ASSESSMENT OF SURFACE WATER QUALITY USING PHYSICO-CHEMICAL AND BIOMONITORING APPROACHES. A CASE STUDY OF LIKANGALA RIVER, ZOMBA MUNICIPALITY.

EMMA MWENECHANYA

Thyolo, Malawi

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.

DISSERTATION APPROVED BY: MUSTREC

SUPERVISOR:

Title, Initials, Name Signature: 

ASSESSOR:

Title, Initials, Name Signature: _____

DECLARATION

I EMMA MWENECHANYA declare that this research project represents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature: 

Date: 20-07-2021

DISCLAIMER

This document describes work undertaken as part of a programme of study at Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology. All views and opinions expressed therein remain the sole responsibility of the author(s), and do not necessarily represent those of the School.

COPYRIGHT STATEMENT:

This copy of the dissertation has been supplied on condition that anyone who consults it is understood to recognize that its copyright rests with its author and that no quotation from the dissertation and no information derived from it may be published without acknowledgement.

ABSTRACT

The study was conducted to determine the water quality of Likangala River using biomonitoring and physico-chemical approaches. Experiments and direct field observations were applied. In order to do the study, water samples collected in three sites in triplicates were analyzed for various water quality variables such as pH, Temperature and DO on site whereas TDS, Turbidity, ORP, EC, Ammonia and Nitrates, TC and FC in the laboratory.

Statistical analysis such as trend analysis, Single factor Analysis of Variance (ANOVA) and Pearson correlation were performed using MS Excel analytical tool. WQI was computed for each site using an online WQI calculator. The results indicated that pH, DO, temperature, turbidity, ammonia and nitrates values were within the acceptable limits of different regional and international standards for surface waters in all site. While some variables surpassed the permissible limits. Besides, correlation analysis showed a significantly strong and weak positive and negative correlation between some variables. The ANOVA revealed that there was a statistical significance of the observed difference ($p<0.05$) in physicochemical and microbiological water quality parameters. The WQI showed that the water quality was medium and unfit for some human purposes and fit for aquatic animals' survival in all sites except downstream.

In biomonitoring assessment, collected samples of benthic environments (vegetation, stone or rocky and GSM) were poured into the white trays and macro invertebrate organisms in each site were identified using the SASS booklet of organisms. The sensitivity scores of organisms were obtained from the miniSASS sensitivity score sheet and the average sensitivity score of each site was computed and compared to the ecological category. In upstream and middle stream the average scores were within the range of 6.2 to 7.2 of rocky river category which indicated good condition whereas downstream was <5.3 which indicated very poor condition of river. The study reflects a medium water quality of water in the river. The results point out the need to take necessary steps before discharging the wastewater into the river and future policies by the responsive authority should be revised and re-enforced in terms of development of the environmental pollution control.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge my supervisor Mr F. Chauluka for patiently assisting me in various aspects I needed to understand in fulfilling my project.

I would also like to recognise my parents who gave me full support in my entire academic life and especially my beloved mother who has been a great inspiration to me and many others. Not forgetting our former lecturer Dr E.C Vellemu, who was from the water resources department, Mr .H. Yapuwa and all other lecturers who have taught me the fundamental concepts of water quality and management with regard to my research project that I have currently undertaken.

I also want to recognise my fellow water quality and management classmates, who together we fought through hardships and helped one another academically, socially, financially, psychologically and where else necessary.

TABLE OF CONTENTS

ACRONYMS
LIST OF FIGURES AND GRAPHS
LIST OF TABLES
1. INTRODUCTION....1
1.1. Background of study....1
1.2. Problem statement....3
1.3. Study objectives....4
1.4. Research questions....4
1.5. Significance of study....4
2. LITERATURE REVIEW....6
2.1. Introduction....6
2.2. Overview of the biomonitoring water quality assessment approach....6
2.3. Water quality variables and aquatic ecosystem's health....8
2.3.1.pH....8
2.3.2.Turbidity....9
2.3.3.Dissolved oxygen (DO)....9
2.3.4.Colour....9
2.3.5.Temperature....10
3. METHODOLOGY....13
3.1. Study area....13
3.2. Study design....14
3.3. Methods and materials for sample analysis....14
3.4. Sampling....15
3.4.1.Sample collection for Physico-chemical approach....15
3.4.2.Sample collection for biomonitoring approach....16
3.5. Procedures in determining physico-chemical variables....16
3.5.1.Nutrients (ammonia and nitrates)....16
3.5.2.Dissolved oxygen (DO), pH and Temperature....17
3.5.3.Turbidity....18

3.5.4.TDS, ORP and EC 18
3.6. Microbiological characteristics 18
3.7. Biomonitoring assessment 19
3.7.1.Interpretation of the mini SASS score 20
3.8. Statistical analysis 21
3.9. Data presentation 21
3.10. Study limitations 21
4. RESULTS AND DISCUSSIONS 22
4.1. Introduction 22
4.2. Physical, chemical and biological analysis 22
4.2.1.DO 22
4.2.2.Nitrates, pH and temperature. 23
4.2.3.EC, FC and turbidity 23
4.2.4.Total coliform 23
4.2.5.Ammonia, TDS and ORP 24
4.2.6.Trend analysis 24
4.2.7.Pearson's correlation analysis 26
4.2.8.ANOVA-single factor 27
4.3. WQI 28
4.3.1.Upstream WQI and DO sat 30
4.3.2.Middle stream WQI and DOsat 31
4.3.3.Downstream WQI and DOsat 32
4.4. Biomonitoring analysis 33
4.4.1.Upstream biotope 33
4.4.2.Middlestream biotope 34
4.4.3.Downstream environment 35
5. CONCLUSION AND RECOMMENDATIONS 38
5.1. Summary of assessment 38
5.2. Recommendation 39
REFERENCES
APPENDIX

ACRONYMS

GPS	Global positioning system
DO	Dissolved oxygen
FC	Fecal coliform
TC	Total coliform
TDS	Total Dissolved solids
EC	Electrical Conductivity
ANOVA	Analysis of variance
WQI	Water Quality Index
TSS	Total suspended solids
pH	Power of Hydrogen
MUST	Malawi University of Science and Technology
NTU	Nephelometric turbidity units
MAC	Maximum allowable concentrations
GSM	Gravel, sand and muddy
SASS	South African Scoring System
NSF	Nation sanitation foundation
NSFWQI	Nation sanitation foundation water quality index
DOsat	Dissolved oxygen saturation
^0C	Degrees Celsius
mg/l	Milligram/litre
SP1	Sampling point 1 (upstream)
SP2	Sampling point 2 (middle stream)
SP3	Sampling point 3 (downstream)
STD	Standard deviation
H_0	Null hypothesis
Ha	Alternate hypothesis
FFGs	Functional feeding groups

LIST OF FIGURES

Figure 1. 1: Map of Zomba district displaying the study area. 13
Figure 2. 1: Study work flow of water quality assessment approaches. 14
Figure 3. 1: Trend of TDS (mg/l) Figure 3. 2: Plot of a trend in pH 25
Figure 3. 3: Trend in EC(*μ*s/cm) Figure 3. 4: Trend in turbidity (NTU).... 25
Figure 3. 5: Plot of a trend in ORP (mV) Figure 3. 6: Plot of a trend in Temp (^{0}C) 26
Figure 4. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish upstream WQI. 30
Figure 5. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish middle stream WQI.....31
Figure 6. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish downstream WQI. 32
Figure 7. 1: A plot of taxa in the upstream with respect to their sensitivity scores. 34
Figure 8. 1: A plot of middle stream taxa with respect to their sensitivity scores. .. 35
Figure 9. 1: A plot of downstream taxa with respect to their sensitivity scores..... 36

LIST OF TABLES

Table 1. 1: Sensitivity score sheet used for identification of sensitivity of different groups of identified organisms. 19
Table 2. 1: Ecological category with particular river category.....20
Table 3. 1: Summary of averaged results for measured water quality parameters after sample analysis and experiments. All values are in mg/L except pH, temperature (°C), EC (μS/cm), Turbidity (NTU), faecal and total coliform (counts/100 ml). 22
Table 4. 1: Results of measured physical and chemical compositions of surface water samples with respect to their standards deviations (STD) which were used to formulate graphs for trend analysis.....24
Table 5. 1: A Pearson correlation table showing a relationship of variables with each other. 26
Table 6. 1: ANOVA table with a P-value for hypothesis. 28
Table 7. 1: The NSFWQI index range showing values from 0(worse) to 100(good) and associated water quality category. 30
Table 8. 1: Overall water quality index for upstream.....30
Table 9. 1: Overall water quality index for middle stream. 31
Table 10. 1: Overall water quality index for downstream. 32
Table 11.1: Ecological data for macroinvertebrates organisms observed in the upstream with respect to their sensitivity score and average score. 33
Table 12.1: Ecological data for macroinvertebrates organisms observed in the middlestream with respect to their sensitivity score and average score. 34
Table 13.1: Ecological data for macroinvertebrates organisms observed at downstream of river with respect to their sensitivity score and average score. 36

1. INTRODUCTION

1.1. Background of study

Water resources are essential for a number of purposes for example irrigation, drinking, hygiene and sanitation, sand mining, laundry and for disposal of wastes and waste water (Ullberg, 2015). The earth's surface is made up of 70% water including rivers, lakes, streams, seas, oceans, ground water and only 3% of it is considered fresh water. Among the freshwaters, approximately 5% is readily accessible for beneficial purposes. Clean water is crucial for both nature and humans alike. Despite this being the case, these surface waters are subjected to enormous pressures and estimates indicate that in developing countries like Malawi surface water may already have been affected by severe pollution due to its easy accessibility for disposal of wastewater. It is very difficult, costly, and often impossible to remove pollutants once water is polluted. Still today, 80% of global wastewater is released untreated into the water resources, containing pollutants from municipal waste to industrial toxic wastes (Nure Jannat1, 2019).

The Likangala River is a perennial river that originates from Zomba Mountain in southern Malawi and passes through both urban and rural areas before it flows into closed Lake Chilwa (no natural outlet or a designated wetland). The characteristics of water quality of the Likangala River depends on a multitude of factors, such as climate, seasonal variations, geology, topography as well as anthropogenic factors (Ullberg, 2015). This study focused much on the anthropogenic factors as different anthropogenic activities are increasingly being practiced in the neighbourhood of the stretch of the river that flow through the urban segment of Zomba due to the growing population which is posing an effect on the water quality of Likangala River. Pollution is likely to occur through contamination from municipal waste disposal commonly the dumping of domestic wastes mostly households, irrigation farming which incorporates the use of artificial fertilizers, sand mining and disposal of

wastewater from Zomba waste water treatment plant, Zomba general and mental hospital and chancellor college wastewater treatment plant.

