

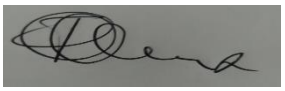
ASSESSMENT OF THE IMPACTS OF HUMAN ACTIVITIES ON WATER QUALITY IN NASOLO RIVER, BLANTYRE, MALAWI

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Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Water Quality and Management

July, 2021

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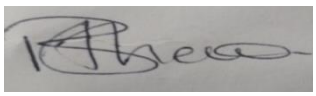
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ABSTRACT

Rivers provide several ecosystem services that support human beings as well as a variety of plants and animal species from all sources, including terrestrial, marine, and other aquatic ecosystems. However, poor water quality as a result of increasing human activities leads to biodiversity losses and high rates of waterborne disease. This study focused on assessing the influence of human activities on water quality in relation to physico-chemical and microbiological water quality analysis and the species abundance of macroinvertebrates in Nasolo River. Firstly, the study employed laboratory and in-situ measurements of physico-chemical and microbiological water quality variables at four sampling sites that were interpreted by developing a National Sanitation Foundation Water Quality Index (NSFWQI) to depict the overall water quality status. Secondly, this study also employed South Africa Scoring System Version 5 (SASS5) biomonitoring techniques to collect and identify suitable biological indicators whose presence or absence, abundance and diversity reflect environmental conditions. The macroinvertebrates data was interpreted by calculating average scores per taxon (ASPT) values to also depict the overall water quality status. A total of six orders of macroinvertebrates were identified including the Ephemeroptera, Diptera, Trichoptera, Annelida, Coleoptera and Turbellaria. Water samples were collected by grab sampling technique. A multi-probe Aqua meter was used to obtain values of pH that ranged from 6.4 to 7.7, conductivity and temperature ranged from 71.7 to 1896.7μs/cm and 19.47 to 23.8^{0}C respectively, salinity and Total Dissolved Solids (TDS) ranged from 0.03 to 1 ppt and 53 to 1234mg/L respectively, dissolved oxygen and oxidation-reduction potential ranged from 2.1 to 5.2 mg/L and -11.6 to 6.27 millivolts respectively. A membrane filtration method was used to determine faecal coliforms that ranged from 10 to 1966 Colony Forming unit/100mL and total coliform that ranged from 126 to 2313 CFU/100Ml. In addition, a hydrotest photometer (HT 1000) was also used to analyze turbidity and total suspended solids that ranged from 10 to 51 NTU and 14 to 52mg/L respectively without the use of coloring reagents. The photometer also helped to analyze nitrates and ammonia that ranged from 20 to 68.9 mg/l and 2.27 to 5.6mg/L respectively with the use of coloring tablets and powdered reagents. Lastly, a

correlation analysis between the NSF water quality index and ASPT (biotic index) was carried out to quantify the degree to which the two indices are related. The results revealed that both the water quality and biotic indices were strongly correlated. Both indices indicated that sampling site 1 at the upstream of Nasolo River was moderately polluted. For the other sampling sites 2,3 and 4, both indices indicated that those sites were seriously polluted. Overall, the outcome of this study showed that human activities led to poor water quality in Nasolo River that poses an ecological risk to aquatic biota. Therefore, biomonitoring techniques have to be employed for surface water resources in Malawi in conjunction with physico-chemical and microbiological water quality assessments to obtain a more comprehensive studies of ecological health of watersheds.

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ACRONYMS/ABBREVIATIONS

CFU Colony forming unit

CO_2 Carbon dioxide

DO Dissolved oxygen

EC electrical conductivity

EPA Environmental Protection Agency

TDS total dissolved solids

Mg/l Milligrams per litre

MoAIWD Ministry of Agriculture, Irrigation and Water Development

NSFWQI National Sanitation Foundation Water Quality Index

NTU Nephelometric Turbidity Units

μS/cm Microsiemens per meter

pH power of hydrogen

p.p.t parts per thousand

SASS South African Scoring System

SASS5 South African Scoring System version 5

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1. CHAPTER 1: GENERAL INTRODUCTION

Water is essential to all forms of life (Mumba et al., 2005). Surface water resources such rivers offer several ecosystem services. The services include those of provisioning such as food, water and timber; regulating such as climate regulation, water purification, carbon sequestration and flood control; cultural services include recreational, aesthetic, and spiritual benefits; and supporting services are such as soil formation, photosynthesis, and nutrient cycling (Mooney, 2005). In addition, rivers serve as a source of water for various human activities. In this industrial age, people depend on water for various activities such as industrial production, agricultural production, sand mining for construction and commercial trade in local markets to fulfil their needs. These human activities may have economic and social benefits but they lead to diverse environmental and health impacts to the rivers (Govorushko, 2007). The management of these human activities is often a challenge in most developing countries including Malawi (Pullanikkatil et al., 2015). Some of the human activities impacts on water quality can include increase in water salinity, high concentrations of nitrates, increase in turbidity, elevated amounts of ammonia, high total dissolved solids (TDS) levels, high presence of fecal coliform and they can be drastic changes in rivers' pH, electrical conductivity, Oxidation-reduction potential and temperature (Peters et al., 2006). As such, there's need for regular water quality monitoring in rivers.

At global scale, human impact on rivers has led to diverse negative consequences in the following ways; physical disturbance of river beds, water clogging, water and thermal pollutions (Govorushko, 2007) . Many studies show that dam constructions on the majority of largest flowing rivers in the world have led to poor water quality and they have created barriers of migration ways of valuable fish worldwide (Hadeed & Thomson, 2006). Some of the major largest rivers that have dams built include Tigris River in Asia, Nile River in Egypt, Amazon River in South America, Yellow River in China and many more.

At regional scale, the African continent is mostly impacted by the contamination of faecal microorganisms, excessive use of agrochemicals, uncontrolled discharges from industries and solid and liquid waste from households and municipal (Kamba et al., 2016). However, according to United Nations Department of Economic and Social Affairs (UNDESA), agriculture through excessive use of agrochemicals like fertilizers and pesticides has high human impact on rivers. This has caused nitrates and phosphates to enter bodies of water, leading to eutrophication (UNDESA, 2019).

At local scale, the quality of the surface water resources in Malawi have deteriorated. According to Mumba et al., (2005), they argued in their study that most rivers flowing through the cities such as Lilongwe, Blantyre, Zomba and Mzuzu are heavily polluted. This is due to poor management of catchment areas, high population growth, poor agricultural practices, weak institutions for enforcing water laws and policies and discharging of industrial effluent without proper treatment. solutions on living organisms. Nasolo River in Blantyre city is one of the rivers that has been negatively impacted by human activities such as bricklaying, deforestation and sand mining. Due to human settlements and a market near to the river, it may have also contributed to poor water quality in the river(Cammack, 2012). Therefore, there are three techniques that can be employed to assess water quality of rivers (Palmer, Berold, & Muller, 2004) such as Water physico-chemistry to analyse physical and chemical water quality parameters, Biomonitoring to measure both taxonomic and functional diversity and Ecotoxicology to analyse the effects of chemicals on the aquatic ecosystem.

1.1. Background of the study

Studies on water quality assessment in rivers have proved to be significant because they enable researchers to understand anthropogenic factors affecting water quality and to come up with recommendations on sustainable ways to mitigate negative consequences that the government and relevant water resources authorities can adopt to help improve water quality in rivers (Govorushko, 2007). Previous studies on assessing water quality in Nasolo river have shown that chemical water quality variables mostly heavy metals were above the WHO and MBS water quality standards (Kaonga et al., 2008). Analysis of phosphates, nitrates and BOD in Nasolo

river have also shown high levels in Nasolo River (Kuyeli et al., 2009). Furthermore, the most and only technique that is employed in Malawi to assess water quality is Water physico-chemistry. This deals with well-known scientific studies to analyse the composition of substances in water and to evaluate the changes that substances in water undergo as a consequence of alterations in the constitutions of their molecules. The physico-chemical variable analysis is the traditional approach to controlling pollution and managing water quality (Odume, 2017). A previous study involved use of algae to assess heavy metal pollution in Nasolo river (Kaonga et al., 2008). However, there are gaps in the use macroinvertebrates as bio-indicators to assess the ecological health of Nasolo River. This technique has not yet been employed in most of the rivers found in Malawi as such there is need for biomonitoring to be used in conjunction with water quality monitoring to obtain a more comprehensive indication of ecological health of watersheds (Pullanikkatil et al., 2015). So far, among the three techniques, biomonitoring is the easiest sampling technique and it uses locally and cheap materials to assess water quality (Dickens & Graham, 2002).

Therefore, this study took place in Nasolo River, one of the main rivers in the city of Blantyre with an estimated population of over 800,000. The river is located within Blantyre district in the Shire Highlands and geographical centre of the southern region of Malawi. This study aimed at assessing human activities impacts on water quality in Nasolo river using the biomonitoring technique. This technique was employed because it was used to collect and identify macroinvertebrates that are good indicators of water quality. Their presence or absence, abundance and diversity reflect environmental conditions. In addition, a land-use survey that was used to come up with a map in order to describe the human activities taking place along the river, a micro-biological analysis was employed to measure faecal and total coliforms and lastly a physico-chemical analysis was carried out to understand the physical and chemical characteristics of the river. This study has produced water quality data that have been used to explain the current state of river and the results have been compared with surface water quality standards set by the United States Environmental Protection Agency (USEPA) and the Malawi Government: Ministry of Agriculture, Irrigation and Water Development (MoAIWD).

1.2. Problem Statement

The water quality of Nasolo River experiences several water quality problems due to various human activities (Cammack, 2012). For example, industries often discharge their effluents without proper treatment into the river (Ho et al., 2012). Sand mining is also a problem. It has dredging impacts on water quality through the ecosystem structure disturbance that also disrupts the ecological functioning of the river. Furthermore, there is excessive use of pesticides and fertilizers on agricultural fields close to river. The use of fertilisers can lead to an increase in water salinity, which is toxic to aquatic life (Kefford et al., 2002, Vellemu et al., 2018). Fourthly, there are also issues of deforestation on Ndirande hill where the river originates up to the downstream. This has led to siltation and widening of the river channel (Masese et al., 2014). Lastly, there are informal human settlements along the river, pit latrines built near the river, poor market structures and lack of well-organized solid waste collection and disposal systems of the markets in Blantyre as well as other urban cities. This has resulted in dumping of wastes into the river that consists mostly of faecal, vegetable and fruit matter and some wastes such as washing detergents, plastics, metals (steel) and electronics for example phone batteries and bulbs, even get carried away by surface water runoff causing water contamination. In return, all the activities above impose threats on the ecosystem and making the water unusable for the people who use the water in Nasolo River.

Past studies have focussed more on heavy metal water pollution monitoring in rivers surrounding Blantyre including Nasolo. They argued that degradation of rivers is often due to agriculture and industrial activities (Kaonga et al., 2008). However, these studies have not used aquatic invertebrates as macro-biological indicators of water quality when assessing impacts of human activities on rivers (Vellemu, 2017). As such, this study will use different approach on the river to validate that the water quality is poor through biomonitoring technique. The water quality of Nasolo river is irregularly studied, with no continuous water quality testing by the Blantyre Water Board. The river lacks recent water quality data on physical, chemical and microbiological variables since physico-chemical water quality analysis is expensive.

Therefore, biomonitoring techniques to analyse water quality can be used as preliminary survey to define water quality status of rivers.

1.3. Research Objectives

The main objective of this study is to analyse the impacts of human activities on water quality in Nasolo River.

1.3.1. Specific Objectives

- To delineate human activities along the river profile with respect to a land use map
- To analyse the water physico-chemical and microbiological characteristics of water in Nasolo river
- To examine macro-biological indicators of water quality in Nasolo river

1.4. Research Hypothesis

Human activities along Nasolo River do not present any effects on the water quality.

1.5. Research questions

- How do human activities affect physico-chemical and microbiological characteristics in water?
- How do human activities affect the macroinvertebrates in a Nasolo river?
- What human activities are taking place along Nasolo River?

1.6. Significance

The study will help to understand issues of water quality on the ecosystem and will contribute scientific knowledge in the water quality and management field by producing water quality data for Nasolo River. The outcomes of this study will be used for the development of water quality monitoring and assessment programmes for rivers in Malawi. Hence, it will be necessary for making sound decisions on managing water quality today and in the future and protecting the ecosystem and aquatic resources. Since there is also lack of awareness on the impacts of waste discharge from households and local markets and there is less engagement of local

people with catchment management committees and water resource authorities at a community level, as such this study will help communities be aware of local water challenges and realize that assessing rivers is critical for ensuring their protection from water-borne diseases such as cholera, typhoid and dysentery and ensuring the protection of the aquatic ecosystem.

2. CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews the relevant literature to the study. It outlines Malawi's water resources, environmental and socio-economic benefits of rivers and the impacts of human activities on rivers. Furthermore, it discusses about water quality parameters. Lastly, it gives details about the national sanitation foundation water quality index, biomonitoring approaches using SASS5, land-use survey using the software ArcGIS and water quality assessment.

2.2. Malawi's surface water resources

Water resources in Malawi are abundant (JICA, 2020). Surface water resources comprise of river systems and lakes. The quality of the surface water resources is deteriorating due to poor management of catchment areas, high population growth, poor agricultural practices, weak institutions for enforcing water laws and policies and discharging of industrial effluent without proper treatment. Most rivers flowing through the cities such as Lilongwe, Blantyre, Zomba and Mzuzu are heavily polluted. Hence, there is need for better management and protection of water resources. Malawi is divided into 17 water resources areas based on the river basins. Some water resources areas divided consist of one river basin and others are composed of several small river basins (JICA, 2014).

2.3. Benefits of river systems

Rivers are important drainage systems. They have many environmental and socio-economic benefits (Meng et al., 2011). Some of the benefits include the sustenance of aquatic and terrestrial animals and plants, replenish wetlands, they are habitat of fish that can be exploited for commercial purposes, provides transportation of people and goods, provides drinking and irrigation water, rivers are source of energy and food, assist in sediment transportation, help in recharging groundwater, facilitate the hydrological cycle and rivers provides biodiversity maintenance. Furthermore, rivers can be used for recreation, scientific study and education (Postolache, Girão, & Pereira, 2012)

2.4. Impacts of human activities on rivers

Humans create and employ some income generating activities to earn a living. However, the activities alter the natural characteristics of water through the addition of chemical, physical and biological wastes (Peters et al., 2006). There are several activities surrounding the rivers that deteriorate the quality of water:

2.4.1. Sand mining

Rivers are a preferred source of sand. Sand mining is one of the activities that help to boost the economy of a country. It is aimed at providing material for infrastructure development as well as providing economical source to the miners (Rizal & Syah, 2018). Even though sand mining has positive impacts, it disturbs the structure of the river and there is ecological disruption. This results in damage of vegetation along the river banks, interrupts continuity of sediment transport, damages aquatic habitats, causes high turbidity and increase in suspended solids (Ashraf et al., 2011). According to JM Weeks, Sims, Harrison & Lawson (2003), assessing the impacts of sand mining on rivers can be done by analysing biota through bio-monitoring. In their study, they used bio-survey techniques to detect the effects of sand mining on aquatic organisms to determine the health of a river (Weeks et al., 2003).

