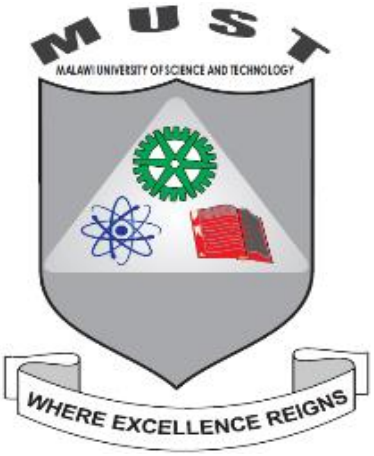


ASSESSMENT OF RIVER HEALTH IN MULANJE DISTRICT USING A BIOMONITORING APPROACH: A CASE STUDY OF LIKHUBULA, RUO, CHITAKALE AND CHANUNKHA.

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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.

19th July 2021.

DISSERTATION APPROVED BY:

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I Jessy Baloyi declare that "ASSESSMENT OF RIVER HEALTH IN MULANJE DISTRICT USING A BIOMONITORING APPROACH: A CASE STUDY OF LIKHUBULA, RUO, CHITAKALE AND CHANUNKHA." is my own work and that the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

Water quality assessment is the overall process of evaluating the physical, biological, and chemical characteristics of water. In developing countries like Malawi, water quality is largely monitored through water quality assessment comprising biological and physicochemical assessments, and to some extent water quality modeling. Biomonitoring is another water quality management approach that has not received much attention in Malawi. This current study investigated the utility of biomonitoring as a water quality management approach for selected rivers in the Mulanje district including Likhubula, Ruo, Chitakale, and Chanunkha.

This research was conducted in order to assess the river health condition of the Likhubula, Chitakale, Chanunnkha and Ruo river. The main environmental stressors that may affect the health conditions of these rivers include imacts from tea plantations where pesticides and fertilizers are used to increase cro yield. In addition to that there are isssues of deforestation in the Mulanje mountain and this study aimed at assessing whether the health condition of these rivers was affected by these factors.

The South African Scoring System (SASS) approach was used in this study. The approach involves sampling and identification of macroinvertebrates from each sampling site followed by the determination of the sensitivity scores of each species and group, and calculation of the Average Score per Taxa (ASPT). The ASPT was calculated as a biotic index and used to determine the ecosystem integrity and establish the ecological conditions of the rivers. The results showed that according the biotic index developed from the biomonitoring approach, the Likhubula, Chitakale and Chanunkha river were in a natural condition with the ASPT values of 7.6, 7.3 and 9. Ruo river on the other hand had an ASPT value of 6.6 which indicated that the river was in good condition with a few modifications

The ASTP values calculated correlated well with the basic physicochemical parameters measured for each site. These results have demonstrated the usefulness of biomonitoring for stream water quality assessments in the absence of physicochemical water quality assessments which are both time-consuming and resource intense. Further studies need to be conducted to assess the river health condition per section so that the overall condition of these rivers is known. In

addition to that, there is a need for studies to characterize the dynamics of nutrient and pesticides loading which are hypothesized to cause the ecological conditions observed in this study.

Keywords: *ASPT, Biomonitoring, Biotic Index, Macroinvertebrates, SASS, Water quality management*

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ACRONYMS/ABBREVIATIONS

DO- Dissolved Oxygen

EC - Electrical Conductivity

TDS- Total Dissolved Solids

pH- The power of hydrogen

Mg/l- Milligrams per liter

NTU- Nephelometric Turbidity Units

µS/cm -Siemens per meter

˚C- Degree Celsius

SASS- South African Scoring System

ASPT- Average Score Per Taxa

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2. INTRODUCTION

2.1. Background

Water quality assessment is defined as the overall process of analyzing the physical, chemical, and biological properties of water (Chapman, 1996). Streams and rivers are among the most endangered ecosystems in the world, there is a need for management approaches to assess the water quality of these ecosystems and to monitor their rate of changes (Li et al., 2010). Physical, chemical, and bacteriological measurements forms the basis of monitoring because they provide a complete spectrum of information for proper water management (Li et al., 2010). However, in running waters, where changes in hydrology are rapid and difficult to estimate, they cannot reflect the numerous environmental factors and the long-term sustainability of river ecosystems for their nature. Biomonitoring has been proven to be necessary supplementary to those traditional monitoring techniques (Li et al., 2010).

Aquatic organisms, such as diatoms and benthic macroinvertebrates, can serve as bioindicators to assess their total environment and their responses to complex sets of environmental conditions. They offer the possibility to obtain an ecological overview of the current status of streams or rivers (Li et al., 2010). According to Choy (2015), in most countries, water quality criteria based primarily on physio-chemical assessment largely ignore these ecological and biological attributes and do not accurately reflect ecosystem status. Therefore, a biological approach is necessary to assess and monitor the health of freshwater ecosystems.