Biomonitoring water quality assessment approach is the use of biological variables to survey the environment (Joao et al., 2012). Macro invertebrates are by far the most frequently used biotic group for bio indication in standard water resources management especially the benthic macro invertebrate community (Ojija & Laizer, 2016). Their presence and absence, abundance, evenness and distribution gives an indication of water quality and health of the rivers and streams. They can be defined as bottom dwelling invertebrates that are visible with our naked eyes (without a microscope) and form an integral part of an aquatic environment and have ecological and economic importance. They are ever-present and abundant throughout the whole river system in the crenal and rhitral as well as the potamal region (Zhushi et al., 2018). They tend to react quickly to changes in water quality variables [pH, ammonia, total suspended solids, suspended solids, dissolved oxygen, temperature, salinity, turbidity and nutrients that cause anoxic conditions from eutrophication (nitrates and phosphates)]. Some are sensitive while others are semi tolerant or tolerant to different pollutants. Thus, these species should reflect deleterious events that have occurred in the aquatic environment especially rivers and streams during any stage of their development (Szczerbiñska, 2015).

Physico-chemical assessment approach is the analysis of water quality parameters like Dissolved oxygen, pH, temperature, turbidity, colour, odour, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) in a water system in order to measure changes and the state of water quality (Madalina & Gabriela, 2014). Unlike the biomonitoring approach which is not known to have been done in most studies of water quality in Malawi, the physicochemical approach is the most widely used approach to assess surface water quality and health of surface water systems for the survival of aquatic ecosystems, irrigation, domestic and recreational purposes.

Water quality management within the catchment of the urban section of the stretch of the Likangala River is crucial. Water pollution is increasing gradually due to the presence of different contaminants which are impacting the water quality in a level that in such cases it cannot be used for aquatic animal's habitat or survival, irrigation

or recreation (Pritchard, 2007). Hence, the study was done to assess the water quality of the stream with the use of biomonitoring and physico-chemical approaches in order to reduce costs of clean up, aquatic integrity, to take trends in water quality, compute a water quality index (WQI) and to consider the water for utility of different domestic purpose and other uses by both people and animals as water users.

1.2. Problem statement

Likangala River runs the whole year and is supplied by the base flow. Municipal waste disposal, irrigation farming, sand mining and wastewater disposal containing both organic and inorganic pollutants are increasingly being practiced in the stretch of Likangala River flowing through Zomba municipality (Ullberg, 2015). Detrimental impacts towards the health and hygiene of the water users (livestock and people) especially those in downstream are suspected to occur, also the integrity of aquatic life in the stream might be compromised.

The river has both point source and non-point sources of pollution in the urban vicinity, these point sources include Zomba sewage treatment works, Zomba Central Hospital and the chancellor college waste water treatment plant which release their treated effluents directly into the river, where as the non-point sources of pollution are farmlands, small industries, sand mining, quarrying and household wastes (Pullanikkatil et al., 2015). During rainy seasons contamination of water becomes high due to increased peak flows and runoff which carries impurities and silt in to the water body as such most variables worsened and cause changes in the water chemistry (Bansal & Dwivedi, 2018). Pollution of the water in the river and depleting its resources puts the lives of water users in danger and also affect the aquatic ecosystem (Chimwanza et al., 2006).

Studies of the impact of anthropogenic activities on Likangala River have been proven with the use of physico-chemical assessment approach rather than the biomonitoring approach. The biomonitoring approach is cheap and easy to use hence local communities can be taught on how to use it as a water quality monitoring tool. A water quality study without physico-chemical analysis is less special. Unfortunately information in reference to the scientific study of biomonitoring

assessment approach to assess water quality of Likangala River specifically the use of macro-invertebrates is currently unavailable.

This study will then display if the results of biomonitoring will align and be compared to those of physico-chemical approach of the current status of the river and help to decide whether the biomonitoring approach could be inserted in surface water quality monitoring programs for various uses and survival of aquatic organisms in Malawi. The physicochemical and biomonitoring water quality assessment approaches were used to meet the goals of this study.

1.3. Study objectives

The main objective was to assess the surface water quality of Likangala River using biomonitoring and physico-chemical approaches.

Specific objectives:

- To characterize the water quality variables/parameters using the physico-chemical analysis.
- To apply the use of macro invertebrates to assess the overall water quality in each of the three selected sites.

1.4. Research questions

The study helped to answer this question;

What is the overall water quality of the stretch of Likangala River that passes through the urban vicinity of Zomba city?

H_0: The water that passes through the stretch of Likangala River of the urban vicinity of Zomba city is not polluted.

H_a: The river has a poor quality of water.

1.5. Significance of study

This work will inform the urban community and water quality expertise to develop and implement best environmental practices by looking at the final or overall water quality of the stream. Knowledge of the current water quality will help to obtain the costs for clean-up in cases where the river was getting highly contaminated the costs

will be reduced rather when it would be totally in bad condition (polluted) and so the earlier the better. Information gap will be filled and other information will be added and recorded with regards to the water quality of Likangala River. Awareness of the water quality of the stream will also assist to sustain the food chain in the aquatic ecosystems and the health of both people and animals (livestock) as the water users of the stream. Lastly, to provide and keep records of detailed water quality data of water bodies especially streams for the betterment of aquatic life and people's needs.

2. LITERATURE REVIEW

2.1. Introduction

Water quality refers to the chemical, physical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of biotic species and any human need or purpose. Surface water quality has different parameters of which upon good standards the water is considered healthier and good for ecosystem sustainability as well as for human consumption and use. These water quality parameters include turbidity, pH, TDS, TSS, dissolved oxygen, electrical conductivity and temperature, TC and EC. Aquatic macro invertebrates are good indicators of pollution in running waters, they are affected by physical, chemical and biological conditions of the river or stream, some are very intolerant of pollution but since they cannot escape pollution they show the effects of short and long term pollution event in their habitat and lastly they are relatively easy to sample and identify (Joao et al., 2012). The literature below provides a review of other studies with reference to the study undertaken.

2.2. Overview of the biomonitoring water quality assessment approach

According to zhushi et al (2018), bio-monitoring involves the use of indicators, indicator species or indicator communities. Benthic macro invertebrates, fish or algae and certain aquatic plants are used as indicator species for pollution including eutrophication. Presence or absence of indicator community reflects environmental conditions (Campbell, 2004). Absence of a species cannot always mean nothing as there may be reasons unlike pollution like predation, competition and geographic barriers which prevented their presence at the site. Absence of multiple species of different taxa with comparable tolerance levels that were previously present at the same site is more indicative than absence of a single species (Zhushi et al., 2018). It is essential to know which species inhabit a certain site in the system. Algae has also been used at times as a bio-indicator of pollution. Growth of algae is dependent on

photosynthesis and nutrient concentrations. Abundance of algae indicates nutrient pollution. They are sensitive to some pollutants at levels that may not noticeably affect other organisms in the short term and may affect other communities at higher concentrations (Kato et al., 2018).

Most countries have a long history in the use of macro invertebrates to monitor the environmental status of river ecosystems. Benthic macro invertebrates are key components of aquatic food webs that link organic matter and nutrient resources (for example leaf litter, algae and detritus) with higher trophic levels (Campbell, 2004).

These organisms have mostly sedentary habits and are therefore representative of site specific ecological conditions. With the sensitive life stage and relatively long life span, they have the ability to integrate the effects of short-term environmental variations. Also, these groupings are made up of many species among which there is a wide range of trophic levels and pollution tolerances, hence providing enough information for interpreting cumulative effects (Zwart, 1995). Community arrangement of the assemblages often changes in response to disturbances in the environment in predictable ways, which is the basis for development of bio criteria to evaluate anthropogenic influences. The responses were summarized into three categories, including reduction in diversity, deterioration to dominance by opportunistic (shorter life-cycle, faster reproduction) species and reduction in individual size of dominating species. For example, in streams and rivers polluted by organic matters or heavy metals, species richness and diversity of the macroinvertebrate community strongly reduces for the direct and indirect impact of contaminants and Chironomidae commonly possesses the dominant status at the expense of other more sensitive groups, such as stoneflies (Ephemeroptera), caddis flies (Plecoptera) and mayflies (Trichoptera).

Studies on the potential use of benthic macro invertebrates as bio indicators for river ecosystems have been widely reported in literatures (Sharifinia et al., 2019). Benthic macro invertebrates, especially aquatic insects, have been traditionally used in the bio monitoring of stream and river ecosystems for assessing various environmental stresses such as organic pollution, heavy metals, hydro morphological degradation,

eutrophication and acidification. Indeed, the assemblages constitute the basis of most bio monitoring program currently in Europe and North America. Many countries (or states or water authorities) even have developed their own biotic indices(Zhushi et al., 2018).

There are several bio monitoring techniques currently employed in river ecosystems. Selection of appropriate techniques depends on the available resources and issues being addressed (Deq, 2000). Potential bio monitoring methods include diversity indices, biotic indices, multi metric approaches, multivariate approaches, functional feeding groups (FFGs) and multiple biological characteristics. Bioaccumulation and toxicity of contaminants in indicator species also remain an important component of several river monitoring programs (Ramakrishnan, 2003). Though not described here since the focus had been on the ecological approaches to measure ecosystem status. In addition, saprobic systems were once used in Europe primarily to indicate oxygen deficits caused by biologically decomposable, organic pollution in running waters, on the basis of Saprobic values of indicator species (mostly bacteria, algae, protozoans, rotifers, some macro invertebrates and fish)

2.3. Water quality variables and aquatic ecosystem's health

2.3.1. pH

It is a measure of hydrogen ions or acidity and is a parameter in water quality. Increase in hydrogen ions causes water to become more acidic whereas hydroxyl ions increase basicity of water in high amounts. pH is measured on a logarithmic scale of 0-14:7 is neutral, below 7 is acidic and above 7 is basic. Chang (2010) extends that there are situations in which the pH goes beyond 14 as, for example, 14.2; a condition that means water is too much basic. Equally enough, the pH values can be less than; 1 as, for example, 0.3 and in such situations, water is highly acidic. Most aquatic organisms have a pH tolerance of 6.5-8.5. Acidic water can cause toxic metals to be released into water due to dissolution of rocks by acid. Mining operations can bring about acid mine drainage which lowers the pH of water bodies and untreated wastes from industries can also have effects on pH ranges hence killing aquatic organisms in the process distorting the ecosystem well-being.