2.4.2. Industrial production

Industrial production is major development in a country that provides job opportunities and increases the economy of a country. However, this activity result in industrial effluents that gets discharged into rivers without proper treatment. As such, this affects water quality of rivers by inducing problems such as high levels of biochemical oxygen demand, chemical oxygen demand, total dissolved solids and pH (Kanu & Achi, 2011). A study on assessment of the impact of industrial Effluent on Water Quality of Receiving Rivers in Urban Areas of Malawi showed that effluents being discharged into the river have negative effects on the water quality and makes the water unsafe for human consumption. There is need to discourage careless disposal of industrial effluent and to install treatment plants at all industries so that wastes are treated before getting dumped into the rivers (Mumba et al., 2005).

2.4.3. Commercial trading in local markets

Most commercial activities take place in market places. Markets facilitate businesses between buyers and sellers. Most rivers pass through highly dense population areas (Boakye, 2012) and pass through market places where a lot of solid wastes from poultry, fish, fruits and vegetables are generated and disposed into the nearby streams and rivers (Olabode & Lawrence, 2014). There has been rise of wastes in markets due to the high demand of food and other essentials. Wastes in markets are not managed properly as a result unattended wastes lying around the place get easily carried into the rivers by runoff when rainfall occurs. Most of the rivers are also filled with plastic wastes produced at markets that have impact on wildlife and environmental health. According to UNEP (2006), plastics cause death to countless fish by heavy metals that get adsorbed to the surfaces of the plastic wastes. Plastics also have ability to attract contaminants such as Persistent Organic Pollutants that pollute the rivers heavily. Solid wastes also result in blocking of the river channel. (Science for Environment Policy, 2011).

2.4.4. Agricultural production

Agriculture is the main source of national income for most developing countries (Cervantes-godoy, 2014). In addition to this, agricultural production provides food for people and raw materials for factories. It also provides employment opportunities. Despite these advantages, agricultural practices may have negative impacts on river's water quality. Improper agricultural methods elevate concentrations of nutrients, pesticides and sediments loads in water bodies (Stoyanova & Harizanova, 2019). This results in eutrophication and damage of river beds eventually leading to the degradation of nation's water resources.

2.4.5. Deforestation

Trees which are one of the important woody plants are mostly used for timber purposes (Seth, 2017). When cut carelessly without replacing them, they often have adverse results towards environment such as water resources. Some of the direct causes of deforestation are extraction of wood for charcoal, expanding land for agriculture, markets and infrastructure such as schools, houses, shops, hospitals and

many more. However, deforestation leads to siltation and widening of the river channel (Masese et al., 2014).

2.4.6. Human settlements

Residents along rivers often discharge domestic wastewater directly (Obarska-pempkowiak et al., 2015). Domestic wastewater is mixture of all household wastewater from a community, including toilet water, showers, dish washing and laundry. It can be categorized into greywater and blackwater. According to Brain et al (2015), greywater is liquid waste from washrooms, laundries, kitchens which does not contain human or animal excreta while blackwater is wastewater generated in toilets. This means that the wastewater content varies from large floating material such as toilet paper, to small suspended particles and dissolved substances(Von Sperling, 2015). Besides the fats, proteins and carbohydrates that primarily make up faeces and urine, wastewater also contains great quantities of intestinal bacteria and parasites (Von Sperling, 2015). These can cause health problems for people if they end up in a water source. Wastewater contains elevated concentrations of nutrients, such as different forms of nitrogen, phosphorous, Sulphur and potassium (Jönsson et al. 2005). Faecal contamination is still the primary water quality issue in rivers, especially in many developing countries where human and animal wastes are not yet adequately collected and treated (Chapman, 1996).

2.5. Water Quality Assessment

Water quality assessment as defined by WHO and UNEP is the overall process of evaluating the physical, chemical and biological nature of the water (Chapman, 1996). Physicochemical variables have been well investigated in monitoring and assessment of rivers and streams (Postolache et al., 2012) .The need of water quality assessment is to verify whether the observed water quality is suitable for its intended uses, to determine trends in the quality of the aquatic environment and how that quality is affected by the release of contaminants due to anthropogenic activities, and/or by waste treatment operations (Chapman, 1996). As such, for one to assess the impacts of human activities on rivers, it involves the measurements of basic water quality parameters such as temperature, dissolved oxygen, Biochemical oxygen demand, pH, turbidity, electrical conductivity, chemical oxygen demand, nitrates,

oxidation-reduction potential and alkalinity (Hamid et al., 2016). Nonetheless, apart from water physico-chemistry, there are other techniques that can be used to assess human activities impacts such as biomonitoring and ecotoxicology (Odume, 2017).

The water physico-chemistry technique analyses physical and chemical conditions that are mostly influenced by human activities such as agriculture, domestic and industrial wastewater discharges, environmental engineering, and natural factors including geology and soils, hydrology, seasonal patterns, geomorphology, climate and weather. Some of the physico-chemical variables that are of interest in water quality assessments are DO, color, temperature, pH, electrical conductivity, turbidity, salinity, total dissolved solids, total suspended solids, water depth and discharge, chlorophyll, oxidation reduction potential, ammonia, ammonium, nitrate, chloride, oil and grease, biological oxygen demand (BOD), Chemical oxygen demand (COD), hardness and heavy metals such as lead, cadmium, zinc, arsenic, copper, iron and mercury (Bartram & Ballance, 1996). There are several instruments available that measure these variables include atomic absorption spectrophotometer (AAS) mostly for analyzing heavy metals, Silt Density Index (SDI) Testers, pocket TDS Testers, portable pH Meters, Digital Thermometers for testing water temperature, multi-probe aqua meter, hydrotest photometer, Turbidity Tube instrument, Secchi disks to measure water clarity (Clark, 2015). These instruments help water-resource managers to measure and analyze the concentrations of pollutants, to determine their fate and transport, as well as their persistence in the aquatic environment.

However, Odume (2017), argued that monitoring physico-chemical water quality variables has high analytical costs compared with other techniques and it provides little or no insights that detect ecological response of aquatic biota to water pollution caused by human activities. On the other hand, Vellemu (2017), stated that the water physico-chemistry alone is inadequate, combining this technique with biomonitoring makes it possible to monitor ecosystem health in order to detect ecological damages.

Additionally, biomonitoring and physico-chemistry approaches alone do not explain other important intrinsic effects or responses of organisms to toxicants such as mortality rate or percentage mortality with respect to time. According to United

States Enviromental Protection Agency (2002), it is ecotoxicology techniques that provide a more time-integrated indication of the consequences of toxicants on organisms. Ecotoxicology. This involves experimental manipulation to establish an evidence-based cause-effect relationship between the toxicant and the observed effects on the organism such as fish. The approach to aquatic ecotoxicology is the single-species tests in the laboratory. Depending on the duration of the exposure and the endpoints measured, these tests are termed acute or chronic (Odume, 2017). Acute toxicity tests are short term, usually lasting between 48 and 96 hours, measuring mortality as an endpoint. Chronic toxicity tests last longer to measure long-term mortality, sub-lethal effects on organismal attributes such as growth, reproduction, behavior, enzymatic activities and histology (Mensah et al., 2015). According to the United States Enviromental Protection Agency (2002), equipment that are used for carrying out ecotoxicology tests include Volumetric flasks and graduated cylinders that are made of borosilicate glass or non-toxic plastic lab ware for making test solutions, volumetric and serological pipets, fillers, droppers, and glass tubing for transferring test organisms, wash bottles for rinsing small glassware and instrument electrodes and probes, glass or electronic thermometers for measuring water temperature continuously, pH, DO, and specific conductivity meters for routine physical and chemical measurements and refractometer for measuring effluent, receiving, and test solution salinity.

2.6. Water quality variables

2.6.1. Physical and chemical water quality variables

(a) pH determines the acidity or basicity of an aqueous solution. It measures the availability of protons for the exchange between chemical species. pH of water is mostly tested in situ. If this is not possible, for example, with well water or when access to a lake or river is very difficult, the measurement should be made immediately after the sample has been obtained (Bartram & Ballance, 1996)

(b) dissolved oxygen (DO), its measurement provides a good indication of water quality. Changes in dissolved oxygen concentrations can be an early indication of

changing conditions in the water body. Oxygen deficiency is fatal to many aquatic animals such as fish (Tessema, 2000)

(c) Oxidation-Reduction Potential, measures the availability of electrons for the exchange between chemical species. It also measures the ability of a lake or river to cleanse itself or break down waste products, such as contaminants and dead plants and animals. When the ORP value is high, there is lots of oxygen present in the water. In general, the higher the ORP value, the healthier the lake or river is. ORP is measured in addition to dissolved oxygen because ORP can provides additional information of the water quality and degree of pollution (Weiner, 2007)

(d) Total Dissolved Solids (TDS) indicates the amount inorganic salts and small amounts of organic matter dissolved in water. In natural waters, the major contributors to TDS are carbonate, bicarbonate, chloride, sulphate, phosphate, and nitrate salts. Taste problems in water often arise from the presence of high TDS levels with certain metals present, particularly iron, copper, manganese, and zinc (Weiner, 2007). In bodies of water, like rivers, higher levels of TDS often harm aquatic species skin as a result of dehydration,

(e) Turbidity is a measure of the clarity of water. Turbidity in water is caused by fine suspended matter such as clay and silt along with small grains of organic and inorganic matter. Also, other microscopic organisms can increase turbidity. As turbidity increases, it reduces the clarity of water to transmitted light by causing light to be scattered and adsorbed. Elevated turbidity in river can signal pollution events in the catchment(Tessema, 2000)

(f) Salinity, it is usually measured as TDS and electrical conductivity. It is mostly a direct reflection of all activities in catchment areas such as mining and agriculture. The use of fertilisers can lead to an increase in water salinity. Salinity has significant impacts on the ecological integrity of freshwater ecosystems. At high concentrations, salts become toxic (Kefford et al., 2002)

(g) Water temperature, it is critical because aquatic organisms as fish and plant metabolism depends on this parameter(Bartram & Ballance, 1996). This variable

influences rates of chemical and biological processes. For instance, the solubility of gases such as oxygen and carbon dioxide as well as the biodegradation of organic material in water and sediments. Most aquatic organisms live in an optimal temperature range of 5-25 degrees Celsius (Weiner, 2007)

(h) Nitrates concentration in unpolluted surface water is normally low (0–18 mg/l) but can reach high levels as a result of agricultural runoff or contamination with human or animal wastes (Tessema, 2000). In waters and wastewaters, the forms of nitrogen of greatest interest are nitrate, nitrite and ammonia (Ullberg, 2015). Nitrate, the most highly oxidized form of nitrogen compounds, is commonly present in surface and ground waters, because it is the end product of the aerobic decomposition of organic nitrogenous matter. Significant sources of nitrate are chemical fertilisers from cultivated land and drainage from livestock feedlots, as well as domestic and some industrial waters. In surface water, nitrate is a nutrient taken up by plants, especially algae. This may cause water quality problems associated with eutrophication. The subsequent death and decay of algae produces secondary effects on water quality such as reduction in dissolved oxygen (Weiner, 2007)

(i) Electrical conductivity (EC) is the ability of water to conduct an electric current. The conductivity of a liquid is related to the concentration of dissolved salts, a potential salinity hazard. The measurement should be made in situ, or in the field immediately after a water sample has been obtained, because conductivity changes with storage time(Bartram & Ballance, 1996). By measuring EC, it helps in understanding how much ionic minerals such as sodium, chloride, magnesium, sulphate and calcium are in water. Ions increase the water's ability to conduct electricity. However, some of these minerals are harmful to aquatic life and to humans, especially at high concentrations (Tessema, 2000)

(j) Ammonia, is produced when nitrogenous organic matter is destroyed by microbiological activity. It is important to monitor ammonia because its higher concentrations indicate water pollution by sewage, fertilisers, agricultural wastes or industrial wastes containing organic nitrogen, free ammonia or ammonium salts (Weiner, 2007). Certain aerobic bacteria convert ammonia into nitrites and then into

nitrates. Nitrogen compounds, as nutrients for aquatic micro-organisms, may be partially responsible for the eutrophication of lakes and rivers (Tessema, 2000).

2.6.2. Biological water quality variables

(a). Total coliforms (TC) encompass both pathogenic and non-pathogenic micro-organisms (Pullanikkatil et al., 2015). It is a broad indicator of possible water contamination. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 °C. Total coliform bacteria without the presence of E. coli are generally not considered harmful, but their presence indicates a potential pathway for contamination to enter water (Chapman, 1996)

(b). Faecal coliforms (FC) are an indicator of water contamination with faecal matter and other warm blooded animals (Clark, 2015). The common lead indicator is the bacteria Escherichia coli or E. coli. E. coli are thermotolerant and disease-causing pathogens (Weiner, 2007). Samples for microbiological testing are very prone to changes during transport and storage as such they have to be preserved in a cool room. Almost all kits for testing for thermotolerant coliforms are based on the membrane filtration method (Bartram & Ballance, 1996).

2.7. Biomonitoring approach using SASS5

The SASS5 is a rapid bio-assessment index based on the presence or absence of selected families of aquatic macroinvertebrates and their perceived sensitivity or tolerance to deteriorating water quality. Some of the materials that are required for the biomonitoring technique mostly in rivers and streams are white trays, pipettes, magnifying lens, forceps, buckets, waders, SASS mesh nets life jackets, field identification book and a SASS sensitivity sheet (Dickens & Graham, 2002). In South Africa, biomonitoring approach is a relatively recent approach and therefore data are sparse (Vellemu, 2017). In SASS5, macroinvertebrate families are given scores in the range of 1–15 in increasing order of sensitivity to deteriorating water quality. Families considered sensitive are presented with high scores and those considered tolerant low scores. The results are expressed both as an index score, that is, SASS5 score, and as an average score per recorded taxon (ASPT) value. The SASS5 score is calculated by summing the scores of all recorded families, while the ASPT value is

obtained by dividing the total SASS5 score by the number of families recorded. In addition to being a useful water quality assessment index, SASS5 is used to assess emerging water quality problems, development impacts, ecological state and spatial-temporal trends of biological assemblages. The biomonitoring method was designed for low and moderate flow hydrology and not applicable for wetlands, estuaries or other lentic habitats or assessing the ecological state of aquatic,(Dickens & Graham, 2002). Aquatic macroinvertebrates are mostly used for this method. These aquatic macroinvertebrates play a key role in nutrient cycling in aquatic ecosystems because they are the primary processors of organic materials. Some studies have suggested that aquatic macroinvertebrates are responsible for processing up to 73 percent of the riparian leaf litter that enters a stream as source of food for their growth and survival (Covich et al. 1999).

