PHYSICO-CHEMICAL PARAMETERS, BACTERIAL LOAD AND HEAVY METALS, IN WATER AND VEGETABLES GROWN ALONG MITHEU RIVER, MACHAKOS COUNTY, KENYA

BY

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DECLARATION

This research thesis is my original work, and has not been presented for any award or a degree in any other University.

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I dedicate this work to the Glory of the God Almighty, and my loving parents, Mr. Daniel Kamau, and Mrs. Emily Kamau for their invaluable support, and encouragement throughout my education.

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ACRONYMS, AND ABBREVIATIONS

ANOVA	Analysis of Variance
ASAL	Arid, and Semi-Arid Lands
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
GoK	Government of Kenya
KNBS	Kenya National Bureau of Statistics
NGOs	Non-Governmental Organizations
SPSS	Statistical Package for Social Sciences
TDS	Total Dissolved Solids
UN	United Nations
UNEP	United Nations Environmental Program
WHO	World Health Organization

ABSTRACT

Urban streams are increasingly utilized for irrigation farming to supplement the demand for food in cities, and towns. The susceptibility of these streams getting polluted by improperly treated industrial, and municipal effluent is high. The objective of this study was to investigate the bacteriological, and heavy metals contamination in Mitheu stream within Machakos municipality, and concentration of selected heavy metals in vegetables irrigated with water from the stream in order to contribute to measures towards safe disposal of effluent. This study investigated the water quality of Mitheu stream with respect to irrigation use, and the levels of selected heavy metals in Kales, and Spinach grown along the stream. Bacterial counts, physico-chemical parameters i.e., temperature, pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), nitrates, phosphates, and sulphates as well as selected heavy metals i.e., Cd, Cu, Zn, Pb, and Cr were analyzed in water. The concentration of these selected heavy metals in kales, and spinach were determined as well. water samples for physico-chemical, heavy metals, and bacteriological analyses were collected in four selected sampling points along Mitheu stream once every month from June to September 2019. Kales, and Spinach samples for heavy metals analysis were collected from farms along the stream adjacent to the selected sampling points. Physico-chemical, and bacteriological analyses were performed in Water Resources Authority Laboratory in Nairobi. Heavy metals analyses in both water, and vegetables were performed in Kenya Plant Health Inspectorate Services Analytical Laboratory in Nairobi. The results were subjected to One-Way Analysis of Variance to test significant differences. Comparison with WHO standards for the respective parameters was done to test suitability of the stream water for irrigation, and the vegetables for human consumption. The stream was found to contain higher-than-recommended levels of pH, TDS, EC, COD, BOD, and Bacterial contaminants. Concentrations of nitrates, and cadmium (Cd) in the stream were also higher than WHO safe limits for irrigation water. Concentrations of COD, BOD, and Total Coliforms bacteria had significant variation along the stream ($p \leq 0.05$). All other parameters investigated, were not significantly varied along the stream. The concentrations of Cd, Pb, and Cr in kales, and spinach exceeded WHO recommended limits. There was no significant correlation between the concentration of heavy metals in water, and in vegetables except for Cu. These findings implied inefficiency in the effluent management system within Machakos municipality. They further indicated that the stream was not fit for use in irrigation farming as it presented a health hazard from bacterial infections, organic chemicals as well as cadmium poisoning to the farmers, and consumers of their produce. Vegetables grown along this stream were also unsuitable for consumption as they threatened the health of consumers via Cd, Pb, and Cr poisoning. The County Government of Machakos working together with the National Environment Management Authority need to take appropriate measures to curb untreated effluent discharge into the stream. Public sensitization of residents of Machakos municipality with respect to the health implications of farming with heavily polluted water is also recommended.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Availability, and adequate access to clean water, and sanitation services is a key target towards the achievement of sustainable development as clarified in Sustainable Development Goal number six (Gallaher *et al.*, 2013). Globally about 844 million people do not have access to clean drinking water. This represents about 29% of the world's population (Antwi-Agyei *et al.*, 2016). As population continues to increase coupled with adverse effects of climate change this number is predicted to rise even further by 2050 (Ogbonna and Ajubo, 2017). Additionally, about 2.3 billion do not have access to proper sanitation services (Qureshi *et al.*, 2016). Moreover, most raw sewage from cities, and municipalities find their way to water bodies (Silverman *et al.*, 2013). World Health Organization (WHO, 2016) further estimates that about 80% of all waste water globally is released to water bodies without undergoing the appropriate treatment process. Rivers, and streams are the main recipients of this raw sewage yet are the main sources of water for irrigation, and domestic use (Benti *et al.*, 2014). The problem is most prevalent in Sub–Saharan African Countries where most cities, and towns are inadequately served with sewage treatment systems (Ogbonna and Ajubo, 2017).

Globally, it is estimated that about 80% of all common hospital visits are occasioned by the consumption of contaminated water (WHO, 2016). The various avenues via which people come into contact with polluted water include either directly drinking it, washing their fresh produce with the polluted water or by irrigating their farm produce with polluted water where the pollutants are absorbed into the plants then passed to humans through the processes of bioaccumulation, and biomagnification (Abakpa *et al.*, 2013). Due to water scarcity in most of the Sub-Saharan African countries, polluted water in rivers is used for irrigation purposes (Zavadil, 2009). As a result, the pollutants are then transmitted through vegetables, and crops grown to the consumers in the market (Qureshi *et al.*, 2016). Some of the common health disorders resulting from heavy metal poisoning include liver, and kidney damage, gastrointestinal problems, high blood pressure, and damage to the reproductive system (Putri *et al.*, 2018).

Most industrial, and municipal wastes contain bacteriological, chemical as well as physical pollutants (Mahmoud and Ghoneim, 2016). Different types of bacterial coliforms are contained in these wastes (Benti *et al.*, 2014). Chemical contaminants such as heavy metals are also in substantial amounts in most industrial wastes because of various industrial processes (Singh, & Kumar, 2017). In most countries, Kenya included, urban population is rapidly increasing as people change lifestyles in an attempt to get better livelihoods (Gallaher *et al.*, 2013). This increases urban farming as well as farming in areas adjacent cities, and towns (Abakpa *et al*, 2013). Irrigation farming in these areas is prone to use of polluted water hence putting to risk the health of the people consuming such produce (Silverman *et al.*, 2013). Farming in the outskirts of Machakos town utilizes water from rivers that receive direct untreated sewage from the town's municipal, and industrial activities. The direct exposure to contaminated water to the farmers combined with the health impacts of consumption of contaminated vegetables by residents of Machakos town hinders sustainable development within the region. This is because consumption of polluted vegetables from the stream contravenes the sustainable development goal number three on good health, and well-being (Silverman *et al.*, 2013). Therefore, this research was designed to investigate the levels of heavy metal pollutants in Mitheu stream within

Machakos municipality, and the vegetables irrigated with the stream water, and supplied in the market, and compare the levels of heavy metals in water, and vegetables with the WHO allowable limits. The outcome of the findings was used in formulation of regulation regarding waste effluent treatment in Machakos town.

1.2 Problem Statement

In Kenya most towns that do not have a functional sewage treatment system channel their raw wastes to urban rivers/streams or other large water bodies (Andersson, 2018). In addition, in the zeal to satisfy the food demand for urban population, especially vegetables, farming along the rivers is highly practiced (Ogbonna and Ajubo, 2017). Urban farming is common in most Kenyan cities, and towns (Gallaher *et al.*, 2013). Machakos town currently does not have a functional sewage treatment system (Wambugu *et al.*, 2015). The existing sewage management system is in a dilapidated state in addition to lacking the capacity to serve the already grown population of Machakos town (Wambugu *et al.*, 2015). This has the implication that all municipal, and industrial wastes end up in the neighbouring Mitheu, and Ikii streams (Andersson, 2018). The streams in turn flow to join rivers Mwania, and Ikiwe respectively that are used by the local community for domestic, and irrigation purposes.

The emptying of raw sewage into these streams potentially exposes the users to multiple bacterial, chemical, and physical pollutants at high concentrations. The subsequent use of this sewage-polluted water for irrigation transfers these pollutants to vegetables through the process of bioaccumulation (Andersson, 2018). The problem is prominent in the neighborhood of Machakos town since most of the vegetables consumed within the town are irrigated with this sewage-polluted water (Wambugu *et al.*, 2015). This was established during the baseline study, where majority of the local vegetable vendors were found to source their vegetables from the farms along Mitheu stream. The vegetables in turn transfer the pollutants to the consumers, both members of the local community, and residents of Machakos town. Absorption of pollution via consumption of polluted vegetables is a common phenomenon that has lasting effects to the health, and well-being of the residents of Machakos town, and its neighborhood (Andersson, 2018). The study therefore investigated the concentrations of bacterial contaminants, and selected heavy metals in the water of Mitheu stream, and vegetables grown along the stream within Machakos town. The findings were used to formulate strategies for the management of the water resource.

1.3 Research Questions

i. What is the state of physico-chemical parameters, and concentrations of heavy metals (Lead, Chromium, Cadmium, Zinc, and, Copper) of water in Mitheu stream?

ii. What is the level of bacteriological contamination in water of Mitheu stream?

iii. What is the level of heavy metal concentration in vegetables (Brassica oleracea, and Spinacia oleracea) irrigated with water from Mitheu stream?

iv. Is there a relationship between heavy metal concentrations in the stream water, and vegetables, and does this concentration exceed the WHO permissible standards?

1.4 Research Hypotheses

i. The status of physico-chemical parameters, and heavy metal concentration in the water of Mitheu stream is not significantly higher than the WHO standards.

ii. The bacterial contamination in the waters of Mitheu stream is not significantly higher than WHO recommended limits for irrigation water.

iii. The heavy metal concentration in the vegetables (Brassica oleracea, and Spinacia oleracea) is not significantly higher than the WHO set standards.

iv. There is no significant correlation between the selected heavy metals concentration in Mitheu stream, and that of the vegetables irrigated using water from the stream.

1.5 Study Objectives

1.5.1 General objective

The main objective of this study was to investigate the chemical, heavy metals, and bacteriological, contamination in Mitheu stream within Machakos municipality, and the bioaccumulation of heavy metals in common vegetables irrigated with water from the stream in order to contribute to measures towards safe disposal of effluent.

1.5.2 Specific objectives

The specific objectives were:

i. To assess the physico-chemical parameters, and concentrations of Lead, Chromium, Cadmium, Zinc, and copper of water in Mitheu stream

ii. To investigate the level of bacteriological concentrations in Mitheu stream

iii. To assess the concentration of heavy metals in selected vegetables (Brassica oleracea, and Spinacia oleracea) irrigated with water from Mitheu stream

iv. To determine the relationship between heavy metal concentrations in the water, and in common vegetables grown along the stream

1.6 Significance of the study

The findings highlighted the current condition regarding the efficiency of the sewage management system for Machakos town. The findings formed a basis for further studies into the health impacts as a result of consumption of contaminated vegetables by residents of Machakos town. Based on the findings recommendations were made to improve the existing sewage management system to ensure better living environment for the residents within, and in the outskirts of the town. This shall aid in the control of the direct discharge of raw industrial, and municipal sewage into the streams. The ministry of Agriculture in conjunction with the ministry of water at both the national, and county governments shall use the findings of this study to formulate policies regarding the use of Mitheu stream for irrigation farming. The findings on the safety of the vegetables irrigated with water from the streams are useful to policy makers to regulate the use of this stream for crop irrigation. The study further informed the state of health of the residents in relation to the direct release of raw sewage into the streams. The ministry of Health, County Government of Machakos shall rely on the findings of this study to initiate further assessment on the status of community health of residents of Machakos municipality. This shall in turn ensure informed policy formulation, and implementation to safeguard community health.

1.7 Conceptual framework of the study

The conceptual framework below (Figure 1.1) illustrates the relationship between the independent variable, the intervening variables, and the dependent variables. The independent variables in this study were stream pollution, irrigation farming along Mitheu stream efficient, and sewage management system. The intervening variables are factors that ensure that the sewage management system functions efficiently while the dependent variables are improved water quality in the nearby Mitheu stream, and improved quality of vegetables consumed within Machakos town, and the neighborhood. These variables were seasonal flow of Mitheu stream, frequency of crop irrigation, type of crop, and duration of growth period. The dependent variables were level of chemical pollution, level of heavy metal pollution, level of bacteriological pollution, and level of vegetable contamination.

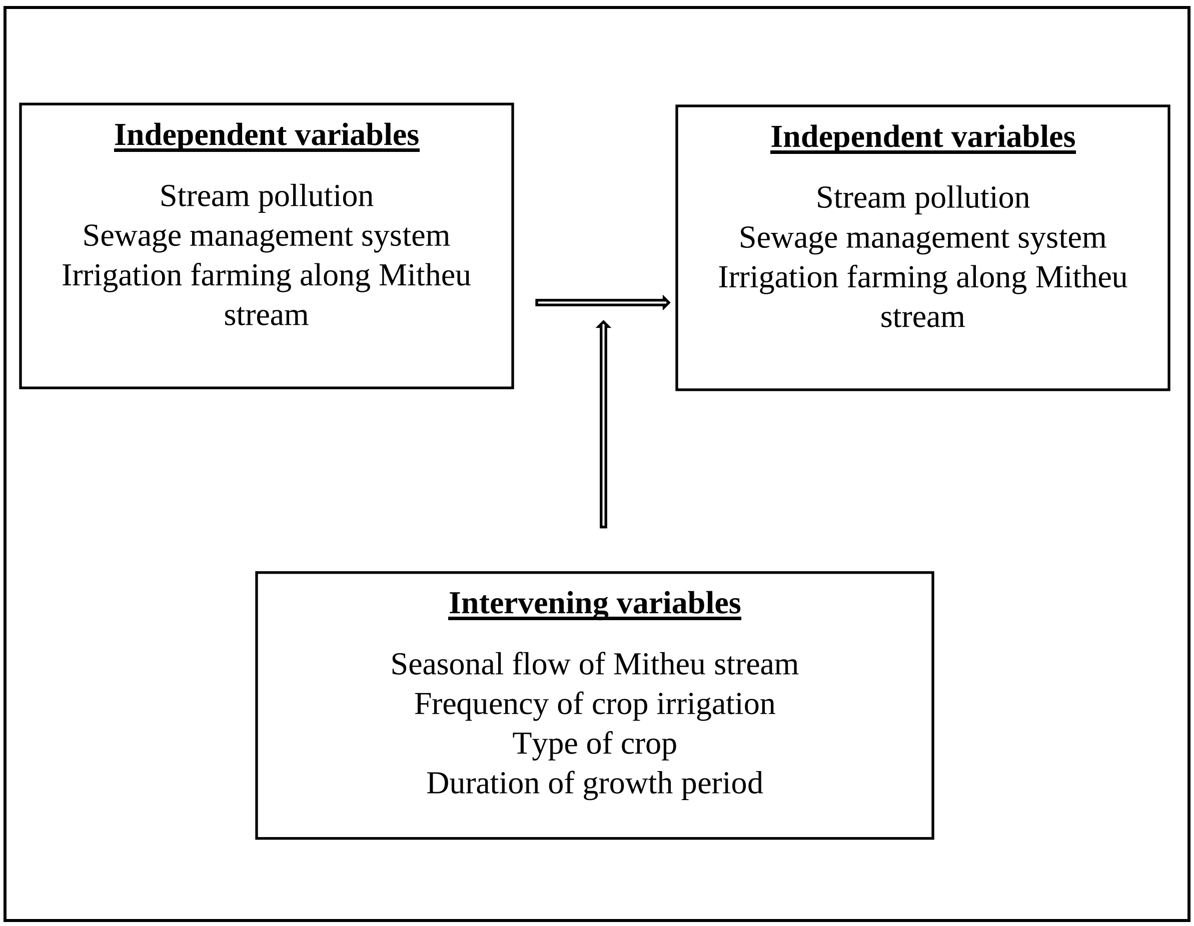

Figure 1.1: Conceptual framework

1.8 Scope of study, and assumptions

This research study involved the assessment of the level of heavy metals, and bacteriological contamination of Mitheu stream by raw industrial, and municipal wastes from Machakos town. The research further investigated the level of heavy metal pollution of vegetables (kales, and spinach) irrigated using polluted stream water from Mitheu stream. A comparative study on the concentration of pollutants upstream, and downstream after getting diluted was performed. The research study assumed that water for irrigating the adjacent farms where vegetables were collected was drawn at the exact point where sampling was done. This allowed for a correlational analysis of the heavy metal concentration in the stream, and vegetables.