2.3.2. Turbidity

Turbidity is a function of suspended materials in water or the measurement of how cloudy or clear the water is and also how easily light can transmit through it. Turbidity is affected by several factors for instance the presence of dissolved and suspended solid, size and shape of particles and composition of particles such as algae, sediments, solid wastes and organic matter from sewage discharges increase turbidity. Turbidity affects organisms that are dependent on light like aquatic plants because it limits the process of photosynthesis. This, in turn, affects other organisms that depend on these plants for food and oxygen. Also, organisms like fish tend to be highly affected by turbidity, when turbidity is high this means suspended material in the water are also high and these solids easily gain energy from the sun and increase heat in the water hence the temperature rises and dissolved oxygen lessens and the fish tend to appear at the top layer of the lake or river basin so as they directly get supplied with oxygen from the interaction of the atmosphere.

2.3.3. Dissolved oxygen (DO)

Oxygen in water is available for aquatic organism's survival. For example fish use oxygen for breathing. Oxygen dissolves in water through the interaction with the atmosphere where aeration takes place and is a by-product of aquatic plants photosynthesis (Island & Oxygen, 2013). However, some activities such as agriculture, mining, municipal waste water and domestic waste introduce impurities into water bodies depleting levels of oxygen by undergoing decomposition that consumes oxygen. This leads to suffocation of aquatic species which depend much on oxygen for their survival like fish hence affecting the food chains in an ecosystem. The health of aquatic ecosystem can be indicated on how polluted the water is and how well the water can support aquatic plant and animal life.

2.3.4. Colour

Suspended and dissolved particles in water influence colour. Suspended material in water bodies may be a result of natural causes or human activity. Transparent water with no accumulation of dissolved materials appears blue and indicates low productivity. Dissolved organic matter such as humus, peat or decaying plant matter

produces a yellow or brown colour. Some algae produce reddish or deep yellow waters and water rich in phytoplankton and other algae appears green. Soil runoff produces yellow, red, brown and grey colours. Colour may also be affected by the concentration of natural dissolved organic acids such as tannins and lignin, which give water a tea colour. These are formed when plant materials are slowly broken down by organisms into very small particles that are dissolved in water. Tannins that are yellow to lack in colour are the most abundant kind found in lakes and streams and can have a great influence on water colour. Lakes that are surrounded by coniferous forests are generally brown in colour because pine needles that fall to the ground are very slow to degrade. Water colours may provide evidence that there is some form of contamination. Coloured water may stain textile and fixtures that can cause permanent damage. Highly coloured water has significant effects on aquatic plants and algal growth. Light is very critical for the growth of aquatic plants and coloured water can limit the penetration of light. Thus highly a coloured body of water could not sustain aquatic life which could lead to the long term impairment of the ecosystem (Yagci et al., 2016).

2.3.5. Temperature

Water quality can also be affected by Temperature as one of the water quality parameter that can affect the heath of both aquatic and terrestrial ecosystems because temperature also affects other water quality parameters such as water density, gas solubility, chemical reaction, organism growth rates, electrical conductivity, pH and dissolved oxygen which are essential for survival of different life in different ecosystems for example some chemical compounds are more toxic to aquatic life at high temperatures. For fish, temperature as an environmental factor affects their development and growth. Reproducing and other biological processes are geared to annual temperature changes.

Temperature can be considered as good or bad it just depends on the type of ecosystem for example discharge of hot water into cold aquatic ecosystem may lead to death of organisms that adapted to live in cold condition therefore temperature directly determines which organisms can live in aquatic ecosystem and which part they thrive because organisms have an optimum temperature in which they can live

and part from warmer temperatures, results in greater lake stratification and turnover which disturb the sediment at the bottom of the lakes, potentially releases more phosphorus, which can lead to more algal blooms and all the associated negative consequences for example toxins, beach closures, low oxygen near the lake bottom which build up in fish and is then consumed by humans.

3. METHODOLOGY

3.1. Study area

The study was conducted in the vicinity of Zomba municipality surrounding Likangala River. The upstream region is Kalimbuka located at an elevation of 1015.52 m asl and middle stream is Namalaka at an elevation of 892.26 m asl and the downstream is Mpondabwino at an elevation of 812.35 m asl.

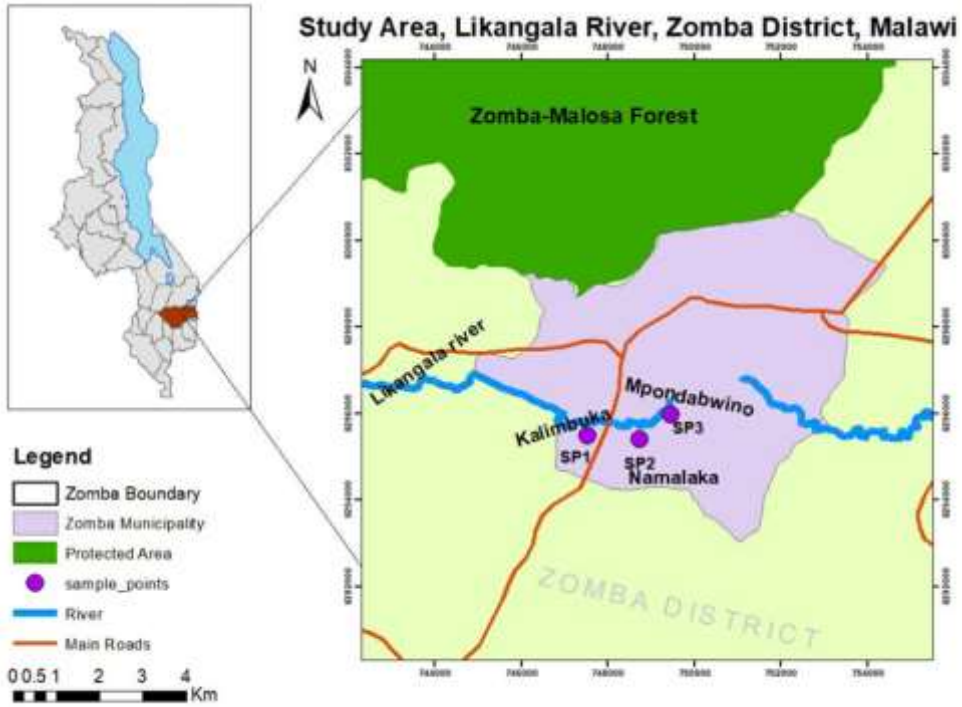


Figure 1. 1: Map of Zomba district displaying the study area.

3.2. Study design

The study incorporated a study design as shown in the flow chart below.

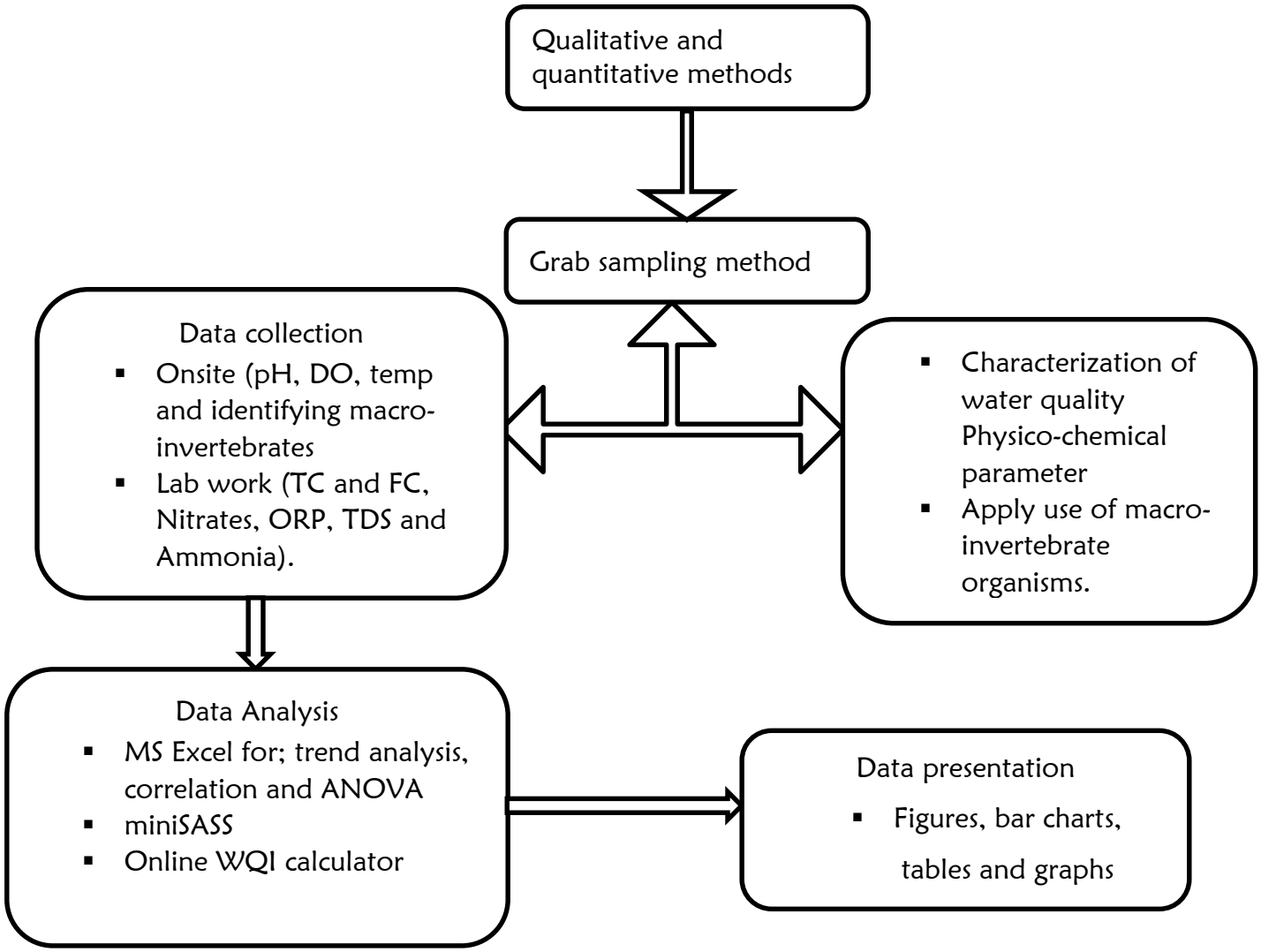


Figure 2. 1: Study work flow of water quality assessment.

3.3. Methods and materials for sample analysis

Qualitative and quantitative methods were used. Qualitative methods mostly applied for the biomonitoring assessment approach where there was the use of direct observational trials whilst quantitative encompassed the use of experiments and obtaining numerical data which applied for the physico-chemical assessment approach. Inclusive to this, face to face interviews with community individuals and

field observations were used to reveal potential point and non-point sources of pollution.

The following materials were used in this study; A pen, a shorthand notebook, marker, three 250ml glass bottles, a 500ml beaker, DO and pH meters, nine 500 mL polystyrene bottles, Phone (for GPS which was used to obtain sample point coordinates and for the use of camera), white plastic trays, Stream Assessment Scoring System (SASS) nets, a reference book of macro invertebrate organisms and wader.

