with a lot of effects to aquatic organisms and humans. Phosphates make purification of water difficult and expensive, impart an unpleasant taste in water and might give water an odour (Moyo and Mtetwa, 2002). Higher phosphate concentrations were also noted in a study by Masere et al.

(2012) in Marimba River (one of the major rivers in Harare), where the mean concentrations of total nitrates and total phosphates were 3.5 mg/l and 4.4 mg/l respectively which were exceeding the ZINWA regulation by 7 - 9 times. In this study nitrates and phosphate concentrations were caused by sewage effluent emanating from sewage outbursts in areas close to Marimba River and industrial effluents (Masere et al., 2012). Sources of these nutrients might be coming as well from non - point sources such as runoff from agricultural lands (stream bank cultivation).

5.1.3 Dissolved Oxygen and Biological Oxygen Demand (BOD)

Biological Oxygen Demand is a measure of the levels of water pollution in water bodies. Biological Oxygen Demand is the amount of oxygen required by organisms that use oxygen to decompose organic matter (Nhiwatiwa, 2011). The biodegradation of organic matter uses a lot of oxygen increasing the biochemical oxygen demand (BOD). Dissolved Oxygen (DO) is the amount of oxygen dissolved in water that is available to sustain life. DO exert a greater influence on the type of organisms found in a water ecosystem. Higher DO levels indicate good quality water whilst low level of DO reflects high water pollution. The low dissolved oxygen content from most of the sampling sites is an indicator of high organic contamination.

The mean oxygen values recorded from the rivers (site 3 - 7) were below the mean prescribed values for survival of aquatic life of 5.0 mg L^{-1} . Although the deoxygenation of a river caused by organic waste is generally a slow process, the outcome is devastating to the ecosystem. The variation in DO from one site to another for the same data set could be due to differences in location, time and more significantly due to differences in organic pollution at the time of sampling. The DO concentration levels are known to fluctuate naturally throughout the day (Masundire, 2013). Aquatic photosynthetic plants can increase the amount of oxygen in water

through photosynthesis but photosynthesis can be reduced by suspended particles floating on water surfaces blocking sunlight to reach these plants resulting in less oxygen released by plants. Dissolved oxygen shows an inverse relationship with time. The results show that the levels of DO are decreasing each year compared to the other studies done prior to the study (Tendaupenyu, 2001; Nyamangara et al., 2008 and Ndebele - Murisa, 2012). Input of sewage effluent from Firlle Sewage treatment plant may have reduced the amount of DO recorded at sampling point 6 (2.54 mg/l). Sewage effluent released undergoes biodegradation, depleting oxygen levels in water. During degradation more of carbon dioxide will be released which has a toxic effect to aquatic organisms such as plants and fish. Site 1 and 2 recorded the highest DO levels in Mukuvisi River. This indicates less pollution levels in the upper part of Mukuvisi as compared to the downstream parts of the river. All the downstream sampling sites of Mukuvisi River recorded low DO levels. The upper part of Mukuvisi is exposed mainly to non - point sources of pollution. Anthropogenic activities such as industrial activities can only be identified around Msasa industrial area. Human activities such as agriculture (stream bank cultivation), heavy industrial effluent discharge, mining and informal dumping sites might have contributed to high oxygen organic wastes depleting oxygen in water downstream of Mukuvisi River

Biological Oxygen Demand was higher downstream compared to upstream showing heavy presence of degrading organic substances. The amount of oxygen needed by microorganisms to decompose organic effluents is shown by BOD levels (Somaya, 2011). The higher the BOD levels, the higher the amount of biological wastes. Domestic and industrial wastes pollutants strength can also be determined by BOD levels, showing the amounts of oxygen required to breakdown them down to end products. Thus BOD indicates the amount of organic pollutants present in water. A low BOD is an indicator of good quality water, while a

high BOD indicates polluted water. Most pristine rivers will have a 5-day BOD below 1 mg/l. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/l and municipal sewage that is efficiently treated by a three stage process would have a value of about 20 mg/l (Shams, 2013). The BOD of Mukuvisi River at the selected sites ranged from 17.4 mg/l to 40 mg/l. The river water BOD level surpassed the values of efficiently treated waste.

High BOD levels could be due to natural and anthropogenic sources. Natural sources of organic matter can be natural or anthropogenic. In rivers, natural sources can include leaf fall from plants and decaying of dead plants. Anthropogenic sources can also accelerate the growth of plants in aquatic systems and biodegradation by continuous release of effluents rich in nutrients (Ndebele – Murisa, 2012). Urban runoff is a huge non-point source of nutrients in rivers as it collects wastes from streets and sidewalks, fertilisers from lawns and biodegradable litter from residential areas. The biodegradable wastes increase the oxygen demand in aquatic ecosystem. Oxygen concentration in water is reduced significantly robbing aquatic organisms' oxygen to survive. Anthropogenic sources of pollution that increase BOD include waste from food processing industries and household wastes. This can be seen by high BOD levels at site 3. Industries in Msasa area may be responsible for the high BOD levels. Untreated sewage varies, but averages around 600 mg/l in Europe and as low as 200 mg/l in the United State, or where there is severe groundwater or surface water infiltration (Agbozu and Rim-Rukeh, 2013). BOD levels in the surface water samples were between 17.4 mg/l to 40 mg/l. Site 6 had the highest BOD. Effluent from Firle Sewage treatment plant has been identified as the source high loads of organic waste discharged into the river.