1.9 Definition of terms

Analysis Critical values- these are the values in statistical testing of hypothesis that are used to either reject or not reject the null hypothesis. These values are such that when the test value is greater that the critical value the null is rejected with statistical significance (Ayyub and McCuen, 2016).

Bio-accumulation- this is the process through which chemical substances, and contaminants are accumulated in bodies of organism when the rate of absorption exceeds the rate at which they are excreted from the body (Ali *et al.*, 2016).

Bio-concentration- the gradual increase in chemical contaminants in the bodies of aquatic organisms such that it exceeds the concentration of the same contaminants in the media (Abakpa *et al.*, 2013).

Bio-magnification- the continuous increase in the concentration of toxic substances in the bodies of organisms from lower trophic level to higher trophic levels (Abakpa *et al.*, 2013).

Domestic Sewage- refers to the wastewater generated by people living in a community

Effluent- a term used to liquid waste discharged into a water body, such as a river or the sea (Lu *et al.*, 2017).

Heavy metal poisoning- this is the accumulation of toxic heavy metals in body organs over time leading to harmful impacts to the body (Ogbonna and Ajubo, 2017).

Heavy metals- these are metallic elements that have relatively high densities, and possess toxic properties at low concentrations (Abdel-Satar *et al.*, 2017).

Industrial effluent- the liquid waste resulting from industrial operations (Lu *et al.*, 2017).

Municipal effluent- this is the liquid waste that results from human settlement, and activities within a municipality (Lu *et al.*, 2017).

Pollution is the introduction, into the environment, of a substance that has poisonous of harmful effects (Abdel-Satar *et al.*, 2017).

Preliminary treatment –the initial stage of wastewater treatment process that removes large solids, and coarse materials (Bismuth *et al.*, 2016).

Primary treatment- this involves the removal of suspended solid particles that settle through sedimentation, and those that float by skimming (Bismuth *et al.*, 2016).

Secondary treatment- the stage of waste water treatment that involves removal of biodegradable substances, and colloidal particles by the use of aerobic bacteria (Bismuth *et al.*, 2016).

Stream is a small body of surface water flowing in a channel bound by banks. It has to be relatively small to differentiate it from a river (Ali *et al.*, 2016).

Tertiary treatment –a description of advanced treatment techniques applied to remove chemical contaminants that have passed the secondary treatment process. They are sometimes specific treatment procedures for specific chemical compounds (Bismuth *et al.*, 2016).

Treated water is the effluent that has been passed through the various stages of wastewater treatment to remove contaminants such that it can be returned to the river ecosystem (Ali *et al.*, 2016).

Urban, and Peri-urban Agriculture – these are agricultural practices including crop farming, fish farming, livestock keeping or agroforestry practices done within cities, and their suburbs (Qureshi *et al.*, 2016).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Industrial, and municipal sewage waste treatment has been an important requirement when setting up cities, and industries (Ogbonna and Ajubo, 2017). The impact of untreated industrial, and municipal wastes in rivers, and other water bodies is detrimental to both aquatic ecosystem, and human beings who consume the water either directly or indirectly (Marrugo-Negrete *et al.*, 2017). Municipal wastes consist mainly of domestic organic wastes, and microbial pollutants from domestic sewage (Ali *et al.*, 2016). The sewage is rich in bacterial coliforms as well as organic compounds from soaps, and detergents used in the domestic set up (Singh and Kumar, 2017). Industrial wastes contain organic effluents, and well as chemical contaminants, and heavy metals from industrial processes (Lu *et al.*, 2017). The release of these pollutants into rivers that in turn are used for irrigation agriculture causes major environmental, and health hazards (Putri *et al.,* 2018).

The problem is mainly persistent among developing countries due to lack of capacity, and modern technology to treat these waste waters to the tertiary level (Antwi-Agyei *et al.*, 2016). Appropriate sewage treatment should involve separation of the industrial from the municipal waste (Abakpa *et al.*, 2013). This is to ensure efficient treatment of each waste water stream, and possible recycling of the sewage from municipal systems for use in irrigation (Benti *et al.*, 2014). In Israel for example, her waste water treatment system is efficiently run with modern technology to produce water that is reusable in irrigation with less health hazards (Bismuth *et al.*, 2016). Israel is leading globally in waste water treatment, and recycled water accounts for about 25% of their overall water demand (Bismuth *et al.,* 2016). This is an indication that the re use of treated waste water in agriculture is being practiced in several parts of the world. The key requirement is that it should be adequately treated (Antwi-Agyei *et al.*, 2016).

Studies conducted in developing countries have identified the presence of significant amounts of bacteriological, and chemical contamination in rivers where sewage is directed into (Fuhrimann *et al.*, 2016). In Nigeria for example, significantly high amounts of bacteria coliforms, and heavy metal content in a river that is used for irrigation within the outskirts of Obio/Akpor Local Government (35602.5 for total coliforms) has been reported (Ogbonna and Ajubo, 2017). Such high level of contaminants are indicators that the waters are unfit for both aquatic life, and domestic consumption (Abakpa *et al.*, 2013). The discharge of poorly treated industrial, and municipal sewage further flows downstream causing pollution effects to people further away from the point of discharge (Zhang *et al.*, 2016). This however, occurs in a decreasing trend due to dilution effect of the contaminants as they flow downstream (Abdel-Satar *et al.*, 2017). The lack of sufficient clean water in most developing countries forces people to consume the polluted water from such rivers without further purification (Singh and Kumar, 2017).

2.2 Physico-chemical parameters

Waste water contains numerous physical and chemical contaminants depending on the human activities at the point where it originates. Appropriate waste water treatment is aimed at reducing these contaminants to allowable levels. The water temperature, and water pH were co-opted parameters since they influence the behavior of contaminants in water. The physico-chemical contaminants of interest in this study were Total Dissolved Solids (TDS), Electrical Conductivity (EC), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), nitrates, phosphates, and sulphates.

2.2.1 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand refers to the amount of oxygen needed to digest oxidizable pollutants in a water body (Islam *et al.,* 2018). It measures the amount of oxygen needed to completely eliminate chemical pollutants in a water body via chemical reactions (Mallika *et al.,* 2017). This oxygen lowers the amount of dissolved oxygen in water (Kakoi *et al.*, 2016). Dissolved oxygen is essential for supporting aquatic life (Donald *et al.,* 2019). Therefore, when a water body contains chemical contaminants that require oxidation for them to be eliminated, they end up lowering the amount of dissolved oxygen (Magadum *et al.,* 2018). This compromises the quality of that water for supporting aquatic life as well as being used for irrigation (Mallika *et al.,* 2017). The greater the amount of Chemical Oxygen Demand the higher the quantities of chemical contaminants in a water body (Islam *et al.*, 2018).

Waste water from municipal set up usually contains high amounts of COD (Abdel-Satar *et al.*, 2017) This is due to high content of organic, and inorganic chemicals in it that require oxidation for them to be removed (Abdel-Satar *et al.*, 2017). Efficient treatment of water before being discharged into river systems is recommended by the World Health Organization to avoid compromising the quality of water (de Medeiros *et al.,* 2017). Irrigation farming with water containing high levels of COD affects the chemical composition of soils (Islam *et al.*, 2018). The high concentration of chemical contaminants reflected in the high levels of COD get deposited in the soils, and alter it with time (Salvador–Oke *et al.,* 2018). They could further be absorbed into the plants hence getting transmitted to humans (Batool *et al.,* 2019).

2.2.2 Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) is a measure of the amount of dissolved oxygen in a water body needed to digest organic chemicals via the help of aerobic microorganisms (Mallika *et al.,* 2017). This parameter measures the amount of oxygen needed by microorganisms to break down organic chemical pollutants in water. Therefore, BOD quantitatively represents the amount of biologically digestible organic chemicals in a water sample. Similar to COD, BOD lowers the amount of dissolved oxygen in a water body (de Medeiros *et al.,* 2017). It is a parameter used to test efficiency of waste water treatment plants since a properly treated water should have WHO permissible levels of BOD (Salvador–Oke *et al.,* 2018). A high amount of Biochemical Oxygen Demand indicates presence of high quantities of organic chemicals in a water system (Donald *et al.,* 2019). Improperly treated waste water contains high quantities of BOD (Abakpa *et al.,* 2013). When such waste water is discharged in a stream, it raises the level of BOD in the stream (Islam *et al.,* 2018). Irrigation water quality standards set by WHO have set a maximum permissible limit of BOD (Magadum *et al.,* 2018). The reason for this is that higher-than-recommended levels of BOD decreases dissolved oxygen quantities thus destroying other forms of aquatic life (Batool *et al.,* 2019). Organic waste that forms a high percentage in municipal effluent contributes to high levels of BOD as they need to be digested by aerobic microorganisms (Kakoi *et al.,* 2016).

2.2.3 Nitrates

Nitrates are one of the existences of nitrogen in waste water (Salvador–Oke *et al.,* 2018). Although a higher percentage of nitrogen in waste water occurs in the form of urea, some part of it still occurs as nitrates, and nitrites (Kakoi *et al.,* 2016). The known sources of nitrates in waste water are the NPK fertilizers, municipal effluent, and animal manure.

These are mainly washed into water bodies by storm waters (Varsani, and Manoj, 2019). Rivers along which irrigation farming is practiced with the use of fertilizers have higher quantities of nitrates (Agwa *et al.,* 2013) High levels of nitrates in a stream lead to quick excessive algae growth that then wither off quickly as well (Al-Bayatti *et al.,* 2012). This increases the organic waste in the stream that then depletes dissolved oxygen as it gets decomposed by aerobic bacteria (Varsani, and Manoj, 2019).

Nitrates are also reduced to nitrite which poses health risks to people using the water for domestic purposes (Magadum *et al.,* 2018). The regulation of nitrates quantities in river systems is to ensure that the use of these waters does not harm human health (Donald *et al.,* 2019). Removal of nitrates in a waste water treatment plant is done with the help of pseudomonas bacteria (Batool *et al.,* 2019). This bacterium reduces nitrates to elemental nitrogen that is then released to the atmosphere (Varsani, and Manoj, 2019). The bacteria use oxygen derived from the reduction of nitrates. As are result this does not deplete dissolved oxygen in the water (Sa'id, and Mahmud, 2013).

2.2.4 Phosphates

Municipal, and industrial effluent is among the leading sources of phosphates in the environment (Varsani, and Manoj, 2019). Phosphate is contained in many washing detergents used for municipal, and industrial purposes (Donald *et al.,* 2019). As these detergents get washed with waste water, they increase the amounts of phosphates in the effluent (Magadum *et al.,* 2018). Human excretion via urine also contribute greatly to the phosphate content in municipal, and industrial effluent (Al-Bayatti *et al.,* 2012). This therefore has the implication that the higher the population of a town or city, the higher the amount of phosphates released via urine (Sa'id, and Mahmud, 2013). Organic fertilizers further contribute to the burden of phosphates in the environment (Tessema et al., 2019). They are then washed to water bodies by storm water (Magadum *et al.*, 2018).

When phosphates find their way to streams, and rivers probably as a result of improper effluent treatment, they cause eutrophication (Agwa *et al.*, 2013) This is the excessive growth of algae that consumes all dissolved oxygen in the water (Kakoi *et al.*, 2016). The excess algae soon dies due to insufficient dissolved oxygen in the water (Sa'id, and Mahmud, 2013). Decomposition of these organic waste by aerobic bacteria further utilizes the remaining dissolved oxygen producing inorganic waste (Batool *et al.*, 2019). Organic waste in water bodies is decomposed anaerobically producing methane, and carbon dioxide (Magadum *et al.*, 2018). Phosphates in rivers, and streams are regulated to prevent eutrophication which destroys other members of a river's ecosystem (Maraşlıoğlu *et al.*, 2017).

2.2.5 Sulphates

Sulphates in stream waters could be as a result of natural occurrence or discharge into the stream from municipal, and industrial effluent (Tessema *et al.*, 2019). Sulphates are also contained in fertilizers, and thus run off from fertilized farms washes considerable amounts of sulphates into streams (Magadum *et al.*, 2018). When sulfates find their way into water bodies, they contribute to eutrophication when in high concentrations (Varsani, and Manoj, 2019). They combine with phosphates, and nitrates to increase excessive algae growth thereby depleting dissolved oxygen in a water body (Batool *et al.*, 2019). In low concentrations, below 250 mg/L, sulphates do not pose any health threats to humans. However, in concentrations exceeding 500 mg/L, they cause laxative effects (Tessema *et* *al.,* 2019). Urban streams are bound to contain high amounts of sulphates if they get untreated industrial effluent discharged into them (Al-Bayatti *et al.,* 2012). When irrigation farming is practiced along these streams, fertilizer residues washed by storm water into the streams add to the sulphates content (Salvador–Oke *et al.,* 2018). When evaluating the efficiency of a waste water treatment system, investigation of sulphates content is necessary (Abdallah, 2018). Irrigation with water containing high sulphates content lowers the anticipated quality of crop yield (Magadum *et al.,* 2017).

2.4 Bacterial contamination

Waste water contains a host of pathogenic bacteria (Abdallah, 2018). A big percentage of municipal effluent is human fecal waste that is rich in pathogenic bacteria (Gebreyohannes *et al.,* 2015). In most cities, and town urban population keeps increasing resulting in increase in municipal effluent (Al-Bayatti *et al.,* 2012). In addition to this, their waste water management systems remain unchanged for long periods piling pressure on their efficient functioning (Agwa *et al.,* 2013). As such, the levels of bacterial contaminants released to urban streams has kept increasing over time (Tessema *et al.,* 2019). Coliform bacteria occur in municipal effluent in large numbers (Dankovich *et al.,* 2016). The coliform bacteria are gram-negative, rode-shaped bacteria that ferment lactose when incubated at 35 ^{0}C. The total coliform bacteria are classified into five genera namely; Citrobactor, Enterobactor, Hafnia, Klebsiella, and Escherichia (Dankovich *et al.,* 2016). Coliform bacteria can live in aquatic environments, vegetation, as well as soils (Wambugu et al., 2015).