2.8. Land-use survey

Land use survey is the study that involves recording the way in which land is being used in an area (Lao-Swedish Forestry Program, 1997). Land use is classified into for types as recreational, transport (roads, railways, airports), agricultural (farmland), residential and commercial (businesses, markets and factories). Land use survey is carried out to collect data on the type and distribution of land use in an area. According to Bartosh (2012), he stated that there are three methods that can be used in land use surveying such as ground survey, air survey and satellite survey. Most studies that conduct ground survey methods, use a GPS meter to obtain data that can be integrated into GIS technologies in order to develop a land use map (Bartosh, 2012). Land use maps of an area provide information that can help users such as water managers to understand the current landscape surrounding ground and surface water resources. Land use information enables the monitoring of temporal dynamics of agricultural ecosystems, forest conservations as well as surface water bodies. To make a land use map, an application for instance ArcGIS can be used. ArcGIS is a geographic information system for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI)(Heywood et al., 2006). In a study done by Malin Ullberg (2015), the author used land use survey

techniques to understand current anthropogenic factors affecting water quality in the middle section Likangala River, where it flows through Zomba city (Ullberg, 2015).

3. CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter will discuss the about the study area, research design and methods that were employed for sampling, data collection and analysis in order to achieve the specific objectives. The data for this study was obtained at Nasolo River in Ndirande through, land use and activities survey, insitu water quality parameter testing, bio-monitoring and laboratory analysis. Furthermore, the data was analysed using Microsoft Excel and a Minitab application

3.2. Study Area

The study took place at Nasolo River. Nasolo River originates from Ndirande Mountain, an area with the highest population in Blantyre and feeds into Mudi River. It is surrounded by peri-urban areas; it passes through markets, sand mining sites, agricultural fields and industries. The industries discharge effluents into nearby streams. The most important economic activities of this study area are retail trade, construction, manufacturing of food products, transport, textile manufacturing, motor vehicle sales and maintenance, and public administration (UN-HABITAT, 2011). This area has a monsoon-influenced humid subtropical climate. It is located at latitude 15^0 45' 18" S and longitude 35^0 3' 26" E. Figure 1 below shows the map of the study area:

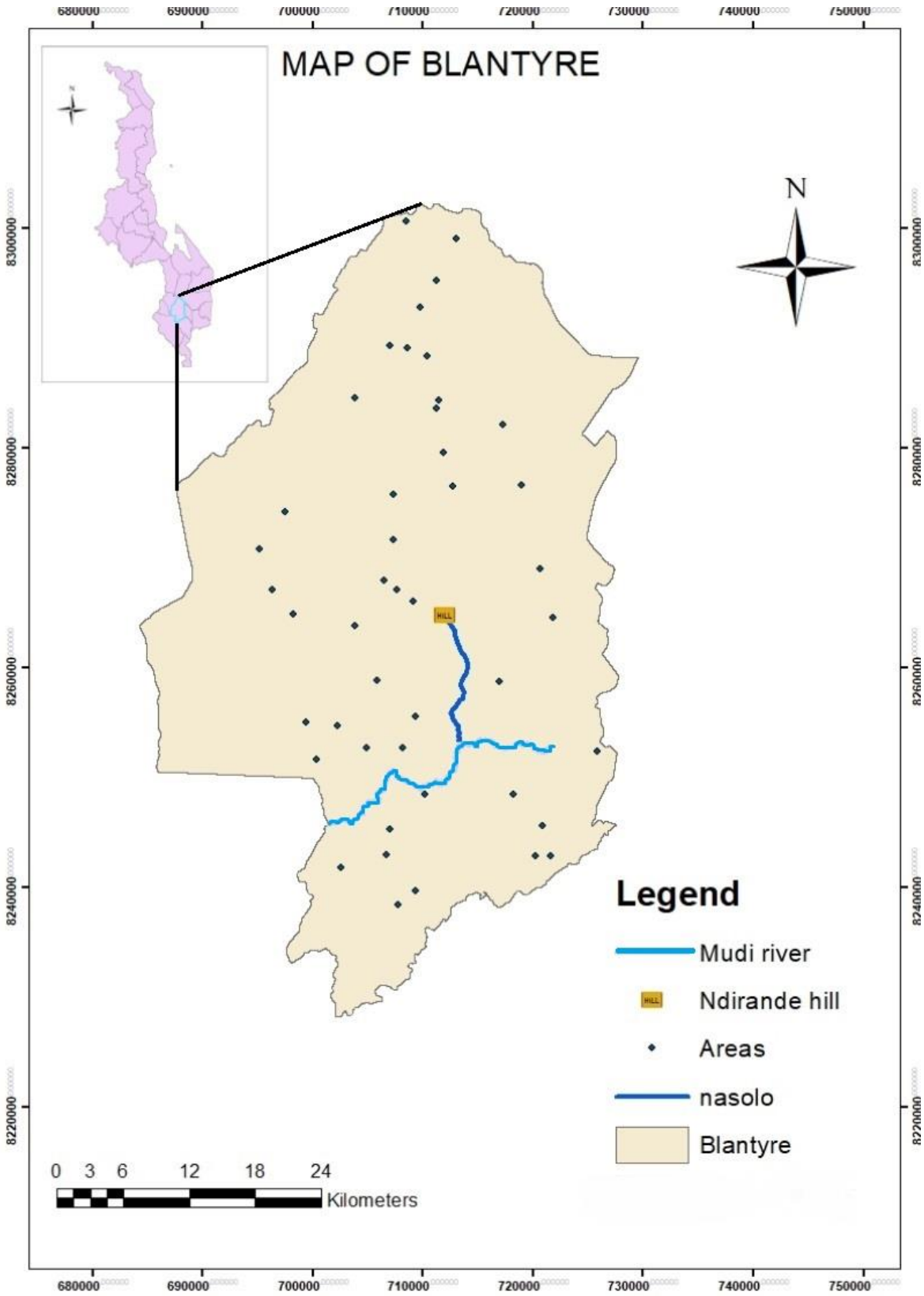
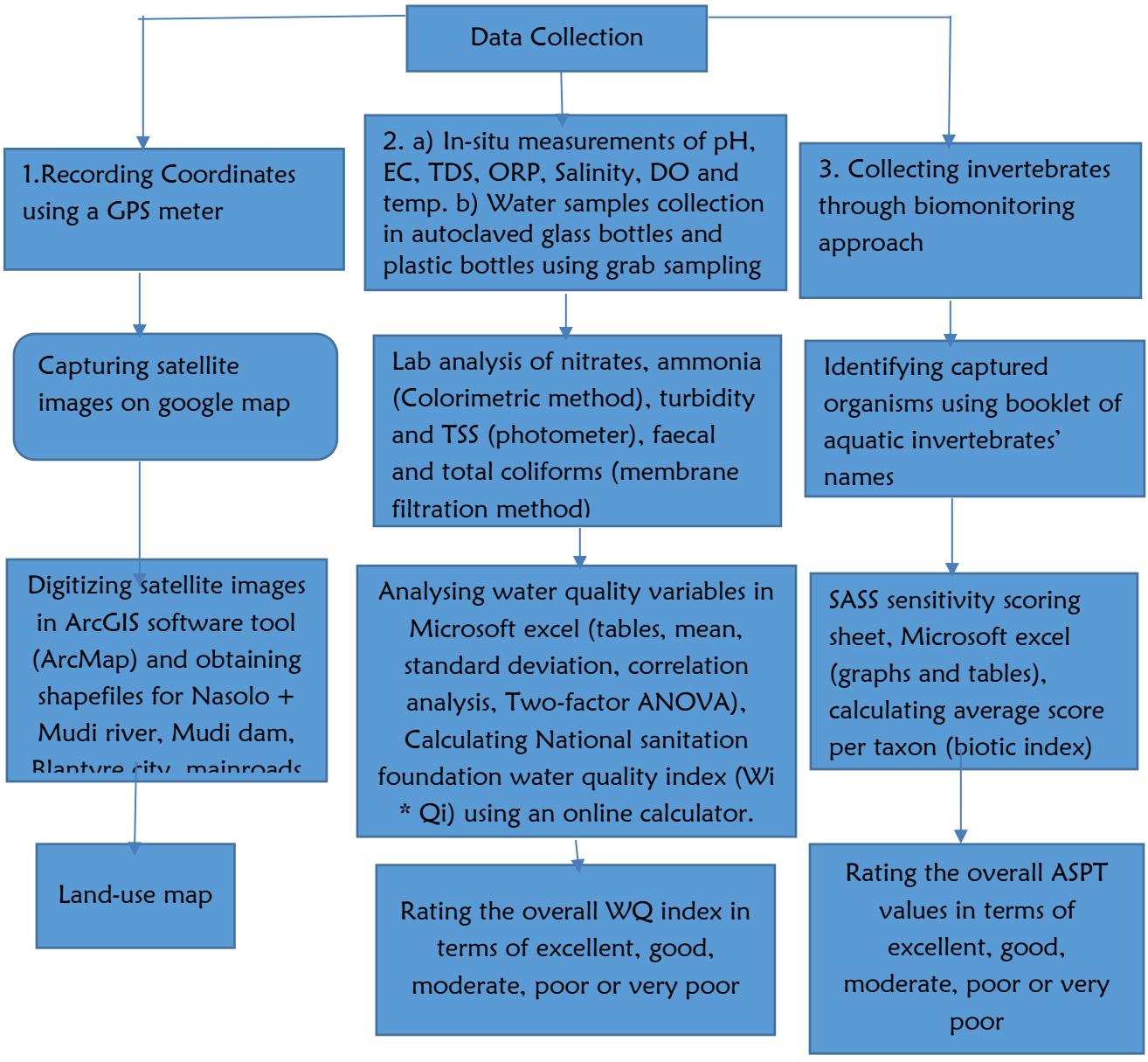


Figure 1: Map showing the study area

3.3. Research Design

This study used a quantitative design and it involved a descriptive cross-sectional study within the river area through field observations, land use and activities survey, insitu water quality parameter testing, bio-monitoring and laboratory analysis. Below is the flow diagram for the methodology.



3.4. Sampling

Sampling points were selected using purposive sampling. The sampling points were chosen based on their accessibility and proximity to pollution sources such as market area, agricultural site, industrial site and sand mining site. Samples of water were

collected in polyethylene and glass bottles using standard methods (APHA et al., 2001).

3.5. Materials

Materials used for this study were as follows; a pH/ORP portable electronic meter, DO/temperature portable electronic meter, multi-probe aquameter probe, hydrotest photometer, GPS meter, polyethylene bottles, SASS mesh net, white trays, pipettes, magnifying lens, forceps, buckets, waders, antiseptic soap, a bottle of clean tap water, field identification book and a SASS sensitivity sheet.

3.6. Data collection

Sampling was done in the month of April 2021. The data collected was both numerical and categorial. Water samples were collected from selected points along Nasolo River using the method of grab sampling. Firstly, water samples were collected to measure pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), nitrates, ammonia, salinity, temperature, faecal coliform and total coliform. Secondly, coordinates were recorded and benthic macroinvertebrates samples were collected from the river. As such, the data for this study was obtained through, land use and activities survey, insitu water quality parameter testing, bio-monitoring and laboratory analysis.

3.6.1. Land use and activities survey

Initially coordinates of all sampling points were recorded using a GPS meter. In order to come up with a land use map, a reconnaissance tour of the study area was undertaken. The tour was conducted on foot, covering most of the study site. Activities of land use in direct proximity to the river (within 100 metres) were observed. GPS-points were taken for later construction of a map using ArcGIS software. During this tour, suitable locations along the river were purposefully selected, for an analysis of human activities impacts on the water quality of Nasolo River. Lastly, the distance was measured in ArcGIS. According to the standard methods by APHA, Global positioning Systems (GPS) was used to supply accurate sampling position data. (APHA. 2001)

3.6.2. Physico-chemical water quality variables in-situ analysis

In order to obtain quantitative information on the physical and chemical water quality variables of water in Nasolo River, grab sampling was done. values of pH, electrical conductivity, total dissolved solids, oxidation-reduction potential, salinity and temperature were recorded insitu by immersing a multiparameter Aqua-probe meter model AP-700 (DO/EC/pH/ORP/Temp/Sal/TDS) into the river. The readings were recorded on paper after two minutes when the meter had stabilized. In situ data was required to aid the interpretation of other water quality results that were analysed in the school's laboratory. Before using the probe, the DO electrode it was firstly calibrated using a RapidCal DO and FullCal calibration method (see Appendices 1A,1B,1C). Standard analytical methods were used for the determinations of all the parameters were followed from the details of collection of samples on part 1000 section 1060 B that (APHA, 2001) and a Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes was also used to provide standard methods for sampling physico-chemical parameters (Bartram & Ballance, 1996).

3.6.3. Standard biomonitoring techniques

In order to assess macro-invertebrates in Nasolo River, the aquatic invertebrates were sampled by a SASS net on a sandy and vegetative habitat. Kick sampling was carried out. First of all, when undertaking the biomonitoring technique, a wader was worn for protection. Then, a net was rested on the bottom of the stream at right angles to the current to collect the invertebrates. The substratum was vigorously disturbed by kicking with the heel of a boot to dislodge the fauna for the organisms to be easily trapped, and then they were allocated into a water filled tray in order to be identified using a booklet of aquatic invertebrates and counted. This method was done according to a guide on use of biota, sediments and water in environmental monitoring (Chapman, 1996) and according to the South African Scoring System (SASS) Version 5 Rapid Bio-assessment Method for Rivers (Dickens & Graham, 2002)

3.6.4. Laboratory Analysis

Water samples for analysing nitrates, ammonia, turbidity and total suspended solids were collected in polyethylene bottles that were rinsed several times with distilled

water. Three samples were collected at each point. Bottles containing water samples were all labelled. Water samples required for microbial analysis were also collected in grass bottles that were sterilized by autoclaving them at a temperature of 121°C for 15 minutes in an oven. The glass bottles were preserved in ice at 4°C. Then, the samples were taken to the laboratory for more analysis of physico-chemical water quality variables. Turbidity and TSS were tested using a hydrotest photometer Model WSL50 Pro, nitrates and ammonia were measured by colorimetric method using a hydrotest photometer. To obtain microbial data for Nasolo River, faecal coliform was measured using a membrane filtration method. All analytical methods and procedures that were done followed details in the Standard Methods for the Examination of Water and Wastewater on part 1000 section 1060 B about collection of data and section 1060 C about sample storage and preservation (APHA et al., 2001). Below are the procedures that were followed

3.6.4.1. Determinations of turbidity and total suspended solids using the photometer

The hydrotest photometer HT1000 was used to analyse turbidity and TSS without use of colouring reagents. Firstly, a clean vial will be filled with a 10 ml of deionized water and closed tightly with a cap, and then the vial was placed on the photometer chamber aligning the marks and the zero key was pressed setting the photometer to give turbidity values. Water samples were then poured in the vial and the vial was placed on the photometer chamber to obtain values of turbidity by pressing the test key. For TSS, deionized water was used again to set the photometer to give TSS values by pressing the zero key. The water samples were also filled in the vial that was placed on the photometer chamber to obtain TSS values by pressing the test key.