3.4. Sampling

All samples were collected during spring as it was indicated in the time frame. Random grab sampling method was used, samples were collected in one day at one time in three places at each site. The water samples for physicochemical and for biomonitoring analysis were collected randomly in upstream, middle and downstream.

3.4.1. Sample collection for Physico-chemical approach

Water samples were collected in triplicates in three different locations near Kalimbuka, Namalaka and Mpondabwino area respectively. A wader was worn to avoid getting in direct contact with the water and each water sample was collected at the depth of about 20cm using a 500ml beaker where onsite variables were measured. Water was collected from each of the three places in a site using a beaker and was measured for onsite variables such as temperature, DO and pH using DO and pH meters. These meters and the 500ml beaker were rinsed thoroughly with distilled water to reduce errors after each measurement. The water samples were then collected into 500 mL polystyrene bottles (three bottles in each site) for offsite measurements at the MUST laboratory using a multi probe aqua meter, filters and HT1000 Photometer with the help of reagents. Before collecting the samples, all bottles were washed properly and rinsed thoroughly several times with distilled water and then dried. Inclusive to this, three autoclaved bottles were used to collect samples for microbiological testing in relation to microbial pollution from the waste waters, each bottle for one site.

3.4.2. Sample collection for biomonitoring approach

Sampling was done onsite where media samples were collected in three biotopes (vegetation, muddy and gravel) to observe benthic organisms. A SASS net was used to trap the organisms and these were then placed in white trays that were filled with clear water from the river for direct observation. The observed organisms were matched with the ones provided in the reference book of macro invertebrates for their scientific name and were recorded into the shorthand book using a pen. The matter was captured using a camera for reference and was placed back into the water and this was done for all the biotopes with respect to each site.

3.5. Procedures in determining physico-chemical variables

3.5.1. Nutrients (ammonia and nitrates)

These were analysed in the laboratory using a HT1000 photometer through spectrometric method which measures the interaction of light with sample. Other materials used were 10ml vial, stirring rod, nitrate test powder, nitrate test tablets. A colour forming reagent was used for example ammonia NO. 1 and NO. 2 for analysis of ammonia, and nitrate powder and nitrate tablet for analysis of nitrate. The samples for both the ammonia and the nitrate were first filtered using the membrane fiber filters

3.5.1.1. Nitrates

Nitrate was measured by using the Nitrate (P260) method by an HT1000 photometer instrument in (T20-AN-P260). A 20ml filtered sample was poured into a test tube in it the one level nitrate test powder was poured and shaken for 1 minute and a single nitrate tablet was crushed and added into the test tube and the tube was shaken vigorously for 2 minutes, then the 10ml from the test tube was poured into the viral and then one nitrite test table was crushed and added straight from the foil into the viral and then shaken vigorous until the content dissolved.

3.5.1.2. Ammonia

Ammonia was measured by using Ammonia (P60) method by an HT1000 photometer instrument in (T20-AN-P60). A 10ml sample was poured into a 10ml, a crushed ammonia number one test tablet was poured in to the sample and stirred using a stirring rod. The content was then poured into the viral which got closed tightly and the viral was shaken vigorously until all the tablet dissolved. A crushed ammonia number two test tablet after all the tablet dissolved was poured into the viral and shaken until all content dissolved the viral was later pressed in to the photometer chamber.

In both the ammonia and nitrate procedure after all necessary content was dissolved in the viral, the photometer was switched on and the viral (whether with Ammonia or Nitrate contents) was placed into the HT1000 photometer instrument making sure that the viral was in good alignment with mark in the photometer where there was to be an interaction of light with sample. The test button was then pressed on to test the content and 10 minutes later the timer on the photometer clocked in seconds then results were displayed on the photometer screen and were manually recorded.

3.5.2. Dissolved oxygen (DO), pH and Temperature

3.5.2.1. pH

A pH meter was calibrated with three different buffer solutions (4.0, 7.0, and 14 pH values), it was then carried to site to determine the pH of samples at each sampling point of the river. The pH meter was inserted with batteries and pressed on and a sample of water was drawn from the river into a 500ml beaker and the meter was dipped into the beaker where the value of pH and temperature were displayed and then recorded on hardcopy.

3.5.2.2. Dissolved oxygen (DO)

A DO meter was calibrated and was then carried to the site to determine the DO concentration of samples at each sampling point of the river. The DO meter was connected to its probe and it was switched on. The same sample of water that was drawn from the river into a 500ml beaker to measure pH was used to measure DO

where the probe was dipped into the beaker and the values of DO concentration and temperature were displayed and then recorded on hardcopy for each site.

3.5.3. Turbidity

The HT1000 Photometer uses the interaction of infrared light with the samples to measure different parameters turbidity inclusive. Samples collected from each site (up, middle and downstream) were measured for turbidity. A 10 ml sample of water was poured into the viral without adding reagents and without filtering. The viral was placed into the HT1000 photometer instrument making sure that it was in good alignment with mark in the photometer. The test button was then pressed on to test the content and 10 minutes later the timer on the photometer clocked in seconds then the turbidity value was displayed on the photometer screen and was manually recorded on hard copy.

3.5.4. TDS, ORP and EC

A multi-probe aqua meter device was used to measure TDS, ORP and EC, which is an electronic instrument that contains sensors, each specific to the field measurement of given water or wastewater property that are bundled in a single housing and deployed in environmental waters. The pH meter and DO meter were used on-site to measure pH and DO respectively and temperature which are influenced by spatial and temporal changes in water quality. A sample collected from a particular site was poured into a 500ml beaker. The aqua meter was connected to the probe and it was switched on. The probe was then dipped into the beaker and readings of TDS, ORP and EC were displayed. This process was repeated with the rest of the remaining samples.

3.6. Microbiological characteristics

These were measured using membrane filtration techniques by following procedures provided in the laboratory manual. The three autoclaved bottles that contained water samples of three sites were brought to the lab. 100ml of water from each sample were filtered on to a sterile filter membranes. These membranes were then taken and placed into autoclaved petri dishes and two droplets of lauryl sulfate broth

were poured on to the filter membranes to act as food for microorganisms and facilitate microbial growth. In order to determine fecal coliform the filters were incubated at 44.5^{0}c for 18 hours and for total coliform the filters were incubated at 37^{0}c for 24 hours.

3.7. Biomonitoring assessment

A stream assessment scoring system method was used to determine the organisms found in three benthic environments (vegetation, sandy/rocky and gravel, sand and muddy (GSM) region) of the river using the following procedures;

- A wader was worn and three white plastic trays were placed on the river banks with clear water drawn from the river. A net was taken along while entering into the river.
- Whilst holding a SASS net in the current opposing the water movement, the habitat (either vegetative, muddy or sandy/rocky region) was disturbed using feet. SASS nets were used to collect the disturbed media so as to trap organisms, any stones or any other materials that disrupted the collection of the sample were lifted or removed out of the current in order to collect large sample size.
- This was done for about 5 minutes whilst ranging across the river to different habitats (biotopes).
- The net was then rinsed with the same water in the river to clean the sample and later the contents were turned into the white plastic tray where each group of organisms were clearly identified using the identification guide.
- The identified organisms were filled in the site information in terms of GROUPS and marked off on the scoring sheet.
- The sensitivity scores were added up and the average score was determined.
- MiniSASS score was interpreted.
- Hands were washed thereafter.

Table 1. 1: Sensitivity score sheet used for identification of sensitivity of different groups of identified organisms.

GROUPS	SENSITIVITY SCORES
Flat worms	3
Worms	2
Leeches	2
Crabs or shrips	6
Stoneflies	17
Minnow mayflies	5
Other mayflies	11
Damselflies	4
Dragonflies	6
Bugs or beetles	5
Caddisflies (cased or uncased)	9
True flies	2
Snails	4
TOTAL SCORE	
NUMBER OF GROUPS	
AVERAGE SCORE (miniSASS Score)	
Average Score = Total Score ÷ Number of groups	

- On the table, the sensitivity scores of the identified organisms in each site were taken.
- All of the sensitivity scores were added up.
- The total of the sensitivity scores was divided by the number of groups identified.
- The result was the average score, which was interpreted into an ecological category given below.

3.7.1. Interpretation of the mini SASS score

An ideal sample site has muddy, rocky, sandy, and vegetation habitats and not all habitats are always present at a site. The largely available biotope in a particular site is the one that was used for interpretation. In this case, the rocky type river category was used to interpret the ecological category. This is true to the fact that in perennial rivers most dominant biotope is rocky type same case with Likangala as observed in the field.

Table 2. 1: Ecological category with particular river category.

Ecological categories (condition)	River category	
	Sandy type	Rocky type
NATURAL CONDITION (Unchanged/untouched – Blue)	> 6.9	> 7.2
GOOD CONDITION (Few modification- Green)	5.9 to 6.8	6.2 to 7.2
FAIR CONDITION (Some modifications – Orange)	5.4 to 5.8	5.7 to 6.1
POOR CONDITION (Lots of modifications – Red)	4.8to 5.3	5.3 to 5.6
VERY POOR CONDITION (Critically modified – Purple)	< 4.8	< 5.3

3.8. Statistical analysis

The data obtained from the water samples were analysed by using a software Microsoft Office Excel 2013. Physico-chemical data was analysed through a trend analysis. Statistical tools such as ANOVA and Correlation from Microsoft excel and an online Water Quality Index (WQI) were used to analyse the measured water quality parameter.

3.9. Data presentation

Various methods and techniques were used to meet the objectives. Bar charts with error bars and tables were used to display resullts and findings.

3.10. Study limitations

Lack of funds for the research study limited the accomplishment of some goals. The study had limited information on surface water quality standards for aquatic waters and which are not present in Malawi it is not available. Low sample size of study where BOD was not tested due to resource constraints.

4. RESULTS AND DISCUSSIONS

4.1. Introduction

This section gives a critical overview of the study and also outlines the results of physical, biological and chemical analysis and the biomonitoring assessment inclusive.

4.2. Physical, chemical and biological analysis

Variables	UPSTREAM	MIDDLE STREAM	DOWN STREAM
Ph	7.61	7.57	7.5
Temperature (0C)	22.67	23.21	22.8
Turbidity (NTU)	39.37	45.55	48.07
ORP (mV)	6.5	8.33	5.66
EC (uS/cm)	202	195	199.67
TDS (mg/l)	131.33	127.5	130.67
Nitrates (mg/l)	12.4	12.6	8.5
Ammonia (mg/l)	0.6	1	0.5
DO (mg/l)	6.54	5	7.38
FC (counts/100ml)	313.00	250.00	714.00
TC (counts/100ml)	313.00	700.00	820.00

Table 3. 1: Summary of averaged results for measured water quality parameters after sample analysis and experiments. All values are in mg/L except pH, temperature (°C), EC (*µS*/cm), Turbidity (NTU), faecal and total coliform (counts/100 ml).