They are further found in large numbers in fecal matter of most animals. Coliform bacteria are indicator bacteria used to investigate the efficiency of effluent treatment systems

(Dankovich *et al.,* 2016). Improperly treated municipal effluent that is channeled to urban stream loads these streams with total coliform bacteria (Wambugu *et al.,* 2015). The presence of total coliforms is further associated with disease causing pathogens (Al-Bayatti *et al.,* 2012). As a result, a stream that has very high total coliforms count has an exceedingly high number of disease-causing pathogens (Gebreyohannes *et al.,* 2015). These bacterial are able to multiply even further in aquatic ecosystems increasing their numbers in streams (Abdallah, 2018). Bacteria are transmitted to leafy vegetables directly via irrigation when the contaminated water splashes on their leaf surfaces (Tessema *et al.*, 2019). Indirect exposure could occur when plants absorb contaminated water (Ogbonna & Ajubo, 2017).

The presence of significantly high levels of bacterial coliforms in water used for domestic, and irrigation purposes poses a threat to the health, and wellbeing of the people (Silverman *et al.,* 2013). Mostly the urban, and peri urban population are worst hit by the impacts of these pollutants (Putri *et al*, 2018). The negative impacts on human health occur either by directly consuming the water for domestic purposes or using the water for irrigation (Paul, 2017). In domestic usage, the bacteria coliforms come into direct contact with human being causing diseases such as cholera, typhoid, and, Bilharzia among others (Fuhrimann *et al.*, 2016).

2.5 Heavy metals toxicity

Heavy metals are cumulative toxicants that become more toxic as they accumulate in the body. Their toxic effects are mostly chronic since there are rare chances of acute poisoning by heavy metals (Kim *et al*, 2015). These heavy metals are also rare metals that exist in small quantities wherever they are found within the earth's crust (Putri *et al.*, 2018). They come into contact with humans through mining activities, and industrial processes where they are part of the raw materials. Lead for example is highly toxic if ingested past certain small quantities (Kim *et al*, 2015). The toxicity of lead affects mostly the kidneys, liver, and the brain (Putri *et al.*, 2018). Chromium, and cadmium toxicity also mostly affects the liver, kidneys, and the brain (Kim *et al*, 2015).

Young children, especially infants are more vulnerable to heavy metals poisoning as compared to adults since their ingestion rate is 4-5 times that of adults (Kim *et al*, 2015). The impacts of these heavy metals on their bodies that have undeveloped immune systems are also severer than in adults (Putri *et al.*, 2018). In an urban setting where industrial effluents are released directly to streams these heavy metals get transmitted to the stream waters. In incidences where the water is used for irrigation or domestic uses, the chances of exposure of these heavy metals to human beings increases (Putri *et al.,* 2018). The cumulative, and long-term effects of heavy metals include retarded mental development in children, organ failure, shortened life spans, and economic loses in the expense of treating disorders caused by the poisoning (Kim *et al*, 2015). The detailed review of individual heavy metals toxicities are done below:

2.5.1 Cadmium toxicity

Cadmium is a heavy metal that is mainly a byproduct of metal refining among other industrial activities (Zhang et al., 2016). The toxicity of cadmium occurs as a result of long-term exposure to cadmium metal via inhalation of ingestion (Kim *et al.,* 2015). Cadmium exposure to humans occurs via inhalation of gas containing cadmium particles, consumption of food contaminated with cadmium or drinking of water with substantially high levels of cadmium (Singh, and Kumar, 2017). Products such as cigarettes, paintings, fertilizers, metal alloys, batteries, and metal coatings contain cadmium in varied amounts (Sultana *et al.,* 2017). People working in environments that have high exposure to these products are thus at a higher risk of cadmium poisoning (Sayo *et al.,* 2020). Cigarette smokers have double chances of encountering cadmium toxicity as their non-smoking counter parts (Lenka *et al.,* 2018). Due to the root of exposure to cadmium poisoning, majority of the people get poisoned by cadmium from their work places (Paul, 2017).

Industrial wastes, however, mainly comprising of paints, and battery wastes can release considerable amounts of cadmium to the environment (Mahmoud, and Ghoneim, 2016). Cadmium contained in metallic alloys could as well be washed into urban streams by storm water (Qureshi *et al.,* 2016). Some fertilizers, such as phosphate fertilizers contain cadmium as well. Their continued use increases cadmium in soils that in turn gets absorbed by crops (Sayo *et al.,* 2020). The cadmium in soils in farms bordering streams get washed into the stream by storm water during the rainy season (Olayiwola, and Emmanuel, 2016). Cadmium bio accumulates in water bodies then biomagnifies as it gets transmitted through the tropic levels (Singh, and Kumar, 2017). As such, irrigation with cadmium-contaminated water transmits a higher concentration of cadmium to vegetables (Marrugo-Negrete *et al.,* 2017). Consumption of contaminated vegetables further transmits higher cadmium contents to humans (Kim *et al.,* 2015).

The health impacts of cadmium poisoning include kidney failure, nausea, and vomiting, stomach cramps, diarrhea, fragile bones, and death at extremely acute levels (Sultana *et al.,* 2017). When inhaled, it could lead to shortness of breath, inflammation of the nose, and pharynx, and flu-like symptoms (Zhang *et al.,* 2016). To minimize cadmium poisoning, people working in places with a high risk of cadmium exposure should adhere to safety guidelines by their Health, and Safety Expert (Paul, 2017). Reduction in the use of phosphate fertilizers is also a proposal to minimize environmental cadmium (Wambua *et al.,* 2019). Efficient treatment of industrial, and municipal effluent before discharging it into rivers is another measure that ensures that human exposure to cadmium toxicity is reduced (Qureshi et al., 2016).

2.5.2 Lead toxicity

Lead is used in numerous industrial processes. The main applications of lead in the industrial set up is in battery making, manufacture of paints, ship building, and machinery making (Wambua *et al.,* 2019). Previously, vehicle fuel was laced with tetraethyle lead to minimize engine knock, and prevent wear, and tear of valve seats (Sayo *et al.,* 2020). Although the use of leaded-fuel has completely been banned in some countries such as the U.S, it still finds application in some third world countries (Sara *et al.,* 2018). Lead pipes were also used in water distribution in the past (Olayiwola *et al.,* 2016). The high exposure to lead poisoning that they caused led to them being banned in some countries (Mahmoud, and Ghoneim, 2016). This ban has however, not been effected in some developing countries further exposing millions of people to potential lead poisoning (Kim *et al.,* 2015).

Lead batteries comprise the highest percent of lead in industrial application currently (Qureshi et al., 2016). Mining activities further contribute to emission of lead to the environment in instances where lead alloys are used (Sayo *et al.,* 2020). The most common exposure to lead compounds in municipal set ups are via lead paints, and their applications

(Ali *et al.,* 2016). Lead paints are applied in construction works as well as painting other household items such as toys (Olayiwola *et al.,* 2016). The home-based exposure is mainly through wall paintings (Gizaw, 2018). In this set up, children are at the highest risk as they keep putting objects, and their fingers in their mouths (Wambua *et al.,* 2019). Improperly treated industrial waste disposed of into urban streams leaks lead into aquatic ecosystem (Kim *et al.,* 2015). Lead fumes from industrial processes further introduce lead to the environment (Sara et al., 2018). It is thus not fully equipped to fight toxic substances in the body (Wambua *et al.,* 2019).

In water bodies, lead is absorbed by fish that then transmit it to humans via consumption of contaminated fish (Zhang et al., 2016). Lead-contaminated water further transmits lead to vegetables via irrigation farming (Singh, and Kumar, 2017). The impacts of lead toxicity are specifically severer in small children (Paul, 2017). This is due to their high exposure risk as well as the state of the immune system (Sultana *et al.,* 2017). The immune system of children under the age of five years is in the developmental stage (Ali *et al.,* 2016). The symptoms of lead poisoning include, behavioral disorders, lower intelligence quotient, and stunted growth in children (Mahmoud, and Ghoneim, 2016). In adults the impacts include high blood pressure, anemia, seizures, kidney failure, and abdominal pain (Sara et al., 2018).

2.5.3 Chromium toxicity

Chromium is a heavy metal that occurs in trace amounts as chromite in nature (Gizaw, 2018). Chromium has varied industrial applications such as hardening of steel, making of metallic alloys with enhanced qualities as well as making pigments for use in dying leather (Ratul *et al.,* 2018). This allows chromium to be used in wide industrial applications (Lenka *et al.,* 2018). Stainless steel contains about 18% chromium by mass to sterilize, and harden it. Chromium further helped prevent corrosion of stainless steel due to its sterile properties. Chromium is further used to make metallic alloys for use in high-stress, and high temperature conditions (Kim *et al.,* 2015). Leather industries use chromium to make pigments used to dye manufactured leather products (Banerjee, and Gupta, 2017). Chromium-containing paints are also used in other industrial applications such as painting of metallic objects (Njuguna *et al.,* 2017). These industrial applications of chromium form the primary source of release of chromium to the environment (Degefu *et al.,* 2013). Small quantities of chromium waste is contained in industrial waste, and effluent from industries dealing with chromium products (Gizaw, 2018) Chromium painted products end up being used by consumers away from their production centers (Paul, 2017). Chromium gets absorbed by fish, and accumulates in their bodies through bioaccumulation. Consumption of chromium-contaminated fish transmits it to the human body of consumers (Ratul *et al.,* 2018). Irrigation of crops with chromium-contaminated water leads to absorption of chromium together with other nutrients from the soil. Similarly, high quantities are transmitted to the human body via consumption of such vegetables (Banerjee, and Gupta, 2017). Chromium ions exist in two main forms i.e., the chromium (VI), and chromium (III) ions (Singh, and Kumar, 2017). Chromium (III) is an essential element in the body that assists in various body functions. This form of chromium is therefore harmless to the body (Njuguna *et al.,* 2017). The hexavalent chromium is, however, highly toxic to the human body (Degefu *et al.,* 2013).

The main roots of exposure are through inhalation of chromium-containing fumes or ingestion of chromium-containing substances (Zhang et al., 2016). Upon entering the blood stream, it causes oxidation reactions that eventually lead to hemolysis, kidney, and liver failure (Lenka *et al.*, 2018). Chromium (VI) is further known to alter the genetic composition of people when ingested in high quantities. Genetic alteration is a potential cause of cancerous tumors (Wambua *et al.*, 2019). The carcinogenic properties of chromium (VI) causes a variety of cancers (Ratul *et al.*, 2018). Chromium toxicity causes gastrointestinal irritation, nausea, diarrhea, and fever upon oral ingestion (Sultana *et al.*, 2017). Acute chromium poisoning results in renal failure, intravascular hemolysis, liver failure, and even death at extreme levels (Ali *et al.*, 2016).

2.5.4 Zinc toxicity

Zinc metal has wide industrial applications. Some of the common industrial uses of zinc include; galvanization, making of zinc-metal alloys, battery making, and as a radiation shield (Singh, and Kumar, 2017). Other uses of zinc include use as a fertilizer, use in making pigments, and paints, and in making explosion-proof equipment. Zinc element is an essential mineral element but only when consumed within the daily recommended levels (Qureshi et al., 2016). The recommended daily intake of zinc is 5 milligrams for children below 8 years, 8 milligrams for children between 9, and 13 years, and 11 milligrams for people above 14 years of age (Paul, 2017). Excessive consumption above these prescribed limits amounts to potential zinc poisoning (Wambua *et al.*, 2019). Acute zinc poisoning could result to nausea, vomiting, fever, diarrhea, and lethargy.

Chronic poisoning over a long period potentially leads to interference with the metabolic functioning of other important trace elements (Mahmoud and Ghoneim, 2016). High levels of zinc in the body is known to inhibit absorption of copper in the body, lower immunity levels, disruption of the efficient functioning of iron, and lower levels of high-density lipoprotein (Paul, 2017). A reduction in the efficiency of copper absorption in the body could lead to copper deficiency. Reduction in efficient functioning of iron leads to hematological problems in the body (Zhang *et al.,* 2016). In addition to these impacts of zinc toxicity, chronic consumption of zinc on a daily basis could further result in long-term defects in the gastrointestinal system, neurological system, and respiratory system (Olayiwola and Emmanuel, 2016).

As a result of its wide industrial applications, zinc metal, and ions are present in industrial waste in substantial amounts (Degefu *et al.,* 2013). Appropriate effluent treatment to the tertiary level is supposed to remove it alongside other trace elements from waste before discharging it to the environment. When effluent is improperly treated, and discharged into rivers, zinc accumulates in the stream water as it is non-biodegradable (Marrugo-Negrete *et al.,* 2017). Via the process of bio magnification, it keeps increasing as it is passed from one tropic level to the other (Singh and Kumar, 2017). Fish living in an aquatic ecosystem with high levels of zinc would therefore have zinc concentration higher than that of the water (Lenka *et al.,* 2018). Exceedingly high concentrations of zinc in irrigation water further increase the zinc levels in vegetables irrigated with such water (Sultana *et al.,* 2017).

2.5.5 Copper toxicity

Copper metal is applied in most industrial processes either individually or as an alloy with other metals. Copper is known to conduct both electricity, and heat more efficiently than any other metal (Zhang *et al.,* 2016). It is also ductile, and malleable allowing it to be formed into different shapes without breaking it. It is therefore, based on these properties used in electrical transmissions in most mechanical equipment (Singh and Kumar, 2017).

Most electrical connections within buildings are also done using copper metal. Copper alloys with other metals have numerous specialized applications as well (Lenka *et al.*, 2018). An example is brass, made up of copper-zinc, and cupronickel made of copper, and nickel that is used for making low value currencies. Copper sulfate is applied to farms as copper fertilizer (Qureshi et al., 2016).

Copper is an essential macronutrient that plays the role of chlorophyll production, seed production, and other enzymatic activities in plants. This necessitates the application of copper fertilizer in many foods farming programs (Degefu *et al.,* 2013). These numerous uses of copper have over time increased the levels of copper within the environment. Release of industrial effluent that is not completely treated into rivers increases the spread of copper to the environment (Kim *et al.,* 2015). Copper is deposited as part of sludge on the banks, and river beds. Copper metal is mainly inert, and hence will not react with other chemical compounds in the environment. This causes copper to last long in the environment (Marrugo-Negrete *et al.,* 2017). Copper is an essential element in the body hence human bodies can with stand high amounts of copper (Wambua *et al.,* 2019).

In the body, copper performs functions such as helping in bone formation, formation of red blood cells, neural functions, development of a strong immune system, and development of healthy blood vessels (Zhang *et al.*, 2016). This necessitates the recommendation of a mandatory minimum daily intake to avoid diseases associated with its deficiency (Mahmoud and Ghoneim, 2016). Common diseases associated with copper deficiency include Wilson's disease, Menkes disease, and Alzheimer's disease (Banerjee and Gupta, 2017) Despite its recommendation for daily consumption, excessive intake of copper still causes harm to body organs (Sultana *et al.,* 2017). Compared with other heavy metals, however, copper can be tolerated in relatively higher quantities in the body (Paul, 2017). An adult human body can accommodate a maximum of 10 mg per day (Olayiwola and Emmanuel, 2016). Beyond this amount, it turns toxic. Copper toxicity is detected by symptoms such as dizziness, headaches, stomachaches, vomiting, and diarrhea (Qureshi et al., 2016).

