IMPACT OF SEASONAL VARIATION AND HIGH INDUSTRIAL EFFLUENT DISCHARGE ON WATER QUALITY IN NANKHAKA RIVER, LILONGWE, MALAWI

MASTER OF SCIENCE IN ENVIRONMENTAL HEALTH DISSERTATION

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UNIVERSITY OF MALAWI

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By

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A Dissertation Submitted to the Department of Public and Environmental Health Sciences, Faculty of Applied Sciences, in Partial Fulfilment of the Requirements for the Award of a Degree of Master of Science Environmental Health

University of Malawi

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DECLARATION

I, Alick Aniter Sataya Chirwa, hereby declare that this thesis entitled Impact of Seasonal Variation and High Industrial Effluent Discharge on Water Quality in Nankhaka River, Lilongwe, Malawi is my own original work and has not been submitted to any other institution for similar purposes. It has not been submitted for any degree or examination to any university or college.

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We, the undersigned, certify that we have read and hereby recommend for acceptance by the University of Malawi, a thesis entitled" *Impact of Seasonal Variation and High Industrial Effluent Discharge on Water Quality in Nankhaka River, Lilongwe, Malawi*".

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DEDICATION

I dedicate all the work in this paper to my family, my wife and son, for your love, inspiration and support.

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ABSTRACT

Water quality is influenced by physico-chemical and biological factors, and in Malawi, surface water faces significant pressure from diverse forms of pollution, including domestic, agrochemical, and industrial effluent. This study aimed to assess the impact of seasonal variation and industrial effluent on water quality of Nankhaka River. Standard laboratory methods and on-site measurements were employed at six sampling sites along the river to generate data on various parameters. The study assessed Turbidity, pH, Alkalinity, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, Suspended Solids, Temperature, Electrical Conductivity, *Escherichia coli*, Lead, Cadmium, Iron, Copper, and Zinc. Statistical analyses, including one-way Analysis of Variance (ANOVA) and paired sample t-tests, were conducted to examine differences between upstream and downstream and seasonal variations in water quality at a 95% confidence interval. Results revealed significant seasonal and spatial differences between upstream and downstream in certain parameters. EC, TDS, BOD, and *E. coli* were notably higher downstream during dry season. Conversely, Temperature and TSS were higher in rainy season. pH, turbidity, DO, and COD showed no significant seasonal variation. The findings suggest fluctuation in selected water quality parameters in Nankhaka River, with higher concentrations downstream attributed to increased industrial activities and effluent disposal. Cadmium, Lead, EC, Turbidity and Alkalinity showed significant risk to downstream water users of Nankhaka river in both seasons. The study emphasizes the importance of industrial effluent treatment before discharge into waterbodies. Additionally, it recommends strict enforcement of existing by-laws by local environmental authorities to prevent high effluent discharge into waterbodies.

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ABBREVIATION AND ACRONYMS

Abbreviation	Definition
ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
Cd	Cadmium
COD	Chemical Oxygen Demand
Cr	Chromium
Dn	Downstream
DO	Dissolved Oxygen
E1	Effluent release point
EC	Electrical Conductivity
EMA	Environmental Management Act
MBS	Malawi Bureau of Standards
MEPA	Malawi Environment Protection Authority
MPHC	Malawi Housing and Population Census
Ni	Nickel
NS	Not Significant
NSO	National Statistical Office
NTU	Nephelometric Turbidity Unit
Pb	Lead
PHA	Public Health Act
S	Significant
SS	Suspended Solids
T	Temperature
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
Up	Upstream
WA WQI	Weighted Arithmetic Water Quality Index
WHO	World Health Organisation
WQI	Water Quality Index
WRA	Water Resources Act
WRB	Water Resources Board

WHO GV	World Health Organisation Guideline Value
pH	Power of Hydrogen
RQ	Risk Quotient

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Background

Water pollution is one of the major global environmental challenges. Water is regarded as polluted when contaminants render it unusable for both domestic and industrial purposes. According to the United Nations Environment Programme (2016), global deterioration of water quality has escalated in recent years because of increased discharge of industrial effluent into large water bodies. Worldwide, countries including Africa are on this trend as 80% of effluent on the continent is disposed into water bodies, and it is estimated that industries dump 300-400 million tons of toxic sludge, heavy metals and other hazardous elements into waterbodies every year (Mwatujobe, 2020). For instance, in the US it was estimated to produce about 32, 175 million gallons in a day in 1996 and it has been reported that the US industrial sector uses 102 billion liters of water in a single day. Elsewhere, in 2008, China produced an estimated wastewater of about 57.2 billion tons where 58% was from municipal and 42% was from industrial (Mwatujobe, 2020).

Water pollution has been largely attributed to population growth, increased urbanization, production of food, and illegal and unregulated disposal of industrial effluents into water bodies thereby deteriorating its quality, rendering it unsuitable for consumption (Ikhajiagbe, 2014). It is estimated that globally, over 2 million tons of waste is produced and discharged in lakes, rivers and oceans and this is responsible for death of 1.8 million under five children from water related illness. Generally, surface water has capability to undergo self-purification, but in high concentration of contaminants, this process is rendered inefficient thereby deteriorating water quality, which makes it unsafe for human usage. Akoth (2018) found that wastewater produced from industries and domestic use contains pathogens, toxic chemicals and heavy metals which have the capability to cause health problems and distort the aquatic ecosystems.

In Malawi, it is evident water pollution is caused by industrial effluent and domestic sewage discharge into water bodies. This is in addition to challenge of dumping solid waste and other hazardous waste in undesignated dumpsites. According to Ngwira and Lakudzala (2018) potential of industrial effluent to disturb stability and equilibrium of water ecosystems cannot be overemphasized. This happens because discharged effluent with little to no treatment at all, contains diverse organic and inorganic chemical compounds, which are toxic to different forms of life in water ecosystem. Toxicity of industrial effluent depends on processes in which wastes originate. This implies that industrial effluent is difficult to handle as it varies in composition.

Ikhajiagbe (2014) noted that complexity in handling industrial waste lies in their diverse nature ranging from relatively clean rinse water to waste liquors as well as having high concentration of substances and mineral matter that are poisonous, explosive, flammable or corrosive.

Waste generated by different anthropogenic activities has become one of biggest environmental problems in developing countries including Malawi. In most cases these wastes are improperly disposed in the natural environment and water bodies, especially freshwater reservoirs, are highly affected by this malpractice (Ikhajiagbe, 2014; Leong et al., 2018). This has caused water to be unsuitable for either primary or secondary usage. Industrial effluent is the major source of contamination of natural water bodies in highly populated cities like Lilongwe where river systems that are in proximity are primary means for their disposal (Ngwira & Lakudzala, 2018). Unequivocally, these industrial effluents have a profound influence on pollution of the river ecosystems with their capability of changing physical and biochemical properties of receiving water bodies. Waste that enters these water bodies is either in solid or liquid forms. These are normally generated from industrial and agricultural activities thereby polluting water bodies. There is great magnitude of the resultant effect of such pollution on population health and the environment.

It is evident that industrial effluent discharge into river systems is the major source of environmental pollution. This has increased deterioration of the quality of water in the receiving water bodies which is a major concern especially in developing countries like Malawi (Schutz, 2013). Leong et al. (2018) argue that in many developing countries, industrial standards and environmental standards are not available and where they are in existence, they are generally not enforced and implemented. For instance, rapid population increase in Nigeria has facilitated dramatic rise in urbanization which results into increased generation of domestic and industrial effluent, which end up into water bodies thereby deteriorating water quality (Mwatujobe, 2020). In Africa only 8% of industrial effluent is treated before discharging it into water bodies (United Nations Environment Program, 2016). Apparently, there is no restriction in discharge of untreated and/or improperly treated industrial effluent into water bodies and it has become a major concern for the aquatic environment. Ogunbanwo et al. (2018) also alluded to the fact that disposal of untreated wastes that contains organic compounds and toxicants, results in compromising water quality. Therefore, it is very imperative to treat industrial effluent before discharging it into water bodies to minimize water pollution.

Additionally, Rahmanian et al. (2015) stated that high levels of effluent in water ecosystems cause an increase in chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), toxic metals that includes Cr, Cd, Pb and Ni and fecal coliform. This renders such water inappropriate for domestic use as well as habitat for aquatic flora and fauna. In Malawi, the practices regarding discharge of effluent are too crude and inconspicuous hence jeopardizing communities within the catchment area of industrial activity. Therefore, this study assessed impacts of high industrial effluent discharge on water quality of Nankhaka River.

1.2 Problem Statement

Industrial effluent is supposed to be discharged into water bodies after proper treatment. However, there is growing concern of high discharge improperly treated effluent, which results in nutrient enrichment, the accumulation of toxic compounds in biomass and sediments, depletion of dissolved oxygen in water bodies and other nuisances (Kanu & Achi, 2011). Treatment of industrial effluent is not a panacea as some of treated effluent still contains chemicals that can lead to contamination, thus, reduction of fresh water.

High concentration of contaminants concentration in river water systems results into an increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS) and fecal coliform and reduced dissolved oxygen (DO) (Badr et al., 2020). Downstream, water is very colored, turbid and vegetation along the rivers appears blackened, which is against the background that water from this river is a key resource for nearby communities' especially squatter settlements of Mgona, which also has poor sanitation. People in these communities use this water for recreation, cleaning utensils and equipment, construction works and irrigating crops. This is also where animals and birds drink to sustain and maintain their health. It is feared that contaminated water not only does it affect aquatic organisms but also causes water borne diseases to human beings (Judd & Judd, 2011).

In Malawi, rivers within Lilongwe City are sources of water for domestic purposes for many communities (Phiri et al., 2005). But there is an increased concern about the discharge of untreated industrial effluent into water bodies and little is invested into treatment facilities for waste (Ngwira & Lakudzala, 2018). There has been increased cases of waterborne diseases reported within the study area especially Mgona squatter where it has been the hotspot for cholera outbreak which is acute enteric infection proliferated by consumption of contaminated food or water and it is highly attributed to lack of access to safe drinking water (Ngwira & Lakudzala, 2018). In 1998, Malawi reported first major outbreak which affected most districts including Lilongwe city and registered about 25,000 case which followed another outbreak occurring from 2001 to 2002 and registered 33,546 cases and 968 fatalities with Mgona, in Lilongwe city being hotspot of the outbreak which started in March 2022 (WHO, 2022). The resurgence of the outbreak has been attributed to consumption of untreated contaminated water which contains high amounts of *E. coli* (WHO, 2022). Area 28 and 29 are specially designated as industrial areas for light and heavy industries respectively where food, beverages, paint and soap processing take place. These industries discharge their effluent through storm channels that is found near their premises and Ngwira and Lakudzala (2018) alluded that industries in these areas discharge effluent that contains organic matter and some heavy metals including cadmium, lead and zinc into Nankhaka river which pose danger to the environment and human beings. Malawi Environmental Protection Authority and Water Resources Board has been pushing to ensure that laws and regulations put forward are followed to control and reduce the impact of effluent on water resources (WRA, 2014). Despite continued worldwide and local efforts, industries continue to discharge effluent into water bodies escalating negative impacts to the environment but also posing health catastrophe (Leong et al., 2018). However, literature is not exhaustive on the impact this effluent is exerting on water resources in the country. The current study, therefore, was designed to assess the impact of seasonal variation and high discharge of industrial effluent on water quality of Nankhaka River.

1.3. Objectives of the Study

The main objective of this study was to assess the effect of seasonal variatin and high industrial effluent discharge on water quality in Nankhaka River. Specifically, the study aimed to:

i. Determine physico-chemical characteristics of industrial effluent, riverbank soils and water samples.
ii. Determine fecal coliform count of industrial effluent and the receiving river.
iii. Examine status and class of water of Nankhaka River using Water Quality Index.
iv. Assess health risks associated with water in Nankhaka river

1.4 Research Questions

i. What are physico-chemical characteristics of industrial effluent, riverbank soils and water samples?
ii. What is the fecal coliform count of industrial effluent and receiving river?

iii. What is the status and class of water of Nankhaka river?
iv. What are the health risks associated with water in Nankhaka river?

1.5 Justification of Study

The study aims to determine the impact of high industrial effluent discharge on quality of water. The increase in industrial development in the country has been manifested with improper disposal of industrial effluent emanating from non-compliance and poor implementation of environmental regulations. In the industrial area of capital city of Malawi, industries dispose of their effluent in the nearby water bodies whilst local people close to these water bodies depend on these water resources for domestic purposes and agricultural use. This implies that people still depend on these water resources, but industries continue to dispose of their effluent in water bodies rendering it useless for domestic and irrigation use.

Noteworthy, it is illegal to release industrial effluent into surface water bodies despite the continued trend by these industries, which signify either failure to implement the laws or non-compliance of the concerned stakeholders. As such, discharging industrial effluent is also increasing chemical pollution thereby reducing the probability of survival of aquatic life because industrial effluent reduces Dissolved Oxygen, which is a vital element for survival of aquatic life. However, composition of the effluent that is discharged into the river systems (especially in Malawi) is not fully understood, therefore, this present study intends to fill the knowledge gap that exist on the extent of chemical pollution manifesting from industrial effluent into river systems.

Additionally, Increased cases of waterborne diseases such as cholera recorded within the study area especially Mgona squatter proliferated by consumption of contaminated water due to lack of access to safe drinking water, has ignited the zeal to conduct this study to navigate the impact of high discharge of industrial effluent into Nankhaka river. The study area has been preferred for its easy access, high population and industrialization which exert tremendous pressure on the water body which runs through it. High population and industrialization are major contributors of increased generation of wastewater which could prove catastrophic to the environment and humans if not properly managed leading to surface water pollution and water related illnesses. It is therefore paramount to assess composition of contaminants that is discharged in Nankhaka river to help determine suitable treatment method, thus likely to improve quality of effluent discharged thereby reducing health repercussions to human beings utilizing the water.

The study will help planners and policy makers in the health sector, in prioritizing the options that need to be done to safeguard the surrounding communities from negative effects attributed to poor disposal and management of industrial effluent. The integration of results in the plan and policymaking processes would enhance the livelihoods of the citizenry. It is also hoped that the results of this study will be of value to various environmental stakeholders like Malawi Environment Protection Authority (MEPA) and other interested partners in order to improve livelihood and environmental safety. Not only that, but the research was also expected to significantly contribute to the general body of knowledge in the environmental conservation for stakeholders' use and be of value to prospective researchers to develop the sector and identify areas that need intervention in order to improve livelihood and environmental safety.

1.6 Structure of the Thesis

This thesis comprises six chapters. The first chapter introduces the study, offers background insights, and justifies the research need. The second chapter provides a comprehensive review of relevant literature, establishing the foundation for this study. Chapter three outlines the materials and methods used in the study, while chapter four presents the results. In chapter five, the interconnections and relationships between the findings are discussed. The final chapter concludes the study's findings and suggests recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 . General Overview

This Chapter reviews relevant previous studies on industrial effluent quality and water quality. It outlines the literature reviewed, with the theoretical segment focusing on definitions, the state of water globally, Africa and Malawi, and the effects of industrial effluent. Simultaneously, it addresses prior research on industrial effluent, forming the basis for identifying the research gap addressed by the present study.

A study by Khiwa (2017) states that water quality of Sialkot could not be considered as good due to heavy metal pollution. Water samples had high values of Iron, Zinc and Lead which surpassed WHO recommended threshold limit. It was also alluded that utilizing treated water for irrigation caused plant diseases and reduced yields. Mainardi and Bidoia (2019) found high values of Chromium, Copper and Zinc which affected the alkalinity, color and BOD/COD ratio leading to poor water quality in southern region of Brazil.

According to Makwe and Chup (2013) Karu Abattoir, Nigeria had poor groundwater quality especially in wet season due high mean values of TDS, TSS, turbidity and *E. coli* which was attributed to increased recharge of groundwater which tend to saturate soil thereby reducing filtration. Akoth (2018) study done in South Africa, concluded that quality of water ranged from medium in dry season and bad in wet season after computing Water Quality Index and suggested conventional treatment before consumption to minimise health implications. Poor water quality was largely attributed to high fecal coliform and nitrate which influenced low WQI.

Phiri et al. (2005) study conducted in Lilongwe River revealed that BOD, DO, EC, Alkalinity and SS were higher in both rainy and dry seasons and concluded that water of the river is chemically polluted and not suitable for human consumption. The study also recommended complete overhaul of improper disposal of waste even though some points exhibited lower values than permissible levels, nevertheless, continued discharge may lead to accumulation of pollutants in the river. Similar study conducted in Blantyre found that EC, Turbidity, *Fecal Coliform* and *Fecal Streptococcus* largely influenced poor water quality as their values were above WHO and MBS permissible limits and classified its water as intermediate risk hence requiring conventional treatment before human consumption.

2.2 Water Pollution

Different scholars define water pollution as the alteration in composition of water that is directly or indirectly due to human activities rendering it unsuitable for human consumption and other related use. WHO (2022) defines water pollution as the introduction of extraneous material, which can change the natural state of water into water bodies rendering it unsuitable for human usage such as drinking, swimming and irrigation. It can also refer to changes in physical, biological and chemical attributes of water that could cause disastrous health problems to human beings but also rendering the water unsuitable for other organisms (Bonareri, 2017, p.13).

Water is also regarded as polluted when there is addition of biological or chemical materials from anthropogenic activities that could cause harm to human beings and the environment. Globally, industrial, municipal and agricultural wastes are regarded as the major contributors of water pollution (Angiro et al., 2020). For instance, agricultural wastes are known to be rich in phosphorus and nitrogen, which originate from the application of fertilizers and poultry waste, thereby increasing water pollution. On the other hand, industrial effluent that is given little to no treatment before discharge into water bodies also poses a risk of pollution.

Water pollution can be attributed to several factors ranging from fertilizers, pesticides, heavy metals, atmospheric deposition and industrial activities that end up producing wastewater and other forms of waste. Bonareri (2017) noted that water pollution could be attributed to different processes including surface run-off, which carries agrochemicals and the direct effluent discharge into water bodies enabling the categorization of water pollution into point and non-point source of pollution.

A study by Paul (2011) found that discharge of improperly treated effluent threatens quality of water in receiving water body. It also indicated that most water bodies act as recipients of untreated wastes from manufacturing industries hence leading to water pollution, which renders water unsafe for domestic use. In this regard, WHO (2022) estimates that 450,000m^3 of waste is discharged into water bodies such as lakes, rivers and other streams globally which required about 6 million m^3 of water to dilute such polluted water.

2.2.1 Point Sources

This is described as pollution that can be identified from single sources disposing off effluents through means of channels, pipes and sewers into water systems (Bonareri, 2017). Because of its nature, it is easy to isolate point pollution and put necessary strategies to minimize its environmental and health impact. In this source of pollution, effluent is channeled into a known pathway that provides the ability to be regulated and controlled.