4.2.1. DO

According to the Department of Environmental Affairs (2018), daily average DO should not be less than 5.0 mg/l with a low of 4 mg/l and regarding the results in table 3 above, the concentrations of DO were in range with the standards provided in the environmental affairs of south African water quality guidelines for Coastal marine waters for all the sites respectively. The results of DO concentration were above 4 mg/l in all the sites this is due to increased water turbulence through continuous vertical mixing and increased water velocity in the river which increased the interaction of water with the atmosphere as observed in the sites.

4.2.2. Nitrates, pH and temperature.

According to Buijs (2007), nitrates should not exceed a standard of 40 mg/l in a water body as used by the Moldovan country in Europe and according to table 3 above all nitrate concentration values did not surpass the limit. The pH and temperature values were also within range with the allowable limits in surface waters for aquatic animal survival of Moldova with a pH range of 6.5 to 8.5 and temperature limits are given by 20^0C and 28^0C for cold and warm waters respectively which applies for all sites that were studied. Time of assessment was in spring, the waters were warm and the values of temperature in up, middle and downstream were 22.67, 23.21 and 22.8 respectively comparing to the 28^0C of temperature the temperature values were not in critical to the aquatic life survival of most species.

4.2.3. EC, FC and turbidity

The electrical conductivity is not to exceed more than 700us/cm and FC organisms shall not exceed geometric mean value of 14colonies/ 100ml sample (Gamble & Tribe, 2005). The turbidity shall also not exceed 5NTU in waters with a natural background of 50NTU.

The water turbidity in up, middle and downstream did not surpass the required limit as such lower turbidity units can not pose a threat to aquatic animal survival and water uses. The EC values did not exceed the required standard in all sites which was also good for aquatic waters. The FC bacteria were more than 14counts/100ml of every tested water sample of each site and any further increase may pose a risk on the health of water users and the survival of aquatic species may become crucial.

4.2.4. Total coliform

Total coliform organisms should not be more than 50 colonies or counts per 100ml filtered water sample (Pullanikkatil et al., 2015). According to the results in table 3, TC counts exceeded the acceptable limits in all sites. The concentrations of total coliform increased from wastewaters from the treatment plants and some sewage matter from motels and lodges which dumped their waste matter directly in to the river. This was according to the responses from face to face interviews with some of the community members in that vicinity.

The presence of pit latrines along the river near the site also increased the risk o;2f the water contamination from the biological contaminants through groundwater percolation. In upstream an equal value of TC and FC was displayed this is due to the fact there was no E-coli in upstream but only faecal coliform whereas in the middle and downstream there were presence of both e-coli and fecal coliform hence a pink colour was displayed on filter membranes of middle and downstream except for upstream filter membrane which showed a yellow colour (meaning only the fecal coliform was present) after removing from an 44^{0}C chamber that lasted for 18hours.

4.2.5. Ammonia, TDS and ORP

MAC of Ammonia should be at least 1.04 mg/l at a given temperature of 25 ^{0}C with a pH of 6.5 which is good for survival of aquatic organisms in surface water systems and the results for Ammonia concentrations in all the sites were below limit (Enderlein & Peter, 1996). The ammonia concentration changes due to variations in pH and temperature. The results for TDS have not been observed to have increased more than the given standard of 1000mg/l as most aquatic ecosystems can tolerate those TDS levels and the result in table 3 have not surpassed the limit hence good water quality.

ORP indicates how sanitised or contaminated your water is based on its oxidation and reduction properties, it measures the net oxidation and reduction properties of all agents present. A good value of ORP in water is between 300mV and 500mV in healthy waters. ORP of the river was too low to conclude that the river can be able to assimilate itself if any serious contaminant is introduced into the river this might be to the fact that there are increased levels of fecal and total coliform which are posing a weakness in the water system.

4.2.6. Trend analysis

Table 4. 1: Results of measured physical and chemical compositions of surface water samples with respect to their standards deviations (STD) which were used to formulate graphs for trend analysis.

VARIABLE	UPSTREAM	MIDDLE STREAM	DOWNSTREAM
Ph	7.61± 0.05	7.57± 0.11	7.5±0.02
Temperature (0C)	22.67± 0.8	23.21±0.8	22.8±0.36
Turbidity (NTU)	39.37±2.6	45.55±1.53	48.07±1.15
ORP (mV)	6.5±2.25	8.33±1.65	5.66±9.68
EC (uS/cm)	202±36.39	195±24	199.67±6.11
TDS (mg/l)	131.33±23.1	127.5±15.5	130.67±5.9
Nitrates (mg/l)	12.4±0.3	12.6±0.2	8.5±0.4
Ammonia (mg/l)	0.6±0.01	1±0.01	0.5±0.02
DO (mg/l)	6.54± 0.5	5± 0.36	7.38±0.28

Standard deviation (STD) gives a range of errors when determining the value of a variable. STDs were calculated to help check the variations in the triplicate values of each variable that were collected. Error

+bars were also used on the graphs to indicate the uncertainty in a reported measurement so as to give a general idea of how precise a measurement is or how far the value is from the reported value a Below are graphs with error bars showing a trend analysis in physical and chemical parameters that were analysed.

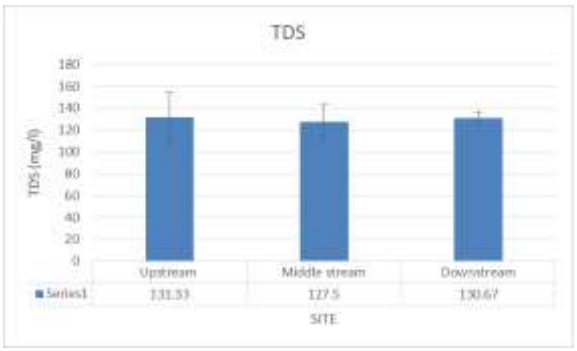


Figure 3. 1: Trend of TDS (mg/l)

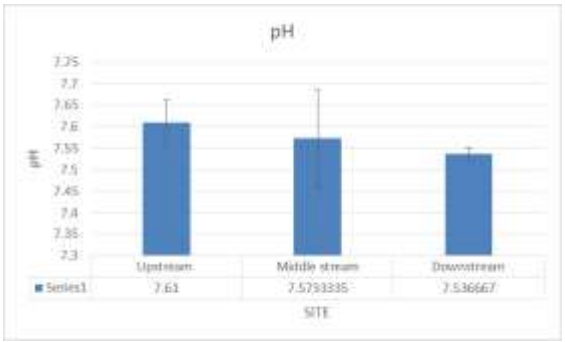


Figure 3. 2: Plot of a trend in pH

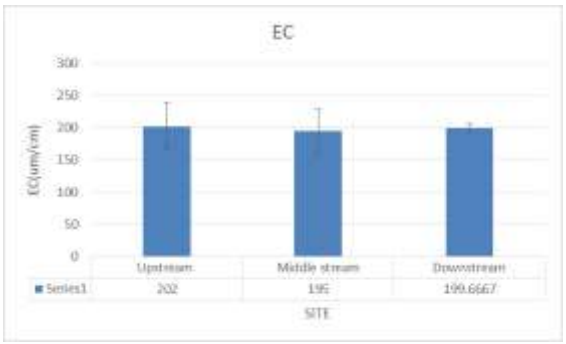


Figure 3. 3: Trend in EC (μs/cm)

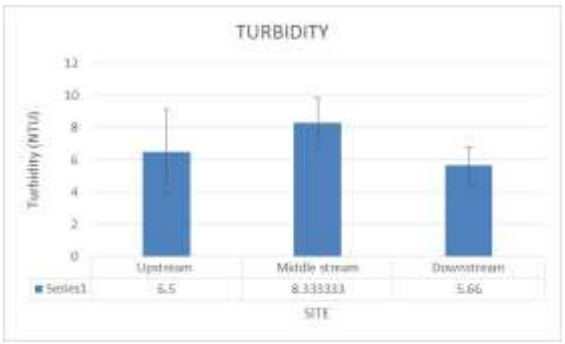


Figure 3. 4: Trend in turbidity (NTU)

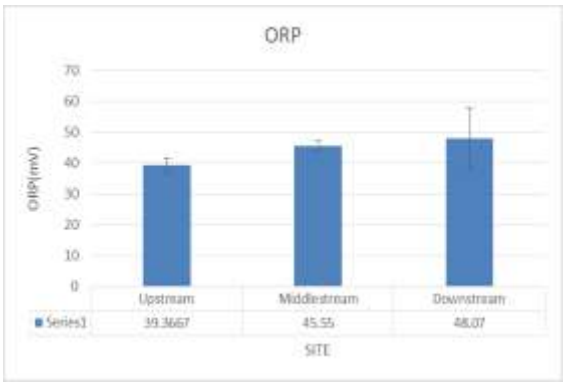


Figure 3. 5: Plot of a trend in ORP (mV)

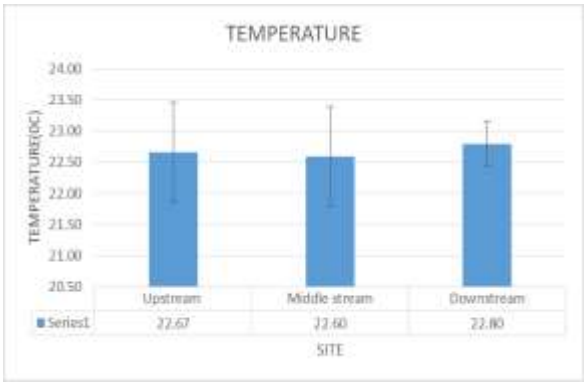


Figure 3. 6: Plot of a trend in Temp (^{0}C)

4.2.7. Pearson's correlation analysis

The Persons correlation analysis was done in order to analyse correlation between different physicochemical parameters under study. Results of correlation analysis were presented in table 5 below which represents the Interrelationship among the measured dependent and independent variables of water quality and the strength of their relationship (r) which could be either positive or negative. A negative correlation signifies that the nature of the relationship is an inverse relationship where an increase one variable leads to a decrease in another, whereas a positive correlation means a direct relationship where an increase in one variable causes to an increase in another variable. Relatively strong interrelationships between variables range from negative or positive 0.5 to 0.9 and weak interrelationships starts from numbers less than 0.5. The strength of the interrelationship of a variable with a corresponding variable for example pH and pH is 1 which means a very strong relationship, whereas relationship of a variable with another variable for example in the table 5 below pH and turbidity is -0.9 which means there is a strong negative relationship between them. All the values with a strong relationship either positive or negative were highlighted with a dark blue colour as shown in table 5 below. It was manifested that pH and Nitrates (r=0.9168), Temperature and TDS (r=-0.9974), Temperature and EC (r=-0.9910), temperature and Ammonia (r=0.9119), Turbidity and TC (r=0.9983), ORP and Ammonia (r=0.9925), ORP and DO (r=-0.9991), EC and TDS (r=0.9854), TDS and Ammonia (-0.9387), Nitrate and FC (r=-0.9966) and

Ammonia and DO (r=-0.9864) (all placed to 4 decimal places) displayed a strongest interrelationship between each other.