2.6 Waste water treatment systems

Waste water treatment systems are essentials of cities across the world. Previously, nature had a sustainable way of neutralizing wastes generated (Newhart *et al.,* 2019). As human, and industrial activities increased, a need arose for nature to be bailed out of the excessive wastes generated (Guven *et al.,* 2019). The natural waste decomposition, and dilution process was enabled by naturally existing microorganisms as well as rivers that diluted waste draining into them (Crini and Lichtfouse, 2019). Industrial activities, however produce huge amounts of physical, and chemical wastes, and in enormous concentrations that have to be reduced to manageable concentrations before discharging them to the environment (Di Maria *et al.,* 2018). The basic waste water treatment mechanisms involves the primary treatment, and secondary treatment processes (Newhart *et al.,* 2019). The primary treatment focuses on removing solid particles from the waste water (Newhart *et al.,* 2019).

This forms the initial process in a waste water treatment plant. Screens are fitted at the entry of effluent, starting with large pore-sized screens, and the pore size keeps reducing as effluent flows (Guven *et al.,* 2019). This removes large objects, and other comparatively large solid substances from the effluent. The screened objects are removed from the system, separated, and disposed of appropriately (Di Maria *et al.,* 2018). The effluent then flows through a grit chamber that removes gravel, and small stones by having them settle at the bottom (Crini and Lichtfouse, 2019). Past the grit the chamber, it flows through a sedimentation tank. Within the sedimentation tank suspended organic solids settle at the bottom, and are thus removed from the waste water (Newhart *et al.*, 2019). The organic waste is removed from the system as sludge (Di Maria *et al.*, 2018). Sludge keeps being pumped from the sedimentation tank continuously. It is then dumped in landfills, incinerated or sold off to fertilizer making companies (Guven *et al.*, 2019).

The secondary treatment involves removal of dissolved organic wastes in the effluent as well as bacterial contaminants (Crini and Lichtfouse, 2019). Most treatment plants use aerobic bacteria to get rid of dissolved organic matter in industrial, and municipal effluent. In this step, the activated sludge process is used (Di Maria *et al.*, 2018). This process makes use of sludge that has been loaded with billions of aerobic bacteria to decompose the organic wastes in the effluent (Schacht *et al.*, 2016). The bacteria convert organic wastes into harmless organic compounds, water, and carbon dioxide (Di Maria *et al.*, 2018). The harmless organic compounds then settle at the bottom of the tank as sludge (Guven *et al.*, 2019). Sludge is pumped from the tanks continuously as the process continues. Past this stage the waste water is usually about 90% free of all harmful chemical compounds (Newhart *et al.*, 2019).

Modern waste treatment systems are fitted with filtration chambers after secondary treatment to remove micro particulate matter as well, and microorganisms larger than 10 microns (Di Maria *et al.*, 2018). This is achieved by use of the 10 microns-diameter polyester media. Past this process, the treated waste water is then disinfected either by use of ultraviolet radiation or chlorination technique (Guven *et al.*, 2019). Once the waste water has been disinfected it becomes secure to be released to streams, and rivers (Crini and Lichtfouse, 2019). In this disinfected state it could even be used for industrial processes, domestic use or irrigation farming (Newhart *et al.,* 2019). Israel waste water treatment system is among the most efficient ones in the world (Tal 2016). The efficiency of their waste water treatment system allows them to reuse about 70% of waste water (Schacht *et al.*, 2016). Their treated waste water is effectively reused for agricultural, and industrial purposes (Crini, and Lichtfouse, 2019).

As industrial activities increase globally, the burden of industrial effluent on both waste water treatment systems, and the environment keeps getting unbearable (Schacht *et al.*, 2016). This has called for more stringent measures in many countries regarding release of harmful effluent to waste water treatment systems (Tal 2016). Industries in many parts of the world are required by law to pre-treat their effluent to meet agreed upon standards before they can release them either to the environment or to conventional waste water treatment systems (Schacht *et al.*, 2016). Internal effluent treatment systems in industries have assisted in lowering the level of environmental pollution by untreated effluent (Tal 2016). Other important mechanisms of ensuring that harmful chemicals do not get to the waste water treatment systems include elimination at the source (Tal 2016). This is achieved by modification of raw materials, and industrial processes as well as technologies to ensure that less harmful wastes are produced (Schacht *et al.*, 2016). Advancement in technology, research, and development keeps industrial processes dynamically improving towards sustainable development status (Tal 2016).

2.7 Research Gaps

Although a few previous studies have been conducted on heavy metal pollution in rivers across Kenya, literature review shows that:

i. No single study has been conducted on Mitheu stream.

ii. No studies have been done to link irrigation farming in the peri-urban region of Machakos municipality to heavy-metal toxicity in vegetables.

This study sought to address these gaps in order to contribute to policy formulation towards urban and peri-urban agriculture designed for the environment (Nature and people friendly).

CHAPTER THREE: MATERIALS, AND METHODS

3.1 Study Area

3.1.1 Study area, and location

This study was conducted in Machakos County of Kenya, specifically within Machakos Central Ward, and Muvuti-Kiima Kimwe Ward (Figure 3.1). These two wards are part of the Machakos municipality. Machakos municipality is within the larger Machakos County. Machakos town is located about 63 kilometers south east of Nairobi City. The Machakos municipality is comprised of six wards namely; Mutituni, Mua, Mumbuni North, Machakos Central, Muvuti Kiima Kimwe, part of Kola. For this study, the stream of interest- Mitheu stream runs through Machakos Central, and Muvuti Kiima Kimwe wards. Mitheu stream flows from the northwestern through the western outskirts of Machakos town. The stream is seasonal only receiving rain water during the rainy season. In the remaining part of the year its flow consists of raw effluent from Machakos town combined with the discharge from the waste water treatment plant. The study was conducted during the dry season when the stream water was mostly used for irrigation. The GPS coordinates of Mitheu stream where the study was conducted are 1.525923^0 S, and 37.263686^0 E.

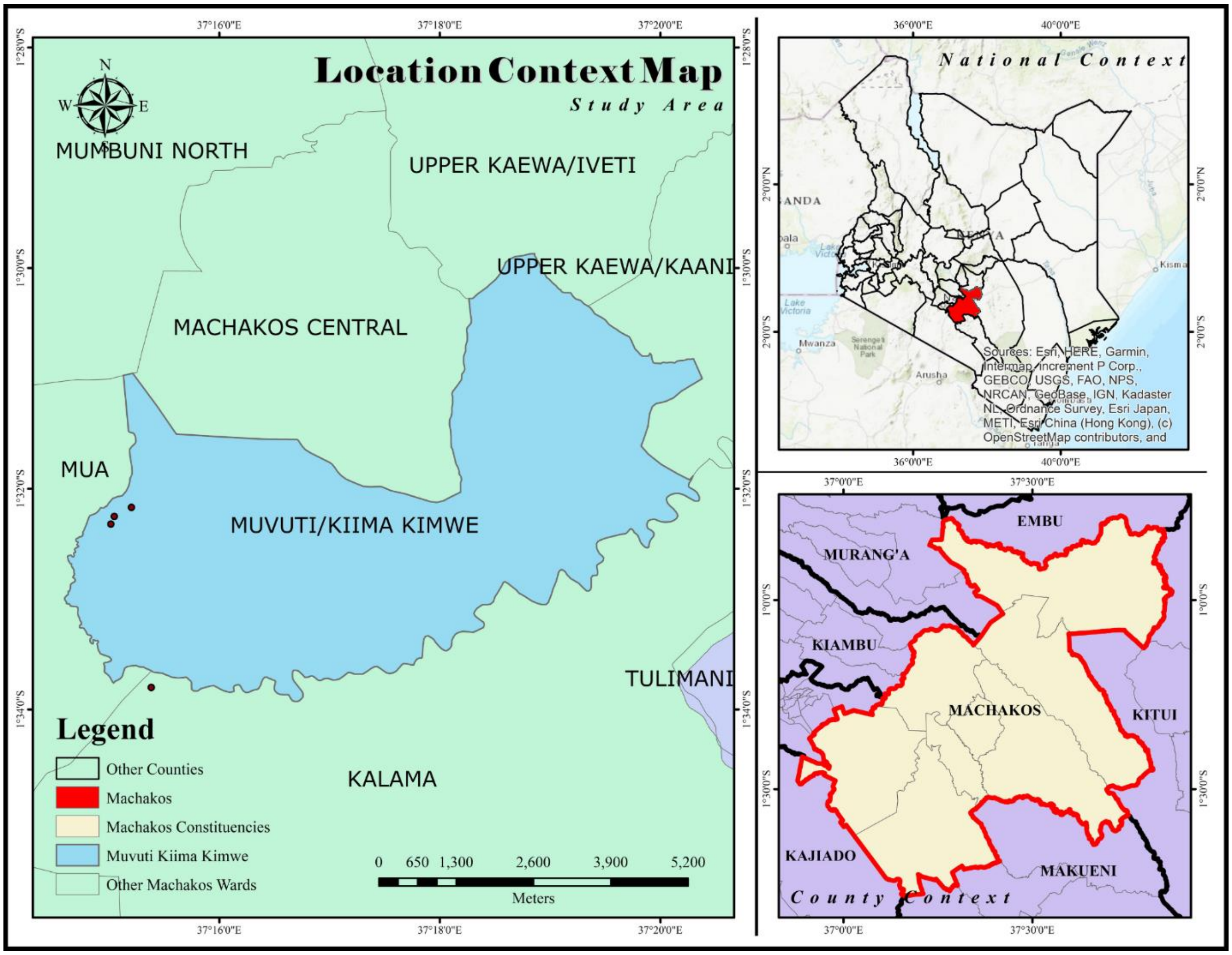

Figure 3.1: Map of Kenya showing Machakos Municipality, and Mitheu stream

3.1.2 Climate

Machakos County comprises of both hilly parts, and arid, and semi-arid parts. The hilly parts of the county comprise Mua, Tala and Kangundo, and the entire Machakos Municipality area. The arid, and semi-arid regions include Katangi, Yatta, and Masinga. Machakos municipality is at an average altitude of approximately 1620 meters above sea level. The average temperature for the region covered in Machakos municipality is about 19 ^{0}C while the annual rainfall amount is approximately 830 mm (Figure 3.2)

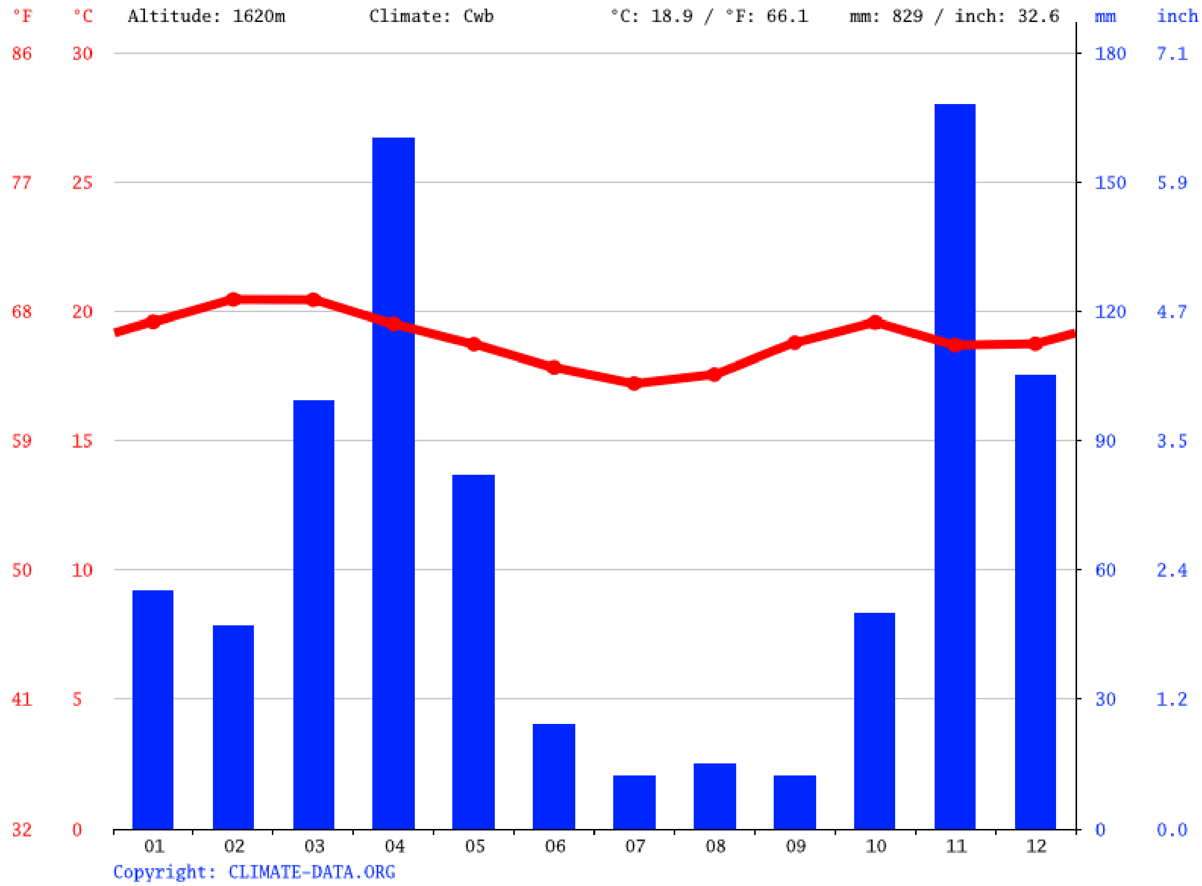

Figure 3.2: Climate graph by month for Machakos

3.1.3 Relief, drainage, and soils

Machakos County is partly hilly, and partly semi-arid. The hilly parts of Machakos County comprise of areas around Tala, Kangundo, Mua hills, and Iveti, and Kiima Kimwe hills surrounding Machakos town. The low land, semi-arid parts of the county include Mwala, Yatta, and Masinga. The average altitude of Machakos town is between 1000, and 2000 meters above sea level. The soils of Machakos County comprise of oxisols, ultisols, alfisols, and lithic soils. Oxisols are spread within the hilly parts of the county that are usable for agricultural production. Lithic soils are also distributed across different parts of the county that have rocky landscapes. Ultisols, and alfisols are distributed within the semi-arid regions of the county. Oxisols are relatively more fertile than ultisols, and aldisols hence the highland parts of Machakos are more agriculturally productive. The agricultural productivity of ultisols, and aldisols is improved by application of organic manure or fertilizers. The soils of Machakos County drain fairly well.