5.1.4 Lead and Copper

This study showed the availability of these metals in the peri - urban river system. Statistically the lead concentration from site 4 to site 7 was higher than the threshold. Site 3, 6 and site 7 recorded the highest mean lead concentration for the duration of the study, recording 3.15 mg/l, 4.75 mg/l and 3.34 mg/l respectively. Urbanisation and rapid industrialization have increased the rate of water pollution and water problems in cities such as Harare. Sanitation has been improved but water management practices and water wasting has led to water shortages and deterioration of water quality in rivers (Mufandaedza and Kamusoko, 2012). The results of this study revealed that Mukuvisi River water is contaminated with unacceptably high levels of lead. High levels of lead above the recommended limits at site 3 were attributed to the heavy industrial activities in Msasa area. The industries might be producing poor effluent either untreated or partially treated not meeting the standards required by ZINWA.

Small scale enterprises that fall under informal sector industries have mushroomed along Mukuvisi River for easy access to free Mukuvisi water and disposable site. Most industries face challenges in treating effluents because of high treatment cost and unavailability of processing facilities. As a result, small industries illegally discharge untreated or partially treated effluent into Mukuvisi River. Lack of adequate monitoring tools in relevant authorities and less penalties than treating waste has increased the rate of dumping and discharging partially treated or untreated waste in rivers increasing pollution rates of rivers in most urban areas (Sato et al., 2013). Site 2 also recorded a mean lead concentration of 0.546 mg/l. Non - point sources polluting the environment with heavy metals make up a continuously increasing share in the total pollution (Petersen, 2015). The possible sources of lead may be the discharge of industrial wastes from leaded gasoline and motor industry, tyre

wear, mechanical wear and tear of brake pads and tyres of cars, as the site is close to Msasa Road Bridge; lead acid batteries fertilisers, lubricating oil and grease, and lead acid batteries, into the river. At site 4 and site 5, high levels of lead were attributed to fertilisers from agricultural lands as well as dumping of household and industrial wastes into the river and soil without treatment. High levels of lead at sampling site 6 and site 7 might have been attributed to effluent discharge from Firle sewage treatment plant. Nhapi (2009) also found that wastewater effluent, irrigation seepage and runoff were significantly increasing the concentrations of nutrients and heavy metals in the river. Wastewater effluent from Firle wastewater treatment plant might be the major metal polluter of the Mukuvisi River. These high levels of lead can pose serious threats to the public health given that Mukuvisi river is the major supplier of water to greater Harare area and surrounding communities. Such elevated levels of human exposure may lead to damage of almost all organs, most importantly the central nervous system (CNS), kidneys and blood, culminating in death at excessive levels (Karuvilla, 2006).

It will be more interesting to determine the current lead pollution in communities which currently consume water from Mukuvisi River. A lot more, lead contamination may remain unreported and would continue to kill people in these areas. Lead in water bodies can become very toxic. Children in Michigan State, (USA) were infected by lead in Flint River (Petersen, 2015). Lead levels doubled in children in 2014 when the council started using water from Flint River. Flint River, just like Mukuvisi River, has poor water quality due to unregulated discharges by industries and municipalities. Lead can permanently impair a child's development. High levels of lead can lead to lower verbal competence, speech processing and lower attention spans in children. Anthropogenic activities such as industrial effluents containing toxic metals, agriculture (pesticides) and surface runoff from urban streets are

sources of metal pollution creating inhabitable environments for aquatic organisms (Mufandaedza and Kamusoko, 2012). Various uses of water are controlled by water quality in terms of physical, chemical and biological status in a river system.

The concentration of copper in water samples of the river was lower than the ZINWA and WHO thresholds. The ZINWA threshold guideline for Cu in domestic water supply is < 1.0 mg/L (Table 9). The values obtained at site 1 to site 5 are low, thus Cu is not supposed to be a problem for domestic use of water from the river except at site 6 which recorded values of 1.2 mg/l on sampling interval 3 and around 1 mg/l on sampling interval 2 and 5 . The mean site copper concentration was gradually increasing from site 1 to site 6. The trace levels of copper at the site 4 and site 5 might be as a result of anthropogenic influence such as discharge by industrial activities upstream. The effluent might be containing trace metal copper. However, the concentration of copper was found to be below the recommended threshold by ZINWA and WHO regulations of 1.0 mg/l. These values might also have originated from natural mineralization of the soil, resulting in trace copper elements.

In the present study, concentrations of most of the metals examined were several folds lower than those previously reported in water bodies in some African cities such as Lake Nakuru in Kenya, Hartbeespoort and Voëlvlei dams in Cape Province, South Africa (Mireji, 2008). A large amount of trace metals in aquatic ecosystems is currently contributed to by domestic and industrial wastes. Metal water pollution of fresh water has greatly affected urban water supplies, damaged aquatic life and has become a World health hazard. Industrial pollution, sewage effluent disposal and pesticides from surface runoff from agricultural areas are the main culprits in contaminating water sources with trace metals. Copper is also used in agriculture as a fungicide. These fungicides can find their way into Mukuvisi River as surface runoff with rampant peri - urban agriculture taking place. Human health requires trace

amounts of copper for growth, helps in reducing premature aging, quick wound healing and an increase in red blood cell formation (Prabu, 2009). Higher amounts of copper damages vital internal organs such as liver, heart and kidneys. It also induces hypertension, coma and sporadic fever. Trace metals may become a health hazard as they accumulate in the ecosystems through processes such as bioaccumulation and bio magnification (Zhang et al., 2011). Trace metals have a tendency of accumulating in aquatic organisms reaching poisonous effect affecting the normal physiological functioning of vital internal organs. Humans can in turn acquire abnormally high levels of heavy metals through consumption of aquatic organisms such as fish.