3.6.4.2. Determination of ammonia using the hydrotest photometer

Firstly, a clean vial will be filled with a 10 ml of deionized water and closed tightly with a cap, and then the vial was placed on the photometer chamber aligning the marks and the zero key was pressed setting the photometer to give ammonia values. The vial was then removed from the sample chamber, another vial was filled with 10ml of water sample, one AMMONIA No. 1 tablet was added straight from the foil to the water sample in a vial and the tablet was crushed using a clean stirring rod,

another tablet labelled AMMONIA No. 2 was added straight from the foil to the same water sample and it was crushed using a clean stirring rod, the vial was tightly closed with the cap and swirled several times until the tablets got dissolved, the vial was placed on the photometer aligning the marks, then the test key was pressed to begin the analysis and after 10 minutes of waiting, the reaction was finished and the values were provided on the photometer screen and were recorded.

3.6.4.3. Determination of nitrates using the HT1000 photometer

A clean vial was filled with 10ml of deionized water and it was closed tightly with a cap and then placed in the sample chamber by aligning the marks. The ZERO key was pressed to set the photometer to give nitrates readings. The vial was emptied. A nitrate test tube was filled with 20ml of the water sample, then a one level spoon of nitrate test powder was added. The tube was tightly closed with its cap and the sample was swirled vigorously for a minute and the tube was left to stand upright for the reagents to settle. Furthermore, the tube was gently inverted for three times and was left again to stand upright for 2 minutes. Later on, 10ml of the prepared sample in the tube was poured into the clean vial, then one NITRITE LR tablet was added straight from the foil to the water sample and was crushed using a clean stirring rod. The vial was then placed on the photometer chamber and the TEST key was pressed. After 10 minutes of waiting for the reaction period, the photometer gave the nitrate reading and it was recorded.

3.6.4.4. Determination of faecal coliform and total coliform using membrane filter technique

Firstly, the area that was used for the determination of total and fecal coliforms and all materials that were used such as a pair of forceps, petri dishes, filtration apparatus were sterilized using alcohol. Secondly, absorbent pads were added onto petri dishes, the pads were then soaked in a nutrient medium called Lauryl Sulphate Broth. Thirdly, sterile membrane filters were removed from their packages with a sterilized pair of forceps and placed on the filtration apparatus, then a desired volume of water samples were mixed and poured into the filter funnel. A vacuum was then be applied to the suction flask and the water samples were drawn through the filter. Fourthly, the filtration apparatus was dismantled to remove the filters using sterile forceps

touching only the edge of the filters. Furthermore, the filters were pressed in the prepared petri dishes. The petri dishes were labelled with sample numbers S1, S2, S3, and S4 and were left to resuscitate for 30 minutes and then those petri dishes prepared for determining fecal coliform were incubated at 44^0c for 18 hours. Whereas, those prepared petri dishes for determining total coliform were incubated at 37^0c for 24 hours. After incubation, the colonies for fecal coliform formed tiny yellow spots and were counted on a bacteria colony counter machine. Thereafter, colonies for total coliform formed tiny pink spots and were also counted. The results were then expressed as number of colonies per volume filtered.

3.7. Data Analysis

Data was analysed using Microsoft Excel statistical package to calculate mean and standard deviation of water quality variables that were measured in triplicates at each sampling point (see Appendix 2A). Firstly, the results of this study were presented in a table by arranging water quality variables data in rows and four different sampling points in columns. Secondly, using a Minitab application, a trend analysis was carried out to present physico-chemical and microbiological water quality data in boxplots. This was done to show the spatial distribution of water quality variables at various sampling points in the river catchment area. In addition, an ANOVA: two-factor without replication for the water quality variables at all four sampling sites was carried out to test the null hypothesis and to find their p-values that showed the variables level of significance at four sampling sites', whereby $p<0.05$ means statistically significant and $p>0.05$ means not statistically significant.

Standard methods that were acquired for determining water samples used the international system of units (SI). The concentration units for chemical and physical results were expressed in mass units/L mostly in milligrams per litre (mg/L). the turbidity results were also expressed in Nephelometric Turbidity Unit (NTU), temperature in Degree Celsius (symbol: °C), salinity in Parts per thousands (ppt) and electrical conductivity in microsiemens per centimetre (µS/cm) (APHA, 2001). Then the results were compared with the USEPA and MoAIWD surface water quality standards.

Thirdly, the obtained data for physico-chemical and microbiological water quality variables was interpreted by correlation analysis to quantify the degree to which two variables are related and to show if two variables have a positive or negative linear relationship. Furthermore, the physio-chemical and microbiological data were also analysed using the National Sanitation Foundation Water Quality Index (NSF-WQI).

Water Quality Index (WQI) was applied for Nasolo River using seven water quality parameters (pH, dissolved oxygen, turbidity, nitrates, total dissolved solids, temperature and fecal coliform). The relative weight assigned to each parameter ranged from 0.08 to 0.17 based on the importance of the parameter for aquatic life and human consumption (Mirzaei et al., 2016)

Table 1: Water quality variables and their weight in NSFWQI index

Variables	Weight
Dissolved Oxygen (% saturation)	0.17
pH	0.12
Total dissolved solids (mg/L)	0.08
Temperature (°C)	0.10
Nitrates (mg/L)	0.10
Fecal Coliform (CFU/100mL)	0.15
Turbidity (NTU)	0.08

*This table has been adopted from the online software of NSFWQI calculator (http://home.eng.iastate.edu/~dslutz/dmrwqn/water_quality_index_calc.htm)

After obtaining the weights (Wi) for the different parameters, quality values (Q-Value) for each parameter were obtained from the mean values of the water quality analytical data and the seven reading curves for each parameter, whereby the x-axis had values of water quality variables and the y-axis had Q-values ranging from 0 – 100 (see graphs in the appendix 2B). After finding the Qi ratings for each parameter, the overall water quality index was then calculated by using the formula below:

$$\text{NSF-WQI} = \sum_{i=1}^{n}(Wi * Qi)$$

The index has a value between 0 and 100 which rates the water quality to excellent (90-100), good (70-90), moderate (50-70), bad (25-50) and very bad (0- 25) situations based on the NSF-WQI index calculated. This index decreases with increasing pollution

Fifthly, the collected organisms on white trays were analysed using a south African booklet of aquatic invertebrates so as to identify the organisms and a SASS sensitivity scoring sheet was used to score them based on their resistance or susceptibility to pollution. After scoring, a total score was calculated by summing up the sensitivity score for each group of organisms and then the total score was divided by the total number of groups present at each sampling points to calculate the average score. The average score was then compared to the ecological category table in order to define the status of the river in terms of excellent, good, fair, poor or very poor.

Table 2: Shows groups of macroinvertebrates with their sensitivity scores

GROUPS	SENSITIVITY SCORE
Flat worms	3
Worms	3
Leeches	2
Crabs or shrimps	7
Stoneflies	14
Minnow mayflies	6
Other mayflies	13
Damselflies	4
Dragonflies	7
Bugs or beetles	6
Caddisflies	9
True Flies	2
Snails	4
TOTAL SCORE = $\sum(Sensitivity\ \mathrm{score})$	
NUMBER OF GROUPS	
AVERAGE SCORE = $\frac{\sum(Sensitivity\ \mathrm{score})}{\mathrm{Number\ of\ groups}}$	
WATER QUALITY STATUS	

After calculating the average score biotic index, this was interpreted on the table below:

Table 3: Ecological category or condition of a river

Ecological category (Condition)	River Category (Sandy Type)
Unmodified (**NATURAL** condition)	>6.9
Largely natural/few modifications (**GOOD** condition)	5.8 to 6.9
Moderately modified (**FAIR** condition)	4.9 to 5.7
Largely modified (**POOR** condition)	4.3 to 4.8
Seriously/critical modified (**VERY POOR** condition)	<4.3

In addition, correlation analysis as well as paired t-Test two tailed for the national Sanitation foundation Water Quality Index and SASS average score per taxon (biotic index) was carried out using Excel. Lastly, a land use map was created using ArcGIS software showing the four sampling sites and the human activities occurring near those sampling sites along Nasolo River.

3.8. Study limitations

Water quality assessment in this study was conducted during rainfall period in April. This may have resulted in low concentrations of some pollutants as they dilute due to high discharge. High velocity of water in the river may have also caused the population of some aquatic species that were studied during the research to decrease.

4. CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Land use survey

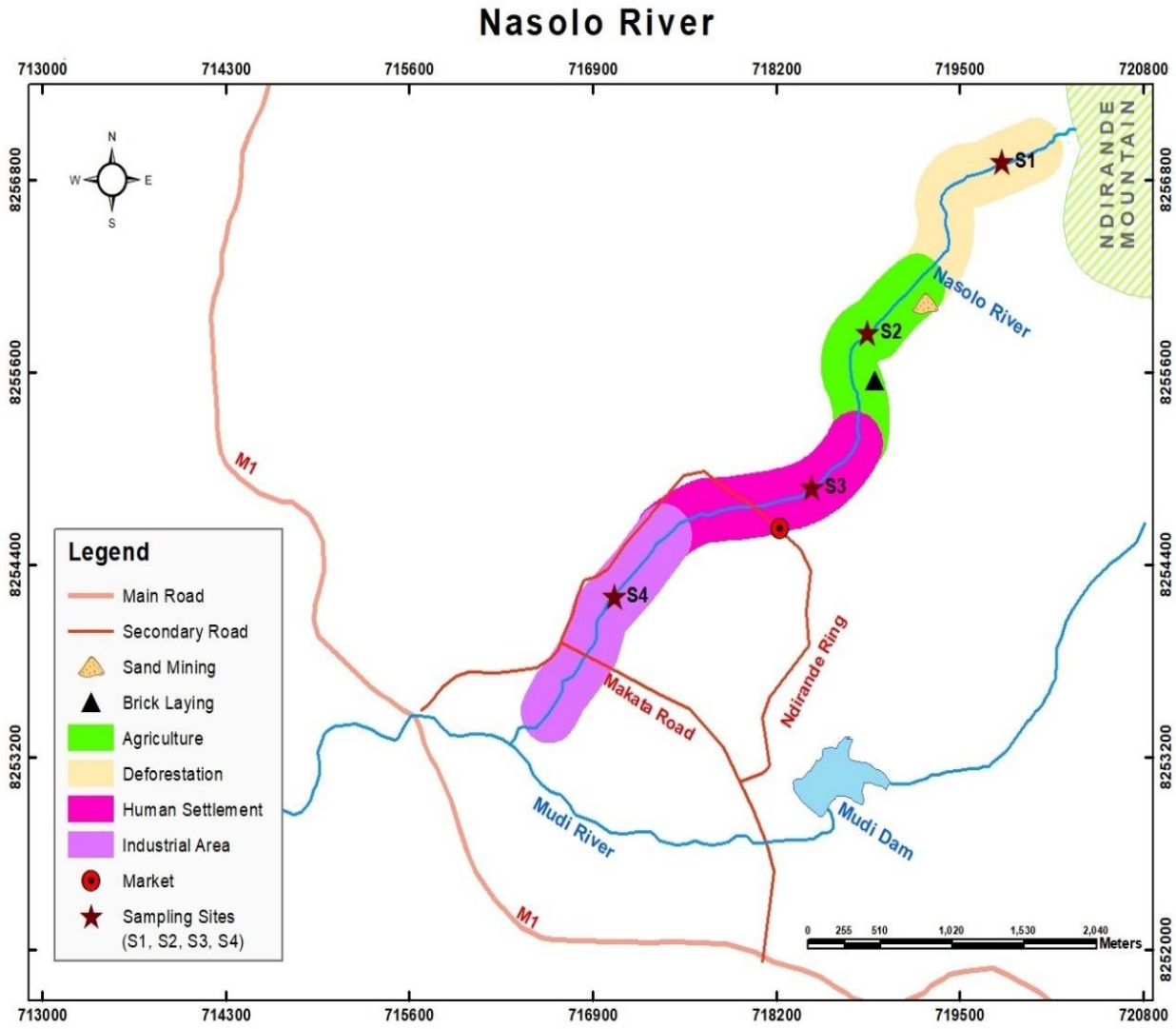


Figure 2: Land use map showing sampling sites and human activities along the river

According to the Figure 2, the map shows that at the upstream of Nasolo River as it flows from Ndirande Mountain (Sampling site 1), there is deforestation taking place. Deforestation leads to siltation and widening of the river channel (Masese et al., 2014). As such, resulting in high turbidity and total suspended solids. The second activity is agricultural production. This site was surrounded by maize crops, tomato, sugar cane and banana plantations. Hence high levels of nitrates and ammonia due to application of inorganic fertilizers (Weiner, 2007). At this site it was also surrounded by sand mining and bricklaying. This may have resulted in high turbidity, conductivity and increased levels of total suspended solids (Ashraf et al., 2011) The

third site was dominated by human settlements. This site was also surrounded by a market area. This may have resulted in high amounts of both faecal and total coliform, low dissolved oxygen, high turbidity and conductivity, increased levels of TSS and TDS due to wastes such as plastics, organic food material for instance, fruits and vegetables and domestic wastewater from pit latrines, bathrooms, dish washing and laundry (Von Sperling, 2015). Lastly, at the downstream of Nasolo River (Sampling site 4), the map shows that it is surrounded by an industrial area known as Makata (UN-HABITAT, 2011). This may have led to high levels of EC, salinity, turbidity, TDS and TSS due to the discharge of industrial effluents without proper treatment (Mumba et al., 2005).

4.2. Physico-chemical and microbiological analysis of water quality variables

After carrying out a two-factor ANOVA, all physico-chemical and microbiological water quality variables at different sampling sites (S1, S2, S3 and S4) obtained a p-value. The results showed that, the sampling sites were significantly different from each. The p-value was less than 0.05 ($p=0.005$). This means that the null hypothesis was tested to be untrue since there is strong evidence against it.

Table 4 below shows the mean values for water quality variables obtained in Nasolo River sampled at four points and table 5 show the correlation between water quality variables.