3.1.4 Economic Activities

The main economic activities of Machakos County are agriculture, commercial businesses, and industrial operations. Fruits, and vegetable farming is widely grown in several parts of Machakos County. Most of the farming is done using water from rivers, and streams for irrigation. The main rivers include, River Athi, and Thwake River. Streams flowing adjacent to Machakos town i.e., Mitheu, and Ikii streams are also used for vegetable irrigation farming. Most of the produce is sold within Machakos town, and Machakos County at large. The county has several towns with commercial activities such as banking, insurance, wholesale, and retail businesses. Machakos County has numerous industries specifically within Mavoko Sub-County. The industries in Machakos County range from heavy cement manufacturing to simple food processing industries. They have offered thousands of employment opportunities to residents of Machakos County.

3.1.5 Population

The population of Machakos County as at 2019 was 1,421,932 (Census, 2019). Out of this population, 710,707 are male, and 711,191 are females. Most of the population is concentrated within the highlands of Machakos county urban set ups of Machakos town, Athiriver, and Mlolongo, and Tala-Kangundo. Machakos municipality has a population of 170,606 as of 2019 (KNBS 2019). Mitheu stream was used by approximately thirty farmers for irrigation with the farm sizes varying from about 1 acre to about 5 acres. Most of the farmers grew vegetables i.e., kales, and spinach. A few farmers grew tomatoes.

3.2 Research Design

In this research study, the correlational research designs was used (Seeram, 2019). Laboratory standard operating procedures were used in carrying out the laboratory analysis to prove or disapprove the hypotheses. The laboratory analyses were carried out in accordance with scientific guidelines. Correlational research design was employed in carrying out the data collection, and analysis from different points of the river as well as the vegetables to establish the possible correlation occurring between the levels of pollution in the stream (Lewis, 2015). The correlational design further explained the nature, and magnitude of the relationship between two variables i.e., the independent, and dependent variables (Lewis, 2015).

3.3 Selection of Sampling points

Samples for this study were collected in selected sections of the stream. Sampling sites along the stream were selected in a manner to illustrate the predicted changes in concentration of contaminants as the water flowed from entry point. Discharge from the waste water treatment plant was collected to investigate the efficacy of the plant in effluent treatment. Sampling point A was selected to be downstream at Mwania Bridge. At this point along the stream significant irrigation farming was conducted and so it was an ideal sampling site to compare both stream water, and vegetable pollution. Sampling point B was about 150 meters downstream of point C but a longer distance from point A. The stream flowed through some rugged terrain between point A, and Point B that did not allow any irrigation activities to be carried on. This justified the comparatively longer distance separating Point A, and Point B. At Point B there also was extensive irrigation farming along the stream. Therefore, sampling points A, and B were downstream of the waste water treatment plant. Point C was at the entry of waste water treatment plant discharge into Mitheu stream. The significance of this point was to test the efficiency of the treatment plant by analyzing its discharge. Point D was selected to be further upstream of point C (about 200 meters from Point C). The significance of point D was to test the impact of raw effluent that entered Mitheu stream before flowing downstream. It was an estimated 150 meters downstream of the last raw effluent entry point into the stream.

3.4 Sampling Procedures

3.4.1 Onsite parameters

pH of the water, and temperature were measured using the Hanna HI 99121 waterproof pH meter. Measurement was made by inserting the tip of the meter into the stream water at the respective sampling points then allowing it a few minutes until a stable reading appeared in the meter screen. Both pH, and temperature were measured simultaneously. The procedure was repeated to record two more pH, and temperature readings.

Figure 3.3: pH meter, and EC & TDS meter

Total dissolved solids (TDS), and Electrical conductivity (EC)

TDS, and EC were measured using Hanna HI 99300 meter that recorded the values of each parameter separately. The meter was switched to the respective parameter to be measured then it was inserted into the stream, and allowed like 5 minutes to stabilize before the reading was made. At each sampling point three trials of readings for each parameter were made. All the parameters were measured, and their values recorded for each sampling point once a month from June to September 2019.

3.4.2 Water Sampling, and treatment

Water samples for both bacteriological, and chemical analysis were collected once every month for four months (June to September, 2019) in the four sampling points along the stream. water samples for bacteriological analysis were collected in sterilized glass sampling bottles that were then immediately placed inside a cooler box for preservation. Water samples were collected with the bottles at the middle of stream at each sampling point. The bottle was immersed into the stream like five centimeters below the water surface the filled with water. The samples were then taken to the Water Resources Authority (WRA) laboratory, Nairobi for analysis on the same date of collection. Water samples for measurement of physico-chemical parameters (COD, BOD, Nitrates, Phosphates, and Sulphates) were collected using pretreated polyethylene sampling bottles, and transported to WRA central laboratory for analysis.

Water samples for the heavy metals analysis were collected from the four established sampling points along the stream using nitric acid-washed 1L polyethylene sampling bottles once each month for four months. Samples were collected at the middle of the stream. In the field the sampling bottles were rinsed three times with the stream water before collecting the samples. The sampling bottle was then immersed in the water to about 5 centimeters below the water surface, and filled with water. The collected water samples were immediately treated with 2 mls of concentrated nitric acid to ensure heavy metals do not get absorbed on the surface of the sampling bottles. The samples were then transported to Kenya Plant Health Inspectorate Services (KEPHIS) analytical laboratories for heavy metal analysis.

3.4.3 Sampling of Vegetables

Vegetable samples were similarly collected at waste water-irrigated farms adjacent the four (4) sampling points along the stream once each month for four months (June to September, 2019). About one kilogram of both harvested fresh kales, and spinach each were collected at each sampling point. After collection, each vegetable sample was put inside clean, labeled carrier bag, and taken to the KEPHIS laboratory on the same day for processing, and heavy metal analysis.

3.5 Sample Preparation, and Laboratory Analysis

3.5.1 Physico-Chemical Parameters

Water samples were tested for the physico-chemical parameters i.e., BOD, COD, Nitrates, sulphates, and total phosphates according to their standard testing procedures (APHA, 1998). The analyses for these parameters were done in the Water Resources Authority (WRA) laboratory in Nairobi.

3.5.2 Bacteriological Tests

Bacteriological analysis was conducted in WRA laboratory in Nairobi. The multiple tube technique that involves a two-step process was used in this analysis. In the first stage fermentation tubes containing lauryl tryptose broth were inoculated with water samples, and incubated at 35 ^{0}C for 24 hours (Hsieh, 2018). Inoculation implies that the sample was added to each tube containing the lauryl tryptose broth. Those samples that formed gas in the inverted tube indicated presence of bacteria, and they were subjected to the next stage-confirmation stage. In this stage fermentation tubes containing brilliant green lactose bile broth were inoculated with a medium from the samples that formed gas. After this, the *E. coli* coliform count was done according to the coliform table (Hsieh, 2018).

3.5.3 Digestion of Water samples, and Heavy metal Analysis

Once the water samples reached KEPHIS laboratory 50 ml of each water sample were treated with nitric acid, and hydrogen peroxide then digested in the microwave for about one hour. The digested samples were diluted with distilled water. Lastly, they were run in the ICP-MS to obtain the heavy metal concentrations.

3.5.4 Drying, and Digestion of Vegetables for Heavy Metal Analysis

Once in the laboratory, the vegetables were first dried in the oven at 100^0C. The dried vegetables were then ground into a fine powder. Approximately 0.3 g of the ground vegetable was weighed onto the ultra-clean, and dry inert polymeric microwave vessels. It was then digested with concentrated nitric acid, perchloric acid, and hydrochloric acid. After the acids had reacted with the sample it was heated in a microwave, the cooled in accordance with the Standard Operating procedure (SOP). The digested sample was then diluted, and run in the ICP-MS machine for heavy metal analysis.

3.6 Data Analysis

The mean concentrations obtained from the laboratory analyses were first calculated for each parameter on each sampling point. The mean data values for each parameter were then subjected to One Way - Analysis of Variance (ANOVA) to find the significant difference in heavy metals in water, and vegetables from different sampling sites. The Pearson's correlation coefficient was used to test whether there was any correlation between the heavy metals' concentration in stream water, and in the vegetables (Ayyub and McCuen, 2016). The determined concentrations for heavy metals in both streams, and in vegetables were then compared with the WHO standards, and the Kenyan standards.

CHAPTER FOUR: RESULTS, AND DISCUSSIONS

4.1 Introduction

This chapter provides an elaborate presentation of the results together with detailed description of the findings. The findings for the concentrations of each parameter investigated are presented in tables, then the discussion of the findings follow below every table.

4.2 Onsite, Physico-chemical parameters, and Heavy Metals in water

4.2.1 Onsite parameters

The onsite physical parameters analyzed in this study were temperature, pH, Total Dissolved Solids (TDS), and Electrical conductivity (EC). TDS, EC, and water pH were found to be marginally higher than WHO recommended limits for irrigation water (Table 4.1).

Table 4.1: Mean ± standard deviations of onsite parameters

Site / Parameter	Point A	Point B	Point C	Point D	WHO limit	P-value
Temperature (^{0}C)	21.45± 1.45	20.4±2.08	21.9±1.09	19.05±0.85		0.256
pH	8.065±1.67	8.845±0.53	8.83±0.61	9.48±0.45	6.5-8.5	0.305
TDS (ppm)	466.5±200.41	1219.48±150.20	2000.95± 256.73	1078.80±162.76	1000	0.134
EC (µs)	870.67±99.66	2390.48±135.28	3399.38±178.96	2096.18±208.46	700	0.248

4.2.1.1 Temperature

The mean temperature recorded along Mitheu stream during the study period varied, the mean temperature ranged from 19.05±0.85 ^{0}C in point D to 21.9±1.09 ^{0}C in point C (Table 4.1). The highest temperature was recorded in point C. The mean temperature measured along the river was 21.45± 1.45 in Point A, 20.4±2.08 in point B, 21.9±1.09 in point C, and 19.05±0.85 in point D. Using Anova there was no significant difference in temperatures among the sampling sites ($p \leq 0.56$) (Table 4.1). Stream water temperature is influenced by channel engineering, weather conditions, thermal pollution, and riparian management. Channel engineering consists of factors such as channel depth, and width, stream flow, channel, and water table elevation, stream bed composition, and tributary temperature. Thermal pollution comprises of industrial pollutants, and urban storm water. The weather conditions contributing to varied stream temperatures include, solar radiation, solar angle, precipitation, relative humidity, wind speed, and cloud cover. The temperature variation in Mitheu stream is attributed to a combination of these factors. The relatively lower temperature in point D was due to channel engineering, and riparian management factors. Solar angle is also a factor that caused variation in temperature along the stream. The solar radiation did not strike all sections of the stream at a similar angle. The comparatively higher temperature at Point C was influenced by thermal pollution for the waste water treatment plant discharge.

4.2.1.2 pH

The mean water pH varied along the stream. The mean pH ranged between 8.065±1.67 downstream at Point A, and 9.48±0.45 upstream at point D. ANOVA test however determined that the pH did not significantly vary along the stream course studied in this research (p = 0.305). The pH at Point A, and Point C was within WHO safe limits. Water pH at Point B, and Point D was, however, higher than the recommended range for irrigation water. The stream water pH indicated that the water was slightly alkaline. The alkaline pH (higher than 7) indicated presence of dissolved alkaline salts in Mitheu stream. The most probable cause of stream water alkalinity is presence of lime from industrial, and municipal activities. Within Machakos town lime was possibly washed down to Mitheu stream from waste paper, and other stationary waste, and cement washed off from buildings. The concentration of these alkaline metal salts decreased downstream via dilution hence the gradual decrease in pH as the stream flowed downwards. Comparatively, the pH of water in Mitheu stream lies within the same range as that found in Adeyemo stream in Kaduna, Nigeria (pH of 6.61) (Yisa et al., 2017), River Meghna in Bangladesh (Flura et al., 2016), and Çinarli Stream in Anatolia Turkey (Mutlu et al., 2016). However, Mitheu stream was alkaline while Qeera stream in Ethiopia in a similar urban set up had acidic waters (Bedassa and Desalegne, 2020).

4.2.1.3. Total Dissolved Solids

The stream's mean Total Dissolved Solids (TDS) ranged between 466.5±200.41 ppm far downstream (Point A, and 2000.95± 256.73 ppm at the point adjacent the waste water treatment plant (Point C). These results signified that the highest concentration of total dissolved solids was contained in the municipal effluent from Machakos town. Analysis of variance found out that the concentrations of Total Dissolved Solids along Mitheu stream did not vary significantly (p = 0.134). Comparatively with the waste water treatment plant discharge the upper part of the stream (Point D) had a lower concentration of TDS despite this section of the stream receiving raw municipal effluent via vandalized drainage pipes. This occurrence pointed out to two possibilities; that the waste water treatment plant had a lowered efficiency in eliminating total dissolved solids from the effluent or that the waste water treatment plant received large amounts of effluent as compared to the amount that flowed freely into the stream. The latter is true as was found out during the study that the waste water treatment plant in Machakos received huge amounts of effluent daily for its small size.

The organic chemicals in the waste water treatment plant discharge contributed to high nitrates, phosphates, and sulphate ions that increased its TDS levels. The stream was further used for irrigation implying a significant amount of dissolved salts from agricultural chemicals were washed back to the stream. These included NH_4^+, PO_4^{3-}, NO_3^-, and SO_4^{2-} ions salts. The decreasing trend of TDS with downstream flow indicated that municipal effluent was the major contributor of TDS in the stream. Fertilizer run off from the farms still added to the TDS concentration but not as significantly as the municipal effluent. The upper section of the stream comprising of Points B, C, and D had water TDS concentrations higher than the recommended limit for irrigation water. The downstream section at point A, however, was suitable for irrigation use based on the concentration of total dissolved solids. The TDS concentration of Mitheu stream was comparatively high as compared to those found in River Meghna, Bangladesh (Flura et al., 2016), Adeyemo stream in Kaduna Nigeria (Yisa et al., 2017), and Qeera stream Ethiopia in similar studies (Bedassa and Desalegne, 2020).

4.2.1.4 Electrical Conductivity

The electrical conductivity of Mitheu stream water was highest at the point of discharge of waste water treatment plant out into the stream (Point C) at 3399.38±178.96 µs, and lowest far downstream (Point A) at 870.67±99.66 µs. The electrical conductivity along the entire stretch of the stream studied exceeded WHO set limits for irrigation water. This had the implication that use of Mitheu stream for irrigation could potentially lead to human poisoning by the excessive concentrations of these inorganic cations, and anions. However, ANOVA test indicated that there was no significant variation in electrical conductivity along the stream. Electrical conductivity of water is determined by the presence of dissolved inorganic anions such as nitrates, sulphates, chlorides, and phosphates, and cations such as sodium, calcium, magnesium, and aluminium. These are the ionic compounds that contain either negative or a positive charge indicating presence of free electrons that facilitate electrical conductivity. Organic compounds do not have free electrons, and hence do not contribute to the electrical conductivity value.

The relatively high electrical conductivity signified a high concentration of the above-mentioned inorganic cations, and anions in Mitheu stream. This parameter does not specify which cations, and anions are present but further specific analysis of the individual anions i.e., nitrates, phosphates, and sulphates would be necessary. Mitheu stream had electrical conductivity far higher than that found in Çinarli Stream in Turkey (Mutlu et al., 2016), River Meghna, Bangladesh (Flura et al., 2016), Adeyemo stream in Kaduna Nigeria (Yisa et al., 2017), and Qeera stream Ethiopia in similar studies (Bedassa and Desalegne, 2020). Compared with these streams in their independent similar studies, the water in Mitheu stream is highly polluted with organic, and inorganic dissolved substances (Yisa et al., 2017).