Table 5. 1: A Pearson correlation table showing a relationship of variables with each other.

	Ph	*Temp (0C)*	*NTU*	*ORP (mV)*	*EC (uS/cm)*	*TDS (mg/l)*	*Nitrates(mg/l)*	*Ammonia mg/l)*	*DO (mg/l)*	*FC*	*TC*
Ph	1										
Temperature (0C)	-0.07647	1									
Turbidity (NTU)	-0.92321	0.45377257	1								
ORP (mV)	0.451892	0.85490369	-0.074368	1							
EC (uS/cm)	0.175847	-0.9949822	-0.540654	-0.79871	1						
TDS (mg/l)	0.005702	-0.9974916	-0.389557	-0.88948	0.985404	1					
Nitrates (mg/l)	0.916843	0.32796632	-0.693007	0.770472	-0.2318	-0.39401	1				
Ammonia (mg/l)	0.339422	0.91192369	0.0481271	0.992496	-0.86629	-0.93868	0.686742834	1			
DO (mg/l)	-0.48955	-0.8319866	0.1168554	-0.99909	0.772303	0.869171	-0.79697319	-0.986374177	1		
FC (counts/100ml)	-0.88096	-0.4044362	0.6314639	-0.82022	0.310902	0.468159	-0.99662247	-0.74411619	0.843883	1	
TC (counts/100ml)	-0.89986	0.50371147	0.9983819	-0.01754	-0.58762	-0.4413	-0.6508903	0.10484808	0.060191	0.586	1

4.2.8. ANOVA-single factor

Single factor Analysis Of Variance (ANOVA) was conducted to reject or fail to reject the null hypothesis. The ANOVA was based on a significance level (α) of 0.05. The ANOVA analysis revealed that there was a significant difference of 3.29E-06 ($p<0.05$) in the water quality parameters of the sites under study highlighted in table 6 below. This indicated a strong evidence against the null hypothesis as there is a less than a 5% chance that the null is correct. Therefore, the null was rejected H_0=no and the alternative hypothesis was accepted Ha=a hence the water quality of the stretch of the river that passes through the study points is poor.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Ph	3	22.68	7.56	0.0031		
Temperature (0C)	3	68.68	22.89333333	0.079433333		
Turbidity (NTU)	3	132.99	44.33	20.0388		
ORP (mV)	3	20.49	6.83	1.8639		
EC (uS/cm)	3	596.67	198.89	12.7063		
TDS (mg/l)	3	389.5	129.8333333	4.192233333		
Nitrates (mg/l)	3	33.5	11.16666667	5.343333333		
Ammonia (mg/l)	3	2.1	0.7	0.07		
DO (mg/l)	3	18.92	6.306666667	1.456933333		
FC (counts/100ml)	3	1277	425.6666667	63344.33333		
TC (counts/100ml)	3	1833	611	70203		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1255579.885	10	125557.9885	10.33839325	3.29E-06	2.296695957
Within Groups	267186.1747	22	12144.82612			
Total	1522766.059	32				

Table 6. 1: An ANOVA table with a P-value for assessing the null hypothesis.

4.3. WQI

Water quality index (WQI) may be defined as a rating, reflecting the composite influence of different water quality parameters on the overall quality of water. Ideally the main objective of computing a WQI is to turn the complex water quality data into information which is easily understandable and usable. WQI indicates the quality of water in terms of index number which represents overall quality of water for any intended use (Nure Jannat1, 2019). The National Sanitation Foundation (NSF) developed a WQI to provide a standardised method for comparing the water quality of various water bodies. Nine water quality parameters were selected to include in the index. These variables included the following; DO, fecal coliform, pH, BOD (5-day), temperature change (from 1 mile upstream), total phosphate, nitrate, turbidity and total solids (NSF, 2005).

Scientists developed a graph that showed a water quality level ranging from 0(worst)-100(best) from raw data. The curves drawn were then averaged to obtain a weighting curve for each parameter. Results of the nine parameters are compared to the curves and a numerical value of a water quality index for that parameter

known as a Q-value is obtained. The Q-value is then multiplied by a weighting factor, based on that test's importance in water quality. The nine resulting values of parameters are evaluated and added to get an overall WQI. When less than nine variable tests are performed, the overall WQI can be estimated by adding the results and then adjusting for the number of tests. For example, if BOD and temperature change are not available, the seven remaining subtotals are added and the seven weighting factors are added. The former is then divided by the latter, to obtain a WQI.

An available online water quality index calculator for NSF was used to acquire an overall water quality of each of the three sites. The following link was used to enter the online WQI calculator;
http://home.eng.iastate.edu/~dslutz/dmrwqn/water_quality_index_calc.htm
Only seven parameters over nine parameter (BOD and temperature change exception) were used in the online calculator to evaluate the WQI for each site. BOD was not analysed as it was not one of the parameters in question to the study design and temperature was used to find the DOsat hence it was already indirectly involved. DOsat was calculated using an online calculator with the following link;
https://www.waterontheweb.org/under/waterquality/dosatcalc.html
DO value, elevation and temperature for each site was entered into the DOsat calculator to find DOsat that was involved in finding the WQI in each site. The available parameters on the NSF WQI were used in exception of EC, ORP and TC whereas Ammonia was used in place of phosphates since it has the same weight with phosphates.
The proposed new index ranges from 0 to 100 and has been used in this study in order to provide a description of the index data outcome (Misaghi et al., 2017). The NSFWQI index divided into several ranges that corresponds to the general description terms of water quality was used to generate the overall water quality index in each site after calculation. The WQI value was compared with the ranges in the water quality index legend and then computed for actual water quality of each of the three sites.

Table 7. 1: The NSFWQI index range showing values from 0(worse) to 100(good and its associated water quality category.

NSFWQI Index value	Water quality category
0-25	Very bad
26-50	Bad
51-70	Average
71-90	Good
91-100	Very good

Results for water quality index in each site were found within the range of 50-70 which is medium water quality. Below are figures of DOsat showing the use of elevation, temperature and DO value to find DOsat for each site. Inclusive to this, below are figures showing the calculation of water quality index for each site.

4.3.1. Upstream WQI and DO sat

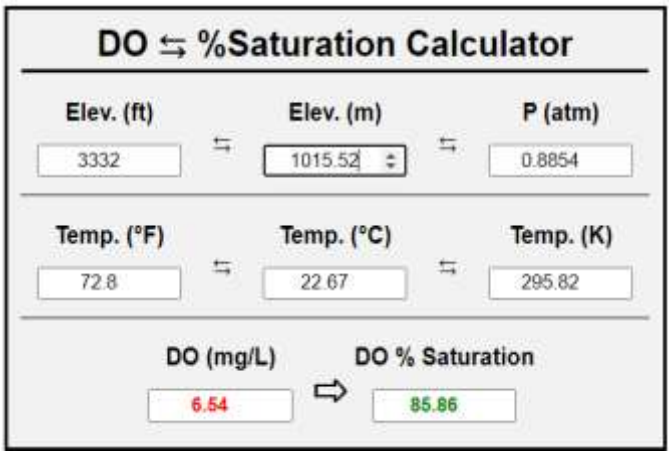


Figure 4. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish upstream WQI.

Table 8. 1: Overall water quality index for upstream

Calculation of Overall Water Quality Index

Factor	Weight	Quality Index
Dissolved oxygen	0.17	92
Fecal coliform	0.16	33
pH	0.11	92
Biochemical oxygen demand	0.11	
Temperature change	0.10	
Total phosphate	0.10	55
Nitrates	0.10	47
Turbidity	0.08	46
Total solids	0.07	81

Calculate

Based on the 7 factors entered,
the water quality index is 64.

4.3.2. Middle stream WQI and DOsat

The figures below show the middle stream WQI with its DO sat which were calculated using online calculators respectively.

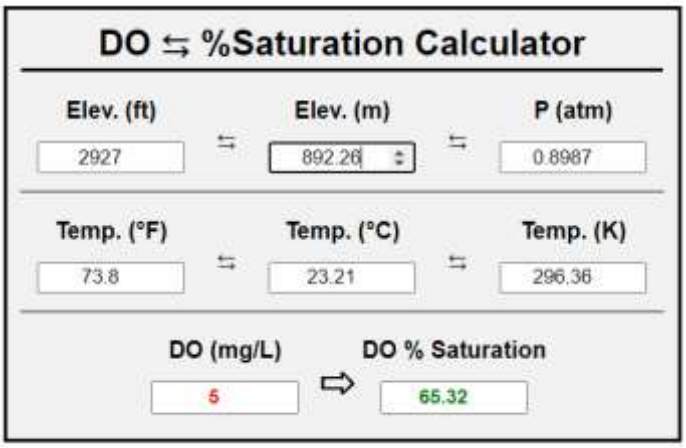


Figure 5. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish middle stream WQI.

Table 9. 1: Overall water quality index for middle stream.

Calculation of Overall Water Quality Index

Factor	Weight	Quality Index
Dissolved oxygen	0.17	67
Fecal coliform	0.16	35
pH	0.11	92
Biochemical oxygen demand	0.11	
Temperature change	0.10	
Total phosphate	0.10	40
Nitrates	0.10	47
Turbidity	0.08	42
Total solids	0.07	81

Calculate

Based on the 7 factors entered,
the water quality index is 57.

4.3.3. Downstream WQI and DOsat

The figures below show the middle stream WQI with its DO sat which were calculated using online calculators respectively.

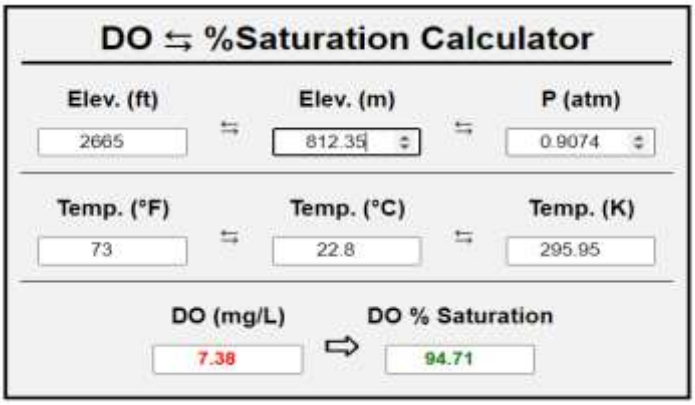


Figure 6. 1: Online DO %sat calculator for calculating DOsat using temperature, elevation and DO (mg/l) that was used to establish downstream WQI.