Table 4: Mean values for physio-chemical and microbiological water quality variables

	SAMPLING SITES					
Water quality variable	S1	S2	S3	S4	EPA acceptable limit	MoAIWD acceptable limit
pH	7.42±0.3	7.7±0.2	6.4±0.1	6.5±0.6	6.5-9	6.5-9
Temperature(°C)	19.47±0.2	21.8±0.4	23±0.7	23.8±0.5	20	Guideline value not stated*
Dissolved Oxygen (mg/L)	5.2±0.3	3±0.2	2.1±0.3	2.2±0.3	4-5	5
ORP (millivolts)	6.27±2.6	-5.7±0.6	-11.6±13.2	-5.7±3.0	Guideline value not stated*	Guideline value not stated*
EC (μS/cm)	71.67±49.8	522.3±134.4	463±13.9	1896. 7±72.2	<500	-
TDS (mg/L)	53.00±32.4	363.3±50.6	300.3±9.1	1234±43.5	<600	-
Salinity (ppt)	0.03±0.0	0.3±0.0	0.2±0.0	1.0±0.1	0.5	-
Turbidity (NTU)	10±0.3	51±0.6	23±1.2	38±0.6	<5	<5
Suspended Solids (mg/L)	14±1.1	52±0.6	22±0.6	23±0.6	20	30
Fecal Coliform (CFU/100mL)	10±5.0	1464±30.7	1966±80.2	618±163.1	15-20	50
Total Coliform (CFU/100mL)	126±36.2	2050±427.2	2313±300.9	1343±126.6	500	-
Nitrates (mg/L)	20±1.0	68.9±1.3	27.2±2.9	32.9±9.2	50	-
Ammonia (mg/L)	2.27±0.8	4.1±0.3	3.1±0.7	5.6±0.4	Odor threshold = 1.2 mg/L	-

4.2.1. Physico-chemical water quality analysis

According to Weiner (2007), the pH of pure water at 25^{0}C is 7. However, the pH changes may be as result of dissolved CO_2 and exposure to minerals. Based on table 4, the pH values for sampling sites 1, 2 and 4 ranged from 6.5 to 7.7. They were within the EPA and MoAIWD water quality standards of pH range from 6.5-9 (USEPA, 2002). The pH of Nasolo River at S1 and S2 may have been slightly raised from 7 to 7.7 due to loss of CO_2 by diffusion to the atmosphere or by consumption during photosynthesis of algae and other plants in the water. Except for sampling site 3 dominated by domestic wastewater and dumping of solid wastes from human settlements and wastes such us metal, plastic papers from market area, the pH value

was found to be slightly low (6.4±0.1). Plastics attracts contaminants such as heavy metals that can lower the pH. The pH may have also been slightly lowered due to the dissolution of CO_2 into the water by diffusion or from microbial respiration in the water. However, pH 6.4 may be considered harmless to aquatic species (Weiner, 2007).

Higher values for EC, TDS and Salinity were obtained at sampling site 4. Since TDS and EC show a degree of salinity. According to the results, its showed that the river was slightly saline. Since the TDS values were all less than 3000mg/L. (Weiner, 2007). For sampling sites 1, 2 and 3, the values for EC, TDS and Salinity were low. This may be as a result of dilution during rainy season.

Higher values for total suspended solids were obtained at sampling site 2, 3 and 4 beyond the EPA water quality standards for freshwater. These sites are dominated by human settlements, market, Makata industrial activities, sand mining, brick laying, laundry and agricultural activities. Suspended solids may have been elevated mostly at S2 (52mg/L) by human use for laundry activities and sand mining. Tessema (2000) argued that suspended solid materials make water aesthetically unpleasant and provide adsorption sites for chemical (nitrates and phosphates) and biological agents such as pathogenic micro-organisms. Nitrates levels were high at all sampling site 2 only beyond the acceptable limit of EPA (50mg/L) due to agricultural activities.

Higher values for turbidity and ammonia were obtained at all the four sampling sites. Turbidity ranged from 10 to 51 NTU. The typical values for rivers during a low-flow period are usually below 10 NTU(Tessema, 2000). In this case, Nasolo river obtained turbidity values above 10 NTU as a result of soil erosion that is greatly facilitated by deforestation and sand mining. Household and industrial wastes such as soaps and detergents may have also contributed to high turbid water. This leads to undesirable tastes and odours as well as providing adsorption sites for chemical and biological agents. Ammonia ranged from 2.27 to 5.6 mg/L. These values were above the odour threshold (>1.5 mg/l) calculated by WHO (Bartram & Ballance, 1996). Ammonia concentrations were high at sampling site 4 because of industrial discharge. This is not suitable for aquatic life.

Lastly, at Sampling site 1, the DO levels obtained were above 4mg/L and ORP value measured was positive. Whereas at sampling sites 2,3 and 4 after the upstream, the DO levels were decreased below 4mg/L and ORP values were negative. DO decreases as a result of degradation of biomass coming from dead algae, plant leaves and other organic matter and ORP decreases as a result of sewage and industrial wastes. According to Tessema (2001) DO values that range from 4.5 – 6.5 defines the river as moderately polluted while DO values below 4.0 states the river as severely polluted. In this case, sampling site 1 had DO level of 5.2 mg/L which means that its water quality was moderately polluted while the other sites 2, 3 and 4 had values that ranged from 2.1 to 3 mg/L which means that the water quality at these sites was severely polluted by human activities.

Furthermore, as stated by Weiner (2007), when the measured REDOX potential is positive, it indicates oxidizing or aerobic conditions. This means that there is sufficient DO present to allow the river to support many aquatic species and to have the ability to cleanse itself.

4.2.2. Microbiological analysis of water quality variables

Faecal coliforms level that was obtained at sampling site 1 was 10 CFU/100mL According to Weiner (2007), natural surface waters almost always contain some background level of faecal coliforms, usually less than 15–20 CFU/100mL. However, at sampling sites 2, 3 and 4, the levels of faecal coliforms ranged from 618-1966 CFU/100mL. The levels were above 15–20 CFU per 100mL. This indicated that the river is heavily polluted by faecal contamination as a result of pit latrines along the buffer zone of the river mostly as sampling site 3, which is dominated by human settlements. Total coliforms levels at sampling site 1 was 126 CFU/100mL. It was less than 500CFU/100mL which was acceptable. Total coliforms bacteria they occur naturally in plant material and soil (Peters et al., 2006). At sampling site 2, 3 and 4, the total coliform count were extremely high. The levels ranged from 1343-2050CFU/100mL. However, their presence does not necessarily indicate faecal contamination (Weiner, 2007).

4.2.3. Correlation analysis

Table 5: Correlation analysis for physico-chemical and microbiological water quality variables

	pH	Temperature	DO	ORP	EC	TDS	Salinity	Turbidity	TSS	Faecal Coliform	Total Coliform	Nitrates	Ammonia
pH	1												
Temperature	-0.72025	1											
DO	0.925318	-0.92108589	1										
ORP	0.60464	-0.25602841	0.536243	1									
EC	-0.52267	0.78826683	-0.64328	0.298491	1								
TDS	-0.50702	0.78635698	-0.63376	0.311395	0.999786	1							
Salinity	-0.43964	0.73384649	-0.56404	0.392305	0.994998	0.996185	1						
Turbidity	0.285831	0.45836279	-0.08328	0.449695	0.442696	0.460099	0.476003	1					
TSS	0.508367	0.18894867	0.146402	0.274653	0.014577	0.033367	0.04543	0.899157	1				
Faecal Coliform	-0.28508	0.52531596	-0.51308	-0.68599	-0.0913	-0.08947	-0.15778	0.327646	0.491558	1			
Total Coliform	-0.31817	0.70186547	-0.60726	-0.51263	0.167489	0.171759	0.109963	0.535988	0.593264	0.958824074	1		
Nitrates	0.668701	0.01432971	0.336905	0.435426	-0.05007	-0.02993	-0.00027	0.867774	0.977014	0.310739574	0.409018564	1	
Ammonia	-0.30864	0.79303633	-0.54213	0.385816	0.941803	0.948045	0.948923	0.718018	0.349514	0.066402964	0.34417703	0.284312	1

The results show that there was a strong positive relationship between pH and other variables above 0.5 such as DO (0.925), ORP (0.604), total suspended solids (0.5), and nitrates (0.66). According to the correlation analysis, salinity showed a strong positive relationship between EC and TDS with both having a Pearson coefficient of 0.99. The Pearson coefficient between TSS and nitrates indicated 0.98. This showed a strong positive relationship between suspended solids and nitrates. According to Weiner (2007), suspended solids act as a medium that continually carries nutrients and enables nutrients to remain in the water from long periods. As such, the higher the TSS, the more the concentrations of nutrients. According to the correlation analysis in table 5, turbidity and ammonia indicated a strong positive relationship of 0.7 meaning that as turbidity is high, it provides adsorption sites for chemicals such as ammonia that result in undesirable odour (Tessema, 2000). The relationship of DO and temperature showed a strong negative correlation (coefficient = -0.92) meaning that DO levels decreases as the temperature rises. Temperature values ranged from 19.7 to 23.8 degrees Celsius. The correlation analysis in table 5 indicated that temperature had strong positive relationship with EC, TDS, salinity, faecal coliform, total coliform and ammonia water quality variables. (Pearson coefficient

> 0.5). This shows that as temperature increases, it results in the growth of more bacteria and in an increase of ammonia, salinity, TDS and EC.