There is a need of strengthening environmental monitoring tools resulting in development of remediation strategies that help to limit and reduce the amount of metal pollutants reaching urban rivers in Zimbabwe. For example in another study on a river in Zimbabwe some remedial measures that the management of the Gwebi River catchment had to implement included: diversion of sewer and urban run-off, construction of sewer and runoff and catch off wetlands and ponds, which helps to purify the polluted water (Utete et al., 2013). Rehabilitation of the existing sewer infrastructure to meet the population increase in urban areas and proper treatment of sewage is the key to nutrients and metal pollution in Zimbabwe. Conservation policies can also reduce the rate of pollution. Human activities can accelerate the increase of toxic metals that occur in water bodies naturally. Effluents from mining, industries and effluent from sewage treatment plants increases metal concentrations in river water.

5.1.5 Total Faecal Coliform Counts

Total coliforms fall under bacteria found in both land and aquatic environments of faecal origin. Sanitary quality of river water can be gauged by assessing the total coliforms present. Total faecal coliform counts differed from site to site during the duration of study. Sites 6 and 7 had higher counts of faecal coliform as compared to site 1 and 2. This revealed a less sanitary quality of water at site 6 and site 7 as compared to the upstream part of the river. Mean total faecal coliform counts (TFCC) in the water body across the sampling points ranged between 51 and 992.60 (mpn100ml⁻¹).

Site 1 and 2 recorded a mean of 51 and 73 mpn100ml⁻¹, respectively. Site 4 and 5 had a mean of 175.6 and 566.6 (mpn100ml⁻¹), respectively. Anthropogenic activities may have contributed to the increase of faecal coliform in water along the river course. The activities include discharge of partially treated or untreated human sewage, discharge of faecal wastes from mammals and birds and surface runoff observed during the period of the study. In Zimbabwe, Chapungu (2008), cited in Magadza (2010) found considerable levels of faecal coliform bacteria in street runoff in Harare. These will often find their way through run off into Mukuvisi River resulting in higher coliform counts. In Victoria Falls, (Zimbabwe), Masere et al. (2012), highlighted considerable levels of total coliform in surface runoff in Livingstone area. Utete et al., (2013), noted that the sewage outflow from sewage treatment ponds at Livingstone town accounted for less than 10% of total sewage output of that river-side town. This means that the bulk of the wastewater was discharged into the Zambezi River untreated. Change in pH and temperature can have an adverse impact on the growth and multiplication of bacteria. High rainfall often results in washing away of animal and human wastes into the river ecosystem. Also physical parameters, such as pH and temperature have a major influence on bacterial population growth. Coliform bacteria quickly multiply being accelerated also by high temperatures which favours rapid growth of bacteria. TFCC at site 6

was highest with 992.60 (mpn100ml⁻¹) and the point source of pollution which is Firl sewage treatment plant might be solely responsible for high total faecal coliform counts at site 6.

The continent of Africa has many large urban areas located close to rivers that have inadequate or no wastewater treatment facilities. The populations in these urban areas are in millions and wastewater disposal is now a major health and ecological consideration. Overcrowding and frequent breaches of the sewer system due to overloading results in overland transport of faecal material during street flooding (Magadza 2010). The incidence of bloody diarrhoea in five year old children in Harare, Mbare high density suburb reflects high levels of water pollution (Muserere et al., 2013). Contamination of river water because of anthropogenic activities releasing human waste has led to potential outbreaks of water borne diseases and infections. Wastewater from industries and sewage collected from homes and offices is released directly into streams and rivers. In a situation where treatment process is available, industrialists have adopted the use of substandard treatment methods that partially treat and in some instances, forego the effluent treatment process (Agbozu and Rim - Rukeh, 2013). Monitoring procedures to reduce and halt discharge of industrial and municipal effluents into main sources of water supply should be implemented. This is to safeguard human health mostly those that rely on water directly from rivers without better alternatives due to poverty, economic constraints and lack of infrastructure to get clean tapped water. Raw sewage also contains toxic chemicals, which directly affect aquatic life. These chemicals include disinfectants, detergents, soaps and dyes.

5.2 Anthropogenic water pollution

Anthropogenic water pollution has become a threat to water ecosystem due to rapid urbanisation and industrialisation. Human activities introduce components either physical, chemical or biological that diminish water quality as well as affecting aquatic habitats (Arimoro, 2010). Water from sewage and industrial effluents is proving to be one of the most pervasive and devastating anthropogenic point – source of pollutants to the aquatic environment. Organic contamination of river water also results from efforts to increase food production by use of agrochemicals and from increased municipal and industrial waste discharges into rivers. This in turn results in higher prevalence of eutrophication in the receiving waters. Effluent high in nitrogen and phosphorus are released that stimulate excessive aquatic plant growth, reducing the Dissolved Oxygen content and increasing Biological Oxygen Demand (Chirisa and Chanza, 2012). Eutrophication is a natural, slow process but can be accelerated by anthropogenic activities. Consequently, this study seeks to evaluate the quality of effluent discharged into rivers and streams so as to ascertain harm to all living organisms relying on Mukuvisi River for survival or habitat.

5.2.1 Surface Water pollution

Water removes waste that humans produce by either simply carrying the waste away or processing it through its biological self-purification processes thus rendering the waste harmless. It is to this attribute of river water that makes human populations to reside close to rivers. Water could be drawn from the river and sent back into the same water system. The river could be able to purify itself. The African continent has many large urban areas located by river banks that have inadequate or no wastewater treatment facilities. Populations in these areas are in millions and wastewater disposal is now a major health and ecological consideration (Kelishadi, 2012). Storm water drainage in the catchment flows into rivers

without undergoing any treatment process. An increase in urbanization has also led to an increase in the number of buildings and pavements which lead to an increase in surface runoff which is channelled into the storm water drainage system. Since these drain directly into the rivers, there is no opportunity for environmental assimilation.