In Malawi, there have not been frequent monitoring and assessment programs assessing the river health conditions which has led to the deterioration and pollution of existing water resources as a proper water quality management strategy to study the trend in water quality and quantity. Mulanje district mainly relies on Mulanje mountain as its main source of rivers providing water for domestic, industrial,

aesthetic, and agricultural needs hence the need for water quality data to ensure proper allocation of water for the different uses and a balance in ecosystem systems. This study will use a biomonitoring approach to assess and monitor the health of Likhubula, Ruo, Chitakale, and Chanunkha.

2.2. Problem statement

Mulanje Mountain is a massif of covering a massive 650 sq. km and it is located in the southwest of Malawi, near the border with Mozambique (Kambwiri et al., 2014). Mount Mulanje is a major catchment area and is a source of all rivers in Mulanje District which supplies clean drinking water to the people and the tea estates (Hecht, 2005). According to Hetch (2005), Mulanje mountain has a rich biodiversity with high endemism, and the Mulanje cedar found in this mountain is considered the national tree of Malawi and is highly valued for its use in silviculture and its contribution to socio-economic development (Joy, 2006). In 2005 it was observed that the use of fuelwood from the protected area exceeded its sustainable yield. Fuelwood demand has grown with population growth, while the current excess of demand over supply has led to the decrease in supply until there is no forest left (Hecht, 2005). From the study conducted in 2005 by the COMPASS II and the Mulanje Mountain Conservation Trust, it was observed that unsustainable harvesting of trees from the mountain led to diminishing forest cover which also affected the climate of this particular district. Climate change may affect the supply of water from the mountain to the rivers in the district. In addition to that, Mulanje is well known for tea production which has several negative impacts on water systems that put the rivers in Mulanje at risk of pollution. According to a study conducted by SOMO (2008) for example, these rivers were affected by the use of chemicals such as pesticides and fertilizers that reacted with the water and changed its composition. There were also issues of improper waste disposal that would affect the quality of water. All these activities in the mountain and the tea estates may have impacts on the health of rivers in Mulanje. This study, therefore, was conducted to assess the river health conditions of the rivers that depend on this mountain as their source was affected by the deforestation and tea fields using a

biomonitoring approach. Biomonitoring will provide an assessment of influences of landscape activities on the functional health of the river, and their potential impacts on ecosystem services. This study will be of relevance as the data for this study will be used to make decisions towards the conservation of the valuable resources from the mountain hence an improved economy of Mulanje and Malawi as a whole. There is a research gap that most studies have not analyzed water quality using a cheap biomonitoring approach, less time consuming, and requires less skill as compared to physicochemical analysis and ecotoxicology.

2.3. Main objectives

To assess the river health condition in the upstream sections of Likhubula, Ruo, Chitakale, and Chanunkha using a biomonitoring approach.

2.3.1. Specific objectives

i. To explore the macroinvertebrate species diversity in the upstream sections of the rivers.
ii. To profile selected physicochemical parameters of the upstream sections of Chitakale, Chanunkha, Ruo, and Likhubula river.
iii. To determine the relationship between the macroinvertebrates species and the river health conditions of the upstream sections of the rivers.

2.4. Research questions

i. How diverse are the macroinvertebrates species in the upstream sections of the Likhubula, Chitakale, Ruo, and Chanunkha rivers?
ii. What do the physicochemical parameters tell about the health of the upstream sections of the rivers?
iii. What is the relationship between the macroinvertebrates species and the upstream river health conditions?

2.5. Study significance

Mulanje river is of great importance to Malawi as a country because it helps the economy grow as far as the tourism industry is concerned. This study will help gain knowledge about aquatic faunal biodiversity in rivers in Mulanje and to develop a method for diagnosis of the health of the river ecosystem which will assist in the formulation of conceptual models for the ecosystem which also help to conserve the resources from this mountain which will boost the economy of Malawi. It will also help in quantifying the human impacts on streams and rivers hence assessments of the quality of water bodies where the results of this study will contribute to the maintenance of the water quality needed for agricultural, fisheries, domestic uses and for potable use which will contribute to sustainable development in the country. This study will also help in providing biomonitoring data for these rivers. To develop a method for diagnosis of the health of the river which is cheap, less time consuming and requires fewer skills that even local people can use it. This study will also contribute to sustainable development in the country by quantifying the human impacts on streams and rivers . This study will also help in providing biomonitoring data for these rivers as studying macroinvertebrate diversity is one of the most effective and inexpensive ways to estimate the ecological quality of the waters.

3. LITERATURE REVIEW

Water is an inorganic, transparent, tasteless, odorless, and nearly colorless chemical substance, which is the main constituent of Earth's hydrosphere and any of the entire range of natural waters that occur on the Earth, regardless of their state and that of potential use to humans. Water is a renewable resource because the water cycle is repeated again and again in a natural way, without the need for human intervention. Among other uses, water is used for agriculture and industries, aesthetic uses, sanitation, and consumption by humans and animals. With the increased population globally there has been pressure that has been put on water resources. However, it is not just the increase in population that is pressuring water resources. Excessive use has also negatively affected the water resources.