2.2.2 Non-Point Source

In contrast to point source pollution where pollutants are from recognized points, non-point source pollution occurs from a wide source covering a large proportion of an area. Bonareri (2017) contended that non-point source pollution is major contributor of water pollution across the globe and claimed that ninety percent of water resources that do not comply with water quality standard are largely because of non-point source pollution. Runoff among many factors stand out to be major causal agent of nutrient enrichment, pathogens and deposition into water bodies rendering water unsuitable for domestic purposes. It is worth noting that non-point sources pollution is difficult to regulate and manage, however best way to deal away with this pollution is to change management practices and land use (Mwatujobe, 2020).

2.3 Industrial Effluent

Industrial effluent is generally defined as waste that is produced from activities of industrial production. These industrial activities may include heating, cooling, cleaning among others. Industrial effluent is one of most notorious industrial products that cause environmental concern especially water pollution. It must be noted that discharge of industrial effluent into water bodies has resulted in deterioration of water quality of many water bodies rendering them unsuitable for domestic and commercial use (Aniyikaiye et al., 2019; Leong et al., 2018).

The unregulated discharge of industrial effluent has potential to pose catastrophic disaster into water bodies that might include toxic pollution. Mwatujobe (2020) reports that complex composition of chemicals and metals in the industrial processes could have devastating impacts on the environment and human beings if improperly discharged into water bodies. Industrial effluent largely comprises of wastewater that contains different contaminants. The amount of water used in an industry depends on the size and type of production the industry requires, thus, the quantity of wastewater generated depends on the amount of water used in the industrial processes.

2.4 Impact of Industrial Effluent on Water Quality

The major source of point source pollution is the discharge of industrial waste into river systems. Industries not only use a large proportion of water, but they are also the major producers of wastewater that cause water pollution. The composition of these effluents is largely dependent on the process through which it was produced. Mostly industrial effluent contains synthetic elements that can change microbial and physiochemical parameters of receiving water bodies (Ipeaiyeda & Obaje, 2017). The change of the natural state of water bodies makes it not suitable for domestic and irrigation purposes. The discharge of improperly treated wastewater and/or untreated wastewater can have disastrous effects on water quality for it can contain pathogens and many undesired chemicals that could cause water pollution (Leong et al., 2018). This could also change the microbial and physiochemical properties of water thereby lowering its quality.

2.4.1 Microbes

The discharge of effluent into water bodies introduces a great number of pathogens including bacteria and this places both animals and humans at great health risk. In this context, WHO (2022) estimates that three million people die annually due to consumption of water contaminated with microbes such as bacteria and viruses, many of them being children of under five years of age. Many diseases including cholera, typhoid, eye and skin infection have been linked to consumption of water contaminated with pathogens (WHO, 2022). Bacteria is one of the major global environmental contaminants present in industrial effluent, surface water, sewage, ground and surface water and these exist in the environment with the aid of feces hence the name fecal coliform (Leong et al., 2018). A good example of fecal coliform is *E. coli* which is an indicator of water quality and its presence in wastewater is proliferated by high nutrient concentration. A study done in South Africa, found that *E. coli* was present in surface water samples which is against WHO guideline of 0 cfu/100mL in drinking water, otherwise it could pose high risk of water borne diseases to people utilizing surface water directly (Akoth, 2018). The presence of *E. coli* in surface water was attributed to poor microbial quality of effluent being discharged into the water bodies.

The presence of bacteria in water bodies poses dangerous threats to the health of people dependent on it. According to Tariq et al. (2020) fecal contamination is rampantly caused by discharge of untreated and improperly treated sewage into the water systems. Leong et al., (2018) found that there was increased bacterial counts way beyond WHO standard limits in the sampled rivers, due to the contamination of water from untreated sewage, and run-off discharges from agricultural activities. In a study done by Angiro et al. (2020); Ogidi and Oyetayo (2012) they associated the increase in *Escherichia coli* to the sweeping of fecal matter from the home into the water bodies by rains. Therefore, there is need to intensify environmental regulations to get away with the discharge of improperly treated and untreated sewage into water systems. A study by Ngwira and Lakudzala (2018) revealed that there were high levels of coliform count in the upstream and attributed such increase to poor sanitation of nearby residential area.

2.4.2 Heavy Metals

Heavy metals contamination poses a global threat due to its corrosive, eco toxic and non-biodegradable nature. A study conducted in Riyadh City-Saudi Arabia by Badr et al. (2020) found that there was increased concentration of heavy metals in the collected water samples with Zinc having highest concentration because of the increased industrial effluent discharge into water bodies. The study concluded that the higher concentration of heavy metals in the river compromised the quality of water, which rendered it unsuitable for domestic and aquatic use. Leong et al. (2018) reported that the Lead levels in the collected samples were beyond the required standards of 0.15mg/l that is hazardous to aquatic life.

Heavy metals are regarded as one of major environmental contaminants across the globe and their presence in water and soil signifies human and natural sources (Leong et al., 2018). It is naturally occurring due to chemical weathering and leaching of soils while anthropogenic sources include urban storms, industrial wastes and runoff just to mention a few. Akoth (2018) alluded that heavy metals discharged as organic compounds are regarded as highly toxic and have profound effect on water quality when it is discharged into waterbody. Anthropogenic activities and precipitation affect concentration of heavy metals in waterbodies. Akoth (2018) argues that anthropogenic activities and increased evaporation leads to high concentration of heavy metals in surface water while high precipitation rate decreases concentration of heavy metals due to dilution effect when uncontaminated runoff water mixes with metals. Industrial production, agriculture and domestic activities proliferate generation of effluent with high concentration of heavy metals which end up being discharged into water bodies.

Akoth (2018) reports that heavy metals retard growth of aquatic organisms and tend to form sulphates and carbonates which increases water pH in an event of acid rains which necessitates size and weight loss in organism such as fish leading to extinction of its species. Consumption of fish from water with toxic metals puts humans at great health risk. Tanzania, Uganda, Nigeria and Egypt are reported to harvest more fish than any other country in Africa from surface water even though industries continue to discharge partially treated or untreated effluent in it (Akoth, 2018.). It is therefore paramount to remove toxic metals from effluent before discharge, as abundance and distribution of fish is highly dependent on water quality. On the other hand, Copper, Iron and Zinc are essential elements for plant growth in right concentration even though consuming plants contaminated with toxic metals could cause biochemical disorders and fatality in humans (Leong et al., 2018).

In a study of Schutz (2013) it reported higher concentration of Chromium, Zinc and Potassium in the samples and attributed it to high usage of such elements in production. This also concurs with the study done in Likangala river in Zomba, Malawi by Ullberg (2015) which found that there were elevated levels of Lead in water samples. This endangers human health since the river was used for different domestic purposes including irrigation, bathing and laundry. The study by Ikhajiagbe et al. (2014) indicated different results as the heavy metal concentration was lower than those permitted by WHO. This means that improved treatment systems for industrial effluents could reduce the heavy metal deposits into water bodies.

2.4.2.1 Zinc

This is a transitional metal, whose concentration is rising unnaturally rendered to anthropogenic activities. Ikhajiagbe (2014) observed that Zinc concentration is amplified by different industrial activities including mining, coal and waste combustion, not forgetting the different foodstuffs that contain certain amounts of Zinc. Generally, Zinc enters water through natural and unnatural means including runoff from soils that contain Zinc. It is reported that the distribution of heavy metals is largely affected by environmental factors including mixing patterns of the aquatic systems (Badr et al., 2020). It is paramount to note that levels of pH and salinity of the water also hamper the absorption of Zinc elements.

2.4.2.2 Lead

It is largely found in natural deposits and one of the most recycled despite its decline on the global market. Lead is a highly sensitive metal and its acute effect range from hallucinations, loss of memory, and delusions to irritability. When children are exposed to Lead, it affects their developmental stages and some of it is kept in their bones which later affects their behavior and neuropathy (Ullberg, 2015). It was also argued that high levels of Lead in water is worrisome, and it could potentially affect human and aquatic organisms given its toxicity.

2.4.2.3 Cadmium

This is regarded as a non-essential element, and it is very toxic even in small concentration. Cadmium is highly soluble in water, and it generally affects metabolic progression in plants and build up in aquatic organisms thereby affecting the overall food chain (Paul, 2011). Even with low exposure to Cadmium it can have devastating effects which could result in pulmonary disease and renal tubular complications. For example, high exposure to Cadmium could lead to emphysema (Paul, 2011). Cadmium descends its toxicological chattels from its chemical resemblance with Zinc, which is an indispensable micronutrient for humans and plants. Cadmium is bio-tenacious and when it is captivated in an organism, it stays occupant for several years even though it is ultimately emitted from the host. Mwatujobe (2020) indicated that Cadmium is a toxic metal with dire consequences therefore it is the obligation of the industries to necessitate its removal before it is discharged into water systems. Coagulation, filtration and chemical precipitation are some of the methods that can be used to remove Cadmium in wastewater.

2.5 The Physical and Chemical Parameters of Industrial Wastewater

2.5.1 Industrial Wastewater

Water is an important raw material and attribute in industrial production as it is used in many processes that may include but not limited to heating, cleaning and cooling. Mwatujobe (2020) reports that 80% of total water used ends up as wastewater that is later discharged into water bodies. If not carefully treated, wastewater can be highly spreadable and toxic which can lead to heavy chemical pollution. There is a wide range of heavy metals and organic compounds, which are incorporated in industrial processes.

Industries must take the sole responsibility of ensuring that discharged effluents comply with the set standards but also covering all the costs required if the need for cleanup arises. Angiro et al. (2020) argued that the most cost-effective methods in dealing with effluent is to minimize their entrance into water bodies by introducing the closed water use system. However, if effluents enter water bodies, they are very toxic to aquatic organisms and threaten human health. A study by Belay (2010) observed that toxicity of industrial effluent depends on the industrial process that produced it and ranked tannery effluent as the highest polluting industrial waste.

2.5.2 Physical Properties

2.5.2.1 Temperature

Temperature is one of the important parameters that define water quality status. This determines how water counters the presence of inorganic material and contaminants. Water temperature is affected by different factors including atmospheric conditions, presence or absence of shades, anthropogenic activities and increased soil erosion. Surface water temperature is also affected by season of the year, altitude and flow of the water (WHO, 2022). Temperature has a stronger influence on the concentration of other physical, biological and chemical water parameters. The increase in water temperature influences an increase in chemical reaction of water.

The increase in water chemical reaction reduces solubility of different gases such as oxygen. Solubility of oxygen is largely affected by the increase in temperature. The decrease in oxygen level entails low dissolved oxygen and increased plant growth in water which affect the color, odor, and taste because not only does the oxygen consumption increases but also increasing the disintegration of organic matter (Bonareri, 2017). The World Health Organization does not provide the guidelines for water temperature; however, it is argued that a wide range of bacteria can proliferate at temperature greater than 25^{o}C and the water becomes less palatable (WHO, 2022).

2.5.2.2 pH

pH of water influences most of the activities including growth of organisms and it is one of the paramount parameters that determines water quality. According to Angiro et al. (2020) beverage industrial effluents normally result in lowering pH and this is attributed to the use of items including yeasts and enzymes causing bitterness of water. This agrees with the findings of Ikhajiagbe et al. (2014) conducted in Benin City, Nigeria where it was indicated that there was low pH at contact point of brewery effluent with river water due to increased concentration of effluent from brewery processes. These results are in contrast with other researchers that found that the sample collected were more alkaline that could pose health problems including acidosis (Badr et al., 2020). For instance, the study conducted by Leong et al. (2018) in the northwest coast of Borneo, recorded an increase in water pH and attributed it to biodegradation of organic particles during the dry season. This implies that pH is highly affected by the concentration of effluent from the industrial processes, and it is dependent on the types of materials used to produce such effluent.

2.5.2.3 Electrical Conductivity

Electrical Conductivity (EC) is defined as the sum of cations or anions in the water. Angiro et al. (2020) argued that high mineral ions in beverage effluent increases EC and this is generally attributed to the excess of dissolved solids and decaying of organic materials that organize conducting ions in the effluent. However, Ikhajiagbe et al. (2014) argued that there was no significant difference between the EC of brewery effluent in Benin City and that of World Health Organization standards. It is also indicated that elevated EC of the water bodies might be because of products that became washed away in rainy season from agricultural activities taking place near the rivers (Angiro et al., 2020). The proportion of dissolved solid in the industrial effluent is inversely related to Electrical Conductivity, thus, the higher the concentration of solutes available in the wastewater the lower the ability of electric current to pass through it (Aniyikaiye et al., 2019).

2.5.2.4 Turbidity

Turbidity is the cloudiness of the water, and it is generally affected by the insoluble particles including clay, silt and chemical precipitates present in the water (Bonareri, 2017). These insoluble particles hinder light from passing through the water. In higher turbidity waters, the light is scattered and absorbed making it impossible to be transmitted. If the water has greater turbidity than the recommendation of World Health Organization of 5 NTU then the water is regarded to have high bacterial count and pathogens that could cause diseases (Ullberg, 2015).

There is an increase in the incidence of diseases associated with high turbidity. However, it is worth noting that the correlation between high turbidity and increase in cases of diseases is not clear. For instance, Ewere et al. (2014) found that the water samples that had high turbidity registered a high number of *E. coli* compared to those with moderate turbidity. The study also indicated that the samples that were collected near industries registered high turbidity and alluded to the increase in turbidity to decomposition of organic matter in the effluent. This implies that treatment of industrial effluent before discharge into water bodies is paramount to reduce the profound effect of high turbidity in the receiving waters. Reducing the turbidity of water is one of the tools to make water safe for drinking

2.5.2.5 Total Dissolved Solid

Total Dissolved Solids measure the total amount of organic and inorganic substances confined in a liquefied molecular structure, deferred form. The main components of TDS are sodium and chloride which at concentration greater than 200-300mg/l of the respective ions can contribute to salty taste of water which can be unsafe to humans (Bonareri, 2017). Dissolved solids in water range from nitrates, sodium, chloride, phosphate and sulfate anions but also calcium, aluminum, Potassium, and magnesium cations. According to Bonareri, (2017), water with high TDS likely leaves taints and scales on cooking utensils and boilers which tend to cause gastrointestinal corrosion capable of resulting into irritations and a state of catastrophe to human beings. World Health Organization (WHO) guidelines articulate that water is palatable with TDS less than 600mg/l and becomes hazards when at a level of 1000mg/l (WHO, 2022).

2.5.2.6 Total Suspended Solids

This is defined as the total number of solids retained in a fiber filtering glass with 0.45µm pore size. This is normally attained by finding the difference between the total solids and TDS. It generally affects the turbidity of the water, which not only poses an aesthetic distress to consumers but also presents adsorption spots for chemical and biological agents. Both Bonareri (2017) and Mwatujobe (2020) established that high levels of TSS pose difficulties in wastewater treatment. Runoff, soil erosion and wastewater have proved to be the major contributors to the increased levels of total suspended solids in water bodies. WHO in their guidelines prescribe 500ml/l as the ceiling value for total dissolved solids (WHO, 2022).

2.5.3 Chemical Parameters

2.5.3.1 Biological Oxygen Demand

Biological Oxygen Demand (BOD) is generally defined as the amount of oxygen required by the organism in the water to decompose organic matter aerobically. BOD is tested to determine the magnitude of pollution in the water (Bonareri, 2017). Biological Oxygen Demand measurement can also be utilized to determine the efficiency of effluent treatment plants. The level of DO in the water body depends on the amount of BOD, thus, more oxygen is depleted when there is high BOD in water (Leong et al., 2018). The deterioration of oxygen in water leads to the depletion of aquatic organisms. Aniyikaiye et al., (2019); Heinonen-Tanski and Matikka (2017) as well as Tariq et al. (2020) found high BOD levels in sampled industrial effluent. The increase was directly linked to presence of organic matter in the discharged effluent. However, the increase in microbial activities in the water bodies could also lead to depletion of dissolved oxygen that can be disastrous to aquatic life. This resulting effect of increased BOD is just similar to low dissolved oxygen. As such, treatment of industrial effluent could drastically reduce the Biological Oxygen Demand to a greater extent and in return have high Dissolved Oxygen for aquatic life to utilize and ensure its survival.

2.5.3.2 Chemical Oxygen Demand (COD)

This implies the amount of oxygen that equates to the amount of organic matter in a sample that can be oxidized through a chemical reaction. The measure of chemical oxygen demand indicates the number of organic particles present in the effluent and this is well determined by using spectrophotometric methods. Chemical oxygen demand is generally expressed in terms of mass of oxygen expended over volume of solution i.e., milligram/liter as standard unit.

2.5.3.3 Alkalinity

The ability of water to neutralize an acid in the presence of carbonate and hydroxyl ions is referred to as alkalinity. The determination of alkalinity is done by titration method using sulphuric acid of known concentration. In their study, Varale and Varale (2013), found that the increase in alkalinity of water was due to the presence of limestone. Thus, water that encounters limestone has high alkalinity due to the presence of carbonate ions thereby increasing the hardness of water. This correlates with the study by Leong et al. (2018) whereby samples that were collected near a sugar factory had high alkalinity probably due to high use of limestone in the production of sugar. A study by Angiro et al. (2020) found that in dry season the alkalinity was high and attributed this increase to decreased levels of Dissolved Oxygen (DO) after the effluent mixes with river water. Contrary, in rainy season it was reduced, and this was attributed to low levels of people utilizing the rivers for bathing and washing due to increased turbidity resulting from runoff.

2.6 Water Quality Index

It was argued that water is an essential resource for both economic and domestic use; however, its quality was largely affected by increased urbanization and industrialization (Leong et al., 2018). Water quality is mostly assessed by utilizing the physical, chemical and microbial parameters. However, it is argued that the convenient method of expressing the class and status of water is by using Water Quality Index (WQI). As indicated by Shweta et al (2013) Water Quality Index has the ability to present huge data set into a single value in a logical form while showing the variation of water quality at lower concentration. The water status that is above 71 WQI value indicates that the water has met the expectation, it is of little concern and classified as clean. In contrast, when it is below 50 WQI value, it is classified as polluted having not met the requirements hence a concern (Mădălina & Breabăn, 2014).

2.7 Policies and Institutional Set Up for Industrial Effluent Management in Malawi

The commitment of Malawian political environment in managing industrial effluent is envisaged in enacting of different existing policies and legal framework. Environmental Management Act (EMA, 2017), Water Resources Act (WRA, 2014) and Public Health Act (PHA, 2014) and other regulatory tools are utilized as the means to lessen the burden from the public. Water and sanitation authorities are responsible for collection, conveyance and treatment of industrial effluent. Malawi Environmental Protection Authority provides the standard of discharge of any effluent into water bodies and stipulates measures of pretreatment of effluent before it is discharged into sewage system (EMA, 2017). Public Health Act (2014) also provides the prerogative to line minister, in consultation with relevant stakeholder to propose standards of quality of effluent to be discharged into any water body. Section 88 of the Water Resources Act prohibits directly or indirectly discharge of effluent into water bodies. It provides that a person who desires to discharge effluent shall apply for a permit for the same to the National Water Resources Authority (NWRA). In section 101 of the Water Resources Act, NWRA has the prerogative to cancel permits to discharge effluent if the permit holder does not comply with the act. Any person who does not comply with the standards and guidelines on collection, conveyance and disposal of effluent provided in the act, if found guilty is liable to a fine of MWK10,000,000 and to ten years imprisonment (Water Resources Act, 2014.)