Table 10. 1: Overall water quality index for downstream.

Calculation of Overall Water Quality Index

Factor	Weight	Quality Index
Dissolved oxygen	0.17	98
Fecal coliform	0.16	25
pH	0.11	93
Biochemical oxygen demand	0.11	
Temperature change	0.10	
Total phosphate	0.10	60
Nitrates	0.10	54
Turbidity	0.08	40
Total solids	0.07	81

Calculate

Based on the 7 factors entered,
the water quality index is 65.

4.4. Biomonitoring analysis

Organisms that were identified were recorded and presented in tables 7. 8 and 9 with respect to their habitat that they were found in each site, order (higher taxa) and family (taxa) and their common organism (groups) name. The common name or group were provided with a sensitivity score as presented in table 1 in order to calculate average sensitivity score. Using the ecological category data provided in table 2 the water quality of the river was summarised for all sites.

4.4.1. Upstream biotope

Table 11. 1: Ecological data for macroinvertebrates organisms observed in the upstream with respect to their sensitivity score and average score.

UPSTREAM HABITAT	HIGHER TAXA	TAXA	COMMON NAME (GROUPS)	SENSITIVITY SCORE
VEGETATION	Diptera	Chironomidae	True flies	2
	Odonata	Corduliidae	Dragonflies	6
	Hemiptera	Vellidae	Bugs	5
	Zygoptera	Coenagrionidae	Damselflies	4
	Zygoptera	Chlorolestidae	Damselflies	4
	Ephemeroptera	tricorythidae	Other Mayflies	11
	Ephemeroptera	Oligoneuridae	Other Mayflies	11
GSM	Hemiptera	Notonectidae	Bugs	5
	Trichoptera	Polymorphanisus	Caseless Caddisflies	9
			TOTAL SCORE	57
			NUMBER OF GROUPS	9
			AVERAGE SCORE (miniSASS Scor	6.333333333
			Average score =Total score/Number of groups	

The average score was found as 6.33 (to two decimal places) and most dominant biotope of the river in upstream was rocky. Using the ecological category in table 2, the Rocky River category was then used to analyse the water quality, the average score value was within the range of 6.2 to 7.2 which indicated that the water quality was in good condition.

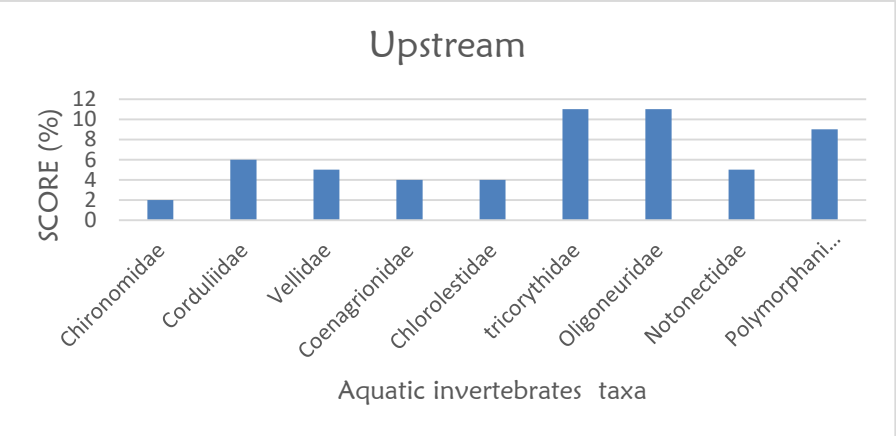


Figure 7. 1: A plot of taxa in the upstream with respect to their sensitivity scores.

4.4.2. Middlestream biotope

Table 12. 1: Ecological data for macroinvertebrates organisms observed in the middlestream with respect to their sensitivity score and average score.

MIDDLESTREAM HABITAT	HIGHER TAXA	TAXA	COMMON NAME (GROUPS)	SENSITIVITY SCORE
VEGETATION	Diptera	Chironomidae	True flies	2
	Ephemeroptera	Oligoneuridae	Other mayflies	11
	Annelida	Origochaeta	Worms	2
GSM	Crustacea	Potamonautidae	Crabs and shrips	6
	Trichoptera	Polymorphanisus	Caseless Caddisflies	9
STONE/ROCKY	Crustacea	Paraemonidae	Crabs and shrips	6
	Mollusca	Physidae	Snails	4
			TOTAL SCORE	40
			NUMBER OF GROUPS	6
			AVERAGE SCORE (miniSASS Score)	6.67
			Average score = Total score/ Number of groups	

The average score was found as 6.67 and most dominant biotope of the river in middle stream was rocky. Using the ecological category in table 2, the Rocky River category was chosen to be used for analysing the water quality, the average score value was within the range of 6.2 to 7.2 which indicated that the water quality was in good condition.

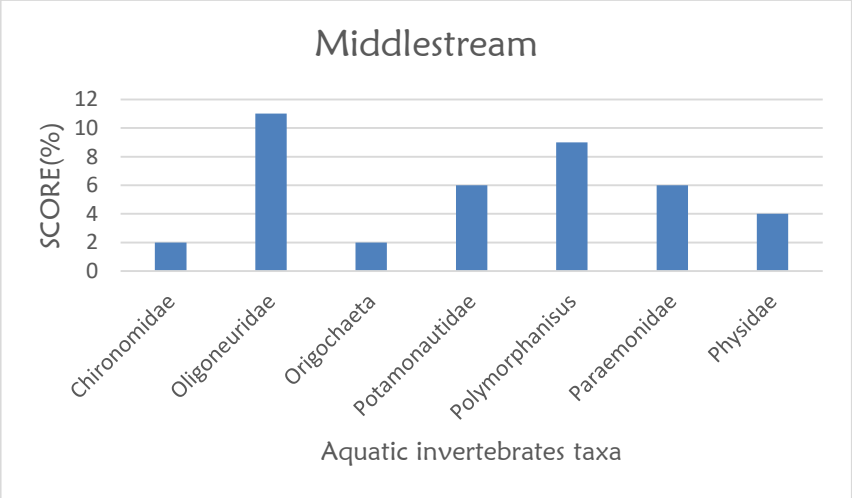


Figure 8. 1: A plot of middle stream taxa with respect to their sensitivity scores.

4.4.3. Downstream environment

Table 13. 1: Ecological data for macroinvertebrates organisms observed at downstream of river with respect to their sensitivity score and average score.

DOWNSTREAM HABITAT	HIGHER TAXA	TAXA	COMMON NAME (GROUPS)	SENSITIVITY SCORE
VEGETATION	Mollusca	Physidae	Snails	4
	Diptera	Chironomidae	True flies	2
	Caddisflies	Trichoptera	Caseless caddisflies	9
	Coleoptera	Elmidae	Beetles	5
	Hemiptera	Nepidae	Bugs	5
	Zygoptera	Coenagrionidae	Damselflies	4
GSM	Odonata	Gomphidae	Dragonflies	6
STONE/ROCKY	Crustacea	Potamonautidae	Crabs and shrips	6
			TOTAL SCORE	41
			NUMBER OF GROUPS	8
			AVERAGE SCORE (miniSASS Score)	5.125
			Average score =Total score/Number of groups	

The average score was found as 5.13 (to two decimal places) and most dominant biotope of the river in the site was rocky. Using the ecological category in table 2, the Rocky River category was selected to analyse the water quality, the average score value was less than 5.3 which indicated that the water quality was in a very poor condition.

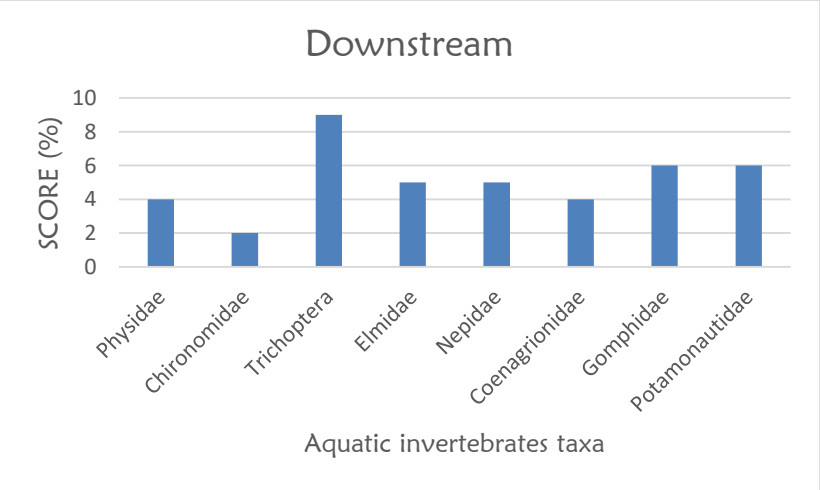


Figure 9. 1: A plot of downstream taxa with respect to their sensitivity scores.

Graphs were plotted to represent the aquatic invertebrates with respect to their scores in each site. The highest common name was other mayflies which showed the most sensitive organisms in the stretch of the river under study. Whereas stoneflies

with the highest score were not present or observed in all biotopes that were under study. The absence of these stoneflies indicated that the river has some levels of contamination that caused the absence of the organisms.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Summary of assessment

This investigation confirmed that results of EC, DO, turbidity, temperature, pH, ammonia and nitrates in each site were within the acceptable limits of different regional and international guidelines and standards of surface waters whereas TDS, FC, TC surpassed the threshold limit for natural waters and ORP values were below the required limit. The variables not within acceptable standards of water quality for surface water were found to be critical for water users and aquatic animal's survival. Pearson's correlation analysis showed a significant strong positive correlation between pH and Nitrates, temperature and Ammonia, turbidity and TC, ORP and Ammonia and EC and TDS. The ANOVA test also showed that there is a statistical significant difference in water quality amongst the sampling sites. The calculated WQI provided an easy way of understanding the overall water quality where a medium water quality of Likangala River was computed for all the sites that were assessed from Kalimbuka to Namalaka through Mpondabwino.

Medium water quality on the WQI legend meant that the water was unsuitable for use and may pose a health and environmental risk to the communities that rely on the river (aquatic animal species inclusive, the flora and fauna in specific and finally humans and their livestock).