4.2.4. Trend analysis for the physico-chemical and microbiological water quality variables

Figure 3 : pH boxplot

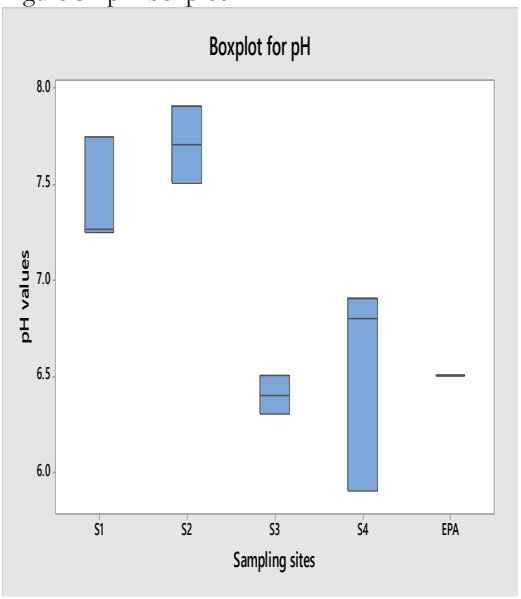


Figure 4 : Temperature boxplot

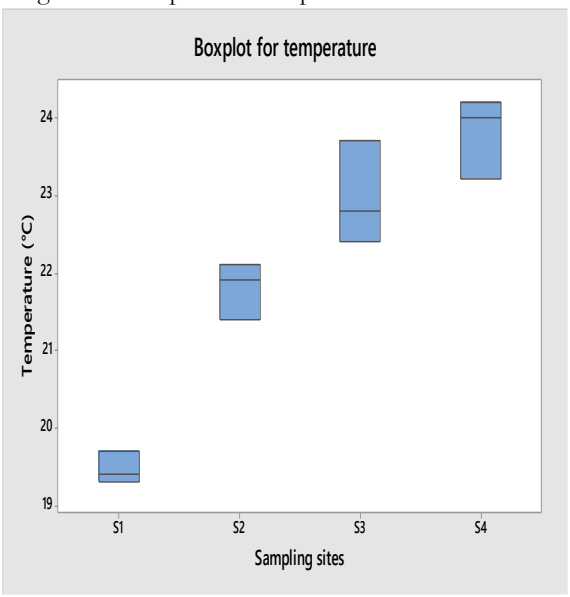


Figure 5: REDOX potential Box plot

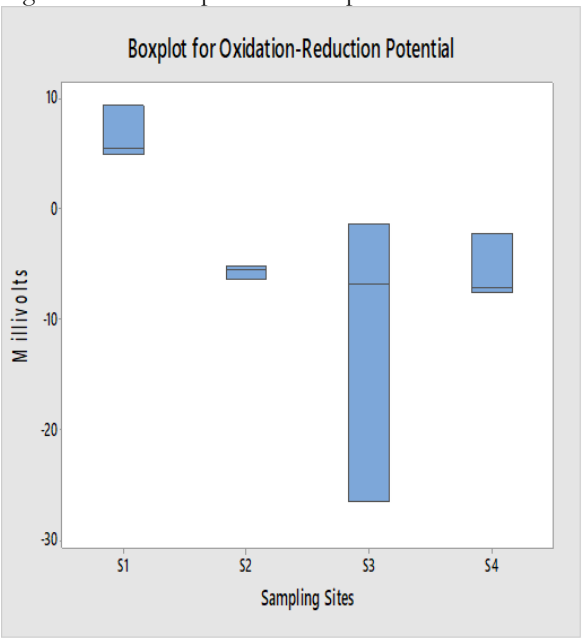


Figure 6: DO boxplot

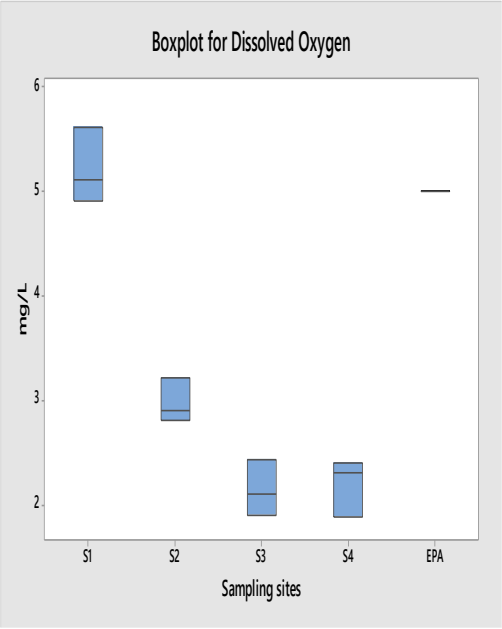


Figure 7: TSS boxplot

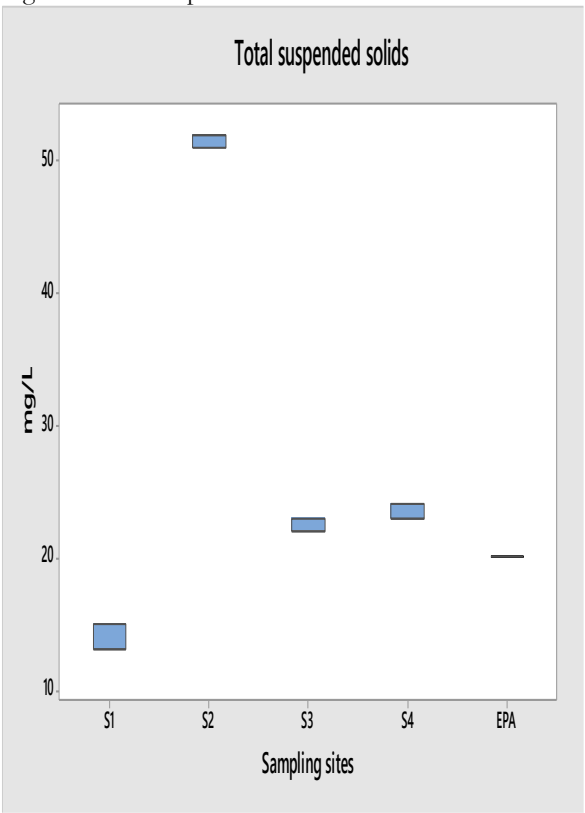


Figure 8: TDS boxplot

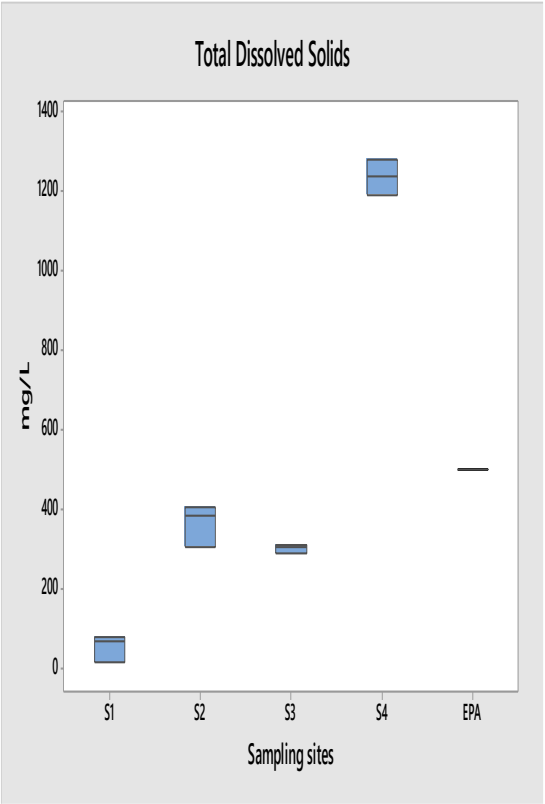


Figure 9: EC boxplot

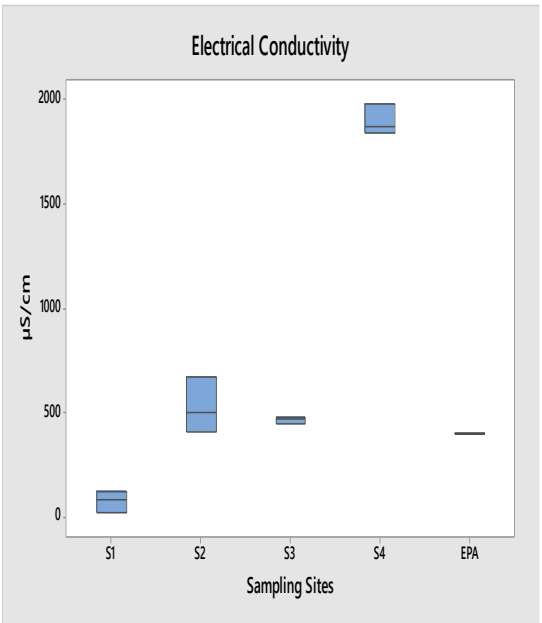


Figure 10: Salinity boxplot

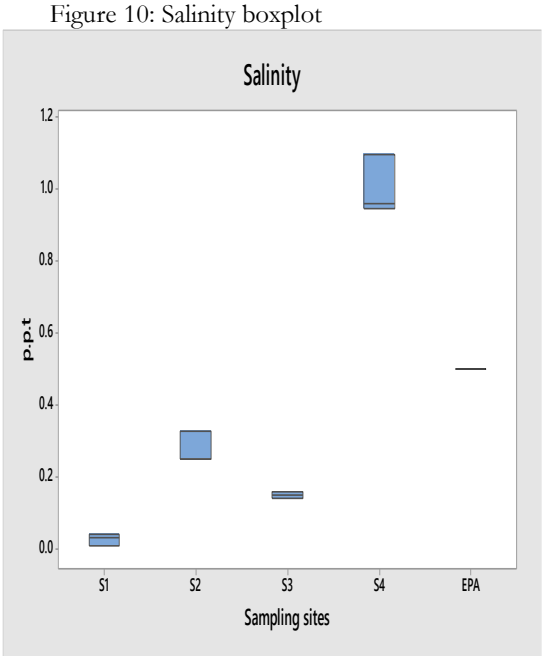


Figure 11: Nitrate boxplot

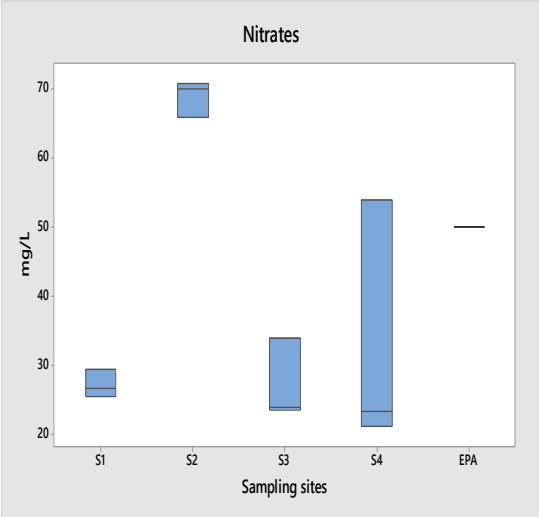


Figure 12: Ammonia Boxplot

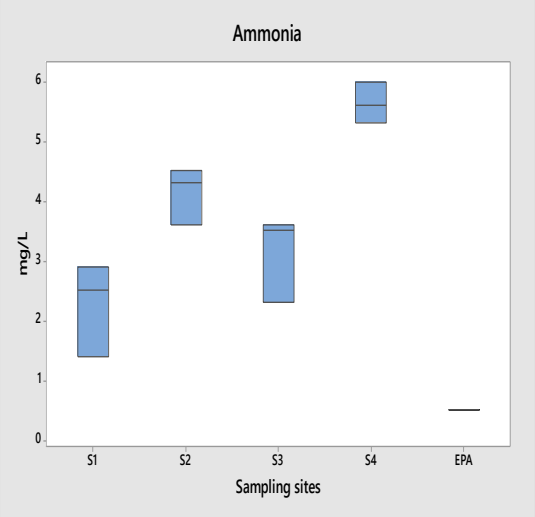


Figure 13: Turbidity boxplot

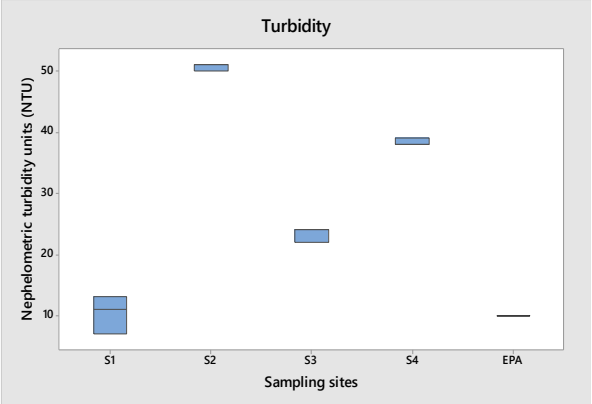
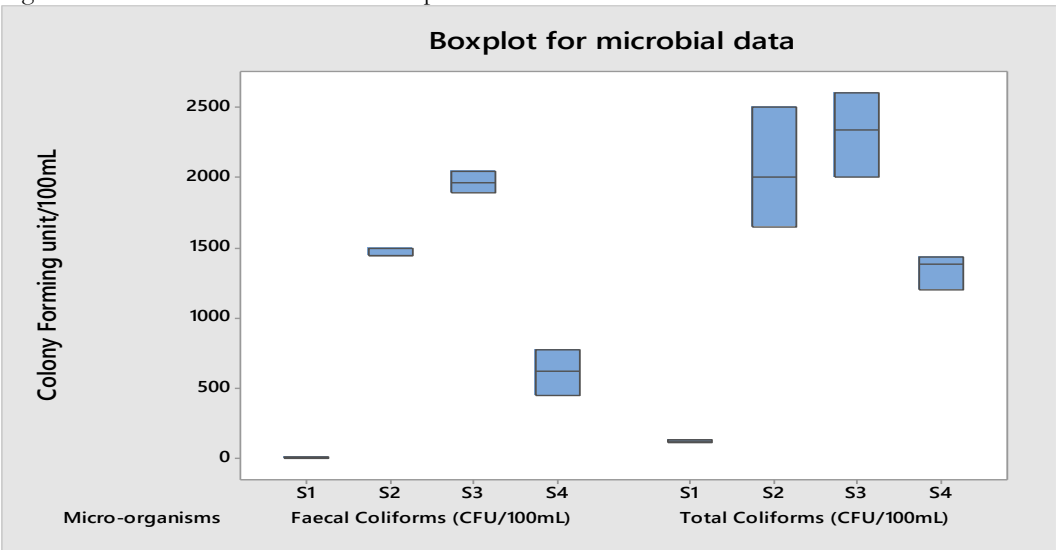


Figure 14: Faecal and total coliforms boxplot



The above figures (2 to 13) show boxplots for physico-chemical and microbiological water quality parameters at four sampling sites (S1, S2, S3 and S4). These boxplots summarise the set of data that was measured in triplicates. When the median line is

closer to the lower quartile, it shows that the data is not normally distributed and has a positive skewness and since skewness of data impact mean values, the mean values are higher than the median. When the median line is closer to the top quartile, it shows that the data is not normally distributed and has a negative skewness which means the mean values are less than the median values. When the median line is at the centre of the box, it shows that the data is normally distributed which means that the mean values are the same as median. Based on figure 3, pH values at S1 are positively skewed, while at S4, the values are negatively skewed and at S2 and S3, the values are normally distributed and are more consistent. Figure 4 shows that temperature values were increasing as the river was flowing from upstream to downstream. S4 had the highest temperature level at 24^{0}C. At S1 and S3, the temperature values were positively skewed while at S2 and S4, the values were negatively skewed.

Based on Figure 5, S1 and S4, ORP values were positively skewed while S2 and S3 values were negatively skewed. Highest ORP was at S1 (+5 millivolts) Figure 6, S1 S2 and S3, DO values were positively skewed while S4 values were negatively skewed. Highest DO level was at S1 (5.2mg/L) while DO levels at S2, S3 and S4 were below the EPA standards (USEPA, 2002). Based on Figure 7, all sampling sites do not have a dotted line inside the box displaying the median. This means that the top side of the box has displayed both the third quartile and the median. Highest TSS value was at S2 (52mg/L). Figure 8, S1, S2 and S3 TDS values were negatively skewed while S4, values were normally distributed. Highest TDS values obtained were at S4 (1234 mg/L) beyond the EPA standards (USEPA, 2002). Based on Figure 9 and 10, both EC and salinity values at S2 and S4 were positively skewed while at S1 and S3, EC and salinity values were negatively skewed. Highest values for EC and salinity were obtained at S4 (1872 μS/cm and 0.96ppt respectively). This is because salinity is measured as EC (Tessema, 2000). On figure 11, sampling sites S1, S3 and S4 nitrates values were positively skewed while S2 values were negatively skewed. Highest nitrates concentration was at S2 (70 mg/L). Furthermore, on figure 12, S1, S2 and S3 ammonia values were negatively skewed while S4 values were slightly positively skewed. Highest ammonia value was at S4 (5.6mg/L) and all sampling sites had ammonia values beyond the EPA standard (USEPA, 2002). Lastly, on figure 13, both faecal and total coliforms counted per 100mL of water samples were higher at S3 than the other sampling sites. This is because of domestic wastewater contamination from pit latrines that are built near Nasolo River (Cammack, 2012).

4.2.5. Water quality Index

Table 6: NSFWQI for Sampling site 1

Site 1 variables	Weight (Wi)	Mean values	Q-value (Qi)	(Wi*Qi)
pH	0.11	7.42	93	10.23
DO sat	0.17	62.94	62	10.54
Temp (°C)	0.1	19.24	23	2.3
TDS	0.07	53	87	6.09
Turbidity	0.08	16	76	6.08
Fecal Coliform	0.16	10	72	11.52
Nitrates	0.1	20.4	37	3.7
Overall WQI				50.46

Table 7: NSFWQI for Sampling site 2

Site 2 Variables	Weight	Mean values	Q-Value (Qi)	(Wi*Qi)
pH	0.11	7.7	91	10.01
DO sat	0.17	36.31	25	4.25
Temp	0.1	21.8	21	2.1
TDS	0.07	363.3	52	3.64
Turbidity	0.08	51	38	3.04
Fecal coliform	0.16	1464	20	3.2
Nitrates	0.1	68.13	5	0.5
Overall WQI				26.74

Table 8: NSFWQI for Sampling site 3

Site 3 variables	Weight (Wi)	Mean values	Q-value (Qi)	(Wi*Qi)
pH	0.11	6.4	68	7.48
DO sat	0.17	25.42	16	2.72
Temp (°C)	0.1	23	17	1.7
TDS	0.07	300	60	4.2
Turbidity	0.08	23	59	4.72
Fecal Coliform	0.16	1966	18	2.88
Nitrates	0.1	27.2	30	3
Overall WQI				26.7

Table 9: NSFWQI for sampling site 4

Site 4 Variables	Weight	Mean values	Q-Value (Qi)	(Wi*Qi)
pH	0.11	6.5	72	7.92
DO sat	0.17	26.63	16	2.72
Temp	0.1	23.8	17	1.7
TDS	0.07	1234	20	1.4
Turbidity	0.08	38	47	3.76
Fecal coliform	0.16	618	27	4.32
Nitrates	0.1	32.9	24	2.4
Overall WQI				24.22

Table 10: Showing the Water Quality Statuses for the sampling sites

Sampling Sites	Overall WQ-Index	Water Quality Status
S1	50.46	Moderate
S2	26.74	Poor
S3	26.7	Poor
S4	24.22	Very poor

Based on table 6, the overall water quality index at sampling site 1 was 50.46. This revealed that the water quality status at the upstream of Nasolo River was moderate. This meant that this site was moderately polluted by deforestation. Most water quality variables at this site were in acceptable levels and below the EPA water quality standards for freshwater. Another reason was only two water quality variables nitrates and temperature obtained Q-values less than 50. In figure 7 and 8, the water

quality status at sampling site 2 and 3 was poor. Q-values for DO, temperature, faecal coliform, turbidity and nitrates at sampling site 2 were below 50 due to laundry, sand mining and agricultural activities. At sampling site 3, DO, temperature, nitrates and faecal coliform obtained Q-values less than 50 due to domestic wastewater from human settlements along the river. Lastly, the water quality status at sampling site 4 was very poor because DO, temperature, TDS, turbidity, nitrates and faecal coliforms obtained Q-values that were less than 50.