Chemical parameters

The chemical parameters of the stream water analyzed in this study were biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrates, phosphates, and sulphates. BOD, COD, and phosphates were found to be marginally higher than WHO recommended limits for irrigation water (Table 4.2). Nitrates, and sulphates concentrations in the stream were however within allowable limits for irrigation water (Table 4.2).

Table 4.2: Mean ± Standard deviations of physico-chemical parameters for water of Mitheu stream

Site/Parameter (mgL^{-1})	Point A	Point B	Point C	Point D	WHO limit	p-value
COD	189±196.436[a]	325.5±132.939[a]	1304±604.445[b]	398±278.750[a]	10	0.003
BOD	74.75±135.517[a]	157.5±137.931[a]	465±292.745[b]	115.75±37.402[a]	5.0	0.033
Nitrates	0.87±0.788	11.335±18.305	3.703±3.824	1.95±2.794	45	0.427
Phosphates	0.10425±0.131	1.679± 2.747	0.376±0.098	1.735±2.911	0.1	0.555
Sulphates	17.21±18.248[a]	29.923±20.964[a]	122.325±86.870[b]	32.59±32.606[a]	250	0.035

Key: Superscript a, b, and c depict sampling points that differed significantly from each other.

4.2.2 Chemical Oxygen demand (COD)

The Chemical Oxygen Demand (COD) for the four sampling points was found to range between 189±196.436 mgL^{-1} at Point A, and 1304±604.445 mgL^{-1} at Point D. The lowest concentration downstream (Point A) still exceeded WHO acceptable limits. This indicated that the stream among the sites did not qualify for use for irrigation based on COD concentration. Low concentration of COD downstream was as a result of dilution by the stream water as it flowed downstream. This indicated that high organic chemicals were present in industrial effluent but then got diluted flowing downstream. Comparatively, COD concentration up stream where most of the untreated municipal effluent entered Mitheu stream was lower than that of the waste water treatment plant discharge. This is purely due to a difference in the amount of effluent entering the stream at the two points. The waste water treatment plant receives a larger quantity of municipal effluent from Machakos in its normal functionality.

The efficiency of the waste water treatment plant in Machakos with regard to removal of organic chemicals from effluent is also relatively low. The combination of these two factors explain why the discharge from the treatment plant recorded the highest concentration of COD among the sites tested in this. COD is a measure of the amount of oxygen needed to oxidize all organic and inorganic chemicals in a waste water before it is discharged into water bodies (Islam *et al.*, 2018). High levels of COD therefore reflect a high concentration of organic chemicals in a water sample (Salvador–Oke *et al.,* 2018). The discharge from the waste water treatment plant in Machakos had high levels of COD indicating that it was not properly cleaned of organic chemicals before being discharged into Mitheu stream. This had the implication that the discharge from the waste treatment plant contributed to high COD levels in Mitheu stream. Compared to a study conducted in Nile River, Egypt by (Abdel-Satar et al., 2017) the levels of COD in Mitheu stream are very high. There was a significant variation in COD levels among the four sampling points selected for the study. After conducting an analysis of Variance, a P value of 0.003 was obtained. This was an indication of significant variation in levels of COD among the four selected points. The significant variation is however in the concentration in the waste water treatment discharge, and that in the stream waters.

4.2.3 Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand (BOD) ranged between 74.75±135.517 mg/L (Table 4.2) in the downstream (Point A), and 465±292.745 mg/L (Table 4.2) in the water treatment plant discharge (Point C). Comparatively in Mitheu stream, the section on the upper side of the waste water treatment plant had a lower amount of BOD than the section on the lower side of the treatment plant. This was caused by the high amount of BOD in the waste water treatment plant discharge that drains into the stream. This implies that the biggest contributor to the high amount of BOD in both streams was the waste water treatment plant discharge. This signified that the treatment plant had low efficiency with regard to removal of biologically digestible organic compounds from municipal effluent. BOD in waste water is a measure of the oxygen needed to aerobically digest organic compounds by biological microorganisms (Mallika et al., 2017). This therefore implies that essentially BOD should be lower than COD. Lower amounts of BOD signify improved efficiency of waste water treatment plants, and vice versa.

For this case the discharge from Machakos waste water treatment plant had comparatively high levels of BOD implying its low efficiency in eliminating bio-organic waste. The low BOD levels downstream was attributed to dilution of the effluent as it flowed downstream. The BOD concentrations had significant variation among the four sampling points ($p \leq 0.05$). However, Tukey's ad hoc test determined that it was concentrations for the point downstream, and that of the waste water treatment plant that had significant differences. The high quantities of BOD in water from the stream indicated that the water was not suitable for irrigation due to excessive amounts of organic chemicals. These organic chemicals pollute soils, and are further absorbed by plants, and transmitted to humans (Magadum *et al.*, 2018). The BOD levels in Mitheu stream were relatively high compared with those found in streams crossing Gondar town in north-west Ethiopia (Tessema *et al.*, 2019). Compared to a study conducted by (Abdel-Satar et al., 2017) in Nile River, Egypt, Mitheu stream has quite high concentration of BOD. Additionally, a similar study conducted in Kano State Nigeria found lower levels of BOD when compared with the concentration found in Mitheu stream (Abakpa *et al.*, 2013). Mitheu stream further had higher concentration of BOD when compared with the one found in urban streams in Sao Paolo, South East Brazil (de Medeiros *et al.*, 2017).

4.2.4 Nitrates

Nitrates had the lowest concentration in Mwania stream at 0.87±0.788 mg/L (Table 4.2), and the highest concentration along Mitheu stream just below the water treatment plant at 11.335±18.305 mg/L (Table 4.2). nitrates are part of the form in which nitrogen exists in municipal waste water. Nitrates usually represents the oxidized form of nitrogen, and is mostly associated with NPK fertilizers. Machakos municipality has numerous households that have their municipal effluent partially treated in the existing waste water treatment plant while the rest flows into Mitheu stream via broken sewer lines. Farming along the stream further contributed to the higher amount of nitrates in the middle of the stream when compared to the concentration upstream near the entry of raw effluent. Nitrate concentration downstream was, however, significantly low. This was attributed to dilution as Mitheu stream joined Mwania stream that had a bigger water volume. Despite a possibility of fertilizer being washed into the streams during the rainy season, the comparatively higher water volume in lower section of the stream diluted nitrates to significantly low levels. The concentration of nitrates along both streams did not vary significantly as indicated by the P value of 0.427.

Nitrates were, however, within WHO safe limits for irrigation water. Comparatively, nitrates concentration in Mitheu stream were higher than those found in Mert stream, Turkey (Maraşlıoğlu et al., 2017). A similar study conducted in Surat City India further found lesser amounts of nitrates as compared to Mitheu stream (Varsani & Manoj, 2019). The concentrations of nitrates were, however, lower than their concentrations in the same study in an urban stream in Gondar town. (Tessema, *et al.*, 2019). An urban stream in Rosslyn, Pretoria, South Africa had a higher concentration of nitrates than Mitheu stream in a similar study conducted in 2018 (Salvador–Oke et al., 2018). This implied that with respect to nitrates, water from Mitheu stream was suitable for irrigation. It further implied that nitrates pollution of the stream did not pose a danger to the health of the farmers, and residents of Machakos municipality.

4.2.5 Phosphates

The concentration of phosphates was highest along Mitheu stream upstream of the water treatment plant at 1.73475±2.91 mg/L, and lowest downstream in Point A at 0.10425±0.131 mg/L (Table 4.2). Phosphates in municipal waste water result from human urine, and detergents used for domestic cleaning (Batool *et al.*, 2019). The raw sewage draining into Mitheu stream contributed to high phosphate concentration on the upstream part of the stream. The concentration of phosphates did not vary significantly along the stream as indicated by the P value of 0.555. The phosphates concentration in Mitheu stream was considerably higher than that found in Vishwamitri River, Gijarat India in a similar study (Magadum et al., 2018), and Mert stream, Turkey (Maraşlıoğlu et al., 2017). Mitheu stream however has lower phosphates concentration as compared to those found in Surat City (Varsani and Manoj, 2019), and Ossah River Nigeria (Donald *et al.*, 2019). A similar study in urban streams in Gondar town comparatively found higher phosphates concentration as compare to Mitheu stream (Tessema et al., 2019).

Phosphate concentration in Mitheu stream was higher than WHO allowable limits for irrigation water. Concentration went decreasing downstream as it got diluted with the flow of the stream downwards. This was despite the fact that fertilizers used in the farms along the rivers got washed into the streams during rainy season but got neutralized by the dilution factor. Higher than recommended phosphate content in irrigation water results in eutrophication. Eutrophication is a process whereby stream water gets enriched with nutrients such as nitrates, and phosphates (Ali *et al.*, 2016). Eutrophication leads to excessive algae growth. When these algae dies, its decomposition consumes lots of oxygen thus depleting dissolved oxygen in the stream and affecting aquatic life (Fuhrimann *et al.*, 2016). The phosphate concentration in Mitheu stream was not in excess since the streams did not have excessive algae growth. Absorption of excess phosphates by vegetables could lead to transmission of these phosphates to consumers resulting in health problems such as liver damage (Lenka *et al.*, 2018). Therefore, except for the upstream section of Mitheu stream, the other sections of Mitheu stream were usable for agricultural purposes based on phosphates content.

4.2.6 Sulphates

The treatment plant discharge (Point C) contained the highest concentration of sulphates at 122.325±86.870 mg/L (Table 4.2). Sulphates were at their lowest concentration in sampling Point A at 17.21±18.248 mg/L (Table 4.2). There was significant variation between sulphates concentration in the treatment plant discharge with that in the stream. This was indicated by the P value of 0.035. The high amount of sulfur in the water treatment plant discharge signified a high concentration of the same in the municipal effluent from Machakos town as well as low efficiency in the elimination of sulfur in the treatment plant. Comparatively sulfates content in the stream waters was lower than that in the treatment plant discharge. Sulphates existing as hydrogen sulfide after decomposition, are responsible for the foul smell of the stream waters. The intensity of the odor from waste water is proportional to the quantity of sulphates in it.

This explains why the waste water discharge had the most noticeable odor of all the four sampling points studied. High amounts of sulphates in irrigation water further can cause scaling of fruits, and vegetable leaves (Batool et al., 2019). This was evident in vegetables that had visible scales. Sulphates are however not known to cause any direct health impacts to humans while present in irrigation water unless in very high concentrations i.e., above 1000 mg/L (Batool et al., 2019). The concentrations of sulfates were lower than their concentrations in the same study in Gondar town (Tessema et al*.,* 2019). Moreover, Mitheu stream had comparatively lower sulphates levels as compared to those found in Vishwamitri River, Gujarat India in a similar study (Magadum et al., 2017). When compared with the concentration of sulphates in Osseh River in Nigeria however, Mitheu stream had a higher sulphates concentration.

4.3 Heavy metals in water

Five heavy metals were analyzed in stream water in this study i.e., Cadmium, Copper, Zinc, Lead, and Chromium. These metals were chosen due to their high probability of occurring in substantial concentrations in industrial, and municipal effluent. Out of these five metals, only cadmium was above WHO standards for irrigation water (Table 4.3).

Table 4.3: Mean ± Standard deviations of heavy metals concentrations in water

Site/Parameter (mg/L)	Point A	Point B	Point C	Point D	WHO limit	p-value
Cd	0.0182±0.0275	0.0118±0.0197	0.0162±0.0276	0.0019±0.0015	0.01	0.827
Cu	0.0015±0.0017	0.0011±0.0019	0.0144±0.0245	0.0040±0.0050	0.2	0.556
Zn	0.1204±0.1329	0.0281±0.0487	0.1102±0.1521	0.0308±0.0420	2	0.592
Pb	0.0024±0.0042	BDL	0.0002±0.0003	0.0289±0.0501	0.5	0.452
Cr	0.0003±0.0005	0.0031±0.0054	0.0018±0.0031	0.0049±0.0049	0.01	0.557

4.3.1 Cadmium

The concentration of cadmium ranged between 0.0019±0.0015 mg/L, and 0.0182±0.0275 mg/L (Table 4.3). The highest concentration was found in the downstream part of the stream, and lowest concentration upstream. The concentration of cadmium in the waste water treatment plant discharge was also considerably high since it exceeded the WHO permitted limit of cadmium concentration in irrigation water. Concentration of cadmium was above WHO safe limits for irrigation water in there out of the four sampling points. Cadmium was mainly deposited into the stream from the municipal waste that partly drains into the stream via vandalized drainage pipes. The discharge from the waste water treatment plant was also directly channeled to Mitheu stream contributing to the high cadmium concentration in the stream. Municipal effluent contains paints washed from buildings among other components. Certain types of industrial paint contain significant amounts of cadmium (Lenka *et al.,* 2018). This paint gradually gets washed into the stream as part of the effluent thus contributing significantly to the cadmium content in the stream.

The high concentration of Cd downstream (Point A) could be linked to usage of phosphate fertilizers in the farms along these streams. Along Mitheu stream, extensive vegetable irrigation farming practiced. It involves use of pesticides, and fertilizers. Some agrochemicals have trace amounts of cadmium, and the continued use of these agrochemicals over a long period of time leads to their accumulation in the soils. They are then washed into the stream when rains pour adding to the increasing concentration of cadmium as the river flows downstream. This is coupled with use of the same stream water for irrigation creating a cycle of cadmium from the stream to the farms, and back to the stream. Higher-than-recommended levels of cadmium in the stream water implied absorption of substantial amounts of cadmium by the vegetable irrigates with water from this stream. This implied unsuitability of water from the stream for irrigation with respect to cadmium toxicity. Comparatively, cadmium concentration in Mitheu stream was lower than that found in Karnaphuli river in Bangladesh (Ali *et al.,* 2016), and in Nairobi River (Njuguna *et al.,* 2017). The concentrations of cadmium along the stream did not differ significantly ($p > 0.05$) as indicated by the ANOVA test.

4.3.2 Copper

The concentration of copper was highest in the discharge from the waste water treatment plant, and lowest at point B (immediately below the entry of the discharge into the stream). All concentrations of copper in the four sampling points were within safe limits (0.2 mg/L) for irrigation water as required by WHO. This meant that, with respect to copper content, the stream water was suitable for use for irrigation. Copper is a metal that mostly results from mining activities since it is found abundantly within the earth's crust (Zhang *et al.,* 2016). Machakos municipality does not have mining activities hence the low amounts of copper in the municipal effluent draining into Mitheu stream. Presence of comparatively higher concentration of copper in the waste water treatment plant discharge indicated lower efficiency in the treatment plant with regard to removal of copper (Degefu *et al.,* 2013). Copper mostly exists in its ionic form as Cu2+ as this is the type of copper that binds to organic matter hence it is biologically available (Marrugo-Negrete *et al.,* 2017). Concentration of copper in the stream decreased downstream implying possible dilution as the stream flowed. When compared to a similar study conducted in Nairobi River by (Njuguna *et al.,* 2017). Mitheu stream has lower copper concentration. Mitheu stream did not indicate significant variation in the concentration of copper ($p > 0.05$) as was proven by the ANOVA test.