According to Laisi et al (2009), Malawi's geographical positioning in southern Africa allows it to receive adequate rainfall influenced by the Inter-Tropical Convergence Zone, the Congo Air, and the South-Easterly Winds leading to normal and above normal flows in rivers and streams during most of the years. Malawi is blessed due to the existence of Lake Malawi and other smaller lakes that provides water resources in the sub-region. However, due to climate variability, climate change, and water use and management practices, the country faces daunting challenges which could see the per capita share of water resources plummeting to very low levels soon (Laisi et al., 2009).

3.1. Global water quality issues

Water is a limited environmental resource and it needs to support a large population of people; and by that date, an estimated 3.9 billion which causes stress on available water resources (Guppy, 2017). There are so many causes of the global water crisis including water pollution, agriculture, population growth, etc. These issues have led to water scarcity which has negative problems for human health as there is an increase in hunger issues and the development of the communities and the country. It also affects the availability of wetlands which are essential for animals, plants as well as agriculture. These impacts can lead to the drying up of natural landscapes and pollution of water resources. Additionally, economies may negatively be affected as

there would be a change of focus on funds and other resources to ensure there is sufficient water. According to a study conducted by the UN, 785 million people lack access to clean water, women and girls spend a lot of time searching for water. Water gets contaminated water, poor sanitation, and unsafe hygiene practices as people are left with no choice but to consume any kind of water that is available.

3.2. Water quality status of sub-Saharan Africa

Even though Sub-Saharan Africa has enjoyed impressive economic growth over the past decade, the region is still faced with substantial and often shared development challenges (Naik et al., 2017). Water challenges are amongst the critical issues faced in sub-Saharan Africa. To ensure sustainable growth and long-term stability, these water challenges must be addressed (Freitas, 2013). Sub-Saharan Africa faces difficulties as compared to other regions in the world when it comes to water access, management, and supply (Naik et al., 2017). Worldwide, water has also become an increasingly scarce resource, and in sub-Saharan Africa, a potential threat to regional security (Freitas, 2013). With its rainy equatorial zone, long rivers, great lakes, and vast shores, Africa is one of the regions in the world that has a lot of water that is unevenly distributed across the region and as a result, most countries in the region are under severe water stress (Laisi et al., 2009). In addition to that, land grabbing is another cause of water shortages and the property deals between sub-Saharan African countries and foreign companies involve selling rights to inland water resources. As property acquired in such a manner is mostly used for extensive, water-demanding agricultural activities (that often entail deforestation), 'land grabbing' further jeopardizes water supplies and, in countries like Ethiopia or Sudan, worsens the effects of already endemic water scarcity (Freitas, 2013). According to Laisi (2009), it is unfortunate that water from the region is not only scarce but also of exceptionally poor quality. As stated by Laisi (2009) almost half of all Africans suffer from water-borne diseases, with cholera and infant diarrhea the most frequently occurring sickness. Most of the countries with the lowest levels of sanitation are located in sub-Saharan Africa, where 45% of the population resorts to using shared or dangerously inadequate facilities – with little progress in the area recorded to date (Wang et al., 2020).

Africa's economic growth, boosted primarily by the exploitation of its natural resources, has also been contributing to water quality - and quantity - shortages. Improper disposal of industrial sewage and waste in addition to the uncontrolled use of agrochemicals and oil spills is also a common challenge as it damages the water reserves and is largely irreversible, compromising the use of inland or marine waters for generations coming (Engineering, 2019).

3.3. Water quality monitoring approaches

Water quality monitoring techniques are necessary for dealing with the increasing deterioration of aquatic environments as most researchers never focus on the discovery and tracing of pollution sources (Monitoring et al., 2012). Water quality monitoring refers to the long-term standardized measurement observation, evaluation, and reporting of the aquatic environment to define status and trends (Engineering, 2019). Changes in land use reflect the history and perhaps the future generations as they are linked with economic development, population growth, technology, and environmental change (Kambwiri et al., 2014). Sala et al. (2000) state that in developing countries anthropogenic activities such as river regulation and pollution harm rivers and wetlands water quantity and quality, hence negatively impacting river-dependent people, often the poorest people in a region.

Monitoring of water quality can be accomplished in two ways: one approach is the operation of a vast network of strategically located long-term observation stations and a second approach is the repeated operation of short-term surveys, each providing limited spatial coverage (Monitoring et al., 2012).