The stretch of the river from upstream to middle is in a quite good condition than that from middle to downstream which is polluted displayed through the increased presence of fecal and total coliforms. The ORP is too low meaning that introduction of any adverse pollutants into the river will reduce the rivers' assimilation capacity and this may impact the use of water and survival of aquatic animals may become crucial.

Outcomes of biomonitoring assessment show that the stretch of the river from upstream to middle stream is in good condition, through downstream is in a very bad condition.

In addition, the biomonitoring approach has shown effectiveness in assessing river water quality conditions, since the results of biomonitoring are not far more different

from the outcomes of physical-chemical assessment. According to Joao (2012) the absence of macro invertebrate organisms in a water body does not necessarily mean that the water is polluted it could be due to predation and temporal and special factors. They have a property of immobilisation and if present in their habitat any different pollutants introduced is sensed as such they can be used as indicators of water pollution in monitoring programs. Such information is vital for the policy makers who should in turn, give proper advice to the communities and institutions in order to follow waste management regulations and also help develop water quality monitoring programs.

5.2. Recommendation

This study recommends a further development of environmental pollution control, catchment management and a routine monitoring of water quality of the river by responsive authorities and expertise.

REFERENCES

Bansal, J., & Dwivedi, A. K. (2018). *ASSESSMENT OF GROUND WATER QUALITY BY USING WATER QUALITY INDEX AND PHYSICO CHEMICAL PARAMETERS : REVIEW PAPER*. *7*(2), 170–174.

Buijs, P. and C. T. (2007). PROPOSED SYSTEM OF SURFACE WATER QUALITY STANDARDS FOR MOLDOVA : Technical Report. *EPA Task Force*.

Campbell, I. C. (2004). *CHAPTER 5 BIOLOGICAL MONITORING AND ASSESSMENT USING INVERTEBRATES*. 1–16.

Chimwanza, B., Chimwanza, B., Mumba, P. P., Moyo, B. H. Z., & Kadewa, W. (2006). *The impact of farming on river banks on water quality of the rivers*. *2*(4), 353–358.

Deq, M. T. (2000). *Water Quality Assessment Process and Methods*.

Enderlein, R. E., & Peter, W. (1996). *Chapter 2 * - Water Quality Requirements*. *2*.

Gamble, P., & Tribe, S. K. (2005). *WATER QUALITY STANDARDS FOR SURFACE WATERS*.

Island, E., & Oxygen, J. G. (2013). *Dissolved Oxygen (DO)*. *1*(II), 12–13.

Joao, C., Perez-Bilbao, A., & Garrido, J. (2012). Macroinvertebrates as Indicators of Water Quality in Running Waters: 10 Years of Research in Rivers with Different Degrees of Anthropogenic Impacts. *Ecological Water Quality - Water Treatment and Reuse*, *May*. https://doi.org/10.5772/32115

Kato, R., Asami, T., Utagawa, E., & Furumai, H. (2018). Pepper mild mottle virus as a process indicator at drinking water treatment plants employing coagulation-sedimentation , rapid sand fi ltration , ozonation , and biological activated carbon treatments in. *Water Research*, *132*, 61–70. https://doi.org/10.1016/j.watres.2017.12.068

Madalina, P., & Gabriela, B. I. (2014). Water Quality Index – an Instrument for Water Resources Water Quality Index – an Instrument for Water. *Air and Water Components of the Environment*, *1*(257), 391–398.

Misaghi, F., Delgosha, F., Razzaghmanesh, M., & Myers, B. (2017). Introducing a water quality index for assessing water for irrigation purposes : A case study of the Ghezel Ozan River Science of the Total Environment Introducing a water quality index for assessing water for irrigation purposes : A case study of the

Ghezel Ozan River. *Science of the Total Environment*, *589*(November), 107–116. https://doi.org/10.1016/j.scitotenv.2017.02.226

NSF. (2005). *BASIN_ The National Sanitation Foundation Water Quality Index* (p. 1).

Nure Jannat1, M. A. M.*and M. N. A. (2019). Assessment of Physicochemical Properties of Surface Water of. *HSOA Journal of Environmental Science*, *2*(014). https://doi.org/10.24966/ESCR-5020/100014

Ojija, F., & Laizer, H. (2016). *Macro Invertebrates As Bio Indicators Of Water Quality In Nzovwe Stream , In Mbeya , Tanzania*. *5*(06), 211–222.

Pritchard, M. (2007). *Biological , chemical and physical drinking water quality from shallow wells in Malawi : Case study of Blantyre , Chiradzulu and Mulanje*. *32*, 1167–1177. https://doi.org/10.1016/j.pce.2007.07.013

Pullanikkatil, D., Palamuleni, L. G., & Ruhiiga, T. M. (2015). *Impact of land use on water quality in the Likangala catchment , southern Malawi*. *5914*. https://doi.org/10.2989/16085914.2015.1077777

Ramakrishnan, N. (2003). *BIO-MONITORING APPROACHES FOR WATER QUALITY ASSESSMENT IN TWO WATERBODIES AT TIRUVANNAMALAI , TAMIL NADU INDIA*. 374–385.

Sharifinia, M., Ramezanpour, Z., & Imanpour, J. (2019). *Water Quality Assessment of the Zarivar Lake Using Physico-chemical Parameters and NSF-WQI Indicator , Kurdistan Province-Iran*. *7*(1), 87–97.

Szczerbiñska, N. (2015). *Biological methods used to assess surface water quality*. 185–196. https://doi.org/10.1515/aopf-2015-0021

The Department of Environmental Affairs. (2018). South African Water Quality Guidelines for Coastal Marine Waters – Volume 1 : Natural Environment and Mariculture. *Environmental Affairs*, *1*.

Ullberg, M. (2015). *Temporal water quality study of the heavily human- impacted Likangala River , Zomba , Malawi*.

Yagci, A., Apaydin Yagci, M., Bilgin, F., & Erbatur, I. (2016). The effects of physicochemical parameters on fish distribution in Egirdir Lake, Turkey. *Iranian Journal of Fisheries Sciences*, *15*(2), 846–857.

Zhushi, F., Ismaili, M. A., & Shala, S. (2018). *parameters and macroinvertebrates*

BIOMONITORING OF WATER QUALITY OF RIVER NERODIME BASED ON PHYSICOCHEMICAL PARAMETERS AND MACROINVERTEBRATES. *April*. https://doi.org/10.7324/RJC.2018.1122087

Zwart, D. De. (1995). *MONITORING WATER QUALITY IN THE FUTURE VOLUME 3 : BIOMONITORING*. *3*.

APPENDICES

APPENDIX 1: Onsite

1. View of upstream and middle stream respectively.





2. Onsite collection of biomonitoring sample in the vegetation biotope and washing the sample while wearing a wader.





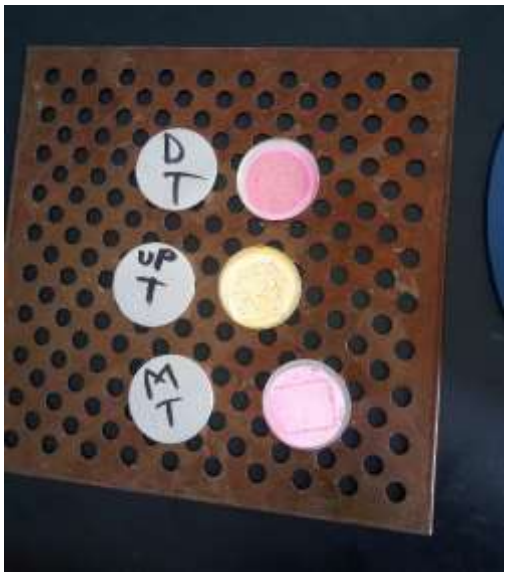
3. Samples of biomonitoring collected in the vegetation and GSM biotopes respectively placed in white trays.





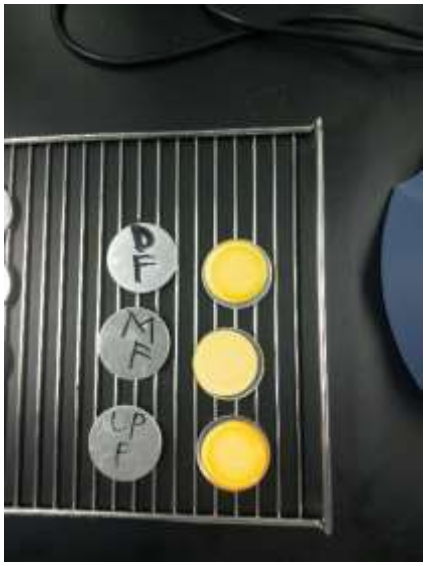
APPENDIX 2: Off-site

4. Analysis of micro-biological parameters of fecal and total coliforms labeled for each site.





- Labels of Up T, MT and DT of the petri dishes meaning upstream total coliform, middle stream total coliform and downstream total coliform respectively. Identified using a colony counter.



- Labels of Up F, MF and DF of petri dishes meaning upstream fecal coliform, middle stream fecal coliform and downstream fecal coliform.

5. A multi probe aqua meter



6. Measuring nutrients and turbidity in the lab using a photometer using reagents





- Nitrate and ammonia testing using a HT1000 Photometer and alongside is the picture showing the nitrate powder that was used in determination of nitrates.





- A sample of water with added reagents hence pink color and was placed in the photometer alongside that recorded its value.

APPENDIX 3: Table showing water quality variable test results in triplicates of Water Samples from upstream middle and downstream of Likangala River.

VARIABLES	SITE1	SITE2	SITE3
PH	7.63	7.45	7.52
PH	7.55	7.6	7.55
PH	7.65	7.67	7.54
Temperature (oC)	22.6	23.4	23.2
Temperature (oC)	21.9	22.6	22.7
Temperature (oC)	23.5	21.8	22.5
Turbidity (NTU)	5	10	7
Turbidity (NTU)	5	7	5
Turbidity (NTU)	9.5	8	5
ORP (mV)	37.6	45.55	59.1
ORP (mV)	41.9	47.2	44.1
ORP (mV)	38.6	43.9	41
EC (us/cm)	244	195	205
EC (us/cm)	182	219	201
EC (us/cm)	180	171	193
TDS (mg/l)	158	127.5	135
TDS (mg/l)	119	143	133
TDS (mg/l)	117	112	124
Nitrates (mg/l)	1.08	1.39	0.4
Nitrates(mg/l)	1.59	1.04	1.18
Nitrates (mg/l)	1.06	1.34	0.96
Ammonia (mg/l))	0.04	0.1	0.06
Ammonia (mg/l))	0.05	0.09	0.08
Ammonia (mg/l))	0.06	0.1	0.05
Dissolved Oxygen (mg/l)	7.21	5.1	7.7
Dissolved Oxygen (mg/l)	6.15	4.6	7.2
Dissolved Oxygen (mg/l)	6.25	5.3	7.25