4.3.3 Zinc

Zinc was in highest concentration downstream at point A at 0.1204±0.1329 mg/L (Table 4.3). The discharge from the treatment plant followed closely with 0.1102±0.1521 mg/L (Table 4.3). The lowest concentration was at the point just below the entry of the treatment plant effluent at 0.0281±0.0487 mg/L. The concentration of zinc in the stream waters was within WHO permissible limits for irrigation water. This signified that the water was usable for irrigation without causing any health disorders to the human body. The high concentration of zinc downstream is attributed to use of agrochemicals in irrigation farming along the stream. There is extensive vegetable irrigation farming along Mitheu stream that is done throughout the year. This contributes to deposition of agrochemicals in the soils in large quantities via the use of pesticides, and fertilizers. These agrochemicals contain substantial amounts of zinc that gets washed into the stream when it rains (Banerjee and Gupta, 2017). As a result, the concentration of zinc keeps increasing as the water flows downstream (Singh, and Kumar, 2017). However, since this is the only considerable source of zinc in the stream waters, tit does not exceed safe limits as dictated by WHO. This concentration of zinc found in Mitheu stream was lower than that found in a similar study in Nairobi River (Njuguna et al., 2017). The concentrations of zinc in all points along Mitheu stream did not vary significantly ($p > 0.05$).

4.3.4 Lead

Lead was present in three of the sampling points studied. Its highest concentration was recorded at point D (upstream near entry of raw effluent into the stream). This highest concentration was 0.0289±0.0501 mg/L (Table 4.3). At point B (below the treatment plant) lead content was below detectable limit. This indicated that it could be present but in very low amounts that it was undetectable. When compared with WHO safe limits of lead in irrigation water, Mitheu stream water was safe for use in irrigation. The concentration of lead in all the sampling points was significantly below the WHO limit. The results further indicated that the concentration of lead in the stream decreased as water flowed downstream. This could be attributed to dilution. Lead in waste water in Machakos municipality mostly resulted from lead paints washed by storm water, and lead pipes.

Lead pipes are widely used as drainage pipes, and corrosion of these pipes dissolves partly the lead that is then drained into Mitheu stream. These sources are just a small percent of the total sources of lead in industrial effluent (Mahmoud, and Ghoneim, 2016). This justified the minimal content of lead in Mitheu stream. After analysis of variance, the results showed that there was no significant variations in the concentration of lead at different points of the stream. The concentration of lead in Mitheu stream was comparatively lower that that found in Nairobi River in a similar study (Njuguna et al., 2017). Mitheu stream further had lower lead concentration as compared to Karnaphuli River in Bangladeshi (Ali *et al.,* 2016). This was an indication that apart from the industrial effluent there was no other contributor to lead content in the stream.

4.3.5 Chromium

Chromium concentration was recorded in highest concentration at point D (upstream) at 0.0049±0.0049 mg/L (Table 4.3). Chromium content decreased downstream with point A (far downstream) having 0.0003±0.0005 mg/L (Table 4.3). These concentrations of chromium in Mitheu stream were safe within WHO limits for irrigation water. The low chromium concentration in the stream that receives raw effluent from Machakos town is attributed to lack of intensive industrial activities within the municipality. Chromium is mostly released to the environment from industrial effluent draining into urban rivers (Banerjee, and Gupta, 2017). Machakos town is not an industrial hub, and hence the effluent channeled into Mitheu stream comprised primarily of municipal effluent. Mitheu stream was thus usable for irrigation without causing health alarm with regard to chromium poisoning. Chromium s highly poisonous even at very low concentrations despite that it is an essential trace element in the human body (Gizaw, 2018). The strict regulation of its limits in irrigation water is to ensure that it does not get absorbed by vegetables thereby being transmitted to humans in quantities that damage internal body organs (Ratul *et al.*, 2018). The study further revealed that chromium concentration does not vary significantly ($p > 0.05$) along the stream. This was an indication that there were no additional sources of chromium as the river flowed apart from the initial quantities in the municipal effluent.

The levels of chromium in Mitheu stream were lower than those found in Nairobi River in a study conducted in 2017 (Njuguna *et al.,* 2017), and those found in Karnaphuli River Bangladeshi (Ali *et al.,* 2016). Compared with heavy metals concentrations in urban streams in a study conducted in Awash River in Ethiopia by (Degefu *et al.,* 2013), the concentrations in Mitheu stream were lower. Both streams were found to contain allowable concentrations of Cu, Zn, Pb, and Cr. It was only Cd that has slightly surpassed the WHO allowable limits in both streams. The potential sources of these heavy metals in the stream were the municipal effluent within Machakos municipality, and the agrochemicals (fertilizers, and pesticides) used in the farms along the streams. One way ANOVA revealed that the concentrations of the metals in the respective sampling points did not vary significantly. All the P values were $P>0.05$.

4.4 Bacteriological parameters

The stream was found to be heavily contaminated with both total coliform bacteria, and the E Coli bacteria. The highest concentration of both total coliforms, and *E. Coli* bacteria were upstream (Point D) while far downstream (Point A) had the lowest concentration (Table 4.4).

Table 4.4: Mean ± Standard deviations of Bacteria counts in water

Site/Parameter	Point A	Point B	Point C	Point D	WHO limit	p value
Total Coliforms (MPN/100 ml	4524.25 ± 4615.316[a]	100508.25 ± 59895.917[a]	180175 ± 78885.079[b]	240000 ± 0.000[b]	1000	0.026
E. coli **(MPN/100 ml)**	1791.75 ± 1685.866	111441.75 ± 96477.922	151300 ± 113913.881	229166.75 ± 21666.5	Nil	0.125

The total coliforms together with *E. coli* were used to estimate the quality of water in Mitheu stream with respect to bacteriological contamination (Gebreyohannes et al., 2015). Comparatively, the downstream section (sampling Point A) had the lowest bacteria count for both total coliform, and *E. coli* at 4524.25±4615.316 MPN/100ml, and 1791.75±1685.866 MPN/100ml, respectively (Table 4.4). Highest concentration of Total Coliforms, and *E. coli* bacteria were found at the point upstream (Point D) at 240000 ± 0.000 MPN/100ml, and 229166.75±21666.5 MPN/100ml, respectively (Table 4.4). These considerably high levels of bacterial contamination in the stream signified the extent to which it has continually over the years been polluted. Raw effluent from Machakos municipality enters Mitheu stream from vandalized drainage pipes. At the waste water treatment plant, inefficient treatment further increases the discharge of bacterial contaminants into the stream. The waste water treatment plant had total coliforms, and *E. coli* concentrations of 180175±78885.079 MPN/100 ml, and 151300±113913.881 MPN/100ml, respectively. An efficiently functioning waste water treatment plant is supposed to release to the environment discharge with total coliforms less than 1000, and nil *E. coli*. *E. coli* counts were not significantly varied (p=0.125) in the four sampling points.

The results indicated that the concentration of *E. coli* bacteria was comparatively within the same range across the entire stream. Total coliform counts in the four sampling points were significantly varied as indicated by the P value 0.026. Bacterial counts decreased downstream due to dilution of the effluent. These concentrations were comparatively very high for irrigation water. The counts for both Total coliforms, and *E. coli* exceeded WHO permissible limits for irrigation water. Heavy bacterial contamination against WHO set standards implies possible transmission of bacterial-carried infections to farmers either by directly handling the stream's water or the residents who consume the vegetables. *E. coli* in particular is required to be below 1 MPN/100ml for irrigation water (Ogbonna and Ajubo, 2017). High concentrations of the virulent strains of *E. coli* leads to diseases such as diarrhea, urinary tract infections, and crohn's disease (Agwa et al., 2013). The high bacterial load was due to the municipal effluent from Machakos town that is channeled directly into Mitheu stream due to vandalism of sewer lines. Municipal sewage contains fecal matter that has high bacterial content. Mitheu stream had comparatively higher bacterial contamination than the one found in Rumuolumini River, Abio Akpor Nigeria (Ogbonna and Ajubo, 2017).

A similar study in Athi River in Machakos County in 2015 found a higher bacterial contamination in River Athi (Wambugu et al., 2015). Mitheu stream is heavily polluted with bacterial contaminants when compared with a study conducted in other urban streams in Gondar town in north-west Ethiopia (Tessema et al., 2019). Comparatively with streams in Limpopo, South Africa, however, the bacterial contamination in this urban stream in Machakos municipality is lower (Dankovich et al., 2016). A similar study conducted in Hanoi Vietnam found comparatively higher bacterial contamination in urban streams when compared to the levels in Machakos municipality (Fuhrimann et al., 2016). Mitheu stream in Machakos had higher bacteria contamination compared to Tigris River in Baghdad city (Al-Bayatti et al., 2012). A comparison with a similar study conducted in Tamale Metropolis Ghana finds the urban stream in Machakos to be heavily polluted with both total coliforms, and *E. coli* bacteria (Abdallah, 2018). This is a reflection of inefficient sewage treatment system within Machakos Municipality.

4.5 Heavy metals in selected vegetables (Spinach, and Kales)

The vegetables analyzed had significantly high amounts of certain heavy metals (exceeding WHO safe limits) while for other metals, the concentrations were within allowable limits (Table 4.5 and 4.6). Kales had cadmium, lead, and chromium above WHO safe limits in different sampling points (table 4.5) while spinach had cadmium, lead, and chromium exceeding WHO permitted limits at points A, B, and D (table 4.6).

4.5.1 Heavy metals in kales

Table 4.5: Mean concentrations of heavy metals in kales

Sampling Point	Point A	Point B	Point C	Point D	WHO Std	P value
Cd (mg/L)	BDL	0.0577±0.0786	0.0666±0.0685	0.3194±0.4860	0.2	0.435
Cu (mg/L)	0.4675±0.809	1.6253±1.775	1.625±1.853	1.0845±1.264	73.3	0.734
Zn (mg/L)	15.3652±24.086	19.2765±12.592	16.1461±11.519	5.7775±6.735	99.4	0.667
Pb (mg/L)	BDL	0.3676±0.482	BDL	0.02±0.034	0.3	0.225
Cr (mg/L)	0.1040±0.180	2.8599±3.628	BDL	BDL	2.3	0.198

BDL = Below Detection Limit

Cadmium

Kales sampled from the farm adjacent point D (far upstream) had the highest concentration of cadmium at 0.3194±0.4860 mg/L (Table 4.5). This value was slightly higher than WHO recommended concentration of cadmium in kales. This was the point nearest to the entry of raw effluent into Mitheu stream. This signified potential poisoning of the consumers of these vegetables by cadmium. Cadmium is a highly carcinogenic element that damages the body organs such as liver, and kidneys. Kales irrigated with water at the point where waste water treatment plant discharge enters the stream (Point C), and the point just below the treatment plant (point B) had detectable amounts of cadmium but were below the safe limits recommended by WHO. Far downstream at point A, the kales grown in adjacent farms had non-detectable amounts of cadmium. The concentration of cadmium in kales grown along Mitheu stream decreased downstream. This pointed to dilution of cadmium in the stream water as it flowed downstream. Kales obtained their cadmium from the irrigation water, and possibly from the soils.

Comparatively, irrigation water was the major source of cadmium since even the soils absorb cadmium when it gets deposited into them by contaminated water. The study further found out that there was no significant difference ($p = 0.435$) in the concentration of cadmium in kales grown along Mitheu stream. Despite the higher than recommended levels of cadmium in kales along Mitheu stream, they were comparatively lower than the cadmium content in kales irrigated with waste water in kitui (Wambua *et al.,* 2019). Cadmium levels in kales grown along Mitheu stream were higher than those grown along Akaki River in Addis Ababa (Gizaw, 2018). Moreover, compared to a similar study conducted in Jos, Nigeria (Lenka *et al.,* 2018), and Embu Kenya (Sayo *et al.,* 2020), kales grown along Mitheu stream Machakos had a higher cadmium content.

Copper, and Zinc

Copper, and zinc in kales from all the sampling points were within WHO safe limits. Kales irrigated from the point below waste water treatment plant (Point B) had the highest concentration of copper at 1.6253±1.775 mg/L while those grown further downstream had the lowest concentration of cadmium, 0.4675±0.809 mg/L (Table 4.5). The concentrations of copper in these kales did not pose any health threats to consumers as they were comparatively very low when compared with WHO limits for copper in kales. Kales grown along Mitheu stream, Machakos had comparatively lower copper content as compared to those grown along an urban stream in Jos, Nigeria (Lenka *et al.,* 2018). They however, had a higher copper content when compared to kales grown along an urban stream in Embu (0.484–1.834 mg/L) in a similar study (Sayo *et al.,* 2020). Copper is an essential element in the body for various body functions such as the making of hemoglobin thus is needed in daily diet (Zhang *et al.*, 2016). This implies that copper would need to accumulate to very high levels to become toxic since it is utilized in the body (Mahmoud and Ghoneim, 2016). With regard to copper amounts, the kales were suitable for human consumption.

Zinc, like copper, is an essential element in the body that is required for various body processes. Kales grown along Mitheu stream had substantial amounts of zinc. Kales grown adjacent Point B had the highest concentration of zinc at 19.2765±12.592 mg/L while kales grown upstream at point D had the lowest zinc levels at 5.7775±6.735 mg/L. Unlike copper, the concentration of zinc in kales did not decrease downstream. This pointed out to a possibility of presence of zinc in soils in the farms downstream in addition to that in the stream water. The continued irrigation of these farms with contaminated water over the years led to accumulation of zinc in the soils. Therefore, the period that these farms had been irrigated with contaminated water could have contributed to the high concentration of zinc in the soils hence the high concentration of zinc downstream. When compared with kales grown along an urban stream in Embu, the concentration of zinc in kales along Mitheu stream was higher (Sayo *et al.,* 2020). Kales grown along Akaki River in Addis Ababa were found to have a higher zinc content as compared to the levels obtained in this study (Gizaw, 2018). Concentrations of both zinc, and copper in kales did not show any significant variation in all the sampling points ($p > 0.05$).

Lead

Lead was only detected in kales obtained from two sampling points i.e., point B (below the waste water treatment plant), and point D (the far most upstream sampling point). Kales obtained in sampling points A (downstream, and C (adjacent entry point of waste water treatment plant effluent) had undetectable amounts of lead. Kales grown along the stream at point B had lead content that exceeded WHO safe limits. Their lead concentration was at 0.3676±0.482 mg/L. Kales from all other sampling points along the stream were safe for consumption with respect to lead concentration. Lead is highly toxic when in concentrations higher than the recommended levels (Paul, 2017). The regulation of lead content in vegetables is aimed at securing the health of consumers since exposure to high concentrations of Pb leads to kidney, and brain damage (Ratul *et al.*, 2018). Lead content in kales grown along Mitheu stream was lower than that found in a similar study in kales irrigated with waste water in kitui (Wambua *et al.,* 2019). Compared to a study conducted in an urban stream in Embu, Kenya, the kales grown along Mitheu stream, Machakos had a higher lead content (Sayo *et al.,* 2020). Kales grown along Mitheu stream were however less contaminated with lead as compared to those grown along Akaki river in Addis Ababa (Gizaw, 2018) as well as those grown along urban streams in Raniganj industrial complex, India (Banerjee and Gupta, 2017).