Sampling frequency depends on the variability of the data. Therefore, knowledge of the variability in the variables of interest is necessary. The water quality variables selected for a station will be determined largely by the water quality measurement objectives. However, to minimize costs of operation, the selection may be based on known characteristics of the water resource, and that of the polluting sources. Furthermore, samples may not always need to be analyzed for all selected variables. Variables can be chosen based on their relative importance and analytical cost. However, analytical procedures must be standardized and adhered to by all laboratories participating in the monitoring program. Monitoring of water quality is

not an activity that stands alone but is instead an important part of any comprehensive water quality management scheme. Water quality data will therefore be compared to criteria and standards, leading to water quality management decisions. Thus, the ultimate aim of monitoring is the assessment of water quality. The design of a monitoring program should therefore start with the definition of the assessment task. Water Quality Analysis is when water quality standards are put in place to ensure the efficient use of water for a designated purpose. Water quality analysis is to measure the required parameters of water, following standard methods, to check whether they are by the standard (Roy, 2019).

3.4. Water quality assessment

As stated by Chapman (1996) 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 one or more biotic species and or to any human need or purpose (Sadgir, 2015). Water quality assessment is the overall process of evaluation of the physical, chemical, and biological nature of the water. It is most frequently used by reference to a set of standards against which compliance can be assessed (Dominic, 2017). Water quality is analyzed in three ways namely; physicochemical parameters, ecotoxicology, and biomonitoring which are explained below.

3.4.1. Analysis of water quality using the physicochemical parameters

Due to undesired changes in chemical, physical, and biological characteristics of air, soil, and water the people on the globe are under tremendous threat (Naik et al., 2017). There is an impairment of water resources due to pollution from the diverse use of water resources. The increased anthropogenic activities have highly polluted water with different harmful contaminants. Physicochemical parameters are measured to determine water quality and these include physical properties like pH, color, turbidity, suspended solids, temperature, conductivity, odor, etc. Chemical properties like COD, BOD, total nitrogen, total phosphorus, total pesticides, etc. Biological properties include total coliform bacteria, fecal coliform counts, fecal streptococci count, salmonella counts, etc. The total review of all these parameters

can give an idea of the water quality (Sadgir, 2015). And thus determining the above factors and providing them in an easily understandable form could provide information to the user or public.

A study was conducted to assess the ecological health of River Berga using physicochemical parameters in December 2016, February, and April 2017. Physio-chemical parameters, such as dissolved oxygen, conductivity, temperature, and pH were measured in-situ, and total phosphorous, soluble phosphorous, ammonia nitrogen, nitrate-nitrogen, and COD were determined in the laboratory. Some physio-chemical parameters (water temperature, soluble phosphorus, pH, and NO3-N) were negatively correlated with the benthic macroinvertebrate metrics in the study area. Pressure from livestock, poor farming methods, destruction of riparian forest, cattle grazing, watering, wallowing and wading along the river shore, washing clothes, and domestic wastes were the major environmental stressors identified in impacting the water quality of river Berga. This observation was confirmed by threshold values where the upper sites fell in high water quality and the downstream site as highly polluted. Thus, mitigation measures should be taken to prevent the further deterioration of the river Berga (Berisa, 2019).

Another study was done after observing the deteriorating state of the Mudi River. The level of pollution was assessed to assist in designing control measures. The assessment was done during the rainy season, a period during which the levels of pollution are at their lowest as the water in the river is diluted by rain to capture the minimum levels to which the Mudi River is subjected. Samples of water were collected and analyzed using standard methods. Sampling was done at five different points depending on the suspected pollution source. In this study, protection of aquatic life, aesthetic properties, and other uses by people other than drinking was considered. There was a very big difference in levels at source as compared to other sampling points for biological and physical parameters. Maintaining the sewage pipes, discouraging cultivation along river banks, open defecation, and disposal of waste in the river will reduce the levels of biological and physical contamination of water in the Mudi river in Blantyre. There is also a need to investigate the possible sources of chemical pollutants which showed very high levels at sampling points other than the source (Kumwenda et al., 2012).

In addition to that, a research study was carried out to determine the effects of different land uses on the water quality of the Ruo River. Water sampling was done both in the upper and the middle sections of the river. The water samples were analyzed for physicochemical parameters using standard methods. Land uses in the area significantly affected the concentration of EC, TDS, sulfates, potassium, and sodium ($p \leq 0.05$) while pH, dissolved oxygen, chloride, bicarbonates, nitrates, phosphates and E-coli did not significantly fluctuate with land-use changes in the area ($p \geq 0.05$). The effect of seasons was significant on pH, dissolved oxygen, phosphates, chloride, bicarbonates, and sodium ($p \leq 0.05$) but not on electrical conductivity, total dissolved solids, sulfates, nitrates, lead, potassium, and e-coli in the Ruo River. The research recommends an integrated water resources management approach where all users and relevant stakeholders should take an active role in the conservation of the Ruo River catchment to avoid further degradation of the catchment through different land uses (Kambwiri et al., 2014).

Another study was conducted on the Al Abasseia river station to study the concentration levels of some water quality parameters. The principal reason for monitoring water quality was to verify whether the observed water quality is suitable for intended uses. The purpose was to assess the level of parameters measured and their effects on the river, statistical analysis was used to describe the relations between parameters of water quality. This study showed that the discharging of domestic sewage, detergents, agricultural effluents with fertilizers, and industrial wastewater from adjacent areas causing some contaminants increased (Abdulmuttaleb & Khan, 2018).