Environmental Management Act (2017) provides that every person has the right to a safe, clean and healthy environment and it is the responsibility of everyone to safeguard the environment. Section 72 of EMA stipulates that the perpetrator may be liable to pay compensation to victims whose land is distorted by their action and cover all the cost related to loss of its beneficial uses because of the activity that has caused degradation (EMA, 2017.). The Environmental Management Act also articulates that MEPA in consultation with lead agencies shall provide guidelines and measures to ensure rivers are conserved and well managed. Government of Malawi (2013) prescribed that buffer zone for a river is 20-30 meters, but it is rarely observ Pried, therefore the need to enforce the recommended buffer zone to stem encroachment cannot be overemphasized. On the other hand, the National Water Polity ensures that standards and guidelines on management, utilization of water resources and disposal of wastewater are adhered to by everyone. Chipofya et al. (2010) observed that in some cases industrial wastewater contains toxic substances and biological process inhibitors, which could potentially affect water quality if discharged without thorough treatment.

The Water Resources Board (WRB) is mandated to monitor adherence of set water regulations and ensure that all water users comply with the Water Resources Act. Ngwira & Lakudzala, (2018) alluded that city by-laws entails that effluent should be discharged in the city sewer system where the city assembly collect and treat them before discharging the same into the water bodies. However, city laboratories are not well equipped and only WRB conducts monitoring through Central Water Laboratories. Monitoring activities must be continuous and conducted monthly but due to inadequate resources this is only done on a needless basis. It is important to note that failure to enforce regulations on effluent disposal has a profound effect on the water quality that could lead to health repercussions to people utilizing the water downstream (Ngwira & Lakudzala, 2018).

2.8 Conceptual Framework

The independent variable of the study is the industrial effluent while the dependent variable is water quality (Rahmanian et al., 2015). This means that the quality of water depends on the availability or absence of industries. As such the availability of these industries triggers the discharge of untreated wastes into water bodies which result in changes in not only the composition but also the quality of water (Angiro et al., 2020). However, the absence of industrial effluents does not provide the assurance of safe and quality water, as there may be other underlying factors such as agricultural activities that could compromise water quality. It is also evident that changes in physicochemical quality could also affect the biological properties of water in the river. Ogidi and Oyetayo, (2012) argued that high concentration of microorganisms in close contact with industrial effluent in water bodies is because of high availability and composition of organic particles that require a considerable number of microbes to degrade it. It is also worth noting that discharge of untreated effluent into the river increases water temperature that causes depletion of dissolved oxygen thereby affecting water quality and rendering aquatic life impossible. This agrees with Badr et al. (2020) who found that there was increased microbial activity on the effluent due to its high content of organic matter and the increased temperatures.

Additionally, Mwatujobe (2020) argues that improper planning and designing of wastewater treatment plants can affect wastewater management. It is alluded that inadequate infrastructure and sewage treatment systems and absence of means to minimize effluent are some of factors that affect management of effluents. It was also found that poor environmental policy and inadequate enforcement of such policies largely affects the compliance of wastewater standards that can be discharged into water body. Therefore, the presence of industries in Lilongwe definitely affects Nankhaka River water quality through discharge of untreated or improperly treated effluent into the river. The figure below summaries the operationalized conceptual framework of the research study which adapted some variables from the study of Mwatujobe, (2020). The adapted variables include physicochemical quality, poor industrial wastewater management which have greater influence on water quality.

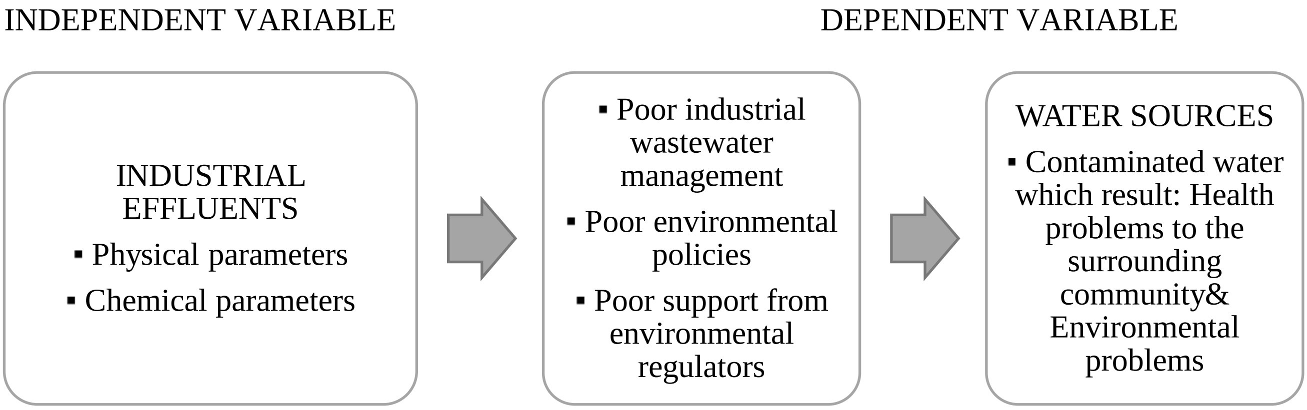

Fig.2.1: Adapted Conceptual Framework (Mwatujobe (2020).

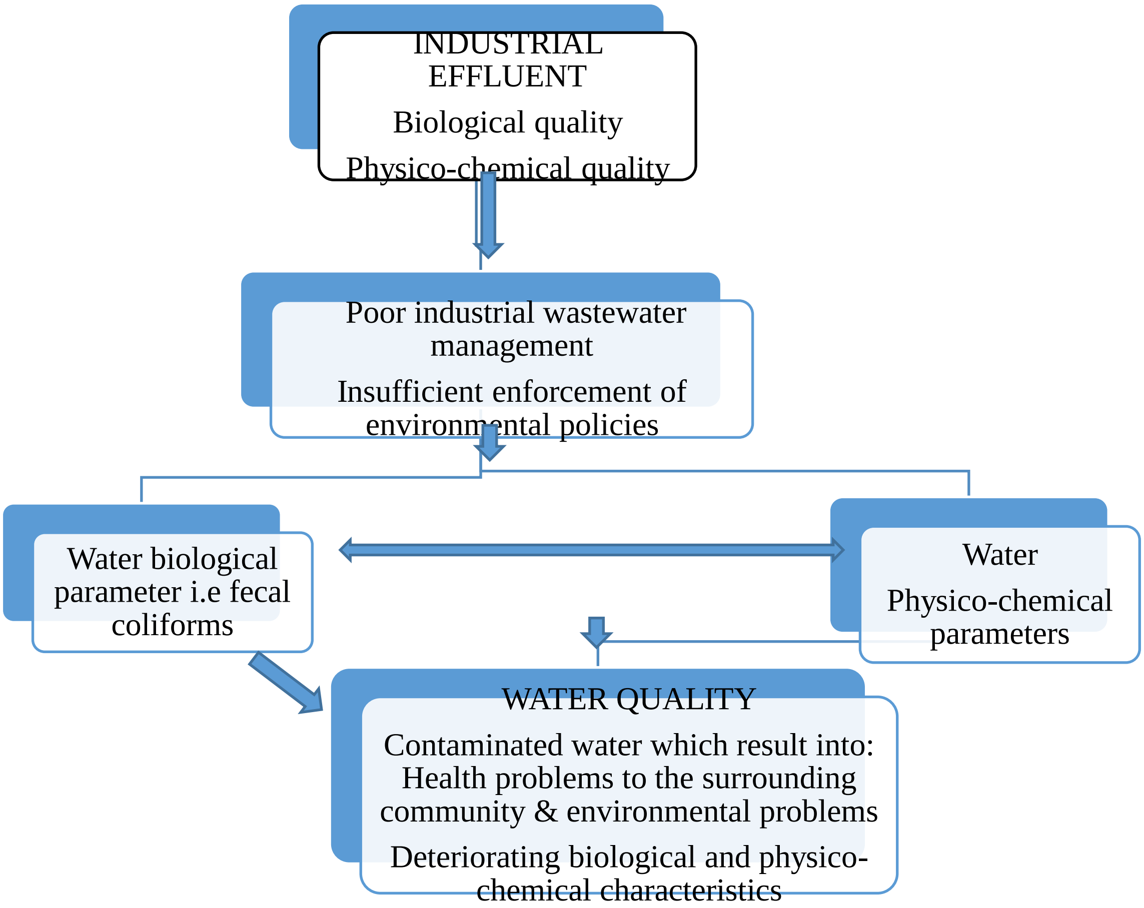

Figure 2.2: Operationalized Conceptual Framework Elaborating the Association between Industrial Effluent and Water Quality.

2.9 Research Gap

A study conducted by Ngwira and Lakudzala (2018) indicated that samples were only collected in dry season, results could have been comprehensive if samples were collected in both dry and rain to ascertain seasonal variation of physicochemical properties of industrial effluent. Similarly, a study by Leong et al. (2018) alluded that heavy metals were not analyzed owing to limited number of resources, the study would have been exhaustive and more appealing if heavy metals were incorporated in the study to understand implications of consuming water contaminated with toxic heavy metals.

2.10 Summary of the Chapter

This chapter reviewed relevant literature by researchers, which found that discharge of improperly treated effluent threatens the quality of the receiving water body. It is argued that most water bodies act as the recipient of most untreated wastes from different industries which results in chemical pollution rendering the water unsuitable for domestic and industrial use. The subsequent chapter provides the analytical procedures and techniques utilized in this study to attain the main objective.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter provides an overview of the materials and methods utilized in this study. This includes study area, sampling design, analytical procedures, data collection, analysis, and ethical consideration.

3.2 Description of Study Area

Malawi is among the least developed countries located in Sub-Saharan Africa with an estimated population of 18,563,749 (NSO, 2018). The country has three regions that is North, Central and South. The capital city, Lilongwe, is in the central region at a latitude of 13°58'0.9" S and a longitude of 33°47.235' E with an elevation of 1050 above sea level. According to the Malawi Housing and Population Census (2018) the city has a population 989,318 with an area of 393 square kilometers (NSO, 2018). It is the biggest city in Malawi and was declared a capital city in 1975 after repositioning from Zomba (UN-HABITAT, 2011). The city has a warm wet season from November to April before a cool and dry season from May to August, which is then proceeded by hot dry season for two months (September to October). Tobacco processing is the major industry in the city; however, the number of industries has increased from the time it was established as a capital and administrative city.

UN-Habitat (2011) indicates that the city is divided into Kanengo, Capitol Hill, Old Town, and Lumbadzi with Kanengo as a designated industrial area split into area 28 and area 29 which are locations for light and heavy industries respectively. This study was conducted in Area 29, where Nankhaka River passes surrounded by many industries including Castel Malawi. Activities that could compromise water quality and quantity in the river were visible. The most visible practice was the drain that carried effluent direct to the river. Washing, swimming and grazing are some of the activities that were also taking place in the study area. Agriculture is the major livelihood economic activity, taking place in the area. Favorable soil and climate enable growth of crops including sugarcane, cabbages, tomatoes, Irish potatoes, bean and maize. Cattle and goats were also grazing near the river. Figure 2.1 is a map of the study area indicating sampling sites in Nankhaka River.

There has been increased cases of waterborne diseases reported within the study area especially Mgona squatter where it has been the hotspot for cholera outbreak which is acute enteric infection proliferated by consumption of contaminated food or water and it is highly attributed to lack of access to safe drinking water (Phiri et al., 2005). Area 28 and 29 are specially designated as industrial areas for light and heavy industries respectively where food, beverages, paint and soap processing take place. These industries discharge their effluent through storm channels that are found near their premises. Ngwira and Lakudzala, (2018) alluded that industries in these areas discharge effluent that contains some heavy metals including cadmium, lead and zinc into Nankhaka river which pose danger to the environment and human beings that utilize the water for domestic purposes.

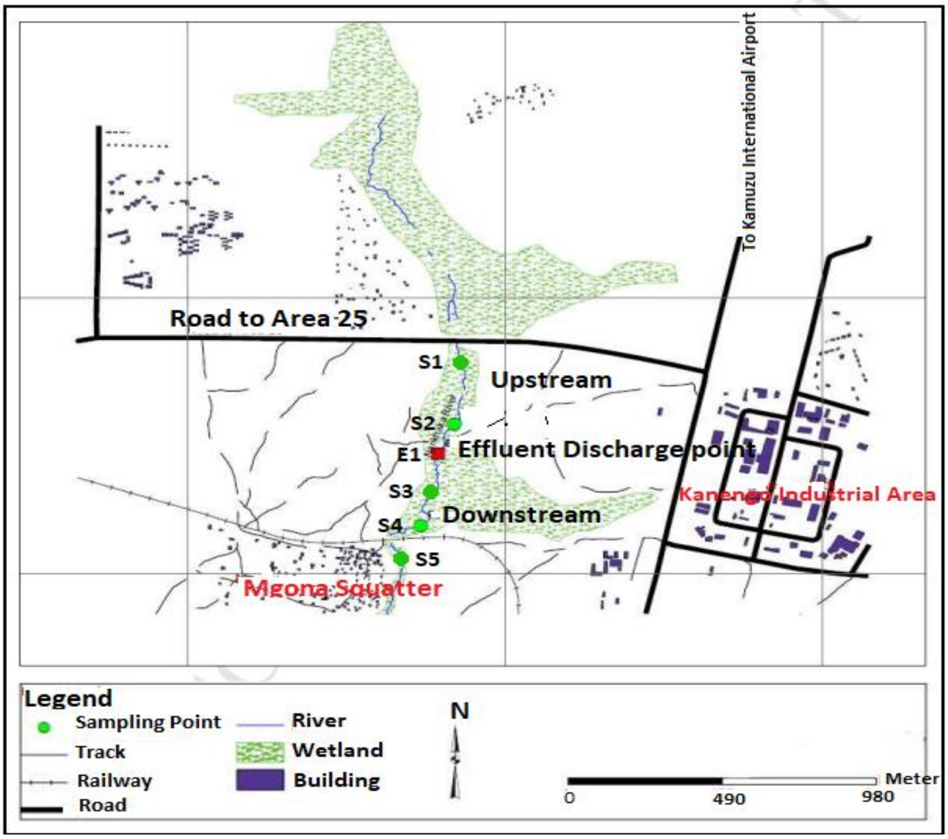

Figure 3.1: Study Area Showing Sampling Points

3.3 Sampling Design

Grab samples were collected at six strategic places i.e., in the effluent channel and in the river where most of the industries discharge their effluent. The samples were collected at point E1 (Effluent release point), and in the receiving river at S1, S2, S3, S4, and S5, this was done in the morning from 9:30am to 12:00 noon once a week for three weeks in both rainy and dry season. Seventy-two water and effluent samples were collected. The points and samples were thoroughly distributed across the river to ascertain whether the impacts were localized or distributed across the river. In addition to that downstream had more sampling points than upstream for a similar reason. All samples were collected in duplicate for reliability of data (Phiri et al., 2005; Leong et al., 2018). The samples were kept in thoroughly clean glass bottles that were tightly closed. The bottle was rinsed three times with the sample before the final sample was collected. The bottles were labelled with appropriate codes and kept in a cooler box for laboratory analysis. The figure below outlines the summary of sampling points. As alluded herein, the samples were collected from both the upstream and downstream. This was ideal to help quantify if the effects of industrial activities are localized or distributed across the river.

Figure. 3.2: Sampling Point

Table 3.1: GPS Coordinates of Sampling Point

No.	Sampling Point	River	Coordinates
1	S1	Nankhaka	-13.864318, 33.7749922
2	S2	Nankhaka	-13.8942888, 33.7855171
3	E1	Nankhaka	-13.9054133, 33.7799933
4	S3	Nankhaka	-13.9139033, 33.77645
5	S4	Nankhaka	-13.9300884 33.7716822
6	S5	Nankhaka	-13.9324774, 33.7703655

Note: S; site and E; Effluent release point

3.4 Data Collection and Analysis

3.4.1 Procedure

Laboratory and on-site data collection procedures followed the standard methods of analysis. Water quality parameters that were analyzed on site included temperature, pH, Turbidity, Total Dissolved Solids and Electrical Conductivity while the rest of the parameters were measured at the laboratory which followed standard procedures as outlined by (APHA, 2012).

3.5 Analytical Procedures

3.5.1 Physico-chemical Analysis

Ten physico-chemical parameters were analyzed according to the set procedures as described in American Public Health Association, APHA, (1999) and these parameters include Turbidity, pH, Alkalinity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Temperature (T) and Electrical Conductivity (EC).

3.5.1.1 Temperature

Temperature of the water was determined on-site by the calibrated pH meter HANNA: H1 99121, having a probe of H1 1292. The probe was immersed in the water sample and the reading was recorded after a few seconds. Every time before and after measuring the temperature, the probe was cleaned with distilled water to avoid cross contamination.

3.5.1.2 Determination of pH

pH was determined on-site by the calibrated pH meter HANNA: H1 99121; having a probe of H1 1292 and temperature compensation of 25^{o}C. The probe was dipped in the water sample and pH reading was recorded after a few seconds.

3.5.1.3 Total Dissolved Solids

Total Dissolved Solids were determined by the TDS meter HANNA; H1 99300 having a probe of H1 76306. The probe was immersed in the water sample. The probe was cleaned with distilled water before and after immersing into the water sample.

3.5.1.4 Total Suspended Solids

Total Suspended Solids was determined by computing the difference of Total Solids (TS) and Total Dissolved Solids (TDS) as follows;

$$TSS\ (mg/l) = TS\ (mg/l) - TDS\ (mg/l)$$

TS was determined by pipetting 100ml of the water sample into a pre-weighed dish. The sample was then dried in an oven for 1 hour at 104^{o}C, left to cool, and weighed. Total Solids is calculated as follows;

$$TS\ (mg/l) = \frac{A - B}{Sample\ volume} * 1000$$

Where, A represents weight of dish and dried sample in (g), B is weight of empty dish in (g) (APHA, 1999).

While TDS of the water sample was determined by gravimetric method, where 100ml of filtered water sample was evaporated to dry in a pre-weighed dish. The weight of the dish was recorded before the procedure. The TDS was calculated as follows;

$$TDS\ (mg/l) = \frac{A - B}{Sample\ volume} * 1000$$

A represents weight of dish and dried filtrate in (g), B is weight of empty dish in (g) (APHA, 1999).

3.5.1.5 Electrical Conductivity

The conductivity of the water was determined by using TDS probe meter HANNA; H1 99300 having probe of H1 76306. Before and after the probe was dipped in the water sample, it was rinsed with distilled water. The reading was recorded after the water sample stabilized from the stirring.

3.5.1.6 Turbidity

Turbidity quantifies the opacity of any fluid largely attributed to the presence of solid elements that are suspended in the liquid medium whereby this somewhat hinders the diffusion of light through the liquid. Turbidity of water samples was quantified using a Turbidity meter HANNA: H1 98703.