Chromium

Chromium was detected in kales from farms at sampling points A (far downstream), and B (below the waste water treatment plant) only. Kales from farms adjacent to sampling points C, and D had undetectable levels of chromium. Kales obtained from point B had the highest concentration of chromium at 2.8599±3.628 mg/L. This amount was also higher than WHO recommended limits of chromium in kales. This implied that consumption of kales from farms within this point posed a health hazard to consumers. These kales are harvested, and supplied to markets within Machakos municipality, and this is a health risk to the residents. Chromium like many other heavy metals is regulated since its excessive intake harms body organs such as the livers, and kidneys. These kales form a big proportion of the green vegetables consumed within Machakos municipality.

A study conducted in Shitalakhya River, Bangladesh, in a similar urban setting found lower concentrations of Cr as compared to their concentrations in kales grown along Mitheu stream (Ratul *et al.*, 2018). Additionally, kales grown along Mitheu stream had a higher concentration of chromium than those grown along Akaki River in Addis Ababa, Ethiopia (Gizaw, 2018). Kales grown along Mitheu stream had comparatively higher chromium levels when compared to those grown along urban streams in Jos, Nigeria (Lenka *et al.*, 2018).

4.5.2 Heavy metals in spinach

Table 4.6: Mean concentrations of heavy metals in spinach

Sampling Point	**Point A**	**Point B**	**Point C**	**Point D**	**WHO Std**	**P value**
Cd (mg/L)	0.5755±0.872	0.0695±0.120	0.0125±0.0216	0.2487±4.898	0.2	0.456
Cu (mg/L)	7.5567±5.700	3.7934±1.753	4.5021±1.866	5.5501±3.508	73.3	0.611
Zn (mg/L)	8.317±9.089	17.9423±12.885	8.9854±6.556	12.4177±5.871	99.4	0.563
Pb (mg/L)	0.3672±0.258	0.4385±0.547	0.2426±0.158	1.4869±2.317	0.3	0.577
Cr (mg/L)	1.2404±1.272	0.3684±0.514	0.4975±0.755	3.4869±3.986	2.3	0.301

Cadmium

Spinach from all the sampling points had cadmium. The highest concentration of cadmium was found in spinach obtained from sampling point A (far downstream) at 0.5755±0.872 mg/L while the lowest concentration was at point C (adjacent to waste water treatment plant at 0.0125±0.0216 mg/L (Table 4.6). Spinach obtained from point A (far downstream), and point D (upstream) had cadmium concentrations that exceeded WHO safe limits. Point D was upstream near entry of raw effluent into Mitheu stream hence the high concentration is spinach is attributed to absorption from the stream water highly concentrated with raw effluent. The high concentration downstream signified possible presence of cadmium in the soils, and agrochemicals in addition to that present in water. Cadmium was however in highest concentration is water at this point as well. There seemed to be a positive relationship between cadmium concentration in water, and that in spinach.

Comparatively, cadmium concentration in spinach was higher than that in kales. Spinach absorb more water from soils, and this accounted for their higher cadmium content relative to kales (Sultana *et al.,* 2017). The cadmium concentration in spinach grown along Mitheu stream was higher than that found in spinach grown in Kudenda, Kaduna metropolis, Nigeria (Sara *et al.,* 2018). Similarly, cadmium concentration in spinach grown along Shitalakhya Rivers in Bangladesh was lower as compared to that found along Mitheu stream Machakos (Ratul *et al.,* 2018). Cadmium concentration in spinach grown in Machakos municipality was however lower than that found in spinach grown in Osun State, Nigeria (Olayiwola *et al.,* 2016), and along streams within Raniganj Industrial Complex, India (Banerjee and Gupta, 2017).

Copper, and zinc

Spinach from all the four sampling points had copper content that was within WHO permissible levels. Comparatively, spinach grown at point A downstream had the highest levels of copper at 7.5567±5.700 mg/L while those grown below the waste water treatment plant had the lowest concentration of copper at 3.7934±1.753 mg/L (Table 4.6). Copper is an element that is found in certain soils, and it could have been present in the soils in those farms downstream. This could have added to the concentration of copper available for absorption by spinach. There was however no significant variation in the concentrations of copper in all spinach from the four sampling points ($p = 0.611$).

In contrast to copper, zinc is most abundant in spinach grown at sampling point B (below the waste water treatment plant), and least abundant in those grown at sampling point A (far downstream). The concentration of zinc in spinach ranged between 8.317±9.089 mg/L, and 17.9423±12.885 mg/L (Table 4.6). From these results, it is evident that spinach grown along Mitheu stream contained zinc at higher concentrations comparative to other heavy metals investigated.

Zinc is an essential element in the body for certain cellular processes as well as for development of the immune system (Paul, 2017). This therefore justified its high WHO limit as compared to other heavy metals. As a result, the spinach were suitable for human consumption without any health risks from the zinc content they contained. Analysis of variance indicated that the levels of zinc in spinach grown along Mitheu stream did not vary significantly ($p = 0.563$). Copper, and zinc levels in spinach grown along Mitheu stream were lower compared to those grown along Shitalakhya Rivers in Bangladesh (Ratul *et al.*, 2018). Comparatively, copper levels in spinach grown along Mitheu stream was lower than those grown along streams within Raniganj Industrial Complex, India

(Banerjee and Gupta, 2017). Additionally, copper, and zinc concentrations in spinach grown along Mitheu stream were lower than their respective concentrations in spinach grown along streams within Osun state Nigeria (Olayiwola *et al.,* 2016). Spinach grown along streams in Kudenda, Kaduna metropolis Nigeria had lower concentrations of copper when compared with those grown along Mitheu stream, Machakos (Sara et al., 2018).

Lead

The highest concentration of lead was identified in spinach grown at sampling point D (upstream). This concentration was 1.4869±2.317 mg/L. This was the point just below the entry of raw effluent into Mitheu stream. At this point irrigation was one with stream water that was highly concentrated with untreated municipal effluent. The high concentration of lead in spinach grown at this point could be attributed to high concentration of lead in the stream waters. The stream waters still had their highest concentration of lead at this same point. This illustrated a direct relationship between the concentration of lead in water, and that in spinach. The lowest lead content in spinach was found in those obtained from sampling point C (entry point of waste water treatment plant discharge into the stream) at 0.2426±0.158 mg/L. this were the only spinach whose lead concentration as within safe limits set by WHO. The other three sampling points i.e., point D (upstream), point B (below the waste water treatment plant), and point A (far downstream) had spinach whose lead levels were higher than WHO recommended limits.

This implied that consumption of spinach grown at these sampling points posed serous health hazards to residents of Machakos municipality. Lead is highly poisonous to humans attacking internal organs such as liver, kidneys, and the brain when ingested in high quantities (Zhang et al., 2016). The concentration of lead in spinach seemed to decrease downstream, say for point C. this was proportionate to the decreasing lead concentration as the water flowed downstream. The concentrations of Lead is spinach grown along this stream had higher lead concentrations than those grown in Kudenda, Kaduna State Nigeria (Sara et al., 2018). The lead concentrations identified in this study were however lower than those found in spinach grown in Osun State Nigeria (Olayiwola *et al.*, 2016), and those grown along urban streams within Raniganj Industrial Complex, India (Banerjee and Gupta, 2017). Comparatively spinach in urban irrigation farming in Machakos had lower concentrations of lead than the one grown along Shitalakhya Rivers in Bangladesh (Ratul *et al.*, 2018). Lead in spinach grown along Mitheu stream was found to be I a lower concentration as compared to that in spinach grown along Shitalakhya Rivers in Bangladesh (Ratul *et al.*, 2018). Like other metals investigated in this study, the concentration of lead in spinach was not significantly varied in all four sampling points ($p = 0.577$).

Chromium

Chromium was in highest concentration in spinach farmed at sampling point D (upstream) at 3.4869±3.986 mg/L, and lowest in the spinach grown at Point B (below the waste water treatment plant) at 0.3684±0.514 mg/L. The Cr concentration in spinach grown at sampling point D was higher than WHO recommended limits for safe human consumption. This sampling point was the nearest to the entry point of raw municipal effluent into the stream. This implied that vegetables grown at this point were irrigated with a highly concentrated municipal effluent. As a result, and coupled with the fact that spinach absorb substantial amounts of water from soils, their chromium content was found to exceed WHO safe limits (Ratul *et al.*, 2018). The spinach grown at all other sampling points along the stream had chromium concentrations that were safely within WHO recommended limits. In essence, consumption of spinach grown at sampling point D posed health hazards to the residents of Machakos municipality. The analysis of variance of chromium concentrations in spinach grown along different sections of the stream indicated that they did not vary significantly ($p = 0.301$)

Spinach contained higher concentrations for all the heavy metals analyzed in this study as compared to kales. This is attributed to their tendency to absorb more water than kales, thereby taking in more amounts of heavy metals contained in contaminated water, and soils (Sayo et al., 2020). The vegetables (kales, and spinach) grown along this stream had one or multiple of the heavy metals investigated except copper, and zinc exceeding WHO safe limits for human consumption. Although at certain points in the stream the heavy metal concentrations of all selected heavy metals were within permissible limits, it would be difficult to separate the vegetables when harvested, and distributed to the market. This therefore implied vegetable farming along Mitheu stream was unsafe as it ended up supplying Machakos municipality residents with vegetables whose Cd, Pb, and Cr levels were above WHO recommended levels for safe human consumption.

Compared to a study conducted in Shitalakhya Rivers in Bangladesh, the spinach grown along Mitheu stream higher concentrations of Cr (Ratul *et al.*, 2018). Similarly, comparison with a study conducted in Raniganj Industrial Complex, India indicated that spinach in Machakos municipality are less polluted with Cr (Banerjee and Gupta, 2017). The lower concentrations of these heavy chromium in spinach along Mitheu stream is explained by absence of heavy industrial activity within Machakos Municipality.

4.6 Heavy metal correlation analysis

The correlation analysis established the relationship between the heavy metal concentrations in water, and those in kales, and spinach separately. The correlation was conducted using the Pearson correlation analysis. It was only copper in kales that showed a significant correlation with its concentration in water.

Table 4.7: Correlation analysis of heavy metal concentration in irrigation water, and vegetables

Heavy metal	Correlation with conc. in water	Correlation with conc. in spinach
Cd	-0.070	-0.115
Cu	0.611	0.156
Zn	0.315	-0.130
Pb	0.219	-0.129
Cr	-0.198	-0.090

All other metals did not show significant correlation between their concentration in water, and that in vegetables. This illustrated that although polluted water was a contributing factor to the presence of heavy metals in vegetables grown along this stream, there were other factors as well. The other possible sources of heavy metals in vegetables included their presence in the soils. Irrigation farming with contaminated water has happened along this stream for many years, and this has possibly deposited substantial quantities of these heavy metals in the soils. Additionally, continued use of fertilizer, and pesticide with trace quantities of particular heavy metals could further have increased their content in soils. The vegetables therefore absorbed heavy metals partly from the stream water, and partly from the soils.

CHAPTER FIVE: SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary of findings

Total Dissolved Solids (TDS), Electrical Conductivity (EC), Chemical Oxygen Demand (COD, and Biological Oxygen Demand (BOD) levels of Mitheu stream were higher than WHO limits for irrigation water. COD levels in the waste water treatment plant effluent, and that in the stream waters had significant differences ($p = 0.003$). Concentration of BOD downstream, and that of the waste water treatment plant effluent were significantly different as well ($p = 0.033$). The stream had nitrates, and sulphates concentrations that were not exceedingly high for irrigation water. Phosphates in the entire stream section studied exceeded WHO set limits for irrigation water. Out of the heavy metals analyzed, only cadmium, (Cd) was found to exceed WHO safe limits for irrigation water. The other heavy metals i.e., Cu, Zn, Pb, and Cr concentration in Mitheu stream were within WHO limits. There was no specific order of variation in concentrations of heavy metals along the stream implying concentrations of heavy metals in the stream waters were influence by multiple local factors, and not the entry of raw effluent alone.

Mitheu stream was highly polluted with both total coliforms, and *E. coli* bacteria. The bacterial counts in this stream exceeded WHO set limits for irrigation water by far. Bacterial contamination of the stream decreased downstream from the point of entry of raw effluent with the far downstream having the least bacterial counts, and the furthest point upstream having the highest bacterial count.

Kales grown along the upper section of Mitheu stream were found to contain Cd, Pb, and Cr in concentrations higher than WHO recommended levels. Those grown downstream had all investigated heavy metals within safe limits as recommended by WHO. Spinach in the farms along Mitheu stream had higher-than-recommended levels of Cd, Pb, and Cr. Both kales, and spinach had Cu, and Zn levels safely within WHO recommendations for green vegetables.

Copper concentration in kales showed a significant positive correlation with its concentration in the stream water. All other heavy metals' concentrations in both kales, and spinach did have any significant correlation with their respective concentrations in the stream water.

5.2 Conclusions

i. To assess the physico-chemical parameters, and concentrations of Lead, Chromium, Cadmium, Zinc, and copper of water in Mitheu stream
ii. To investigate the level of bacteriological concentrations in Mitheu stream
iii. To assess the concentration of heavy metals in selected vegetables (Brassica oleracea, and Spinacia oleracea) irrigated with water from Mitheu stream
iv. To determine the relationship between heavy metal concentrations in the water, and in common vegetables grown along the stream

Based on TDS, EC, COD, and BOD concentrations, Mitheu stream is not suitable for irrigation use since it exposes the farmers as well as consumers of the produce to health risks from organic chemicals. Concentrations of Higher-than-recommended levels of Cd further disqualified its use for irrigation.

Mitheu stream was found to present high risk of bacterial infections to the farmers, and consumers of vegetables grown along the stream based on the total coliforms, and *E. coli* counts. The waste water treatment plant serving Machakos town was not optimally functional as its discharge contained comparatively high quantities of the parameters tested.

The high concentrations of Cd, Pb, and Cr in both kales, and spinach irrigated with water from Mitheu stream implied that consumption of these vegetables posed health risks to residents of Machakos municipality, and were thus unfit for human consumption.

There was no significant correlation between heavy metals concentrations in water, and that in vegetables. This indicated that the vegetables possibly obtained additional heavy metals from soils, and agrochemicals used on the farms.

5.3 Recommendations

Based on the findings of this study it was recommended that:

1. A more elaborate sewage management system for Machakos should be constructed to prevent the entry of raw effluent into Mitheu stream. In the current state of the stream, farmers should be advised on the health implications of utilizing it for irrigation.
2. Regulatory bodies such as NEMA, and the County government public health department should enlighten residents of Machakos municipality on the potential health hazards they are exposed to with continued consumption of vegetables irrigated with water from this stream.
3. Further studies on the presence, and concentration of heavy metals in soils should be conducted to establish the source of the higher-than-recommended levels of Pb, and Cr in the vegetables.

4. Further studies, should focus on the relationship between consumption of vegetables irrigated by Mitheu water and specific health conditions within the populace

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