4.3. Biomonitoring analysis of analysis of Nasolo river

Below is the trend analysis for macro-invertebrates showing the families of the organisms as well as their abundance at four sampling sites; S1, S2, S3 and S4. This section of results also shows tables for macro-invertebrates collected at each sampling site, their sensitivity scores. Lastly, the tables also show the average score per taxon value for each sampling site that define the status of the river in terms of excellent, good, fair, poor or very poor.

Figure 15:Shows a graph of aquatic macro-invertebrates for sampling site 1

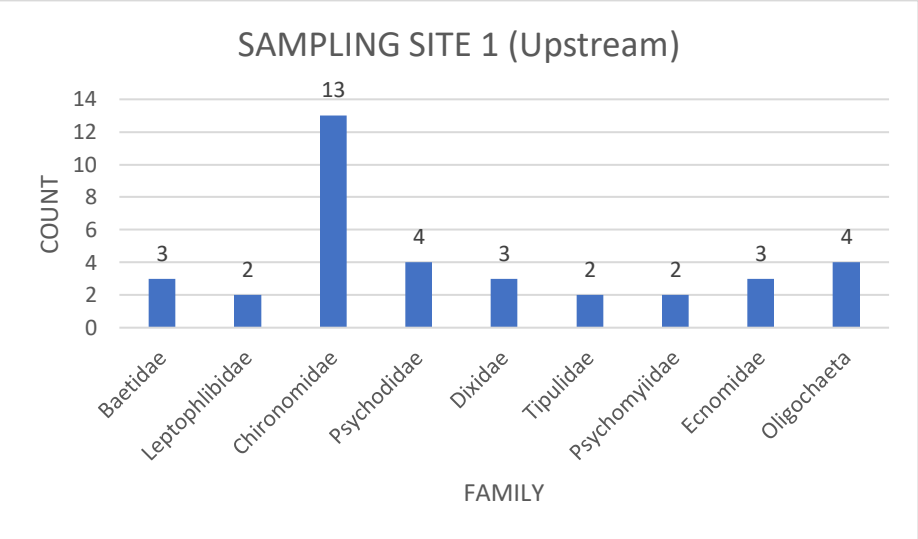


Table 11: Shows the Average Score Per taxon (ASPT) Value for Sampling site 1 (Upstream) and groups of macro-invertebrates collected with their orders, families, common names and sensitivity scores

# of groups	ORDER	FAMILY	COMMON NAME	COUNT	SENSITIVITY SCORE
1	Ephemeroptera	Baetidae	Small minnow mayflies	3	5
2	Ephemeroptera	Leptophlibidae	Prongills (Other Mayflies)	2	11
3	Diptera	Chironomidae	Midges (True flies)	13	2
4	Diptera	Psychodidae	Moth flies	4	2
5	Diptera	Dixidae	Meniscus midges (flies)	3	2
6	Diptera	Tipulidae	Crane flies	2	2
7	Trichoptera	Psychomyiidae	Caseless caddisflies	2	9
8	Trichoptera	Ecnomidae	Caseless caddisflies	3	9
9	Annelida	Oligochaeta	Aquatic earthworms	4	2
TOTAL SCORE = $\sum(Sensitivity\ score)$					44
NUMBER OF GROUPS					9
AVERAGE SCORE = $\frac{\sum(Sensitivity\ score)}{Number\ of\ groups}$					4.9
WATER QUALITY STATUS					Moderate

According to figure 15, the graph for sampling site 1 (at the upstream of Nasolo river) shows that the most dominant order of macro-invertebrates was Diptera, especially the family of Chironomidae. These are less sensitive and more tolerant to pollution with a small score of 2 (Dickens & Graham, 2002). At this site, the most sensitive order of macro-invertebrates called Ephemeroptera were also collected such as the small minnow mayflies in the family of baetidae and Prongills mayflies in the family of leptophlebiidae. Ephemeroptera macro-invertebrates serve as bioindicators of good water quality if they are in high abundance. However, this sampling showed that they were not abundant. This means that the ecological condition of the upstream is fair (moderate) as it is shown in table 11 that the average score calculated was 4.9. This further describes that the upstream of Nasolo river is moderately modified by human activities and it shows that the water quality status is fair. According to the land use map in figure 2, sampling site 1 is modified only by deforestation.

Figure 16: A graph showing aquatic macro-invertebrates for sampling site 2

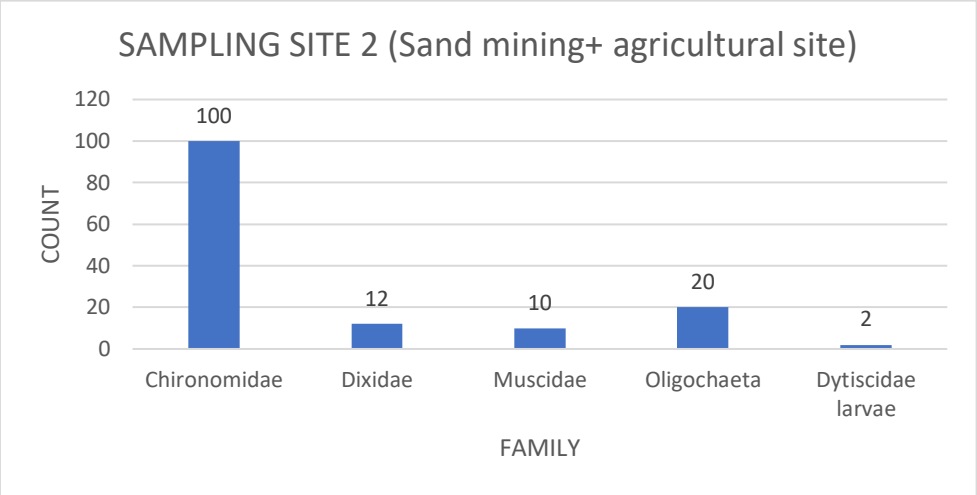


Table 12: Shows the Average Score Per taxon (ASPT) Value for Sampling site 2 and groups of macro-invertebrates collected with their orders, families, common names and sensitivity scores

# of Groups	ORDER	FAMILY (Groups)	COMMON NAME	COUNT	SENSITIVITY SCORE
1	Diptera	Chironomidae	True flies	100	2
2	Diptera	Dixidae	Meniscus midges (flies)	12	2
3	Diptera	Muscidae	House flies	10	2
4	Annelida	Oligochaeta	Aquatic earthworms	20	2
5	Coleoptera	Dytiscidae larvae	Predacious diving beetle	2	5
TOTAL SCORE= $\sum(Sensitivity\ score)$					13
NUMBER OF GROUPS					5
AVERAGE SCORE= $\frac{\sum(Sensitivity\ score)}{Number\ of\ groups}$					2.6
WATER QUALITY STATUS					Very poor

According to figure 16, the graph for sampling site 2 (near Sand mining, bricklaying and agricultural activities) shows that the most dominant order of macro-invertebrates was also Diptera, especially the family of Chironomidae. The second dominant macro-invertebrates are aquatic earthworms in the family of Oligochaeta and order of Annelida. These are less sensitive and more tolerant to pollution with a small score of 2(Dickens & Graham, 2002). At this site, there is absence of the most sensitive macro-invertebrates such as mayflies and stoneflies. In table 12 shows that the average score was 2.6. This means that the ecological condition as well as the water quality is very poor. This further describes that this site of Nasolo river is critically and seriously modified by human activities. According to the land use map

in figure 2, sampling site 2 is modified by sand mining, bricklaying and agricultural activities. Therefore, this means that these activities result in a huge loss of most sensitive macro-organisms and they deteriorate the water quality at a large scale by leading to low dissolved oxygen (at 3mg/L), high turbidity (at 51 NTU), elevated levels total suspended solids (at 52mg/L) and nitrates (at 68.9mg/L).

Figure 17: A graph showing aquatic macro-invertebrates for sampling site 3

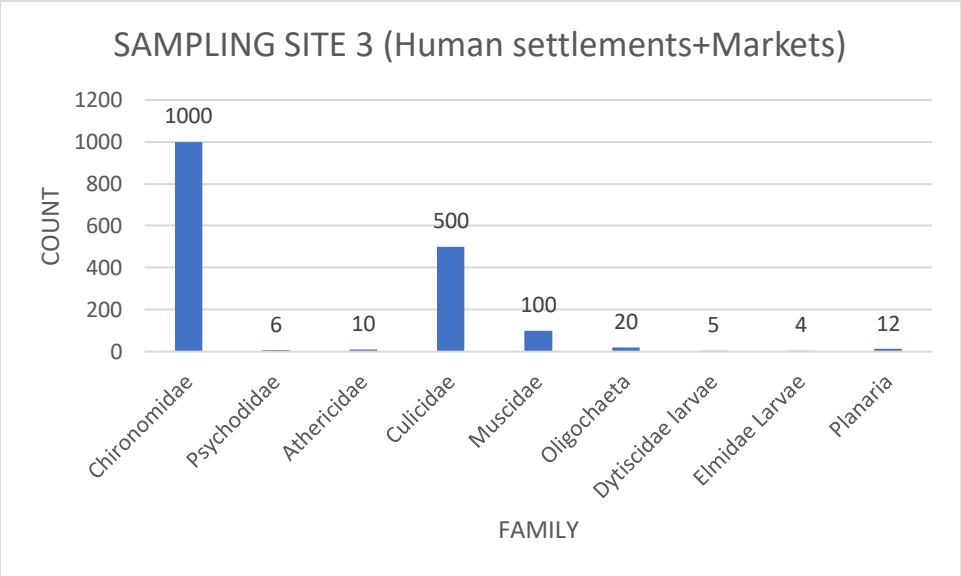


Table 13: Shows the Average Score Per taxon (ASPT) Value for Sampling site 3 and groups of macro-invertebrates collected with their orders, families, common names and sensitivity scores

# of groups	ORDER	FAMILY	COMMON NAME	TOTAL NUMBER	SENSITIVITY SCORE
1	Diptera	Chironomidae	True flies	1000	2
2	Diptera	Psychodidae	Moth flies	6	2
3	Diptera	Athericidae	Snipe flies	10	2
4	Diptera	Culicidae	Mosquito (flies)	500	2
5	Diptera	Muscidae	House flies	100	2
6	Annelida	Oligochaeta	Aquatic earthworms	20	2
7	Coleoptera	Dytiscidae larvae	Predacious diving beetles	5	5
8	Coleoptera	Elmidae Larvae	Riffle beetles	4	5
9	Turbellaria	Planaria	Flatworms	12	3
TOTAL SCORE = $\sum(Sensitivity\ score)$					25
NUMBER OF GROUPS					9
AVERAGE SCORE = $\frac{\sum(Sensitivity\ score)}{Number\ of\ groups}$					2.8
WATER QUALITY STATUS					Very poor

Based on table 13 for sampling site 3 (near a market and human settlements), the most dominant order of macro-invertebrates was also Diptera, especially the family of Chironomidae. The second dominant macro-invertebrates are mosquito flies in the family of Culicidae. These are less sensitive and more tolerant to pollution with a small score of 2(Dickens & Graham, 2002). At this site, there is absence of the most sensitive macro-invertebrates such as mayflies and stoneflies. In table 13 shows that the average score was 2.8. This means that the ecological condition as well as the water quality is very poor. This further describes that this site of Nasolo river is critically and seriously modified by human activities. According to the land use map in figure 2, sampling site 3 is modified by commercial businesses in the market and human settlements along Nasolo river. Therefore, this means that these activities result in a huge loss of most sensitive macro-organisms and they deteriorate the water quality by leading to low dissolved oxygen, high levels of faecal and total coliforms and high turbidity.

Figure 18: a graph showing aquatic macro-invertebrates for sampling site 4

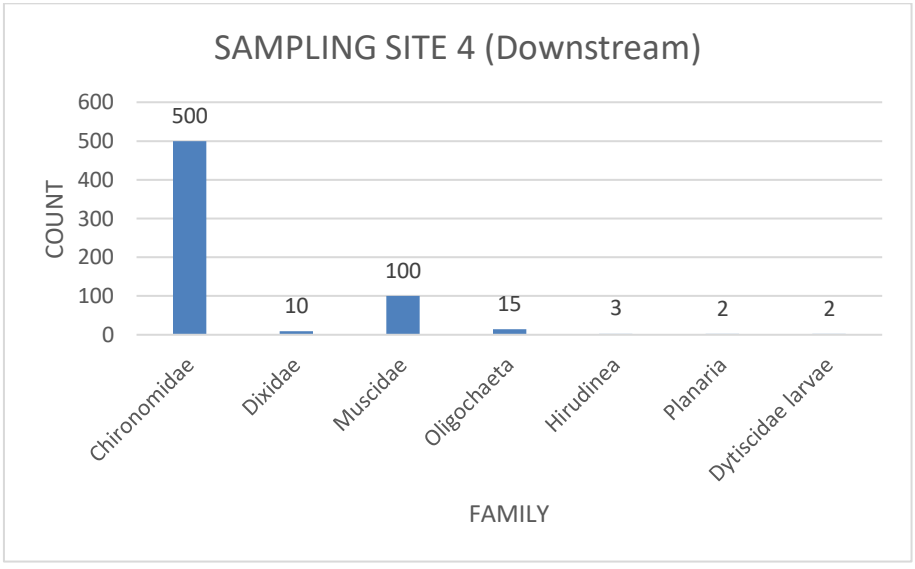


Table 14: Shows the Average Score Per taxon (ASPT) Value for Sampling site 4 and groups of macro-invertebrates collected with their orders, families, common names and sensitivity scores

# of groups	ORDER	FAMILY (Groups)	COMMON NAME	TOTAL NUMBER	SENSITIVITY SCORE
1	Diptera	Chirinomidae	True flies	500	2
2	Diptera	Dixidae	Meniscus midges (flies)	10	2
3	Diptera	Muscidae	House flies	100	2
4	Annelida	oligochaeta	Aquatic earthworms	15	2
5	Annelida	Hirudinae	leeches	3	2
6	Turbellaria	Planaria	Flatworms	2	3
7	Coleoptera	Dytiscidae larvae	Predacious diving bettle	2	5
TOTAL SCORE =					18
NUMBER OF GROUPS					7
AVERAGE SCORE =					2.57

Based on figure 18, the graph for sampling site 4 (downstream of Nasolo River near industrial activities) shows that the most dominant order of macro-invertebrates was also Diptera, especially the family of Chironomidae. The second dominant macro-invertebrates are houseflies in the family of Muscidae. These are less sensitive and more tolerant to pollution with a small score of 2(Dickens & Graham, 2002). At this site, there is absence of the most sensitive macro-invertebrates such as mayflies and stoneflies. In table 14 shows that the average score was 2.57. This means that the ecological condition as well as the water quality is very poor. This further describes that this site of Nasolo river is critically and seriously modified by human activities. According to the land use map in figure 2, sampling site 4 is modified by industrial activities that discharge their effluent into the river. Therefore, this means that this industrial effluent result in a huge loss of most sensitive macro-organisms and they deteriorate the water quality at a large scale by leading to low dissolved oxygen, high turbidity, elevated levels total suspended solids and total dissolved solids as well high concentration of Ammonia that may have resulted in bad odour. The bad odours attract house flies in the family of muscidae and heat provides optimal temperatures for bleeding and pupae development in water (Chapman, 1996).