3.5.1.6.1 Procedure

Turbidity meter determines turbidity by utilizing the source light beam that is normally placed at a right degree angle to the direction of source light beam. Turbidity is determined in accordance with the intensity of light that was dispersed by the sample in the cuvettes. The meter is first calibrated by using known concentration standard suspensions then the turbidity of the sample is thus measured by comparing with the standard suspension.

3.5.1.7 Alkalinity

Alkalinity is defined as the ability of water to counteract strong acid. The presence of hydroxyl ions, carbonate and bicarbonate in water is attributed to its ability to neutralize strong base (Sahoo, 2017). The primary source of carbonate ions is calcium carbonate or limestone in natural water systems. Therefore, the water that is encountering limestone is highly expected to have higher concentrations of carbonate ions thereby increasing the hardness and likely elevate alkalinity levels (Sahoo, 2017).

3.5.1.7.1 Procedure

The alkalinity of water is calculated by titration of water against sulphuric acid of known pH, strength and volume. In this procedure, the OH- ions are detached from H_2O molecules and this is achieved based on the chemical attribute of the water sample. To neutralize the OH- ions 50ml of water sample was titrated with sulphuric acid. The volume of sulphuric acid used in the titration process was noted and used in the alkalinity calculation. Phenolphthalein indicator was added to the sample before titration, this changes the water sample into pink color. The end point of titration is noted when the pink color has disappeared, and this indicates that all the OH- ions are consumed.

3.5.1.8 Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) largely refers to the quantity of oxygen that is prerequisite for the biological disintegration of organic matter liquefied in it, in standard investigational environment at a perpetual temperature for a fixed time (Sahoo, 2017).

3.5.1.8.1 Procedure

To determine the Biological Oxygen Demand, the initial Dissolved Oxygen is measured then the sample is prepared and put in airtight glass bottle and then placed at 20°C for 5 days inside Biological Oxygen Demand incubator at a specific temperature for 5 days. After the incubation of sample at about 5 days, the final Dissolved Oxygen is determined. The Biological Oxygen Demand is then obtained by the difference between the initial and the final Dissolved Oxygen. DO Meter HANNA: H1 9146 was used in the procedure.

3.5.1.9 Chemical Oxygen Demand

This implies the amount of oxidant that potentially reacts with the sample in a controlled environment. The utilization of strong oxidants is employed in the measurement of chemical oxygen demand. This is generally performed in the presence of acid solution and heat to oxidize the organic to carbon dioxide and water (APHA, 1999). The amount of oxidant expended is regarded as the oxygen correspondence.

3.5.1.9.1 Principle

The sample of 2ml was placed in a COD reactor while raising temperature to about 150^o and allowing oxygen to get into the prepared sample and left to react for about two hours. After the reaction was done, the COD reactor was left to cool and then the oxygen concentration in the sample is measured. The final COD is calculated by comparing the prior oxygen concentration in the sample and the final oxygen concentration when the reaction has been completed.

3.5.1.10 Bacteriological Analysis

The bacteriological analysis involves the use of media to allow the bacteria to grow. The presence of fecal coliform, the *Escherichia coli,* was determined in all the water samples. Steps adapted from Mainardi and Bidoia (2019) were followed to prepare and dilute the water samples at an appropriate dilution of 10^{-6} for the bacteria. Each water sample was added to the petri dish with prepared Levine Blue Agar, and this was incubated at 35^0 degrees for 24hrs (Mainardi & Bidoia, 2019). The sterile petri dish that was saturated with an appropriate medium enables growth of the desired organisms, which eventually made colonies. Each cell developed into a separate colony, which was then counted directly.

3.5.1.11 Heavy Metal Determination

Heavy metals including Lead, Cadmium, Iron, Copper, and Zinc were determined in both water samples and riverbank soils. The identified heavy metals in water samples were analyzed at Central Water Laboratory in Lilongwe while soil samples were analyzed at Agriculture Research Trust (ARET) Soil Laboratory. Samples were digested by nitric acid and the digest was then analyzed using Atomic Absorption Spectrophotometry, (Varian AA20). Calibration curves were plotted for each of the metals separately, by running various concentrations of standard solutions at specified wavelengths. A reagent blank sample was also analyzed. The concentration of the metal was obtained from the difference between the readings of the samples and that of the blank.

3.5.1.12 Water Quality Index

Water Quality Modelling involves the classification of water that utilises the mathematical simulation and prediction of the quality of water (Bowie et al., 1985). The models generally contain mathematical formulae that indicates the process of quantifying the position and level of effluent in water system. These models are also of paramount importance in describing some hydrogeological systems such as surface runoff and seepage. Water Quality Index is widely used to show the overall water quality using mathematical models and this considers most water quality parameters. Bowie et al. (1985) indicates that the main aim of using WQI is to convert multifaceted water quality data set into simple understandable narratives that can be used by public health practitioners in decision making and producing data that can be easily understood by the public.

Water quality modelling can be useful when monitoring is not upheld. Different modelling techniques especially the water quality index and regression analysis are widely used in place of monitoring which associates the quantity of contaminants in the water bodies with elements such as runoff. Water quality modelling is paramount in forecasting quality of water given different environments created through different water quality management strategies.

3.5.1.12.1 Weighted Arithmetic Water Quality Index

This technique classifies water depending on the level of its clarity. The most frequently analysed water quality parameters that are used to compute water quality index include turbidity, pH, total dissolved solids, total suspended solids, biological oxygen demand, dissolved oxygen, chemical oxygen demand and electric conductivity. The expression below by Brown, (1972) was used to calculate the Weighted Arithmetic Water Quality Index (WA WQI).

$$WQI = \Sigma QiWi/Wi$$

Where WQI represents Water Quality Indicator

Qi represents quantity rating scale and can be computed by;

$$Qi = 100\ x \left\lfloor \frac{Vi - Vo}{So - Vo} \right\rfloor$$

where;

Vi is the determined concentration of *i*th parameter in the analysed water

V0 is the ideal value of ith parameter and

$$\text{Vo} = \begin{cases} 7 & for\ pH \\ 14.6 & for\ DO \\ 0 & for\ all\ other\ parameter \end{cases}$$

So represents standard permissible value of *i*th parameter

Wi represents the weightage for *i*th parameter which is computed by;

$$Wi = \left(\frac{K}{Si}\right)$$

where;

K represent proportional constant and computed by;

$$Wi = \left(\frac{1}{\sum 1/Si}\right)$$

3.5.1.13 Risk Assessment

To attain objective four of the study which was to assess health risk associated with water in Nankhaka river, risk assessment was conducted by utilizing Risk Quotient (RQ) which is defined as rate of exposure and effect (Akoth, 2018.). It is paramount to determine whether contaminants concentration exceeds the recommended standards to ascertain health risks to human beings. To characterize and assess the risk associated with Nankhaka water a tier 1 approach was utilized. Potential health risk associated with usage of Nankhaka river water for domestic purposes were determined using risk quotient for all pollutants that were analyzed. The equation below was utilized;

$$Risk\ quotient\ = \frac{concetrantion\ of\ pollutants}{regulatory\ limit\ of\ pollutants}$$

A risk quotient less than 1 means that risks are acceptable, or none is available while a risk quotient equal or greater than 1 means potential health risks exists and means to minimise exposure are paramount.

3.5.2 Statistical Data Analysis

After data collection, the generated data was entered in excel spreadsheet. Errors were checked and amended before committing the data to any analysis. The IBM SPSS Statistics version 20 was used in the statistical data analysis at 95% confidence interval. A paired sample t-test was used to compare the means in terms of spatial and seasonal variation of effluent and water quality of Nankhaka River with 95% confidence interval. The results of the study were also subjected to the comparison with the Malawi Bureau of Standards and World Health Organization guidelines.

3.6 Ethical Consideration

The National Health Sciences Research Committee granted the researcher permission (Approval Number of 3174) to collect data from the selected river. The data collected remains confidential and was used for academic purposes only.

3.7 Summary of the chapter

This chapter gives details of the methodologies employed to achieve the study objectives. The investigation involved the real-time assessment of certain parameters, including temperature, electrical conductivity (EC), dissolved oxygen (DO), pH, and turbidity. Simultaneously, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), *Escherichia coli (E. coli),* and all heavy metals were analyzed in the laboratory. The section further details the procedures employed for quantifying the concentration of each parameter. Subsequently, these concentrations were utilized to categorize the water quality in Nankhaka River through the application of the Weight Arithmetic Water Quality Index.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter presents results of a study aimed at assessing the impact of industrial effluents on Nankhaka river in Lilongwe City. The presentation of results is structured in alignment with the specific objectives outlined in Chapter 1, offering a detailed exploration of the impact of industrial activities on the water quality and ecological health of this vital river system. The parameters of interest included pH, Turbidity, Electrical conductivity C, Alkalinity, Temperature, TDS, TSS, DO, BOD, COD, *E. coli* and heavy metals - Lead, Cadmium, Iron, Copper, and Zinc. These parameters were analysed in both water and soil samples obtained from the riverbanks on both sides, contributing to a holistic understanding of the environmental impact.

4.2 Physico-chemical Parameters in Water Samples

The mean values for all the water quality parameters that were analysed are presented in tables 4.1 and summarized in figures 4.1 to 4.11. Table 4.1 indicates the mean and standard error (SE) values of all the physico-chemical and bacteriological parameters for all the sampling sites in both dry and rainy. All the mean values for heavy metals in dry and rainy season for water samples for all the sampling sites is presented in table 4.3 whilst, heavy metals in soil samples have been presented in table 4.4.

Table 4.2 represents the seasonal variation of all physico-chemical parameters and coliform count following paired sample t-test to check for concentration significant differences in dry and rainy season. Table 4.5 and 4.6 represent the paired sample t-test results for difference in mean concentration of heavy metals for both seasons, in water and soil samples, respectively.

Table 4.1: The Mean and SE Values of Physico-chemical and Faecal Coliform for all Sampling Sites in Dry and Rainy Season for all Sampling Sites

					Rainy Season					
Site	pH	Turbidity (NTU)	EC (µscm$^{-1)}$	Alkalinity (mg/l)	Temp (^{o}C)	TSS (mg/l)	DO	BOD (mg/l)	COD (mg/l)	*E. coli*
WHO G	6.5-8.5	5	400	100-200	NS	500	5	5	NS	0
p- value	0.034	0.365	0.002	0.001	0.021	< 0.001	0.003	< 0.001	< 0.001	< 0.001
S1	7.3 ± 0.1	34.0 ± 9.9	576 ± 33	183 ± 15	23.1 ± 0.7	5 ± 1.5	4.4 ± 0.4	9.70 ± 0.9	242 ± 6.2	46 ± 9.3
S2	7.2 ± 0.2	44.4 ± 9.9	565 ± 34	181 ± 8.8	23.5 ± 0.2	13 ± 2.0	2.3 ± 0.08	5.30 ± 1.3	179 ± 4.5	69 ± 12
E1	7.6 ± 0.0	77.0 ± 5.8	812 ± 31	231 ± 17	24.5 ± 0.4	11 ± 4.0	3.3 ± 0.3	14.7 ± 0.9	163 ± 5.3	727 ± 90
S3	7.4 ± 0.0	23.2 ± 6.7	679 ± 37	199 ± 5.6	24.8 ± 0.0	39 ± 5.9	7.2 ± 0.5	2.70 ± 0.7	214 ± 2.9	56 ± 25
S4	7.4 ± 0.0	75.2 ± 7.8	694 ± 32	242 ± 1.2	24.5 ± 0.2	110 ± 5.8	5.2 ± 0.1	2.70 ± 0.7	146 ± 4.6	68 ± 15
S5	7.4 ± 0.0	79.5 ± 5.6	708 ± 37	248 ± 1.4	24.6 ± 0.2	124 ± 7.6	5.0 ± 0.1	3.30 ± 0.9	144 ± 3.6	86 ± 19
					Dry Season					
p- value	< 0.001	0.001	< 0.001	0.009	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001
S1	7.2 ± 0.0	23.7 ± 6.1	669 ± 4.6	214 ± 3.5	22.3 ± 0.3	2 ± 0.3	3.1 ± 0.4	0.28 ± 0.1	37 ± 3.6	221 ± 14
S2	7.2 ± 0.0	58.8 ± 5.1	670 ± 4.7	175 ± 25	22.4 ± 0.2	15 ± 0.3	4.3 ± 0.2	6.62 ± 0.4	123 ± 8.9	209 ± 7.0
E1	6.3 ± 0.0	63.5 ± 47	833 ± 14	159 ± 19	19.0 ± 0.2	46 ± 2.5	3.3 ± 0.1	35.3 ± 2.2	1261± 0.7	480 ± 56
S3	7.5 ± 0.0	85.5 ± 7.3	872 ± 14	231 ± 20	18.4 ± 0.2	2 ± 0.0	4.3 ± 0.3	16.8 ± 0.8	38 ± 2.1	214 ± 48
S4	7.6 ± 0.1	32.3± 18	885 ± 19	252 ± 15	21.4 ± 0.4	7 ± 0.3	4.2 ± 0.1	21.1 ± 0.8	26 ± 4.6	280 ± 19
S5	7.9 ± 0.2	46.1 ± 3.2	909 ± 17	260 ± 17	22.4 ± 0.5	60 ± 1.2	4.1 ± 0.1	21.2 ± 2.8	22 ± 1.8	294 ± 20

Table 4.2: Paired Sample t-test for Difference in Concentration between Dry and Wet Season of Physico-chemical Parameters and *E. Col*i Counts

Parameter	Pair	Mean ± SE	t -value	Remarks
Ph	Wet Season	7.4 ± 0.04	2.31	NS
	Dry Season	7.3 ± 0.13		
Turbidity (NTU)	Wet Season	97.5 ± 46.0	2.31	NS
	Dry Season	55.5 ± 6.09		
EC (µscm-1)	Wet Season	672 ± 23.5	2.31	S
	Dry Season	806 ±24.6		
Alkalinity (mg/l)	Wet Season	214 ± 7.46	2.31	NS
	Dry Season	215 ± 11.0		
Temp (^{o}C)	Wet Season	24.2 ± 0.20	2.31	S
	Dry Season	21.0 ± 0.42		
TDS (mg/l)	Wet Season	404 ± 14.1	2.31	S
	Dry Season	484 ± 14.8		
TSS (mg/l)	Wet Season	50 ± 11.9	2.31	S
	Dry Season	22 ± 5.55		
DO	Wet Season	3.88 ± 0.14	2.31	NS
	Dry Season	4.57 ± 0.38		
BOD (mg/l)	Wet Season	6.39 ± 1.12	2.31	S
	Dry Season	16.9 ± 2.77		
COD (mg/l)	Wet Season	182 ± 8.88	2.31	NS
	Dry Season	265 ± 116		
E. coli	Wet Season	175 ± 61.4	2.31	S
	Dry Season	283 ± 25.4		

NS= Not Significant; S= Significant

Table 4.3: Comparison of Physico-chemical Parameters and E. Coli Count between Upstream and Downstream using Paired Sample t-test.

Parameter	Pair	Mean ± SE	p-value	Remarks
Ph	Upstream	7.24 ± 0.04	.023	S
	Downstream	7.67 ± 0.15		
Turbidity (NTU)	Upstream	28.83 ± 5.68	.332	NS
	Downstream	62.79 ± 7.99		
EC (µscm-1)	Upstream	622 ± 25.7	.000	S
	Downstream	808 ± 48.5		
Alkalinity (mg/l)	Upstream	199 ± 9.77	.000	S
	Downstream	254 ± 8.26		
Temp (^{o}C)	Upstream	22.7 ± 0.38	.631	NS
	Downstream	23.5 ± 0.56		
TDS (mg/l)	Upstream	373 ± 15.6	.000	S
	Downstream	486 ± 29.3		
TSS (mg/l)	Upstream	3.66 ± 0.91	.000	S
	Downstream	91.8 ± 14.6		
DO	Upstream	3.74 ± 0.34	.001	S
	Downstream	4.57 ± 0.20		
BOD (mg/l)	Upstream	4.97 ± 2.14	.005	S
	Downstream	12.3 ± 4.20		
COD (mg/l)	Upstream	139 ± 45.9	.002	S
	Downstream	95.6 ± 66.4		
Cadmium	Upstream	0.24 ± 0.01	1.000	NS
	Downstream	0.25 ± 0.11		
Iron	Upstream	0.21 ± 0. 08	.000	S
	Downstream	0.55 ± 0. 23		
Copper	Upstream	0.01 ± 0.001	.240	NS
	Downstream	0.03 ± 0.01		
E. coli	Upstream	134 ± 39.7	.000	S
	Downstream	190 ± 48.2		

Table 4.4: The Impact of Industrial Effluent on Water Quality

Parameter	Dn	Up	Change (Dn –Up)	**% increase**
pH	7.53	7.23	0.30	4.13
Turbidity (NTU)	56.95	40.21	16.74	41.63
EC (µscm-1)	791.19	619.79	171.40	27.65
Alkalinity (mg/l)	238.42	188.23	50.19	26.67
Temp (^{o}C)	22.64	22.82	-0.18	-0.81
TDS (mg/l)	474.97	371.99	102.98	27.68
TSS (mg/l)	56.78	8.75	48.03	548.90
DO	5.01	3.515	1.49	42.48
BOD (mg/l)	11.28	5.56	5.72	102.94
COD (mg/l)	98.28	145	-47.01	-32.36
Cadmium	0.25	0.235	0.01	5.94
Iron	0.53	0.238	0.29	122.76
Copper	0.02	0.006	0.02	297.22
E. coli	166	136	30	22.8

The study revealed that introduction of effluent at E1 (Effluent discharge point) impacted on all physio-chemical parameters and *E. coli* count with exception of Temperature and COD which registered higher mean value upstream than downstream. For instance, the introduction of effluent influenced an increase of *E. coli* mean value by +30 representing 22.8% increase downstream reaching mean value of 166 compared to 136 upstream (Table 4.4). This could pose significant health risk to water users downstream evidenced by increase in mean values of most of the parameters beyond WHO and MBS guidelines.

4.2.1 pH

The figure below indicates that all the mean pH values for both rainy and dry season are within the standard limits of 6.5 to 8.5 as prescribed by WHO, (2022). It can be observed that the lowest pH value of dry season was 6.3 ± 0.05 at E1 (Effluent release point) with highest mean pH of the same season of 7.92 at S5 downstream. The trend was different in the rainy season where the pH was almost the same across all sampling points with minimum of 7.20 ± 0.15 at S2 upstream and maximum of 7.6 ± 0.03 at E1 (Effluent release point). A study by Mkwate et al. (2017) conducted in Balaka, Malawi, found that pH ranged from 7.10 to 7.6 which were within MBS and WHO GV limit.