3.4.1.1. Electrical conductivity-EC in $\mu S/cm$

When the water is without any dissolved solutes, electricity conducted naturally. The amount of electricity that can pass through water is influenced by how many ions are dissolved in the water solution (Shield et al., 2008.). By measuring EC, we can get an idea of how many ionic nutrients are in the water. For most aqueous solutions, a higher concentration of dissolved salts leads to more ions and higher conductivity (Rahmanian et al., 2015). Aquatic animals and plants are adapted for a specific range of EC and being outside this range, they will negatively be affected and may die as

the ions that conduct electric current may bioaccumulate in them (Shield et al., 2008.).

3.4.1.2. Potential Hydrogen ion-pH

pH determines whether aquatic life can use it. Low pH tends to be toxic for aquatic life. The pH is a numeric scale from 0-14 to determine the acidity and basicity of the water solution. The pH of the solution plays an important role in plant nutrient uptake. Water pH affects essential nutrients' availability; in other words, when the water pH is out of range, plants cannot absorb nutrients even when there is plenty in the water (Robertson- Bryan, 2004). pH is an indicator of water that is changing chemically. It determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals (Hetherwick, 2010.).

3.4.1.3. Temperature in °C

The temperature of water governs the types and kinds of aquatic life that live in it. Warm water can affect the aquatic life as it holds less dissolved oxygen than cool water and may not contain enough dissolved oxygen for the survival of different species of aquatic life as the increase in temperature increases the solubility of oxygen decreases, photosynthesis of aquatic plants, metabolic rates of aquatic organisms and the sensitivity of these organisms to pollution, parasites and diseases (Hazen et al., 2013.). Aquatic organisms have a preferred range and once the temperature is far above or below the preferred range the number of individual species decreases until there are none. Some compounds are also more toxic to aquatic life at high temperatures. High water temperature may stimulate or retard migration, spawning, feeding, and growth of aquatic life may influence enzyme and hormone activities and other physiological processes and may speed up the action of toxicants (Tarzwell & Tarzwell, 1970). According to Hazel et al. (2013), the optimal temperature range for most aquatic organisms is 5 - 25^{o}c.

3.4.1.4. Total Dissolved Solids-TDS in mg/l

Total Dissolved Solids is a measure of the combined total of organic and inorganic substances contained in water. Anything present in water other than the pure water

molecules is TDS. These solids are primarily minerals, salts, and organic matter that can be an indicator of water quality (APHA, 2005). TDS has been due to mineral springs, carbonate deposits, salt deposits, stormwater, agricultural runoff, etc. TDS affects one's health after consuming certain substances such as heavy metals, taste, and color from a high concentration of TDS can be bitter and unpleasant (Rahmanian et al., 2015). In water with high TDS concentration cells of an organism shrinks causing it to malfunction and die. It also affects an organism's ability to move in a water column, causing it to float or sink beyond its normal range (Shield et al., 2008.).

3.4.1.5. Dissolved Oxygen-DO in mg/l

A measure of how much oxygen is dissolved in the water and is available to living organisms is Dissolved Oxygen. Rapid moving water such as in a mountain stream or large river tends to contain a lot of dissolved oxygen whereas stagnant water contains less (Chapman, 1996). Aquatic life can have a hard time in stagnant water and DO in the surface water is all used by all forms of aquatic life and this is typically measured to assess the health of lakes and rivers (Hetherwick, 2010). Photosynthesis also largely depends on the amount of dissolved oxygen in a water body.

3.4.1.6. Turbidity T in NTU

Turbidity is a measure of water clarity and if water appears to be highly turbid it means a small amount of light can penetrate through the water which indicates that the number of particles or sediment suspended in or dissolved in the water (Island et al., 2008.). Any increase in turbidity decreases the amount of light for photosynthesis and it also leads to an increase in water temperature as suspended particles absorb more heat(Quality, 2008).

3.4.2. Analysis of water quality using the biomonitoring approach

In biomonitoring, macroinvertebrates are used to analyze the quality of water. As stated by Dickens et al., (2002) biomonitoring may be used to assess the ecological state of aquatic ecosystems, assess the spatial and temporal trends in the ecological state, assess emerging problems. Macroinvertebrates are of great diversity and ecological importance and it consists of invertebrates of macroscopic size, living permanently or during certain periods of their life cycle linked to the aquatic

environment (Li et al., 2010). They include insects, crustaceans, annelids, molluscs, leeches, etc. and these are excellent indicators of contamination as they are very useful bioindicators in determining the characteristics of aquatic environments (Benetti & Garrido, 2010). Benthic macroinvertebrates, in particular, are recognized as valuable organisms for bio assessments, mainly because of their visibility to the naked eye, ease of identification, and rapid life cycle often based on the seasons. Studies of biodiversity, species abundance, dominance, and distribution of macroinvertebrate fauna to determine the extent of changes in their structure and composition associated with water quality changes therefore should be conducted. Studying macroinvertebrate diversity is one of the most effective and inexpensive ways to estimate the ecological quality of the waters (Orribhabor, 2002). It is necessary to combine physical, chemical, and biological as the measurement of the physical and chemical properties of water can also be utilized to estimate its quality but such measurements cannot exactly represent the actual state of the waters (APHA, 2005).