Effluent from car wash areas mainly constitute oil and grease which have a harmful effect on water quality of the effluent receiving waters. The results obtained from the study showed trace metal elements in Mukuvisi River, might be from a number of anthropogenic activities including car wash that contribute to reduced water quality of the Mukuvisi River. Other aspects include BOD, DO, total faecal coliform count, nitrates and phosphate concentrations. Most rivers have a tendency of purifying themselves to improve water quality and their biophysical integrity, but according to the results from this study, Mukuvisi River is failing to purify itself because of high loads of pollution. Oil and grease also affect aquatic organisms' especially photosynthetic plants where light visibility is reduced limiting the rate of photosynthesis. Effluents released from car wash often carry phosphates that could have increased phosphate concentration at site 3 to site 5. These phosphates were promoting rampant algal blooms and promote weed growth. At site 6 there was rampant algal growth covering large part of the water surface. Mukuvisi River is polluted by detergents also as local people, because of water shortages, end up doing their laundry directly in the river.



Fig 5.1 Family doing its laundry in Mukuvisi River close to Glen Norah high density area.
(Source: Lee: Newsday 2013)

Fig 5.1 shows a family doing its laundry in the river close to site 5. These activities can contribute to higher phosphate levels at site 5 as shown in table 4.4. They use detergents which contain organic compounds. Detergents can be classified into 2 distinct groups of surfactant detergents as well as phosphate detergents (Masere et al., 2012). Toxic detergents fall under surfactants whilst alkaline and caustic are classified under phosphate detergents. High detergent levels in water will have harmful effects to aquatic organisms such as fish by destroying the external mucus layers. The external mucus layer prevents fish from parasites and also bacterial infections (Nhiwatiwa et al., 2011). Presence of phosphates in detergents can also stimulate algal blooms in freshwater resulting in dissolved oxygen depletion in aquatic bodies. These detergents' entry into water ecosystem used to be mostly through effluent from sewage works but now it's also directly into the water bodies through washing and bathing. Phosphorus from domestic waste is largely contributed to by detergents. Illegal dumping of waste has contributed to voluminous quantities of biodegradable organic matter in aquatic environments.

5.2.2 Urban Agriculture

In Harare, most open spaces have been turned into urban agricultural areas by urban dwellers to supplement their food sources. Cultivation of open spaces has been passively encouraged in Harare town since the great drought of 1991 - 1992 (Nhapi, 2007). This has resulted in growth of high density settlements with poor services. Because of the low status of such residential areas, urban agriculture is widely practiced to supplement income. In Africa the main force behind increasing urban population is rural - urban migration which is not complemented by the employment opportunities. Crops normally grown in Harare urban include maize for mealie meal and sweet potatoes. Plot cultivation and open space agricultural activities are rampant in most of Harare's residential areas.

Zimbabwe has been facing economic hardships resulting in food shortages and a higher rate of unemployment, has forced many urban dwellers to cultivate any open space. Wet lands are not spared. Agricultural activities in wet lands, open spaces and bank streams has increased pollutants that find themselves in Mukuvisi River rendering treatment of water more expensive. Siltation and enrichment of water sources with nutrients has been on the rise as well as destruction of vegetation and water bodies. Wetlands are regarded as flat fertile lands with more water supply therefore are easily converted to agricultural lands in urban areas. Ecologically sensitive areas (wetlands) are receiving higher amounts of nutrients as fertilizer application is intensive on small pieces of land to maximise harvest (Somaya, 2011). The cultivation of wetlands is a widespread and long - established land use practice in many arid and semi - arid regions of Africa, due to their capacity to retain moisture for long periods, and sometimes throughout the year (McCartney, 2009).

Maize crops are grown less than 50m from the river (stream bank Cultivation). This has created problems of siltation and washing of pesticides and fertilizer used in agriculture into Mukuvisi River. There are no institutions or mechanisms to control these practices and ensure that appropriate conservation measures are taken to minimise nutrient runoff into water bodies (Nhapi, 2007). Water quality is hindered by pollution from agriculture. Use of chemicals such as pesticides and fertilizers has been intensive over very small pieces of land. Chemicals have a cumulative effect on land surfaces. During heavy rains some of the chemicals and nutrients find their way into water bodies as surface runoff (ENDA – Zimbabwe, 2006). Agriculture, especially in urban centres has increased the total nutrients in urban rivers accelerating the growth of water hyacinth.

5.2.3 Waste water Disposal

Nhapi (2009) did a research on waste emanating from Firle sewage treatment plant into Mukuvisi and concluded that the effluent was poor and above ZINWA effluent discharge limits of phosphates and nitrates. This is mainly due to plant breakdowns and poor maintenance. Proper maintenance of facilities by the responsible authorities in order to turnaround the water quality is needed. The situation has been worsened by repeated years of drought, resulting in less water in the river to dilute the effluent discharge. Upgrading wastewater treatment plants to match inflows will aid in reducing the current nutrient levels to permissible levels. The treatment plant is releasing wastes with high nitrogen and phosphates which can be clearly seen at site 6 and 7 of this study. The mean nitrates were 17.54 mg/l and 15.97 mg/l on site 6 and 7, respectively (Table 4.3). Mean phosphate levels were 5.9 mg/l and 4.42 mg/l at site 6 and 7, respectively, after the Firle effluent discharge (Table 4.4).