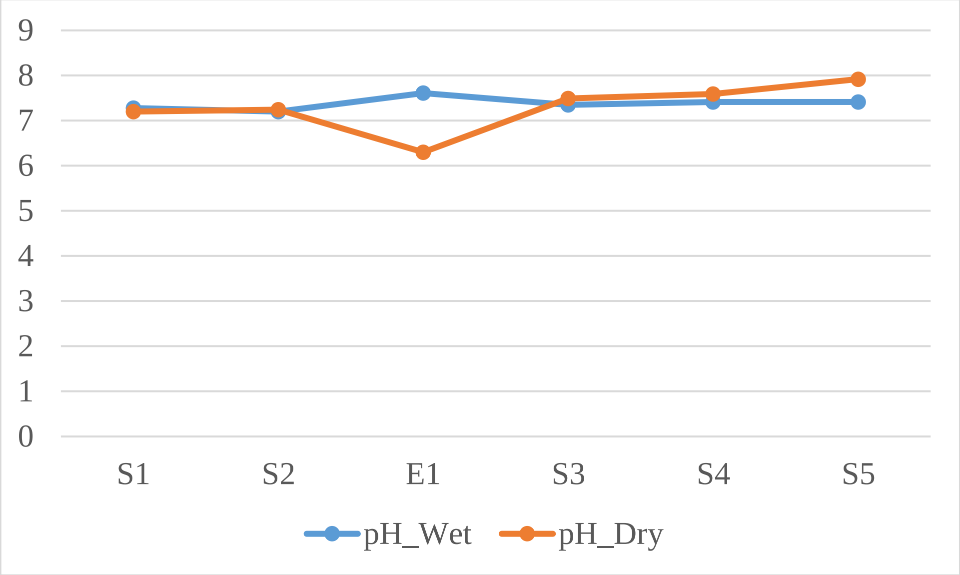

Figure 4.1: Mean pH Value for Rainy and Dry Season

4.2.2 Temperature

The mean temperature values of the study at all the sites indicates that they were less than 25°C which when exceeded makes the water to become less palatable. In rainy season, the temperature ranged from 21.7°C to 24.9°C at S3 with the lowest mean temperature of 23.1°C at S1 and highest mean temperature of 24.8°C at S3. In dry season, the temperatures were a bit lower with minimum of 18.1°C and maximum of 23.3^{0}C. The lowest mean temperature was recorded at S3 downstream with 18.4°C whilst the highest mean temperature of 22.4 °C was recorded at S2 upstream and S5 downstream. The figure below summarises the mean temperature per sampling site.

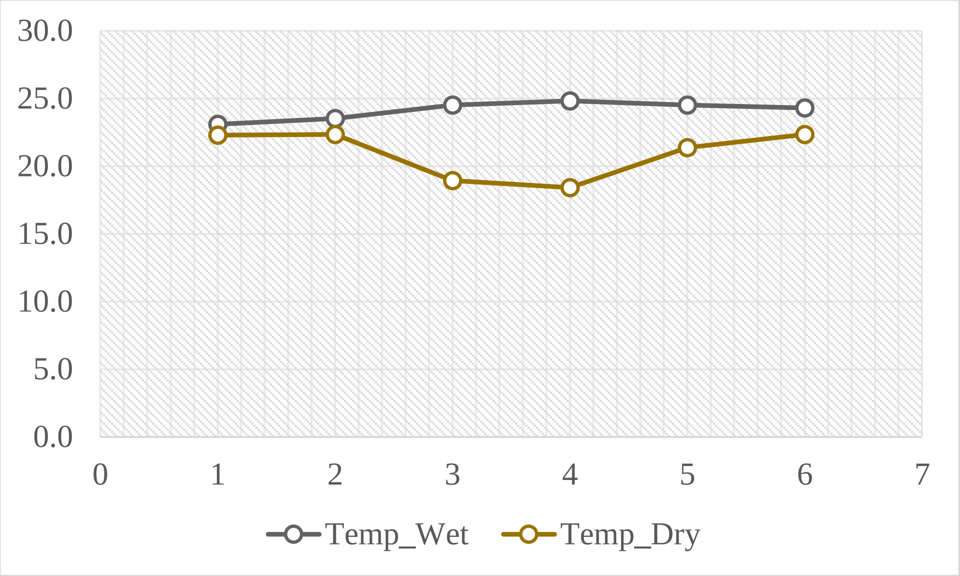

Figure 4.2: Mean Temperature Variation for Wet and Dry Season

4.2.3 Turbidity

It can be observed from the fig. 4.2 that in most sampling points the mean turbidity values were high in rainy season than dry season except for S2 upstream and S3 downstream. However, the highest mean turbidity was recorded in dry season at S3 with the mean of 85.7 ± 7.26 NTU. It is also worth noting that the values for all the sampling points were beyond the WHO recommended value of 5NTU (WHO, 2022).

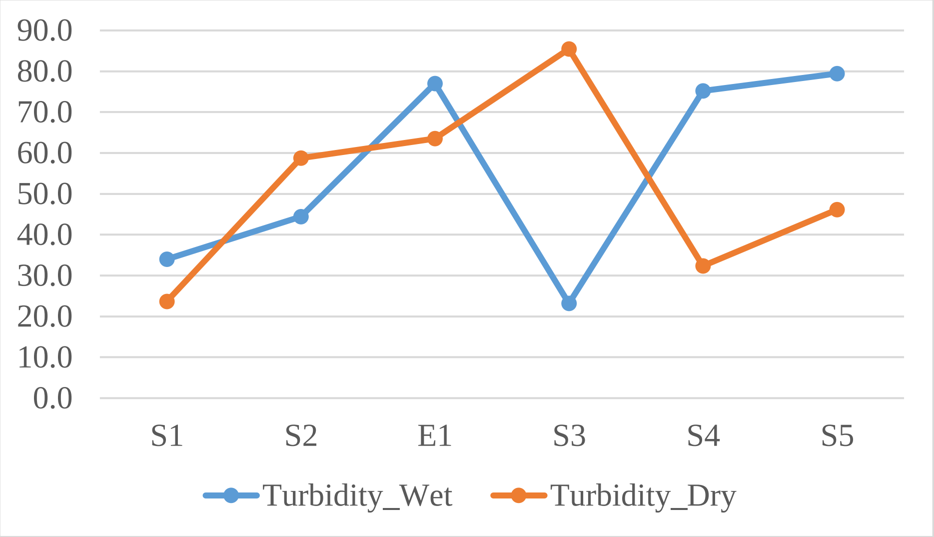

Figure 4.3: Mean Turbidity Variation for Rainy and Dry Season

4.2.4 The Electrical Conductivity

The electrical conductivity recorded showed a unique trend in dry season where it was increasing from the upstream to downstream. The mean electrical conductivity value in dry season ranged from 669 – 909 µscm^{-1} with the lowest EC observed at S1 upstream with mean value of 669 ± 4.62 and the highest EC of 909 ± 17.03 was recorded at S5 downstream. A study by Phiri et al., (2005) conducted in Lilongwe Malawi found the same results where EC values were higher and significant ($p < 0.05$) in dry season than rainy season. The higher values in the rainy season were directly associated with ground and surface water runoff from agricultural activities that swept with its ions including chlorides, nitrates and phosphate from fertilizer.

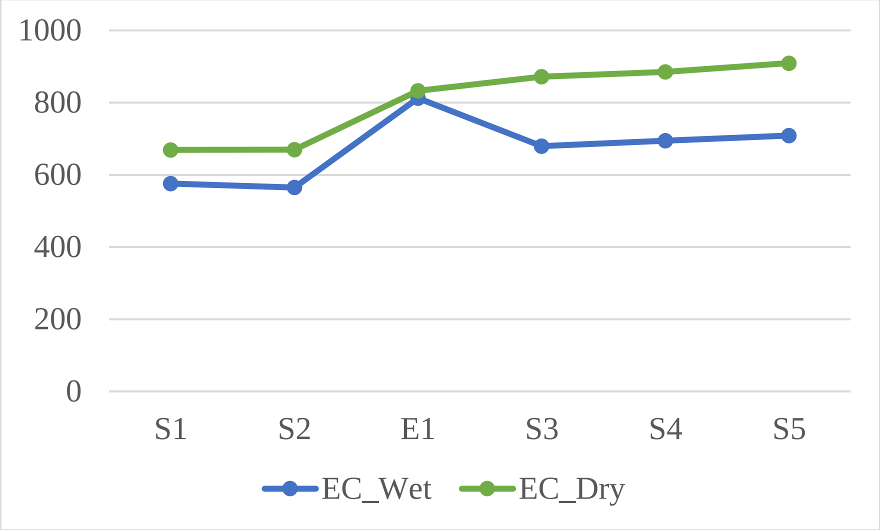

Figure 4.4: Mean Electrical Conductivity Value for Rainy and Dry Season

4.2.5 Total Dissolved Solids

The results of total dissolved solids indicate that all sampling points in both rainy and dry season are below WHO permissible limit of 600 – 1000mg/l (WHO, 2022). The lowest TDS in rainy season was recorded at S2 upstream with mean TDS of 339mg/l and the highest mean TDS of 488 mg/l at E1 (Effluent release point). In dry season, the TDS increased from upstream to downstream with lowest mean recorded at S1 upstream and highest mean TDS at S5 downstream. The mean TDS ranged from 402mg/l to 547mg/l.

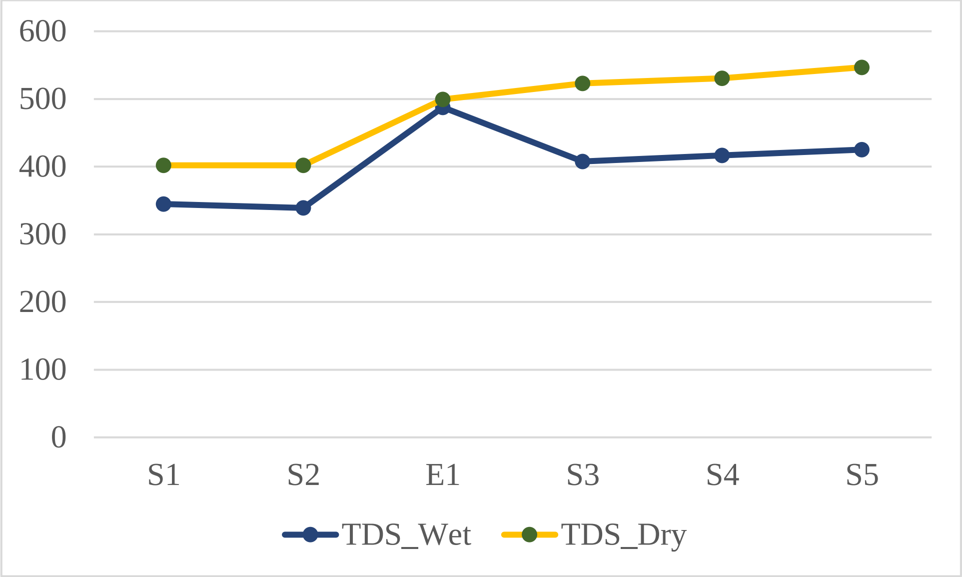

Figure 4.5: Mean TDS Variation for Rainy and Dry Season

4.2.6 Total Suspended Solids

The mean TSS was higher in rainy season with maximum value of 120mg/l recorded at S5 downstream while in dry season the mean TSS was lower compared to rainy season with maximum mean TSS of 60mg/l determined at S5 downstream as well. The mean TSS in rainy season started increasing from S3 to S5 downstream. The lowest value of 13mg/l in rainy season was recorded at S1 while in dry season the lowest mean value of 2mg/l was recorded at S1 upstream and S3 downstream.

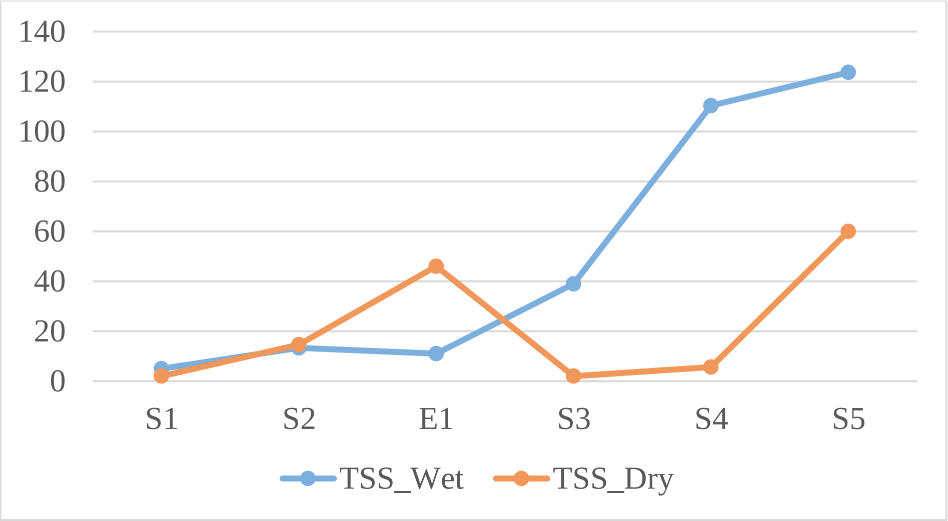

Figure 4.6: Mean TSS Variation for Rainy and Dry Season

4.2.7 Alkalinity

The results show that mean alkalinity was higher in dry season than rainy season at S1, S3, S4 and S5 with mean values of 214 ± 3.48, 231 ± 19.9, 252 ± 14.8 and 260 ± 17.3 respectively. In rainy season, E1 (Effluent release point) registered higher mean value of 231 ± 17.0 than in dry season while the lowest value in rainy season was observed at S1 upstream with mean value of 181.3 ± 8.82 and the highest mean value of 247.67 ± 1.45 was recorded at S5 downstream.

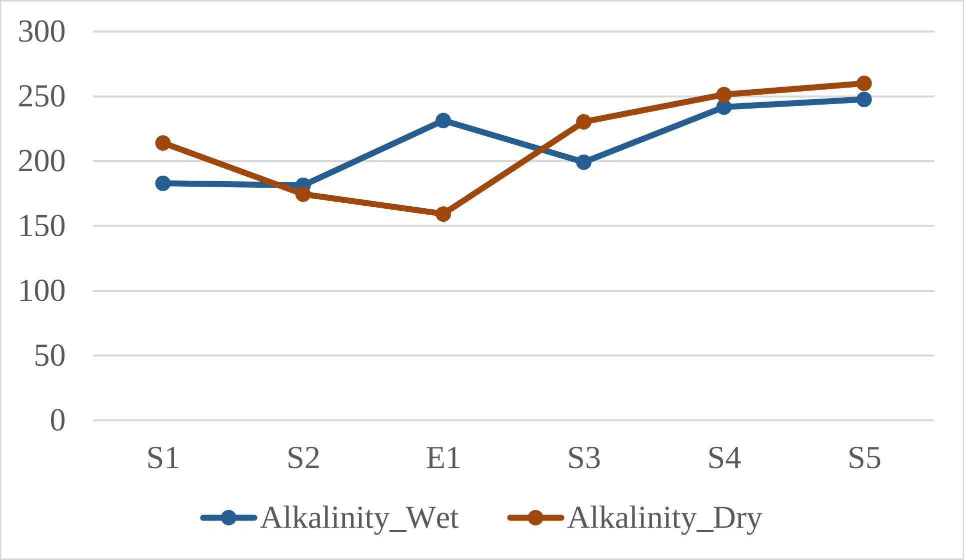

Figure 4.7: Mean Alkalinity Variation for Rainy and Dry Season

4.2.8 Dissolved Oxygen

In rainy season the lowest mean DO of 2.27 ± 0.08 was recorded at S2 upstream while S3 with the mean value of 7.19 ± 0.49 was the highest value registered. In the dry season, the highest mean value of DO was recorded at S2 upstream with the value of 4.31 ± 0.16. However, the results showed that there is no significant difference between the mean values of rainy and dry season. However, Dissolved Oxygen mean values of rainy season were higher compared to dry season with exception of S2 upstream and E1 (Effluent release point).

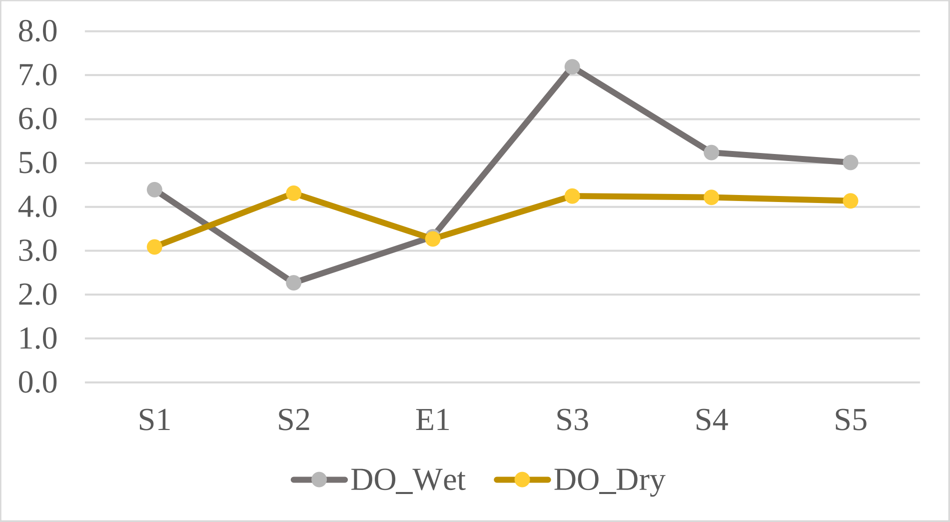

Figure 4.8: Mean DO Variation for Rainy and Dry Season

4.2.9 Biological Oxygen Demand

In dry season lowest mean BOD of 0.28 ± 0.07 was recorded at S1 upstream while highest mean BOD of 35.3 ± 2.23 was recorded at E1 (Effluent release point). In the rainy season, the highest mean value of BOD was also recorded at E1 (Effluent release point) with the value of 14.7 ± 0.88. However, the results showed that there was significant difference between the BOD mean values of rainy and dry season. However, all the mean value for BOD for dry season were a bit higher compared to rainy season except sampling point S1 upstream. A study by Ngwira & Lakudzala (2018) conducted in Lilongwe Malawi found that mean BOD of effluent was 186 mg/l which is much higher than the value recorded in this study even though they are both above the MBS and WHO water quality specifications.

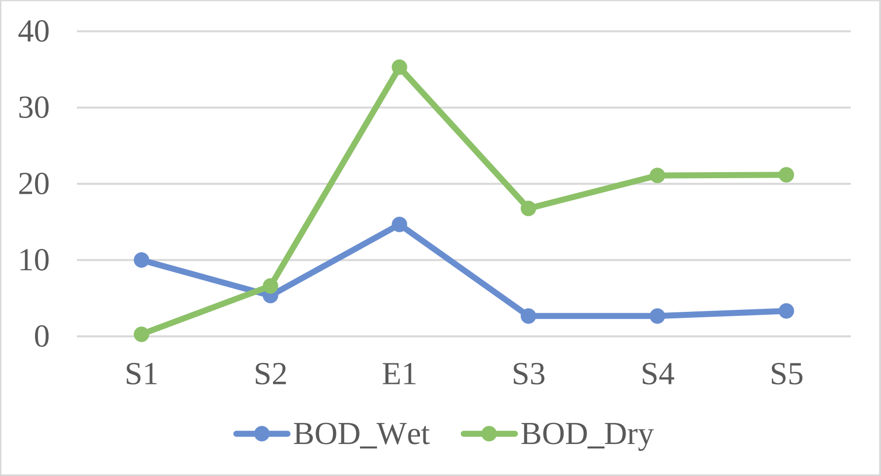

Figure 4.9: Mean BOD Variation for Rainy and Dry Season

4.2.10 Chemical Oxygen Demand

In figure 4.10 it can be observed that the highest mean COD was recorded in dry season at E1 (Effluent release point) with mean value of 1261 ± 0.67. The lowest value of 22 ± 1.76 in dry season was recorded at S5 downstream. In rainy season, the mean values of COD ranged from 144ml/l to 242mg/l with S1 upstream registering the highest mean value. The results of variation between sites indicates that there is significant difference ($p < 0.05$). However, the t-test results for seasonal variation for COD indicate that there is no significant different in its mean concentration between rainy and dry season ($p > 0.05$).