Biological monitoring using macroinvertebrates has been found accurate and advantageous compared with using other organisms because macroinvertebrates are extremely sensitive to organic pollutants, widely distributed, and easy and economical to sample. An increase or decrease of the macroinvertebrate population in the water body indicates pollution, presence of stress factors, and damage to the ecosystem (Chapman, 1996).

According to Dickens et al. (2002), Southern African Scoring System 5 ($SASS_5$) will be applied where macroinvertebrates samples for invertebrates, physical and chemical water quality parameters such as pH, turbidity, Electric Conductivity, Dissolved Oxygen, temperature, etc. will be obtained. ($SASS_5$) approach is an empirical, carefully designed, and refined methodology used to provide a scientific and credible assessment of the status or health of a river after examining the aquatic macroinvertebrates found in a particular river. When applied correctly and routinely with careful consideration for external environmental factors, a great rapid assessment tool for determining and monitoring the health status of sections of rivers (Dickens & Graham, 2002).

At each site along a river, the $SASS_5$ protocol is followed and the specified sampling techniques are used to collect macroinvertebrates. Macroinvertebrates have been assigned various scores based on sensitivities and habitat requirements. Insects with greater sensitivities to pollution or disturbance are likely to score higher. The more varied the creatures found in a particular section of the stream, the greater the overall $SASS_5$ score will be when the results are added up. Sensitivity scores are then assessed by external factors such as the season and geographical location which has bearing on aquatic species in the same way it has bearing on terrestrial species. Macroinvertebrate families are a very diverse, sensitive population to pollution of a water body and may be suitable for assessment of the relative impact of water pollution on living organisms inhabiting surface water (Dittmann et al., 2018).

Biomonitoring is the systematic use of living organisms or their responses to determine the condition or changes of the environment and it is used for observing the impact of external factors on ecosystems and their development over a period, or of ascertaining differences between one location and another (Zhou et al., 2008). Macroinvertebrates samples are collected from three biotopes namely; Gravel, Sand & Mud, Stone, and Vegetation biotopes (Dickens & Graham, 2002). These biotopes are explained below.

i. Stone (S) biotopes

The net should be placed close to but downstream of the stones to be kicked, in a position where the current will carry the dislodged biota into the biomonitoring net. Where possible the stones should be kicked or turned over against each other to dislodge the invertebrates. Stones, in particular bedrock, may also be rubbed with the hands or boots. Hold the net sufficiently far from the feet as to avoid picking up coarse sediments, which will sink to the bottom faster than the dislodged invertebrates. The kicking of stones should continue for approximately two minutes. If the stones are embedded or difficult to move, especially bedrock, then sampling may continue for up to a maximum of five minutes, which must be recorded. Samples collected are Stones (S) biotope samples.

a. Vegetation (Veg) biotopes

in rivers, this is the vegetation hanging into or growing at the edge of the stream, often emergent. The net is pushed vigorously into the vegetation moving backward and forwards through the same area. Particular care should be taken in strong currents to catch dislodged invertebrates. To avoid the tendency to collect organisms from above the water surface, the net should be kept below the surface. It is useful to record the dominant plant species, as this will give insight into the type of biotope present. Samples are Vegetation (Veg) biotope samples.

a. Gravel, Sand & Mud (GSM) biotopes

Samples are collected by ranging between all of the following three biotopes of GSM (where available). The gravel should be stirred by shuffling or scraping with the feet, whilst continuously sweeping the net over the disturbed area to catch dislodged biota. The sand should be stirred by shuffling the feet, whilst continuously sweeping the net over the disturbed area to catch dislodged biota. A few seconds should be allowed for large sediments to settle before sweeping the net otherwise, excessive sediment will be collected. Collection effort should concentrate on slow-flowing or still water. Mud should be stirred by shuffling with the feet whilst sweeping the net over the disturbed area to catch dislodged biota, but avoiding collecting mud into the net. Samples collected are Gravel, Sand & Mud (GSM) biotope samples.

b. Hand-picking and visual observation

During sampling, approximately 1 minute of hand-picking for specimens that may have been missed by the sampling procedure must be carried out. Commonly, this will also involve noting (not necessarily collecting) snails and fast-moving pond skaters. In very thick mud, lumps of the substrate should be dug out and broken into pieces with the hands, looking for burrowing organisms.

In the biomonitoring approach, studies were conducted over 10 years (1998-2008) in 10 rivers in the Autonomous Region of Galicia (North-western Spain) located in areas with different degrees of anthropogenic impacts. Benthic macroinvertebrates and their indices were used for the quality assessment. The biotic indices environment and assemblage composition-environment relationships were analyzed to study

responses to structural characteristics of the habitat (natural or artificial) and variations in water quality parameters (Benetti et al., 2012).