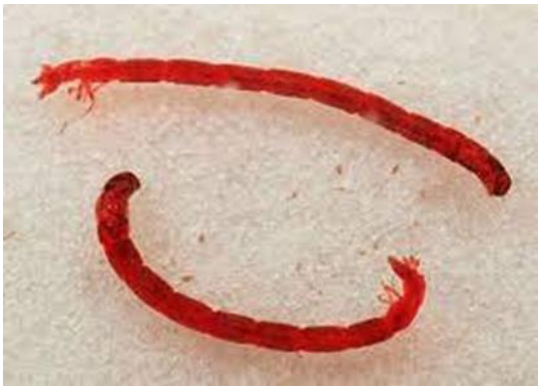

Source: bugguide.net

Figure 19: shows a microscopic image of Chironomidae larvae (An indicator of poor water quality)

4.4. Correlation analysis between National Sanitation foundation Water Quality Index (NSF-WQI) and Average Score Per Taxon (ASPT)/Biotic Index score

Table 15: Comparison between NSFWQI and ASPT/biotic index score

	NSF-Water Quality Index	*Average Score Per Taxon Value*
NSFWQI	1	
ASPT	0.997254054	1

Table 15 above shows that there was a strong positive relationship between the national sanitation foundation water quality index and the SASS average score per taxon (biotic index) as the correlation coefficient indicates that it was 0.997. Lastly, a paired t-test two tailed showed that the NSF-WQI and ASPT are statistically significant, whereby the p-value was 0.01 ($p<0.05$).

5. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSION

In summary, this study has assessed the impacts of human activities on water quality in Nasolo rivers. The water quality status of the river at different sampling sites have been defined by the application of the National Sanitation Foundation Water Quality Index and South African Scoring System biotic index scores. Both indices have shown the same results. At sampling site 1, the water quality is fair while at sampling site 2, 3 and 4, the water quality is very poor. The results have revealed that, the river is not appropriate for any usages such as drinking, fishing and washing, and it has only the ability of supporting a limited number of the aquatic animals. As such, necessary measures to improve the water quality of Nasolo River must be taken up to ensure the safety of the river.

5.2. RECOMMENDATIONS

It is recommended that waste discharge into the Nasolo river can be reduced through better waste management such as by upgrading of industrial wastewater treatment works and improving solid waste collection and disposal systems in Ndirande market. It is further recommended that buffers need to be maintained along river banks, river bank cultivation should be prevented, illegal sand mining should be stopped and afforestation be encouraged. Lastly, biomonitoring technique that involves use of macroinvertebrates has proved to be useful in supplementing water physico-chemistry technique to define the ecological conditions of rivers. This is a simple method that could be used by authorities in Malawi to determine the health of waterbodies and does not need extensive analysis or large resources. It can also be easily taught to local communities and to the youth in primary and secondary education level. Therefore, this can help people become more aware about water quality management at grassroot level.

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7. APPENDICES

APPENDIX 1A: To calibrate the pH electrode, follow these steps:

1. Fill a 300mL calibration bottle with fresh pH 7.00 solution or RapidCal, remove the storage cap from the pH electrode, wash the Probe in distilled water, then drop the Probe in all the way.
2. Switch the Aquameter on and wait until the temperature and pH measurements are completely stable.
3. Ensure the temperature of the solution is between 5ºC and 40ºC
4. Press the MENU key then select Calibration. The screen will be displayed to either select RapidCal DO 100% or Full Cal)
5. Select Full Cal. The screen will display to either select pH/ORP or DO/EC
6. Select pH/ORP. The screen will display the dates of the last successful calibration
7. Select pH7.00. The screen will display a command saying to wait. If the calibration is successful, the counter will reach 100% and the following screen will be displayed (Calibrating 100%)
8. Press [OK] key then the ESC key repeatedly to return to normal operating mode.
9. Remove the Probe from the calibration bottle, rinse thoroughly in de-ionized water, shake off any excess and dry the outer sleeve with a soft cloth.
10. Now fill a 300mL calibration bottle with fresh pH 4.01 solution and drop the Probe in all the way. Follow the procedure detailed above, but at step 6, select pH4.01. Wait while the Meter stabilizes and calibrates. When the 'Calibrating 100%' screen is displayed, press OK then press the ESC key repeatedly to get back to the main display.
11. Remove the Probe from the calibration bottle, rinse thoroughly in fresh water, shake off any excess and dry the outer sleeve with a soft cloth. Dampen the sponge in the storage cap with storage solution and fit it to the pH/ORP electrode.

APPENDIX 1B: To calibrate the DO/EC electrode at the DO Zero Point follow these steps:

1. Remove the lid from a 150mL bottle of DO Zero calibration solution, remove the storage cap from the pH electrode if fitted, wash the Probe in distilled water, then drop the Probe in all the way. The Sleeve End Cap should not be fitted.
2. Switch the Aquameter on and wait until the DO reading is completely stable.
3. Ensure the temperature of the solution is between 5°C and 40°C (41°F - 104°F).

4. Press the MENU key then select Calibration. The screen will be displayed to select either RapidCal DO 100% or Full Cal
5. Select Full Cal. The screen will be displayed to select either pH/ORP or DO/EC
6. Select DO/EC. The screen will display the dates of the last successful calibration.
7. Select DOZero. The screen will display a command saying to wait Stabilizing 000%. If the calibration is successful, the counter will reach 100% and the screen will display "Calibrating 100%"
8. Press [OK] key then the ESC key repeatedly to return to normal operating mode.
9. Remove the Probe from the calibration bottle, rinse thoroughly in fresh water, shake off any excess and dry the outer sleeve with a soft cloth.

APPENDIX 1C: To calibrate the DO/EC electrode at DO 100% Saturation Point in Moist Air follow these steps:

1. Wash the probe in fresh water, then shake off ensuring there are no droplets adhering to the DO membrane.
2. Take an empty calibration bottle, rinse with fresh water, then empty it leaving the inside wet but with no standing water.
3. Insert the Probe and wait until the temperature measurement is completely stable. Temperature must be between 5ºC and 40ºC.
4. Press the MENU key then select Calibration. The screen will be displayed to select either RapidCal DO 100% or Full Cal
5. select DO100%
6. Wait while the Aquameter carries out the calibration procedure until the 'Calibrating 100%' screen is displayed.
7. press OK then ESC repeatedly to return to normal reading mode.
8. If a problem occurs during calibration, an error message will be displayed. Refer to Calibration Error Codes in section 10 for error message handling. If Error 09 persists when calibrating a Galvanic DO sensor, replace the DO Electrode Membrane

APPENDIX 2A: The results for physico-chemical and biological water quality variables

Tables 16: A table showing results of water quality variables in triplicates

Variables	Samples in triplicates	S1	S2	S3	S4
pH	1	7.25	7.7	6.4	6.9
pH	2	7.74	7.9	6.5	6.8
pH	3	7.26	7.5	6.3	5.9
Temperature	1	19.7	21.9	23.7	24.2
Temperature	2	19.3	22.1	22.8	23.2
Temperature	3	19.4	21.4	22.4	24
DO	1	5.1	3.2	2.43	2.4
DO	2	5.6	2.8	1.89	1.88
DO	3	4.9	2.9	2.1	2.3
EC	1	19	668	470	1978
EC	2	78	496	472	1840
EC	3	118	403	447	1872
TDS	1	16	402	304	1277
TDS	2	67	382	307	1190
TDS	3	76	306	290	1235
SAL	1	0.01	0.25	0.15	0.96
SAL	2	0.03	0.33	0.16	1.1
SAL	3	0.04	0.25	0.14	0.95
ORP	1	4.9	-5.3	-6.9	-7.6
ORP	2	9.3	-6.4	-1.4	-7.2
ORP	3	5.5	-5.5	-26.5	-2.2
Turbidity	1	11	51	24	38
Turbidity	2	13	51	24	39
Turbidity	3	7	50	22	38
TSS	1	15	52	22	24
TSS	2	13.1	51	22	23
TSS	3	13	52	23	23
Faecal Coliform	1	8	1445	1960	624
Faecal Coliform	2	12	1500	1890	780
Faecal Coliform	3	9	1449	2050	450
Total coliform	1	132	2000	2600	1390
Total coliform	2	120	2500	2000	1440
Total Coliform	3	125	1650	2340	1200
Nitrates	1	25.4	70	23.6	21.2
Nitrates	2	26.6	66	24	23.4
Nitrates	3	29.4	70.8	34	54
Ammonia	1	1.4	3.6	3.6	5.6

Ammonia	2	2.9	4.5	3.5	5.3
Ammonia	3	2.5	4.3	2.3	6

APPENDIX 2B: Water quality variables curves used for finding their Q-ratings for the NSFWQI

Figure 20: DO curve

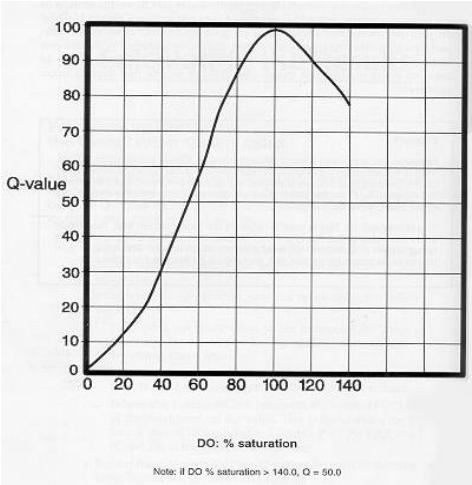


Figure 21: Faecal Coliform Curve

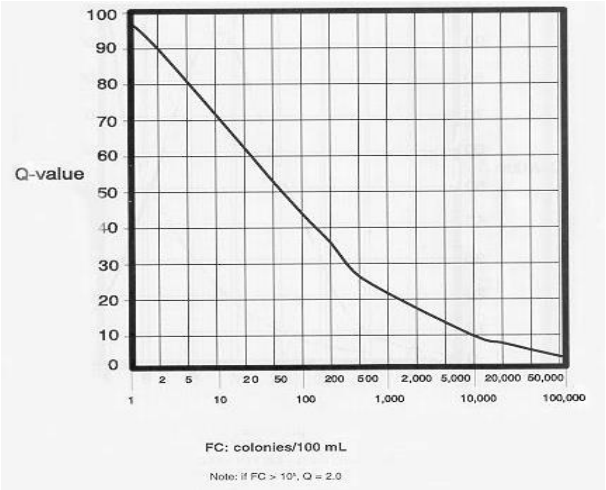


Figure 22: pH curve

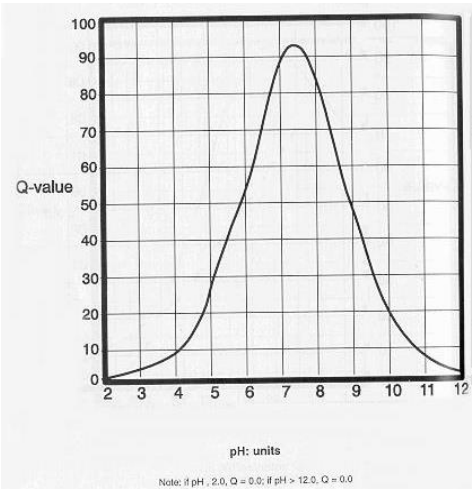


Figure 23: Nitrates Curve

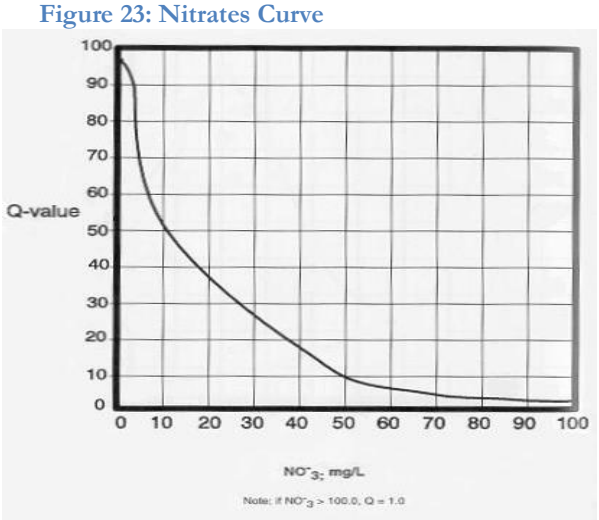


Figure 24: Turbidity Curve

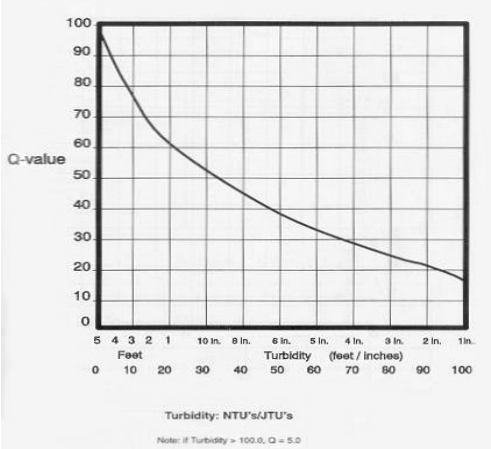


Figure 25: Total dissolved Solids

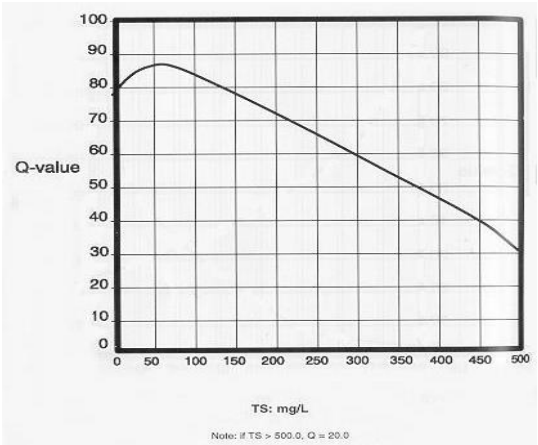


Figure 26: Temperature Curve