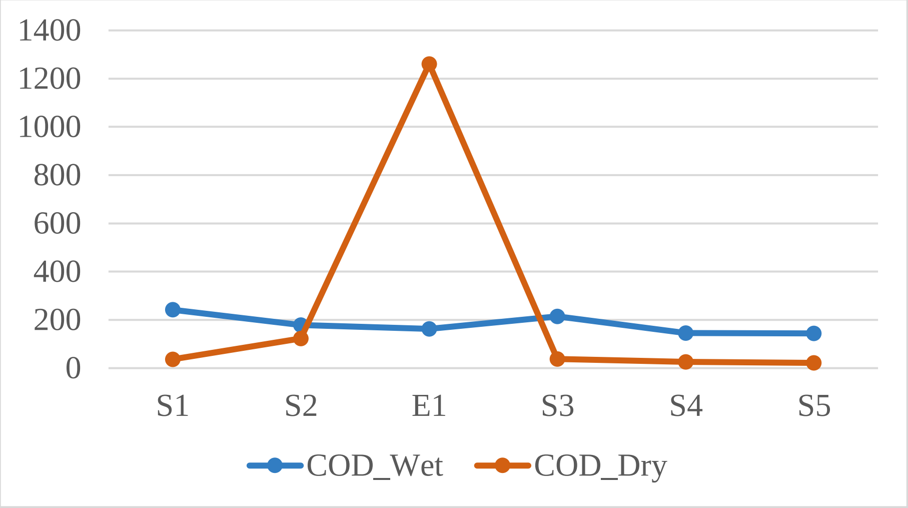

Figure 4.10: Mean COD Variation for Rainy and Dry Season

4.3 Faecal Coliform

Figure 4.11 above indicates that all mean values for both rainy and dry season are higher than the permissible value of zero count of *E. coli* for drinking water as prescribed in WHO (2022) guidelines. Higher value of *E. coli* in rainy season was attributed to easy transportation of wastes especially domestic and human fecal matter which was rampant along the river as evidenced during data collection. It was observed that the lowest mean value of *E. coli* count in dry season was 46 ± 9.26 at S1 upstream. The highest mean value of *E. coli* was at E1 (Effluent release point) in both rainy and dry season with mean value of 727 ± 89.8 and 480 ± 55.6, respectively. Paired t-test indicate that there is significant difference in mean values between the sampling sites for the entire study period with $p < 0.001$. The results for seasonal variation also indicated that there is a significant difference in mean concentration between rainy and dry season with $p = 0.021$, lower in wet season than dry season except for E1 (Effluent release point). According to Pritchard et al. (2007) study conducted in Blantyre, Mulanje and

Chiradzulu Malawi, fecal coliform is generally higher in rainy season than dry season and noticed an increase in fecal coliform in wet season in comparison to dry season owing to easy transportation of contaminants to water points by rainfall.

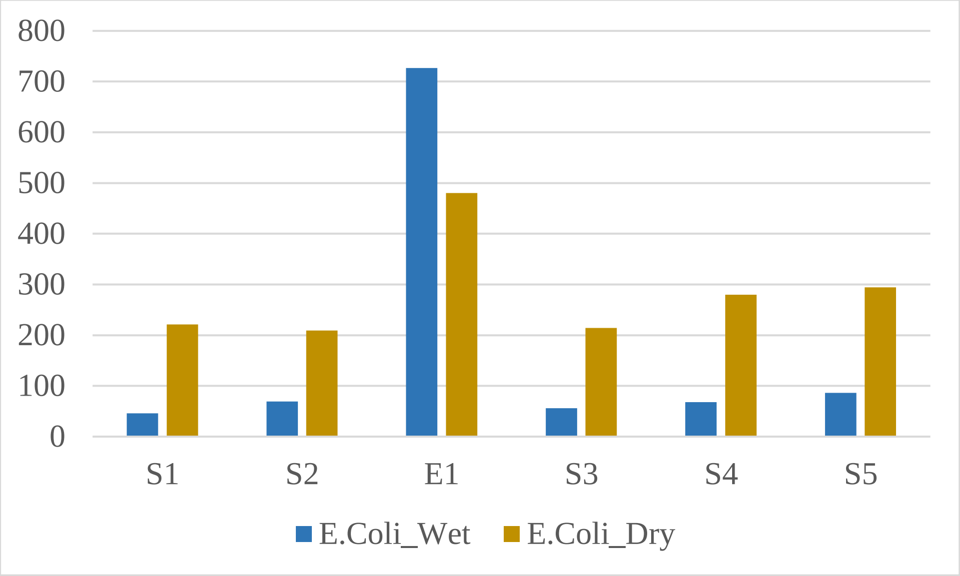

Figure 4.11: Mean *E. coli* Variation for Rainy and Dry Season

4.4 Heavy Metals in Water and Soil Samples

The mean values for all heavy metals in both water and riverbank soils have been analysed and presented in tables 4.3 to 4.6. All the mean values for heavy metals in both rainy and dry seasons for water samples from all the sampling sites have been presented in tables 4.3 whilst heavy metals in riverbank soil samples have been presented in table 4.4. The data was analyzed with a 95% confidence interval. Table 4.7 and 4.8 represents the paired sample t-test results for difference in mean concentration of heavy metals for both seasons, in water and soil samples, respectively.

Table 4.5: Comparison of Mean and SE Values of Heavy Metals in Water Samples for Upstream and Downstream in Rainy and Dry Seasons.

	Rainy Season				
Site	Lead (mg/l)	Cadmium (mg/l)	Iron (mg/l)	Copper (mg/l)	Zinc (mg/l)
S1	ND	0.466 ± 0.01	0.386 ± 0.027	0.008 ± 0.001	ND
S2	ND	0.462 ± 0.01	0.446 ± 0.068	0.008 ± 0.000	ND
E1	ND	0.475 ± 0.00	1.28 ± 0.158	0.043 ± 0.006	0.061 ± 0.00
S3	ND	0.484 ± 0.01	0.944 ± 0.035	0.037 ± 0.013	ND
S4	ND	0.492 ± 0.00	1.06 ± 0.032	0.047 ± 0.004	ND
S5	ND	0.492 ± 0.00	1.06 ± 0.035	0.047 ± 0.004	ND
	Dry Season				
S1	ND	0.011 ± 0.01	0.042 ± 0.003	ND	ND
S2	ND	0.002 ± 0.00	0.078 ± 0.001	ND	ND
E1	ND	0.003 ± 0.00	7.90 ± 0.024	ND	0.028 ± 0.00
S3	ND	0.022 ± 0.01	0.040 ± 0.000	ND	ND
S4	ND	0.003 ± 0.01	0.004 ± 0.000	ND	ND
S5	ND	0.003 ± 0.001	0.039 ± 0.001	ND	ND

Table 4.6: Variation of Mean and SE Values of Heavy Metals in Soil Samples for All Sampling Sites

Site	Lead (ppm)	Cadmium (ppm)	Iron (ppm)	Copper (ppm)	Zinc (ppm)
S1	ND	0.280 ± 0.010	346 ± 37.6	2.23 ± 0.090	5.30 ± 0.170
S2	ND	0.380 ± 0020	65.7 ± 1.40	2.96 ± 0.150	0.420 ± 0.150
E1	ND	0.470 ± 0.032	317 ± 4.09	5.90 ± 0.200	24.6 ± 1.21
S3	ND	0.140 ± 0.002	154 ± 3.21	1.42 ± 0.210	3.79 ± 0.090
S4	ND	0.230 ± 0.018	288 ± 1.78	2.31 ± 0.100	10.5 ± 0.810
S5	ND	0.380 ± 0.023	250 ± 4.21	2.69 ± 0.110	5.36 ± 0.230

ND = Not Detected

Table 4.7: Paired Sample t-test for difference in Concentration between Wet and Dry Season of Heavy Metals in Water and Soil Samples

Parameter	Pair	Mean ± SE	t-value	Remarks
		Water Samples		
Lead (mg/l)	Wet Season	-	-	-
	Dry Season	-	-	
Cadmium (mg/l)	Wet Season	0.479 ± 0.004	-5.32	S
	Dry Season	0.007 ± 0.002		
Iron (mg/l)	Wet Season	0.862 ± 0.084	2.23	NS
	Dry Season	1.36 ± 0.709		
Copper (mg/l)	Wet Season	0.032 ± 0.005	-	-
	Dry Season	-	-	-
Zinc (mg/l)	Wet Season	-	-	-
	Dry Season	-	-	-
		Soil Samples		
Lead (mg/l)	Wet Season	-	-	-
	Dry Season	-	-	-
Cadmium (mg/l)	Wet Season	0.313 ± 0.049	-4.13	S
	Dry Season	0.348 ± 0.057		
Iron (mg/l)	Wet Season	229 ± 41.0	-1.50	NS
	Dry Season	246 ± 47.2		
Copper (mg/l)	Wet Season	2.81 ± 0.625	-2.24	NS
	Dry Season	3.02 ± 0.643		
Zinc (mg/l)	Wet Season	7.88 ± 3.34	-2.30	NS
	Dry Season	8.76 ± 3.69		

NS = Not Significant; S = Significant

Table 4.8: Paired Sample t-test for difference in Concentration between Upstream and Downstream of Heavy Metals in Water Samples

Parameter	Pair	Mean ± SE	t-value	Remarks
Lead (mg/l)	Upstream	-	-	-
	Downstream	-	-	
Cadmium	Upstream	0.24 ± 0.01	1.000	NS
	Downstream	0.25 ± 0.11		
Iron	Upstream	0.21 ± 0. 08	.000	S
	Downstream	0.55 ± 0. 23		
Copper	Upstream	0.01 ± 0.001	.240	NS
	Downstream	0.03 ± 0.01		
Zinc (mg/l)	Upstream	-	-	-
	Downstream	-	-	-

Table 4.9: Comparison of Levels of Physicochemical Parameters of Effluent with MBS and WHO GV.

Parameter	Rainy Season	Dry Season	MBS Standard	WHO GV
Ph	7.6	6.3	6.5-9.0	6.5-8.5
Turbidity (NTU)	77.0	63.5	10	5
EC (µscm-1)	812	833	N	400
Alkalinity (mg/l)	231	159	N	100-200
Temp (^{o}C)	24.5	19.0	N	N
TDS (mg/l)	488	500	500	600-1000
TSS (mg/l)	11	46	N	500
DO	3.27	3.27	N	5
BOD (mg/l)	14.7	35.3	20	20
COD (mg/l)	163	1261	60	N
E. coli	727	480	N	N

Comparing concentration of effluent with Malawi Standard (MS 539) as shown in the table above, indicates that quality of effluent does not comply with the standard, as most of parameters are way beyond the prescribed limit. Therefore, it is important to treat these effluents before being discharged into the river. The study conducted in the same area by Ngwira and Lakudzala (2018) found similar results however, the mean concentration values of effluent were much higher than the findings of this study. It was indicated in the study that increased concentration of effluent could alter the physico-chemical and bacteriological quality of water thereby rendering it unusable for domestic purposes. The findings of the study also concur with Msilimba and Wanda (2013) conducted in Malawi, which revealed higher levels above recommended standard of physico-chemical and bacteriological parameter in effluent from three treatment works at Kauma treatment plant in Lilongwe and Blantyre city. The major challenge is that water users may not be aware of the risks that they are subjected to when using it. Other studies also noted that surface water is sometimes used by local people for bathing, washing and irrigating crops which are at times eaten raw and other resident use the water for drinking purpose (Chipofya et al., 2010; Ngwira & Lakudzala, 2018; Phiri et al., 2005).

4.5 Water Quality Index for Nankhaka River

Water Quality index is widely used to describe the state at which the water is and help in the valuation of its status at a particular site. WQI is also paramount in guiding the public and the legislative body make not only informed decisions and put strategies in place to conserve the water quality. WA WQI was employed in this study, which defines the quality of water based on its clarity by utilising different water quality parameters. The following water quality parameters were used to determine water quality index, these are pH, Turbidity, EC, Alkalinity, Temperature, TDS, TSS, DO, BOD, COD and *E. coli*. The status and class of water quality is presented using the Water Quality Index as outlined by Leong et al (2018) in their study. The water quality index rating computed is presented in Table 5.2.

Table 4.10: Weighted Arithmetic Water Quality Index Grading

WA WQI Value	Status	Class
0-25	Excellent water quality	A
25 - 50	Good water quality	B
50 - 75	Poor water quality	C
75 - 100	Very Poor Water Quality	D
>100	Unsuitable for drinking purpose	E

Adapted from Sahoo, (2017).

Table 4.11: WA WQI of all Sampling Sites of Nankhaka River

Sampling Site	WA WQI	Remarks
S1	49	Good water quality
S2	50	Good water quality
E1	94	Very poor water quality
S3	76	Very poor water quality
S4	76	Very poor water quality
S5	67	Very poor water quality

Table 4.12: Computed WAWQI and class of water of Nankhaka River

Sampling site	S1	S2	E1	S3	S4	S5
WQI	49	50	94	76	76	67
Class	B	B	D	D	D	C

4.6 Risk Assessment

Assessment of risks of different pollutants was done based on Risk Quotient equation in subsection 3.5.1.13 above. MBS and WHO standards were utilized to determine the risk quotient of each parameter as presented in table 4.8 and 4.9. However, some parameters were not computed because there are no set guideline values for either MBS and/or WHO.

Table 4.13: Risk Quotient of Different Parameter in Nankhaka River during Rainy and Dry Season

Parameter	Mean Concentration		MBS Standard	WHO GV	MRQ		WRQ	
	Rainy	Dry			Rainy	Dry	Rainy	Dry
Turbidity (NTU)	77	63.5	10	5	7.7*	6.35*	15.4*	12.7*
EC (μscm-1)	812	833	-	400	-	-	2.03*	2.083*
Alkalinity (mg/l)	231	159	-	100	-	-	2.31*	1.59*
Temp (^{o}C)	24.5	19	-	-	-	-	-	-
TDS (mg/l)	488	500	500	600	0.976	1*	0.813	0.833
TSS (mg/l)	11	46	-	500	-	-	0.022	0.092
DO	3.27	3.27	-	5	-	-	0.654	0.654
BOD (mg/l)	14.7	35.3	20	20	0.735	1.765*	0.735	1.765*
COD (mg/l)	163	1261	60	-	2.72*	21.02*	-	-
E. coli	727	480	0	0	-	-	-	-
Lead	0.012	0.012	-	0.01	-	-	1.2*	1.2*
Cadmium	0.479	0.007	-	0.003	-	-	159.5*	2.44*
Iron	0.862	1.356	-	-	-	-	-	-
Copper	0.032	0.004	-	2	-	-	0.016	0.002
Zinc	0.013	0.007	-	-	-	-	-	-

MRQ = Risk Quotient based on MBS water quality standard; WRQ = Risk Quotient based on WHO water quality guidelines; *RQ> 1= health risk

Table 4.14: Comparison of Risk Quotient Between Upstream and Downstream of Nankhaka River

Parameter	Mean Concentration		MBS S	WHO GV	MRQ		WRQ	
	Up	Dn			Up	Dn	Up	Dn
Turbidity (NTU)	28.85	62.79	10	5	2.885*	6.28*	5.77*	12.56*
EC (µscm-1)	622.50	808.83	-	400	-	-	1.556*	2.022*
Alkalinity (mg/l)	198.5	253.8	-	100	-	-	1.985*	2.54*
Temp (°C)	22.70	23.33	-	-	-	-		
TDS (mg/l)	373.5	485.92	500	600	0.747	0.972	0.623	0.809
TSS (mg/l)	3.5	91.84	-	500	-	-	0.007	0.184
DO	3.74	4.58	-	5	-	-	0.748	0.915
BOD (mg/l)	5.14	12.25	20	20	0.257	0.612	0.257	0.613
COD (mg/l)	140	83	60	-	2.325*	1.382*	-	-
E. coli	134	190	0	0	-	-	-	-
Lead	0.012	0.012	-	0.01	-	-	1.2*	1.2*
Cadmium	0.239	0.247	-	0.003	-	-	59.5*	82.47*
Iron	0.214	0.550	-	-	-	-		
Copper	0.006	0.026	-	2	-	-	0.003	0.013
Zinc	0.003	0.003	-	-	-	-	-	-

MRQ = Risk Quotient based on MBS water quality standard; WRQ = Risk Quotient based on WHO water quality guidelines; *RQ> 1= health risk, Up = Upstream, Dn = Downstream

Table 4.15: Pearson correlation coefficient among various water quality parameters water quality parameters

	Ph	Turbidity	EC	Alkalinity	T	TDS	DO	BOD	COD
Ph	1								
Turbidity	0.12	1							
EC	0.19	0.21	1						
Alkalinity	0.64	0.22	0.48	1					
Temp	0.34*	0.21	-0.48	0.18	1				
TDS	0.19	0.21	1.00	0.48	- 0.48	1			
TSS	0.04	- 0.06	0.04	0.33*	0.39*	0.04			
DO	0.36*	- 0.17	0.43	0.45	- 0.36*	0.43	1		
BOD	- 0.27	0.13	0.69	- 0.04	- 0.68	0.69	0.12	1	
COD	-0.84	0.02	0.08	- 0.15	- 0.39*	0.08	- 0.35*	0.61	1

*. Significant correlation at the 0.05 level (2-tailed).

According to correlation analysis carried, there is a perfect positive relationship between electrical conductivity and total dissolved solids where if one increases the other also increases by the same margin even though the correlation is not significant ($p > 0.05$). There is also a strong correlation between TDS and BOD with the coefficient of 0.692. Total dissolved solids contribute positively to the change in DO and COD with the correlation coefficient of 0.431 and 0.692, respectively. There is a significant correlation between the change in pH and DO with the correlation coefficient of 0.363. Temperature negatively and significantly correlated with DO and COD of the water with correlation coefficient of -0.385 and 0.387, respectively.

4.7 Summary of the Chapter

The study revealed notable variations in *E. coli* counts between rainy and dry seasons. Significant seasonal differences were observed in temperature, TDS, TSS, BOD, and EC. However, no significant differences were found in COD, DO, alkalinity, turbidity, and pH between the rainy and dry seasons.