Another study was also conducted to rapidly assess the ecological status of the river Pcinja, based on macroinvertebrate fauna. During the summer period of 2009, hydrobiological research was conducted at eight sampling sites along the entire river course. Severe deterioration of the water quality was detected at the mouth of the Kumanovska River (the right tributary of the Pcinja River). A decrease was recorded in the number of families along the watercourse in the downstream direction, which indicates environmental stress. The observed change in the community structure indicates the presence of pollution, but also a change of the type of watercourse (Valentina et al., 2011).

To determine the state of river systems based on differences in tolerance levels that various taxonomic groups of organisms have on the physical and chemical properties of a freshwater system biological indices are used (Valentina et al., 2011).

Biological monitoring approaches were designed to make a scientifically reliable, rapid, and low-cost technique that could be an alternative to physical and chemical methods to monitor river water quality by both scientists and non-scientists.

The SASS approach calculates the ecological water quality index based on the average score per taxon (ASPT). ASPT is calculated by dividing the sum of scores per present taxa by the total number of scoring taxa. The highest number of taxa with the highest number of abundance gives the high value of ASPT which can classify a better condition of river water quality (Turley et al., 2016).

Macroinvertebrates have different degrees of tolerance and response to environmental stressors, like eutrophication and heavy metal pollution. On the other hand, benthic macroinvertebrates are good indicators of local conditions as they have a limited movement and live long enough to integrate the effect of temporal variability and some species and life stages have a short life span, and they respond rapidly to stressors (Taylor et al., 2010).

Benthic macroinvertebrates are ideal candidates for biomonitoring for several reasons such as their abundance in aquatic systems, their sedentary nature which allows spatial impacts of pollution to be detected, differences in taxonomic groups

have different sensitivities to pollution, they are generally easy to collect and identify, and finally, they act as continuous water quality monitors. Unlike chemical monitoring, which provides information about water quality at the time of measurement, biological monitoring can provide information about past and/or episodic pollution (Zhou et al., 2008).

3.4.3. Analysis of water quality using Ecotoxicology

Ecotoxicology is a study where a certain organism is exposed to a certain concentration to analyze the impacts of effluent discharge in the river's macroinvertebrates (Römbke, 2013). Heavy metals are well-known environmental pollutants due to their toxicity, persistence in the environment, and bioaccumulative nature. The natural sources of Heavy metals include weathering of metal-bearing rocks and volcanic eruptions and anthropogenic sources include mining and various industrial and agricultural activities. Mining and industrial processing for extraction of mineral resources and their subsequent applications for industrial, agricultural, and economic development has led to an increase in the mobilization of these elements in the environment and disturbance of their biogeochemical cycles (Ali et al., 2019). Contamination of aquatic and terrestrial ecosystems with toxic heavy metals is an environmental problem of public health concern (Sujaul et al., 2013). Being persistent pollutants, heavy metals accumulate in the environment and consequently contaminate the food chains. Accumulation of potentially toxic heavy metals in biota causes a potential health threat to their consumers including humans. It is very important to assess and monitor the concentrations of potentially toxic heavy metals and metalloids in different environmental segments and the resident biota (Heloisa et al., 2011). A study was conducted by Tapia-salazar (2020), where the Emerging contaminants (ECs) were not monitored nor regulated consistently, but may have had negative effects on human health and ecosystem balance. Although pharmaceuticals and personal care products were among the main ECs found in surface and wastewater, their toxicity and fate were currently not sufficiently studied. In this study, for the first time, a group of 46 ECs in the secondary effluent of the wastewater treatment plants (WWTP) of Prague was analyzed. These biochemical markers complemented the toxicity profile of these contaminants in aquatic

ecosystems and highlighted the need for further research on other ECs and their implications, and the regulations required to protect human and ecological health (Czech et al., 2020). According to a study by Vellemu (2017), acid mine drainage (AMD) and increasing salinity of freshwater ecosystems pose serious threats to water quality in water-stressed South Africa. These threats are exacerbated by mining activities, mainly gold and coal from both active and abandoned mines that continue to release acidic water that is rich in toxic metals and high sulfate concentrations. Therefore, the overarching hypothesis for this study was that "the combination of AMD and sulfate salts confers high ecological risk to the aquatic biota". The study employed both laboratory and field investigations to test this hypothesis and provide appropriate tools to protect freshwater ecosystems from increasing anthropogenic impacts. The study recommends incorporating different life stages of indigenous species tested to determine if their sensitivity to AMD and sulfate would correspond to current findings because early life stages could be more sensitive to aquatic stressors than juveniles or adults. This is important for the derivation of strong and relevant Water quality guidelines. The trait-based approach requires further refinement for its incorporation in ecotoxicology on a wide scale (Vellemu, 2018). Heavy metals and metalloids are environmental pollutants in both aquatic and terrestrial ecosystems. The hazard of an environmental chemical is a function of its environmental persistence, toxicity, and bioaccumulative potential. Toxic environmental chemicals which are persistent and bioaccumulative are more hazardous. Heavy metals are considered hazardous due to these three characteristics: persistence, bioaccumulation, and toxicity (PBT). Environmentally relevant most hazardous heavy metals and metalloids include Cr, Ni, Cu, Zn, Cd, Pb, Hg, and As. The trophic transfer of these elements in aquatic and terrestrial food chains/webs has important implications for wildlife and human health. It is very important to assess and monitor the concentrations of potentially toxic heavy metals and metalloids in different environmental segments as well as in the resident biota. A comprehensive study of the environmental chemistry and ecotoxicology of hazardous heavy metals and metalloids shows that steps should be taken to minimize the impact of these elements on human health and the environment (Czech et al., 2020).