Nitrogen and phosphorous are the important nutrients that stimulate growth of aquatic plants. These are important for the food chains in an aquatic system since they are the primary producers. However, growth of algae and other aquatic organisms can result in negative impacts on the river ecosystem. Assuming the current unstable socioeconomic situation in Zimbabwe, improved water quality will contribute towards the finance directed to water treatment. Apart from population pressure, high concentrations of nutrients are attributed to plant breakdowns and poor maintenance. High nutrients rich effluent reaching water surfaces could be reduced by upgrading the existing wastewater treatment works. Negligence at sewage plants results in water pollution. The city of Gweru has also faced water quality problems over the years and in the year 2003, the municipality negligently discharged sewage into drinking water pipes and this contamination caused an outbreak of cholera and diarrhoea in Mkoba suburb (Mtisis, 2008). Table 5.1 shows the sewage received by the treatment plants in Harare.

Table 5.1: Sewage treatment plants servicing the City of Harare

Wastewater treatment Plant	Design Capacity (ML/day)	Current Capacity (ML/day)	Received flows (ML/Day)	Capacity Utilization %
Firle	144	60	150	42
Crowborough	54	5	120	9
Hatcliffe	2.5	1	3	45
Donnybrook	12	3	7	30
Malborough	7	3	7	45
Total	219.5	72	287	

Source: Harare Water 2014

Wastewater that is received at most of the plants is higher than the design capacity. Firle sewage plant is designed to receive and process 144 ML/day but is receiving 150 ML/day. The current capacity of Firle treatment plant is as low as 60 ML/day because of constant breakdowns and poor maintenance (Muserere, 2013). This pressure has resulted in partially treated effluent being discharged into Mukuvisi River thus higher phosphate and nitrogen levels in the river. The pressure has also resulted in sewage burst in high residential areas. Fig 5.3 shows sewage burst in Mbare high density suburb. This is one of the oldest suburbs in Harare facing serious problems with burst sewage flows. This is due to the fact that the facilities are old and system overload due to high population pressure. The sewage system is failing to cope with the high populace.



Fig 5.2: Sewage burst in a high residential area (Mbare)
(Photo taken by Researcher in March 2015)

Other wastewater treatment plants like Crowborough, Hatcliffe and Malborough have their current capacity not meeting the design capacity. In most African states, wastewater reaches river water untreated posing river water as major health hazard. The spread of water borne diseases such as cholera will be rampant reducing population numbers. In Harare, the main

challenge on water quality emanates from discharge of untreated or partially treated effluent from industries and sewage treatment plants (Ndebele - Murisa, 2012). It is believed that Firle STW, the largest sewage treatment plant in Harare, with a design capacity of 144,000 ML/day and approximately 10 km upstream of the lake, is the major single polluter of the aquatic ecosystem (Muserere et al., 2013). Untreated or partially treated sewage has a tendency of reducing DO levels in water during degradation thus low DO levels recorded during the study. This results in death of aquatic plants and animals that are deprived of oxygen by decomposing material and growing alien species that thrive in anorexic conditions as well as in areas with high nitrogen and phosphorus content. In - order to meet future challenges of water demand, waste water treatment technology now needs to be upgraded to standards that can produce reusable water as a matter of routine.

5.3 Eutrophication in Mukuvisi River

River systems in most developing countries are facing problems of eutrophication (UNEP 2012). Eutrophication is mainly as a result of anthropogenic driven enrichment with two nutrients, phosphorus and nitrogen. Eutrophication can easily be identified with algal blooms forming a green layer on river water surfaces. Algal blooms prevent sunlight to reach lower aquatic plants and the decomposition of these alien invasive plants consumes a lot of oxygen creating anorexic conditions. Anorexic conditions will make water uninhabitable for aquatic organisms such as fish resulting in fish death and poor water quality (Muserere et al., 2013).



Fig 5.3: Algal blooms in Mukuvisi River after sampling site 6.
(Photo taken by Researcher in February 2015)

Fig 5.3 shows that parts of Mukuvisi are now infested with green algae as a result of high nutrient loads in the river system. Eutrophication results from processes associated with plant nutrients particularly phosphorous and nitrogen. Mukuvisi River is highly eutrophic because of high nutrient content (phosphates and nitrates). This can easily be revealed by the presence of blue - green algal blooms that thrive in nutrient rich environments. Causes of eutrophication include human activities in the Upper Mukuvisi catchment. Waste substances have found their way into the water drains and eventually into Mukuvisi River. The following are the immediate causes of eutrophication in Mukuvisi River, population pressure in the catchment as the City of Harare continues to grow resulting in the demand for water increasing dramatically. This has impacted severely on the river's water quality. Upstream of the catchment area, the catchment comprises of both residential and peri - urban farmlands as well as urban run - off, and industrial effluents that are discharging nutrient enriched effluents in the river.

Structural development in Harare has clearly outstripped urban infrastructure. Its sewerage system is insufficient to deal with sewage flowing into it, with the result that raw sewage outflows onto the streets, and eventually ends up in rivers untreated as surface runoff. This increases the nutrient levels in the river. Rapid algal growth will affect the visibility of the water, results in high competition for nutrient and sunlight leading to the early death and decay of photosynthetic species. Oxygen levels in the river will thus be depleted as decay of the dead material takes up a lot of oxygen (Alberti, 2010). This further affects other aquatic life as the oxygen levels become low. On the whole, the environment will not be conducive for life.