CHAPTER FIVE: DISCUSSION OF THE STUDY FINDINGS

5.1 Introduction

This chapter discusses the impact of physico-chemical parameters, heavy metals, and fecal coliform counts on river water quality. The study compares findings with WHO, (2022) guidelines, focusing on pH, turbidity, EC, alkalinity, temperature, TDS, TSS, DO, BOD, COD, and heavy metals (Lead, Cadmium, Iron, Copper, Zinc).

5.2 Physico-chemical Properties of Water

5.2.1 pH

The analysis of the data obtained in the study indicated that there is significant difference between the mean pH of all sampling sites ($p < 0.05$). During dry season E1 (Effluent release point) recorded lowest pH value and the lower pH was attributed to the decaying organic matter that releases carbon dioxide hence lowering pH in the process. Results also indicates that there was significant difference between mean value of upstream and downstream ($p < 0.05$), being higher upstream than downstream and attributed the difference to introduction of effluent at (Effluent discharge point). Water in Nankhaka River indicates that it is neutral to slight alkaline since most pH values during the entire study period are greater than 7. Results of the study agree with the results of Leong et al. (2018) conducted in Northwest Coast of Borneo.

In the study of Bonareri (2017); Sahoo (2017); and Mwatujobe (2020) it was alluded that there are different factors that influence pH variation between seasons. These factors may include but not limited to hydrogen imbalance occurring from runoff, decomposition of organic matter, high percentage of organic matter in the water, anthropogenic activities but also increased nutrient enrichment in the water, which is a favourable environment for plant growth. High growth of aqua plants including algal blooms produces more carbon dioxide during decomposition and this leads to decrease in pH value of the water body (Leong et al., 2018). The decrease in pH during the rainy season could also be attributed to the increased organic matter that comes in the waterbody with runoff.

The study found that the minimum and maximum mean pH values in rainy season were 7.20 ± 0.15 and 7.41 ± 0.01, respectively while that of the dry season were 6.3 ± 0.05 and 7.20 ± 0.15. The findings for all the seasons were within the WHO guidelines of 6.5 to 8.5 for drinking water except for effluent sample in dry season, which did not conform to the set guideline. This study concurs with the findings of Mussa & Kamoto, (2023) conducted in Area 25 Lilongwe where it was established that there was possible contamination in the ground water as pH values were elevated below or above neutral levels. The elevated values of pH were associated to dissociation of hydroxides, carbonates and organic matter in the bedrock.

5.2.2 Temperature

Results indicated that temperature was lower in dry season than rainy season. This was directly linked to the cold temperature of month of July. For instance, the minimum mean temperature in dry season was 18.4 ± 0.24 and maximum mean temperature of 22.4 ± 0.48 while in rainy season mean temperatures ranged from 22.4^{o}C to 24.6^{o}C (Table 4.1). In a study by Pritchard et al. (2007) conducted in Blantyre, Chiradzulu and Mulanje Malawi, temperatures of water samples were slightly higher than 25 ^{o}C especially in Blantyre and Chiradzulu. This level elevated microbial activities and other chemical reactions in the water. Sahoo (2017) and Bonareri (2017) in their separate studies argued that daily temperature variation, cloud cover, humidity of air among other factors largely affects the daily temperature of the water. It was also argued that the higher turbidity renders high heat absorption rate of water thereby contributing to temperature variation.

Temperature in this study was observed to be higher in rainy season than dry season and main factor that induced this variation is the cold weather conditions of data collected in the month of July/August, which lowered the temperature in dry season. Decreased riparian vegetation cover due to agriculture was also linked to increase in temperature variation for its attributes of reducing canopy cover. The higher temperature at S5 downstream during rainy season was as the result of increased turbidity of the water at the site (79.5 ± 5.61, table 4.1). Water with high turbidity is known to have more clay, silt and microorganisms, which traps heat that results in increased water temperature. In a similar study by Omezuruike et al. (2008) carried in Lagos State, Nigeria, it was reported that high temperature of water samples was attributed to the elevated intensity of sunlight and insulating effect of nutrient load from industrial discharge.
The World Health Organization does not have a set standard for temperature but water with a temperature of more than 25^{o}C is not palatable (WHO, 2022) and in this study temperature for all sites were below 25^{o}C. Temperature is an important parameter in water quality as it distresses the toxicity and solubility of heavy metals which when present in abundance could have health repercussions to human beings.

5.2.3 Turbidity

In fig. 4.3 as alluded to earlier, for most sampling points, the mean turbidity was high in rainy season than dry season except for S2 upstream and S3 downstream. However, the highest mean turbidity was recorded in dry season at S3 with the mean value of 85.7 ± 7.26 NTU and the turbidity recorded for all sampling sites in both seasons exceed the WHO guideline value of 5NTU (WHO, 2022). In the rainy season, the lowest turbidity of 23.2 ± 6.66 was observed at S3 downstream and the highest turbidity of 79.5 ± 5.61 was recorded at S5 downstream. The lowest turbidity in dry season was recorded at S1 upstream with a mean value of 23.7 ± 6.11. Even though there is a significant difference between mean values of the sampling sites during the dry season, the results of the rainy season showed that there is no significant difference between the sampling sites. Paired sample t-test also revealed that results were not statistically significant between rainy and dry season ($p > 0.05$). Results also indicate that there is no significant difference between upstream and downstream ($p = 0.332$). According to the study of Ngwira & Lakudzala, (2018) done in Lilongwe, Malawi, it was argued that high turbidity in rainy season was directly linked to the increasing runoff during rainfall that carries with it a lot of debris deposited into the water body. It is also claimed that high turbidity in rainy season was attributed to the high circulation rate of the river, which leads to suspended solids to be moving all the time. Water with high turbidity contains many debris including clays, microorganism, suspended solids that obstruct the clarity of the water and suitability by making it present a cloudy appearance (Badr et al., 2020). While the low turbidity recorded in dry season in most sampling sites except S3 downstream was because of reduced flow of the river thereby allowing the sediments to settle down. The higher turbidity recorded at S3 downstream during dry season was due to the increased human activities at the site including swimming, washing clothes and car washing.

5.2.4 Electrical Conductivity

Electrical conductivity recorded from the study showed a unique trend in dry season where it was increasing from the upstream to downstream. The mean electrical conductivity value in dry season ranged from 669 – 909 μscm^{-1} with the lowest EC observed at S1 upstream with value of 669 ± 4.62 and the highest EC of 909 ± 17.0 was recorded at S5 downstream. However, there is a significant difference between the means of the sampling sites ($p < 0.05$) in the rainy season and the lowest mean value of EC was recorded at S2 upstream with its value and SE of 565 ± 33.7. The results also showed that there is significant difference between all sampling sites ($p < 0.05$). It is also worth noting that there is seasonal variation of EC and the results of paired sample t - test showed that there is significant difference between the seasons ($p < 0.05$, table 4.2), being lower in rainy season than dry season. Results also indicates that there is significant difference between mean value of upstream and downstream ($p < 0.05$, table 4.3), registering mean value of 622 ± 25.7 and 808 ± 48.5 respectively.

All the results for all the seasons indicate that they are above WHO guidelines of 400 µscm^{-1}. However, Bonareri, (2017) argued that EC of freshwater is generally low, and the elevated mean values of EC was because of increased improper disposal of domestic waste, increased runoff and industrial effluent discharge into the water body. It was also argued in the same study, that geological set up of an area could also affect the surface water electrical conductivity. Thus, rivers that passes through areas having ionizable metals have higher electrical conductivity than rivers that do not have ionizable metals.

Electrical conductivity is expected to be higher in the rainy season than dry season due to the increased runoff that sweeps away the agricultural lands that are in proximity with the water (Sahoo, 2017). Electrical conductivity is largely affected by the decomposition of organic matter and the addition of inorganic materials from different sources including industrial effluent. The water with high electrical conductivity indicates that there is high amount of dissolved inorganic matter and its dependence on total dissolved solids cannot be over emphasized (Bonareri, 2017; Leong et al., 2018).

Figure 5.1: Agricultural Field in Study Area

All the sampling sites except E1 (Effluent release point) recorded lower values of EC in the rainy season as compared to the dry season and this can be attributed to the increasing rainfall which, influenced runoff leading to dilution of most ions in the water body. The higher electrical conductivity observed in the dry season was because of low precipitation and increased evaporation rate. The results of the study are in line with a study conducted in Northwest Coast of Borneo by Leong et al., (2018) where it was found that the electrical conductivity in rainy season had the mean of 149 ± 37.6 whilst in dry season the mean was 161 ± 28.7. Mussa and Kamoto (2023) reported high levels of EC in most sampling points in their study, which caused salty taste as reported by different water users across the study area. Salty taste was associated with increased levels of dissolved ions in the water.

5.2.5 Total Dissolved Solids

It is safe to say that all the sampling sites during both rainy and dry seasons recorded lower values of total dissolved solids than the WHO permissible limit of 600 – 1000mg/l (WHO, 2022). The lowest TDS in rainy season was recorded at S2 upstream with mean TDS of 339mg/l and the highest mean TDS of 488 mg/l at E1 (Effluent release point). In the dry season, TDS increased from upstream to downstream with the lowest mean recorded at S1 upstream and highest mean TDS at S5 downstream. The mean TDS ranged from 402mg/l to 547mg/l; however, the results showed that there was a significant difference between the mean of all sampling sites in both seasons ($p < 0.05$). The results illustrate that there is significant difference between mean TDS of rainy and dry season ($p < 0.05$), the values were higher in dry season than rain season.

The variation in the TDS between the seasons was because of a couple of factors including the reduced canopy cover due to increased need for agricultural land, natural salinity of water, other human activities and reduction in volume of water during the dry season (Ikhajiagbe et al., 2014). In this study, the water reduction played a bigger role in terms of TDS variation especially in dry season where the volume of water was low hence lower TDS levels. In both season E1 (Effluent release point) registered a high level of TDS and this was associated with having huge quantity of ions in the wastewater.

The TDS levels kept on increasing from E1 (Effluent release point) to S5 and this was because of human water usage downstream such as car washing, swimming and washing clothes. This contrasts with the study by Bonareri, (2017) conducted in Rupingazi River, Embu County, Kenya which found that total dissolved solids were reducing downstream, and it was attributed to ability of the river to assimilate the contaminants. However, the overall findings of the study agree with the study by Ngwira & Lakudzala, (2018) in Nankhaka River, Lilongwe where it was found that TDS was higher in dry season than rainy season with the mean value of 85.42 ± 15.3 in dry season in comparison with the mean value of 79.0 ± 19.9 in rainy season.

Figure 5.2: Sampling Point in Study Area

5.2.6 Total Suspended Solids

Total suspended solid (TSS) is defined as the measure of microscopic elements of liquid and solid matter that are suspended in the water (Bonareri, 2017). The results were in the range of 5–124mg/l in the rainy season and 2-60mg/l in the dry season (table 4.1 and 4.2, respectively). TSS mean values were higher in rainy season than dry season with 120mg/l as the maximum value while 60mg/l was the highest value in dry season. The findings indicated that there was significant difference between the sampling sites in both seasons ($p < 0.05$). It is also of paramount importance to indicate that paired sample t-test revealed that the results are significantly different between dry and rainy seasons ($p < 0.05$) where it was higher in rainy season than dry season.

Rainy season recorded TSS mean value of 50 ± 11.9 while the mean value in dry season was 22 ± 5.55. It can be argued that surface runoff and churning effect of the water contributed to the high TSS in rainy season than it is the case in dry season where the water is generally calm, and the sediments sink to the bottom of the river. During heavy rainfall there is a lot of soil that is washed away into the river from riverbank and the agricultural land, even though, this is constrained by the soil type, vegetation cover and land use within the catchment of the river

(Ngwira & Lakudzala, 2018). High TSS recorded at S5 downstream was associated with the disturbance of water at the site with activities such as swimming and washing clothes, which can suspend more particles including soils.

The findings of this study suggest that downstream recorded high total suspended solids than upstream attributed to discharge of chemical effluent at E1 (Effluent discharge point). Paired sample t-test also indicates significant difference between upstream and downstream ($p < 0.05$), being lower in upstream than downstream. This can be directly linked to rainfall and the high flow of the river, which wash away contaminants and riverbank soils and the increased runoff from different areas including the agricultural sites that are in proximity with the river. The finding of the study agrees with what Bonareri, (2017) found where the mean value of rainy and dry season was 103 ± 12.4 and 42.7 ± 4.33, respectively. However, the findings of the study are in contrast with what Ikhajiagbe et al., (2014) found in Nigeria where dry season recorded higher TSS than rainy season although the researcher was not conclusive of the reasons justifying the findings.

5.2.7 Alkalinity

Results indicated that there is significant difference between sampling sites in all seasons. However, there is no significant difference between mean values of rainy and dry season ($p > 0.05$). Low alkalinity obtained in rainy season could be directly attributed to frequent rainfall which freshens up water in the process of dilution while higher values in dry season was due to reduced water levels that tend to have high salt concentration. The highest mean value in both rain and dry season was observed at S5 downstream with the value of 248 ± 1.45 and 260 ± 17.3, respectively. Higher mean values of alkalinity in dry season correlates with a study conducted in Ethiopia by Teame & Zebib, (2016) on relationship of seasonal fluctuation of water volumes and alkalinity. This was attributed to human activities including washing and bathing that uses soap thereby elevating alkalinity at the site.

5.2.8 Dissolved Oxygen

In rainy season lowest mean DO of 2.27 ± 0.08 was recorded at S2 upstream while S3 with mean value of 7.19 ± 0.49 was highest value registered. In dry season, highest mean value of DO was recorded at S2 upstream with value of 4.31 ± 0.16. However, results showed that there is no significant difference between mean values of rainy and dry season ($p > 0.05$) being higher in rainy season than dry season. Paired sample t-test indicate that there is significant difference between upstream and downstream (p = 0.001), being higher downstream than upstream owing to high effluent discharge at E1 (Effluent discharge point). Dissolved oxygen mean values of rainy season were a bit higher compared to dry season with exception of S2 upstream and E1 (Effluent release point) owing to frequent rainfall that freshen up the water in the river as concurred by Phiri et al., (2005) study conducted in Lilongwe Malawi.

Several studies by different researchers confirm that DO is normally higher in rainy than dry season with exception of sewer waste and this was attributed to the interaction of oxygen with rainwater in the atmosphere (Bonareri, 2017; Aniyikaiye et al., 2019; Ikhajiagbe et al., 2014). It is paramount to note that discharge of effluent from industrial waste and decaying of organic matter reduces dissolved oxygen levels in the water. This is mainly due to microbial processes that take place during decomposition of organic matter and oxygen utilisation is generally high in water with high amount of organic matter and it also depends on the kind of bacteria working on the degradation of the organic matter (Bonareri, 2017). The study by Aniyikaiye et al. (2019) conducted in Lagos Nigeria ascribed the variation in dissolved oxygen in the water bodies to the flow of water, temperature, light intensity, present or absence of phytoplankton and availability of nutrients.

The lowest DO concentration was recorded at E1 (Effluent release point) and S2 during rainy season and this was linked to the high amount of organic matter present in the industrial effluent that increased the microbial activities thereby reducing dissolved oxygen. The lower value of DO registered in dry season was because of high microbial activities in the water from the decomposition of organic matter that enhanced oxygen utilization thereby reducing the dissolved oxygen concentration (Aniyikaiye et al., 2019). However, WHO does not have permissible limit for DO even if it is of particular importance in the quantification of water quality as it has capability to affect other water quality parameters such as odor and taste.

5.2.9 Biological Oxygen Demand

The recorded lowest mean BOD of 0.28 ± 0.07 during dry season was at S1 upstream while the highest mean BOD of 35.3 ± 2.23 was recorded at E1 (Effluent release point). In rainy season the highest mean value of BOD was also recorded at E1 (Effluent release point) with the value of 14.7 ± 0.88. The results showed that there is a significant difference between BOD mean values of both rainy and dry season with the mean values higher in dry season than rainy season.

Additionally, all the mean values for BOD during dry season were a bit higher compared to rainy season except at S1 sampling point upstream.

The higher values of BOD that were recorded from site E1 (Effluent release point) to S5 downstream was because of increased wastewater that was discharged from different industries in the effluent drainage that end up in the river. The findings of the study indicated that in both rainy and dry season E1 (Effluent release point) recorded high BOD compared to other sampling points with mean values of 14.7 ± 0.88 and 35.3 ± 2.23, respectively. The results showed that there is a significant difference between the mean values of the sampling sites ($p < 0.05$). The values were higher in dry season than rainy season with effluent release point registering higher values in both seasons than other sampling points. Paired sample t test also indicated that there is a significant difference between the mean values of rainy season and dry season ($p < 0.05$), where it was lower in rainy season than dry season. Lower values of BOD recorded at S3 to S5 downstream during rainy season was as a result of high-water volumes. While the higher value was attributed to the high presence of decaying organic matter in the river. The higher mean values of BOD recorded at E1 (Effluent release point), S4 and S5 during dry season makes the water not suitable for drinking and other domestic purposes and this may require treatment by addition of some coagulants and/or flocculants to make the water safe for drinking and irrigation purposes.

5.2.10 Chemical Oxygen Demand

In figure 4.10 it can be observed that the highest mean COD was recorded in dry season at E1 (Effluent release point) with mean value of 1261 ± 0.67. The lowest value of 22 ± 1.76 in dry season was recorded at S5 downstream. In rainy season, the mean values of COD ranged from 144ml/l to 242mg/l with S1 upstream registering the highest mean value. The results of variation between sites indicates that there is significant difference ($p < 0.05$). However, t-test results for seasonal variation for COD indicate that there is no significant difference in its mean concentration between rainy and dry season ($p > 0.05$).

The higher value of COD recorded at E1 (Effluent release point) during dry season was attributed to the domestic water usage such as washing and discharge of various chemical element from the industries in the vicinity. This was shown in the results of heavy metals analysis, where during dry season there was high concentration of Iron in the effluent samples. The results of the study agree with the findings of Mwatujobe, (2020) conducted in Dar es

Salaam, Tanzania where it was argued that the higher concentration of COD recorded during dry season was due to discharge of chemical elements from different pharmaceutical industries.

5.3 Faecal Coliform

The study found that all the sampling sites both in rainy and dry season did not conform to the WHO guidelines of zero count of *E. coli* for drinking water (WHO, 2022). *E. coli* was utilised in this study as an indicator of faecal coliform. It can be observed that the lowest mean value of *E. coli* count in rainy season was 46 ± 9.26 at S1 upstream. The highest mean value of *E. coli* was at E1 (Effluent release point) in both rainy and dry season with mean value of 727 ± 89.8 and 480 ± 55.6, respectively.

The results determined indicate that there was a significant difference between the means of all sampling sites for the entire study period ($p < 0.05$). Paired sample t-test results for also indicated that there is a significant difference in mean concentration between upstream and downstream with ($p < 0.05$), being high in downstream than upstream. The presence of *E. coli* in the water samples poses a health threat to human beings and this could also signify the presence of other disease-causing pathogens like viruses. It is safe to argue that the high presence of *E. coli* during the rainy season in all sampling sites was associated with the increased runoff that washes fecal matter from different areas into the river.

The study area is near squatter settlements of Mgona, which has poor sanitation, and open defection is rampant. The variation of fecal coliform is because of its nature as it is regarded as nonpoint source of pollution but also the water pH largely affects the growth of microbes as most of pH in all sampling points were between 6.6 and 7.5. The higher count of fecal coliform could also be directly linked to the wastewater drainage of effluent from different industries within the study area that end up in the river. However, the results of this study are much lower compared to those found by Aniyikaiye et al., (2019) where the counts ranged from 3 to 1500 counts/100ml water sample.

5.4 Heavy Metals in Water and Soil Samples

In rainy season, Lead and Zinc were below the detection limit in all the water samples except for effluent sample where Zinc was detected, and its mean value recorded was 0.061 ± 0.000. Cadmium levels during rainy season ranged from 0.4617 to 0.4923 mg/l while in dry season it ranged from 0.0023 to 0.0222mg/l. The highest mean value of Iron was observed at E1

(Effluent release point) with the mean value of 1.276 ± 0.158 during the rainy season and 7.90 ± 0.024 during the dry season. Copper was only detected in rainy season with the highest mean value of 0.047 ± 0.004 observed at S5 downstream. Paired sample t-test for Cadmium showed significant difference between the means of rainy season and dry season ($p < 0.05$), being higher in rainy season than dry season while that of Iron indicate that there was no significant difference between the means ($p > 0.05$).

In the riverbank soil sample, all heavy metals were detected except for Lead that was below detection limit. Copper, Zinc and Iron showed no significant difference between the means of rainy season and dry season. However, Cadmium in soil samples indicated that there is significant difference ($p < 0.05$) between the mean of rainy and dry season signifying some chemical pollution of water to some extent. The study reveals that the level of Cadmium in the water is life threatening to aquatic life and public health repercussions would be envisaged for it is above WHO permissible limit of 0.01mg/l for drinking water and 0.15 to 0.25mg/l for aquatic life support (WHO, 2022). In water, most of the heavy metals were below the permissible limits and this was attributed to the ability of the river to assimilate the pollutants naturally. These results comply with the findings of Mwatujobe (2020) conducted in Dar es Salaam, Tanzania where it was found that downstream copper levels were low rendered to ability of the river to undergo natural purification.

5.5 Water Quality Index for Nankhaka River

The results indicate that Nankhaka River water quality is deteriorating owing to increased discharge of effluent into the river. pH has a profound effect on the quality of E1 (Effluent release point). It was found that turbidity is impacting the water quality on the river across all the sampling points. Overall WQI indicates that only S1 and S2 have good water quality while the rest of sampling stations have poor water quality (Table 5.2). Turbidity and faecal coliform highly influenced poor water quality rating downstream. Generally, water with high *E. coli* and turbidity is considered poor water and not suitable for consumption as such water pose high health repercussion to humans. Poor water quality downstream could be directly linked to the influence of discharged effluent at E1 (effluent release point) which affects water quality downstream. This is unfortunate because, the water from sampling point S1, S3, S4 and S5 are used for other purposes including bathing and agriculture. Deterioration of water quality in Nankhaka is largely due to discharge of industrial effluent into water body as evidenced by

WQI of S1 upstream which was 49 as compared to S5 downstream which registered higher WQI of 67 after the introduction of effluent at E1 (Effluent discharge point).

Electro-coagulation is widely utilised across the globe to reduce turbidity and total dissolved solids and it has demonstrated to be very reliable with 98% and 99% efficiency, respectively (Sahoo, 2017). To normalise low pH value at E1 (Effluent release point) in dry season the use of lime neutralisation can be very efficient while heavy metals can be extracted from the water by utilising the Ion Exchange Membrane Method. However, the use of Ion Exchange Membrane Method has proved to be costly in high quantity of water (Sahoo, 2017).

5.6 Risk Assessment

The results indicate that most pollutants that were analyzed indicated significant health risks. Cadmium and lead carried significant health risk in both rainy and dry season in the order of Cadmium > Lead as presented in table 4.8. Alkalinity, Turbidity and EC also carried significant health risk in both rainy and dry season in the order of Turbidity > EC > Alkalinity. Total dissolved solids and biological oxygen demand also portrayed significant health risk but only in dry season. The risk quotient for *E. coli* was not computed because both MBS and WHO recommends 0 fecal coliform count per 100 ml of water, however, higher fecal coliform values already signifies that it could pose high health risk to consumer of such water. To give comprehensive health risk assessment there is need to evaluate the dose intake and period of exposure to these contaminants which is out of scope of current study. Health risk based on spatial analysis indicates that Turbidity, Alkalinity, EC and Cadmium had high health risk downstream compared to upstream which showed minimal health risk.

5.7 Impact of Industrial Effluent on Water Quality

Discharge of untreated and/or partially treated effluent into water body has profound short- and long-term effect on human beings and the environment. Surface water has been largely affected by discharge of effluent which are either not treated or partially treated (Akoth, 2018). However, the impacts depend on concentration, composition, volume and frequency of effluent being discharged into waterbodies. Discharge of such effluent also enriches water sources with different nutrients that cause eutrophication creating an environment that promotes growth of cyanobacteria that produce toxins which are hazardous when exposed to humans (Edokpayi et al., 2017).

5.7.1. Health Impacts

The study reported high mean values of *E. coli* in both rainy and dry season attributed to wastewater drainage of effluent from different industries and open defection which is rampant. within the study area. However, Surface water contamination with pathogens poses significant risk of causing waterborne related illness to water user downstream as evidenced by 22.08% increase of *E. Coli* downstream from the initial value of 136 colonies upstream. It is reported that three million people die annually from infectious diseases due to consumption of water contaminated with microbes representing 25% of world deaths (WHO, 2022). There are many disease-causing microorganisms being discharged into water bodies and these include bacteria, viruses, fungi and protozoa just to mention a few. Current study emphasized *E. coli* contamination which signifies the present of fecal coliform causing public health concern. Microbial contamination poses immediate health risk to human beings that utilize surface water for irrigation and domestic purposes compared to environmental impacts which accumulate over time.

Increased cases of waterborne diseases such as cholera and diarrhea have been reported within the study area (Ngwira & Lakudzala, 2018). This stance agrees with Edokpayi et al. (2017) study conducted in South Africa which alluded that many episodes of cholera and diarrhea was reported in different parts of South Africa and contributed it to increased discharge of wastewater effluent into surface water. In 1998, Malawi reported first major outbreak and registered about 25,000 case which followed another outbreak occurring from 2001 to 2002 and registered 33,546 cases and 968 fatalities (WHO, 2023). The country has been experiencing the lethal outbreak since March 2022 with all 29 districts being hit and recorded 36,943 cases and 1,210 fatalities with Mgona being hotspot of the outbreak in Lilongwe city. WHO linked the recurrent outbreaks to lack of access to clean and safe drinking water and recommended increasing access to safe water and improvement on sanitation infrastructure. Therefore, continued disposal of effluent into water bodies also has capability to necessitates the recurrent of cholera outbreak as different studies confirms that even treated industrial effluent does not comply to WHO guiding principles for effluent discharge (Edokpayi et al., 2017; Leong et al., 2018; Akoth, 2018.). Calculated health risk quotient also indicates that water characteristics posed higher health risk downstream than upstream. For instance, Cadmium downstream registered RQ of 22.97 higher than upstream with turbidity in downstream showing 6.79 RQ higher than upstream. This could be argued that introduction of effluent at E1 (Effluent discharge point) attributes to rise in health risk to water user downstream as they are more likely to be affected than upstream users.

5.7.1 Environmental Impacts

Partially treated industrial effluent has a significant influence on water quality of receiving waterbody. The impact could be acute or cumulative, where the later occurs because of gradual buildup in waterbody and become noticeable when threshold level is exceeded whilst acute impacts occur due to increased levels of ammonia, high heavy metal concentration and oxygen demanding substances (Edokpayi et al., 2017). Current study specially found lower values of DO which was attributed to high presence of decaying organic matter in the river emanating from discharged industrial effluent that increased microbial activities. Generally, there is depletion of DO in water bodies that receive untreated or partially treated effluent as most treatment facilities produce lower values, which does not conform to standard of 8 -10mg/L (Akoth, 2018). Additionally, different microorganisms survive and function at a specific temperature and high DO values and any slight fluctuation could threaten their growth and life. For instance, most fish species find it difficult to survive in water with low dissolved oxygen (Edokpayi et al., 2017).

Levels of Chemical Oxygen Demand and Chemical Oxygen Demand are good indicators of chemical pollution in water. BOD increased by 102.94% from the baseline value of 5.56mg/l upstream indicating the magnitude of chemical pollution downstream owing to introduction of effluent at E1 (Effluent discharge point). Higher BOD and COD mean values recorded in this study imply that life sustenance of aquatic organism will be difficult owing to high biodegradable organic matter in water which depletes DO, thereby affecting reproduction and growth of aquatic organism (Edokpayi et al., 2017). On the other hand, TSS registered a highest increase from upstream to downstream indicating 548.9% increase from the baseline value of 8.78mg/l upstream owing to increased organic matter downstream proliferated by effluent addition of effluent at E1 (Effluent discharge point).

The Calculated Water Quality Index indicates that water quality is deteriorating from upstream to downstream as evidenced by the increase in WQI from 47 to 67 at S1 and S5 respectively, representing a 42.5% increase in deterioration of water quality. This has been directly attributed to introduction of effluent at E1 (Effluent discharge point) which caused WQI to proliferate downstream.

5.8 Summary of the Chapter

The findings of the study reveal that quality of water in Nankhaka River is compromised as evidenced by the WQI of most sampling sites, which indicated that the quality of the water is poor and not suitable for domestic purposes and conventional treatment of such water is required before use.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In the lead-up to the conclusions of the study, methodology detailed in Chapter 3 forms the cornerstone of the research approach. This study focused on sampling water and soils along Nankhaka River. Water samples were systematically collected at various sampling stations, including S1, S2, S3, S4, and S5. Simultaneously, soil samples were gathered from both sides of the river at the exact locations where water samples were collected. Additionally, effluent samples were specifically obtained from station E1, corresponding to the effluent release point. This systematic sampling approach ensured comprehensive coverage of the study area and provided representative data for further analysis.

The analysis of the data obtained revealed that turbidity, TSS, temperature and Cadmium were significantly higher in rainy season than dry season. Spatial variation indicates that EC, Alkalinity TSS, TDS BOD, Iron and *E. coli* were significantly higher downstream than upstream ($p < 0.05$). This signifies to some extent contamination of the river due to high effluent discharge at E1 (Effluent release point). Temperature, Turbidity, Cadmium and Copper showed no significant variation between upstream and downstream ($p > 0.05$).

Overall, only S1 and S2 had good water quality while all the other sampling points have poor water quality. Poor water quality downstream could be directly linked to the influence of discharged effluent at E1 (effluent release point) which contains high levels of contaminants including faecal coliform, cadmium and iron which affected water quality downstream. This could imply that health problems may arise if people continue to utilise water from the river for domestic purposes. It is also important to note that TSS, TDS and Alkalinity were higher downstream than upstream, and this could also be attributed to increased activities at most sites which disturbs the water and suspends more solids thereby increasing its readings.

6.2 Recommendations

i. There is need to enforce the existing by-laws to completely deter discharge of effluent into Nankhaka River.
ii. There is need of community sensitisation on the importance of safeguarding the river catchment but also deterring farmers from encroaching the river buffer zone.
iii. Deterring industries from discharging effluent into the river

iv. The community members in the catchment area of Nankhaka Stream should also be sensitised on the importance of good sanitation practices.

6.3 Limitations and need for further research

i. The study did not determine all water quality parameters due to financial and time constraints.
ii. Rainy and dry season samples were collected in an interval of two months i.e., April and March. This was due to late approval of the study by ethics board. Therefore, most contamination levels reported in this study showed minimal variations based on seasons.
iii. The study primarily focused on physicochemical properties; however, it is essential to investigate the bioaccumulation of contaminants in crops cultivated at various sampling sites, particularly E1 (Effluent release point), where sugarcane and vegetables are grown. This additional research will provide valuable insights into potential impact of contaminants on crops and the potential risks associated with consumption.
iv. It is recommended to conduct a comprehensive study on sediment load of the river, focusing on soil erosion and its impact on aquatic life. This investigation would provide valuable insights into dynamics of sedimentation, helping to understand the potential effects on river ecosystem and aquatic organisms.
v. To give comprehensive health risk assessment there is need to evaluate dose intake and period of exposure to these contaminants.

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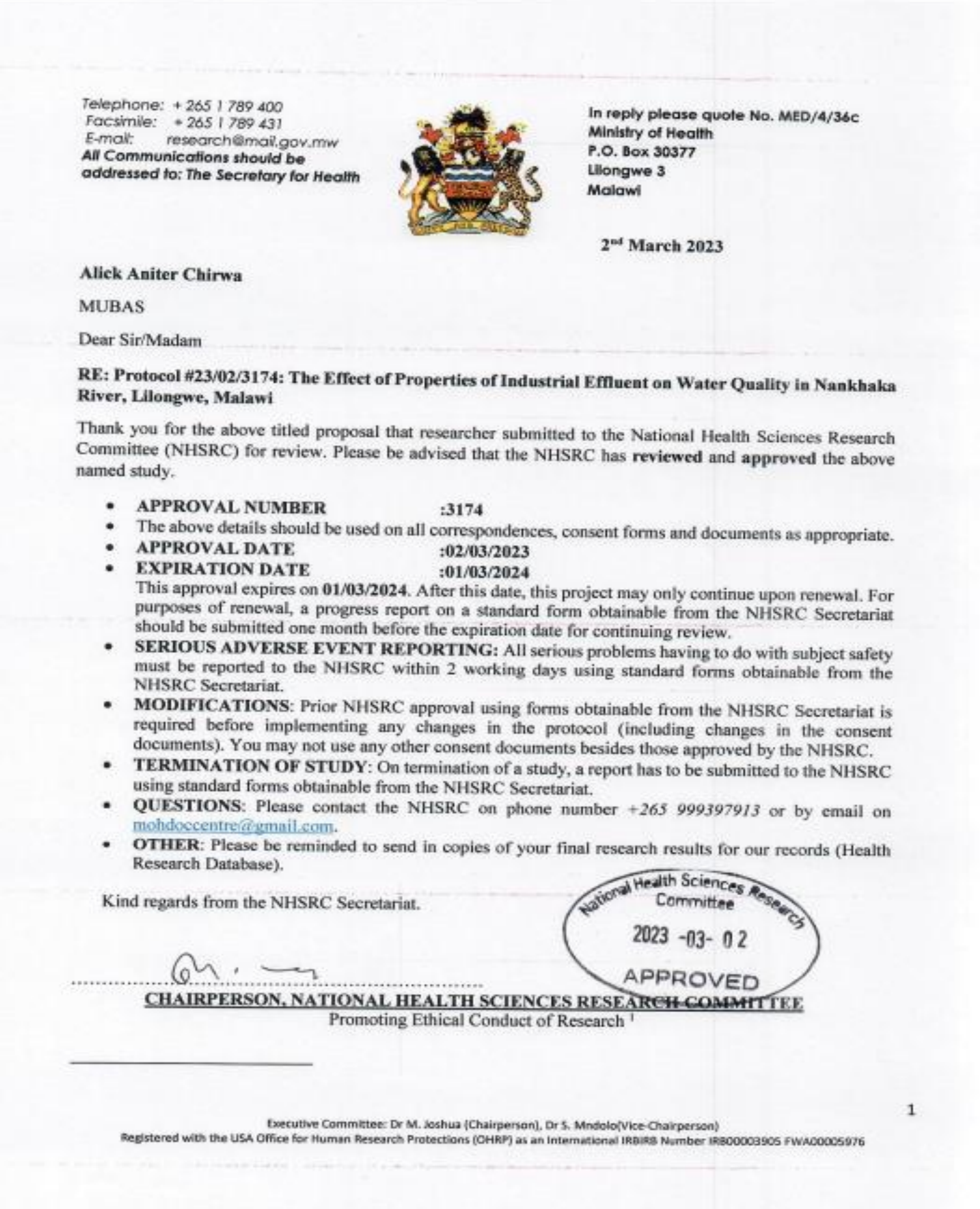
APPENDICES



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2nd March 2023

Alick Aniter Chirwa

MUBAS

Dear Sir/Madam

RE: Protocol #23/02/3174: The Effect of Properties of Industrial Effluent on Water Quality in Nankhaka River, Lilongwe, Malawi

Thank you for the above titled proposal that researcher submitted to the National Health Sciences Research Committee (NHSRC) for review. Please be advised that the NHSRC has **reviewed** and **approved** the above named study.

- **APPROVAL NUMBER** **:3174**
- The above details should be used on all correspondences, consent forms and documents as appropriate.
- **APPROVAL DATE** **:02/03/2023**
- **EXPIRATION DATE** **:01/03/2024**
  This approval expires on **01/03/2024**. After this date, this project may only continue upon renewal. For purposes of renewal, a progress report on a standard form obtainable from the NHSRC Secretariat should be submitted one month before the expiration date for continuing review.
- **SERIOUS ADVERSE EVENT REPORTING:** All serious problems having to do with subject safety must be reported to the NHSRC within 2 working days using standard forms obtainable from the NHSRC Secretariat.
- **MODIFICATIONS**: Prior NHSRC approval using forms obtainable from the NHSRC Secretariat is required before implementing any changes in the protocol (including changes in the consent documents). You may not use any other consent documents besides those approved by the NHSRC.
- **TERMINATION OF STUDY**: On termination of a study, a report has to be submitted to the NHSRC using standard forms obtainable from the NHSRC Secretariat.
- **QUESTIONS**: Please contact the NHSRC on phone number *+265 999397913* or by email on mohdoccentre@gmail.com.
- **OTHER**: Please be reminded to send in copies of your final research results for our records (Health Research Database).

Kind regards from the NHSRC Secretariat.

National Health Sciences Research Committee
2023 -03- 02
APPROVED

CHAIRPERSON, NATIONAL HEALTH SCIENCES RESEARCH COMMITTEE

Promoting Ethical Conduct of Research [1]

Executive Committee: Dr M. Joshua (Chairperson), Dr S. Mndolo(Vice-Chairperson)
Registered with the USA Office for Human Research Protections (OHRP) as an International IRBIRB Number IRB00003905 FWA00005976

CERTIFICATE OF ETHICS APPROVAL

This is to certify that the National Health Sciences Research Committee
has reviewed and approved the study titled:

Study Title: Protocol # Protocol # 23/02/3174: The Effect of Properties of Industrial Effluent on Water Quality in Nankhaka River, Lilongwe, Malawi

Investigator: Alick Aniter Chirwa

StartDate: 03/02/2023

EndDate: 02/02/2024

Date of issue: 03/02/2023

Dr Martias Joshua
Chairperson-NHSRC

2023 -03- 02
APPROVED

Mr Billy Nyambalo
NHSRC Administrator