5.4 Legislation Governing Water Pollution in Zimbabwe

There are laws and policies in Zimbabwe that govern water quality, effluent discharge and enforce compliance. Environmental Management Act, Water Act and Waste and Effluent Disposal) Regulations constitute some of the policies and laws. Policies are there to prescribe measures to be taken to maintain good water quality. Problems in governing pollution levels in Zimbabwe primarily emanates from poor local governing structures and intentional disregard of water quality standards. This is compounded by national economic decline and interferences from political structures on decision making and enforcing the policies. Total compliance with laws and policies governing water quality is important so as to safeguard human health by supplying good quality water which is a basic need. Residents using water directly from the Mukuvisi River have been exposed to water borne diseases such as cholera because some individuals, industries and effluent treatment plants are not adhering to stipulated policies.

Environmental Management Agency is the department overseeing the policies and steering environmental initiatives in Zimbabwe. The department efforts range from control, regulation

and facilitation or promotion of environmental policies. The policies include, National Environmental Policies and Strategies (NEPS), National Environmental Policy (NEP), the Local Environmental Action Plans (LEAP), Environmental Impact Assessment (EIA), Water Act and others. Zimbabwe has committed itself to Rio Convention on Environment and Development also known as Agenda 21 by coming up with National Environmental Policy (NEP). The 1998 Zimbabwe Water Act calls for the formation of catchment authorities, responsible for catchment development, water - allocation and pricing, and water quality under supervision of the Zimbabwe National Water Authority (ZINWA) (Magadza, 2003). The Water act was the first act enacted to curb water pollution in rivers and catchments. The Water Act focuses on the development and use of water resources. It has a short term basis on use “here and now” and as a result it does not reflect provisions for environmental issues such as pollution (Moyo and Mtetwa, 2002). This promotes reaction to pollution rather than preventative and the process of prosecution is very slow. The state of water quality in Zimbabwe’s water bodies now needs preventative measures and remediation to try and conserve the available water resources sustainably.

The Environmental Management Act (Chapter 20:27) gave rise to Environmental Management Agency. The Environmental Management Agency statutory body is responsible for ensuring the sustainable management of natural resources and protection of the environment, the prevention of pollution and environmental degradation, the preparation of Environmental Plans for the management and protection of the environment (EMA, 2014). The Environmental Management Act specifies that every industry or authority must have a description of its activities, policies pertaining to their core activities and compliance in reference to the environment quality standards. Most companies comply with the act to have the documentation but lack the implementation. Most companies end up discharging poor effluent to the river system.

Local Environmental Action Plan (LEAP) is a plan that focuses on the cohesion of the community in protecting the environment. LEAP has its weaknesses highlighted in Environmental Management Act (2011) as a time consuming, needing a huge financial muscle to meet the expectations. It was realised that it was not realistic as it raises the hopes of the local community without meeting the expected. EMA (2014) also highlights the importance of LEAPS. Vision is shared from various individuals with different interests, goals and values to achieve sustainable development in communities. In the formulation and implementation of LEAP, both the local authority and community brainstorm on the plan, though the co-ordination done by the local authority. This creates a feeling of ownership towards safeguarding the natural resources. This looks good on paper but the execution of the LEAP is very slow or is not done as resources are channelled to pressing issues such as health. Kelishadi (2012) has stated that: in a city or town, the only strategy that can achieve the expected goals is to identify the strength of the city and build upon the strength to improve the indigenisation. It is effective to use home grown solutions to solve environmental problems than use borrowed solutions. This brings a solid foundation for effective sustainable development of any community. In Zimbabwe it looks good on paper but the implementation is very slow. This has resulted in higher levels of pollution in aquatic ecosystems from indigenisation.

Environmental Impact Assessment (EIA) is provided for in the EMA Act. EIA is a process that looks at impacts during development putting into cognisance possible impacts on both human beings and the environment, putting more emphasises on social, economic and physical environment. EIA tries to identify likely impacts during development and after, ways to reduce or minimise the negative impacts brought about as well as the benefits that comes along (EMA 2011). This is a good strategy to protect the environment. Most companies comply on registration but the implementation in the long run is not fully followed

up by EMA. This might be as a result of lack of resources. Environment Management Act (CAP 20:27) which focuses on effluent and solid waste disposal regulation, controls water pollution by industries in Zimbabwe. The act states that no waste water or effluent should be discharged into water bodies directly or indirectly except given the green light by EMA in form of a licence (EMA 2011). Offenders shall be liable to a penalty or pay the restoration of polluted environment. This is known as “polluter pays principle”. The polluter pays principle is not effective as it focuses on concentration rather than the load of effluent. Pollution loads should be put into cognisance to curb water pollution through effluent discharge. The polluter pays principle, to some extent, has some weakness. Most industries prefer to dump and pay for their effluent rather than treating and using environmental friendly methods to dump their wastes. Paying is cheaper than treating the effluent. Implementation of charging both the concentration and load of pollutants will deter industries as most industries dilute their waste before discharge to meet the concentration based discharge limits (Muserere et al., 2013). This will create a situation or force industries to shun pollution control and implement water pollution measures rather discharging. The fines charged to industries are not deterrent enough and cannot remediate the polluted environment.

A company close to Epworth (a small town outside Harare), dumped dangerous chemicals that contaminated wells used by residents to draw water for drinking but was fined a mere US\$600 by the local board (Chirisa 2012). However, in most developing countries the focus is more on pollution remediation than pollution prevention (UNEP, 2012). The fines charged are not even enough to remediate the polluted environment. It's high time countries incorporate legislations that address issues of pollution reduction to achieve sustainable development. Mulwa, (2013) in the Herald Zimbabwe on the 8 August, 2013, highlighted that local authorities in Harare were pumping untreated sewage into Harare's main water sources that supply drinking water. This was because of the treatment plants were old and dilapidated,

pump stations and bio filters were no longer functioning. The rivers now pose a serious health risks to Harare population. On August 23 2010, EMA dragged Harare City council to court over alleged discharge of untreated sewage effluent into Mukuvisi River (Chirisa, 2012). A ruling was made to stop the council from pumping raw sewage into rivers but the damage had already been done. All stakeholders should be involved in policy making, implementation and remediation procedures otherwise these policies will remain ineffective and meaningless (Bain et al., 2012).

River water protection should be placed as an urgent matter. Zimbabwe needs to incorporate water quality and regulations in both the national legislation and train the enforcement agencies on how to deal with pollution matters. Enforcement agencies have to ensure the compliance and enforcement of the water policies to curb water pollution and preserve water resources for the future generations.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The following conclusions were made after analysing the results and discussions:

Water quality in Mukuvisi River is highly polluted and impacted by human activities. Water quality levels are not within the recommended ZINWA and WHO standards for some of the parameters rendering it unsuitable for its multiple domestic purposes. The results from the study highlight that point and non - point sources of pollution, especially from anthropogenic activities such as urban agriculture, illegal dumping of waste on river banks, industrialization and sewage effluent discharge, are the main sources of Mukuvisi River pollution.

Both of the two Hypotheses (H_0) were accepted. Rapid urbanisation in major Zimbabwe towns especially Harare, has greatly resulted in water pollution. This is because infrastructural development (water and sewage effluent treatment plants) is not expanding and upgraded to accommodate an influx of people into urban centres. Overloading and total disfunctioning of the plants have resulted in discharge of partially treated or untreated sewage into water bodies. Activities such as stream bank cultivation and urban agriculture in general have also posed threats to water quality in water sources in Harare including Mukuvisi River. Due to economic hardships facing Zimbabwe, urban agriculture if properly managed, can be boosted by use of nutrients removed from waste waters. The public is often not aware of the economic, social, health threats and ecological consequences of water quality deterioration in Mukuvisi River. Mukuvisi River water quality showed a decreasing trend as the river meandered through the city.

The river is showing signs of eutrophication as a result of total nitrates and total phosphates that are discharged into the river most likely from industries, Firle Sewage treatment plant and urban agriculture. These activities are responsible for the deteriorating quality of water along the Mukuvisi River. Industrial effluents and sewage waste contributed much of the metal (copper and lead) concentrations into the river, which were found to be above the recommended concentrations on river water quality by ZINWA and WHO standards. Higher population growth rates in the city of Harare had adverse effects on water resources. Sewage treatment plants are under immense pressure leading to discharge of partially treated or untreated waste. Firle sewage treatment plant was failing to cope with the amount of sewage received daily because of the population influx into the city as shown on Table 5.1. This has resulted in bursting of sewage pipes and flowing of sewage in streets as well as untreated sewage finding its way into water bodies.

Generally, physico - chemical parameters phosphates, nitrates, DO, BOD, were above the recommended ZINWA and WHO thresholds. Only pH (excluding site 2) and temperature fell within the recommended river water standards. Traces of faecal coliform were found both in the upstream and downstream of the river with higher concentrations recorded downstream. Evidence of faecal coliforms in Mukuvisi River points to the fact that sewage effluent from treatment plants discharged in the river is of poor quality. Firle treatment plant has faced a lot of system failure due to aging system and pressure on the dilapidated plant resulting in discharge of raw sewage in the river. High population in Harare requires an urgent overhaul and constant upgrading of the five treatment plants (Firle, Crowborough, Hatcliff, Donnybrook and Malborough) to significantly reduce continuous deterioration of water quality.

6.2 RECOMMENDATIONS

Due to the fact that Zimbabwe has limited water resources as most parts of the country are semi-arid, water sources and quality should be preserved to meet sustainable development. Mukuvisi River water is highly polluted in terms of both physico-chemical parameters and coliforms. The following recommendations are made:

Nutrients and heavy metals in the river can be neutralised or removed. There are plant species such as dark weed that have a great potential to remove heavy metals and nutrients. Dark weed can be used to take up nutrients and heavy metals in water without disturbing the aquatic ecosystem therefore reducing the excessive amounts of pollutants in the river. Total phosphates, total nitrates and trace metals such as copper, and lead are easily removed from water surfaces by dark weed (Bain et al., 2012). These weeds can slightly increase eutrophication but proper management and harvesting can reduce the effects as they can be used as stock feed. A study done in Vietnam reviewed that dark weed provides both energy and protein ruminant animals and poultry (Shahriari, 2012). Dark weed use as stock feed pose a risk of bio magnification of metal elements in tissues of organisms at successively higher levels in a food chain. If given sufficient space and time, therefore, the varied aquatic vegetation and wetlands that act as sponges for nutrients and pollutants within the waters can revitalize this river system (Ndebele – Murisa, 2012).

To curb water pollution in urban areas, all stakeholders must be involved and contribute to instil a feeling of ownership therefore safe - guarding the resources. Reduction of pollution entering Mukuvisi River is another long term management of the aquatic system. City councils need to upgrade the sewerage system at Firle treatment plant to meet the higher numbers in its residents. Controlling pollutants at their source is ideal as the producers know

the compositions of their waste. This will bring about cost effective and effective measures to reduce discharge of concentrated effluents by industries. The polluter pays principle has failed to address the issues relating to reduction in water pollution by industries and sewage works. Industries prefer to pollute and pay, as it is cheaper to pay than have treatment facilities at their industrial sites. Penalties which deter polluters should be enacted and enforced. Alternatively the polluter pays principle should be replaced by policies that reduces effluent discharges rather than paying for the discharge. The rate and quantity of pollution will be greatly reduced thus reducing the impacts thereof. Sustainable development calls for ways to prevent water pollution than to remediate the water source after aquatic ecosystem has been disturbed or destroyed. It has been highlighted that industries are the main culprits through their release of waste material that clearly overshoot the legal emission levels. Industries should realise that their activities are major threats to the health of millions of people as well as the welfare of the ecosystem. Since the fines are so low that they do not inhibit such practices, it is only right and sensible to impose prohibitive fines that result in industries investing in water purifying machinery that will enable them to release effluent that conforms to the WHO levels.

By-laws and policies clarifying water quality standards must be evaluated to meet with the change in technology and urban demands in City of Harare. Town councils should enforce by-laws which ensure that all organizations within the jurisdiction, which emit pollutants into the river, must have viable departments which cater for effluent sample monitoring and assessment programs. Policies that address diffuse pollution which is difficult to control should be emphasised as much of the pollution emanates from diffuse sources. Public awareness is recommended to curb diffuse pollution. A lot of research has been carried out but the findings and recommendations in the area of study have not been put into practice.

Remedial actions and planning and participation have to be taken by all stakeholders in the catchment. Public awareness campaigns and training should also be provided to Harare residents to ensure knowledge and understanding of better ways to abstract water with minimum pollution levels. The residents, users of the water, have not been involved in the decision making process. Policy makers as well as the decision makers have been on the forefront to make decisions. Integrated Water Resources Management (IWRM) emphasises development and management of water resources as a participatory approach (Sato et al., 2013). All stakeholders or affected parties including city planners, policy makers as well as residents (users) have to contribute and come up with solutions to reduce water pollution. Public participation is also a mechanism whereby people can express themselves. Water pollution prevention should be done in a “bottle up approach”, where the ordinary citizens are involved in decision making as they are the custodians and direct consumers of the water resources. Residents will have a feeling of owning the water resources. All this will install the attitude of owning the water resources resulting in less of pollution from residents.

Harare council authorities must make preservation of wet - lands one of their major priorities. Wetlands have an important ecological role. Besides providing a habitat to aquatic organisms such as fish, wetlands helps in preserving water quality by trapping pollutants such as nutrients and heavy metals. Nutrients and toxic chemicals might find their way into wetlands as surface runoff, increasing chances of pollutants removal before water is discharged into rivers. Nutrients from agricultural activities can easily be absorbed or converted to less harmful forms before it reaches rivers. Community health and animals should be constantly monitored, especially those relying on river water as their water source.

Funds and time permitting, more of heavy metals and bacteriological pollution needs to be addressed to reduce intoxication of river systems and organisms in and surrounding the water source. Effects of bacteriological pollution and heavy metal pollution are intense to the health of the river and organisms.

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THEODORE Z NHERERA
QUALITY ASSURANCE SCIENTIST

Head office
2nd Floor Pax House
Cnr S. Nujoma/K. Nkrumah Ave, Harare
P.O Box CY 617, Causeway, Harare
Tel/Fax: 263-4-703035/705900/707054

CELL: 0779 994144
email:tnherera@zinwa.co.zw

218 Princess Park Heights

3 Church Street

Pretoria Central

Republic of South Africa

Cell +27 71 813 8345

Email: bschimuriwo@gmail.com

10 November 2014

The Secretary

Att: The Manager ZINWA

Harare Bulk Water Supply, Manyame Catchment

Harare

Zimbabwe

Dear



Ref: Request to Collect Research Samples from Mukuvisi River in Harare

I am studying for a Masters of Environmental Science degree at the University of South Africa, UNISA. I am writing to ask for permission to collect research samples in Mukuvisi for about 5 months starting December 2014 to May 2015.

The results of the water quality will be analysed and reported in chapter 5 of the thesis. Thereafter the results will be destroyed by shredding. The title of the thesis is "An Assessment of Water Quality along Mukuvisi River."

I am committed to respecting and protecting the privacy of data collected and analysed and to the ethical use of information. The results will be treated with the highest level of confidentiality. Photographs taken will not include people or private properties where consent and confidentiality will be required. The results will not be published or give to the media. There are no foreseeable risks in participating in this research. This is in compliance with the provisions of the UNISA CAES Research Ethics Policy.

The study will add to the in-depth knowledge of the quality of water in Mukuvisi River during this present moment. It can also increase the awareness to protect the water resources for the future generations, by implementing measures to prevent pollution.

Should you have any concerns and questions about the study you may use the following details to contact my supervisor

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 27/11/2014

Ref #: **2014/CAES/171**

Name of applicant: **Mr B Chimuriwo**

Student #: **50830007**

Dear Mr Chimuriwo,

Decision: Ethics Approval

Proposal: An assessment of water quality along Mukuvisi River (Harare, Zimbabwe)

Supervisor: Prof M Tekere

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.

Please consider point 4 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 27 November 2014.

The proposed research may now commence with the proviso that:

- 1) The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
- 2) Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
- 3) The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and*



scientific standards relevant to the specific field of study.

- 4) *The researcher must take note of the dangers involved in collecting samples from a river, and should take the necessary precautions to ensure his own safety.*

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,



Signature

CAES RERC Chair: Prof EL Kempen



Signature

CAES Executive Dean: Prof MJ Linington

*Please note conditions
good luck.*