4. METHODOLOGY

4.1. Study area

In southern region of Malawi there is a district known as Mulanje. According to NSO (2018), the area covers an area of 2,056 km^2 and has a population of 684,107 with 325,115 males and 358,992 females. It is well known for its tea growing industry and Mulanje mountain which is one of the highest peaks in Southern Africa and it serves as an essential water catchment area surrounding lowlands and tea and pine plantation that have replaced much of the original vegetation. Mount Mulanje is a major catchment area and is a source of all rivers in Mulanje District which supplies clean drinking water to the people and the tea estates.

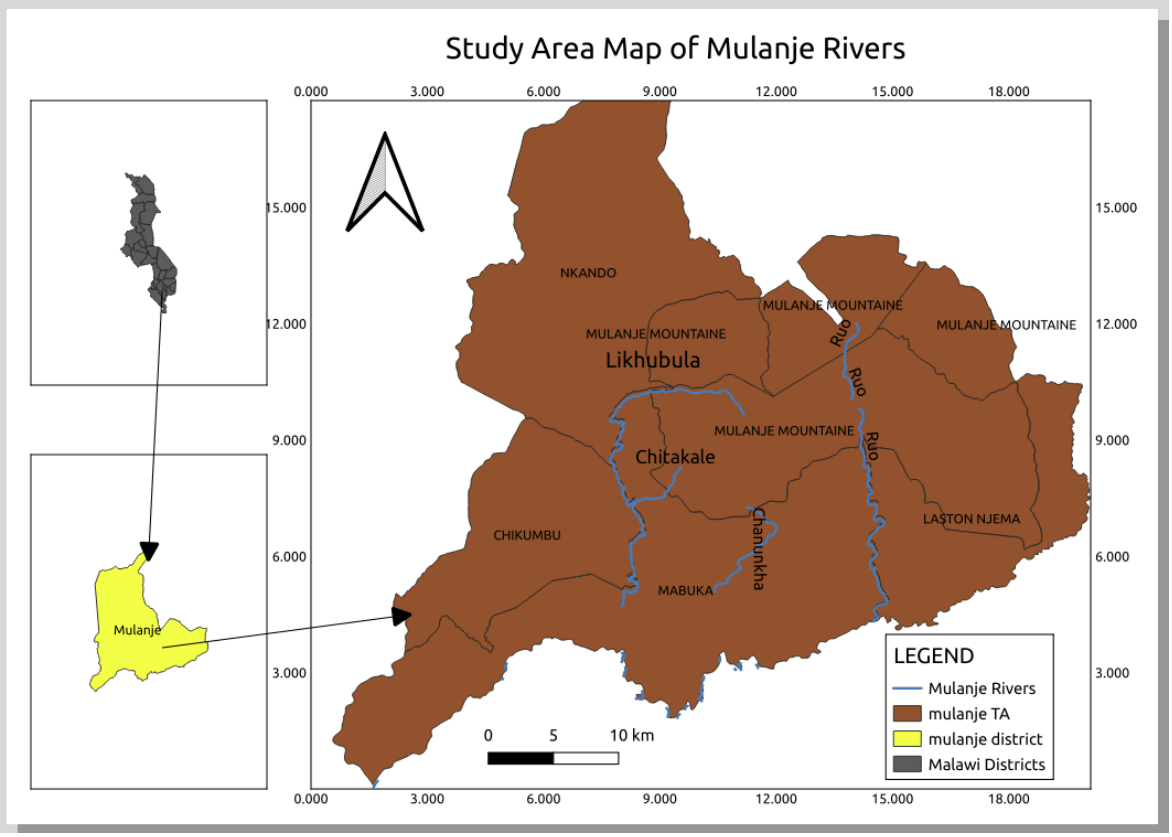


Figure 1: Map of selected rivers in Mulanje district

NB: only the upstream section of the rivers was assessed.

4.2. Sampling frequency

These macroinvertebrates and physicochemical parameters were sampled for 3 days.

Data collection was done in November 2020.

4.3. Research design

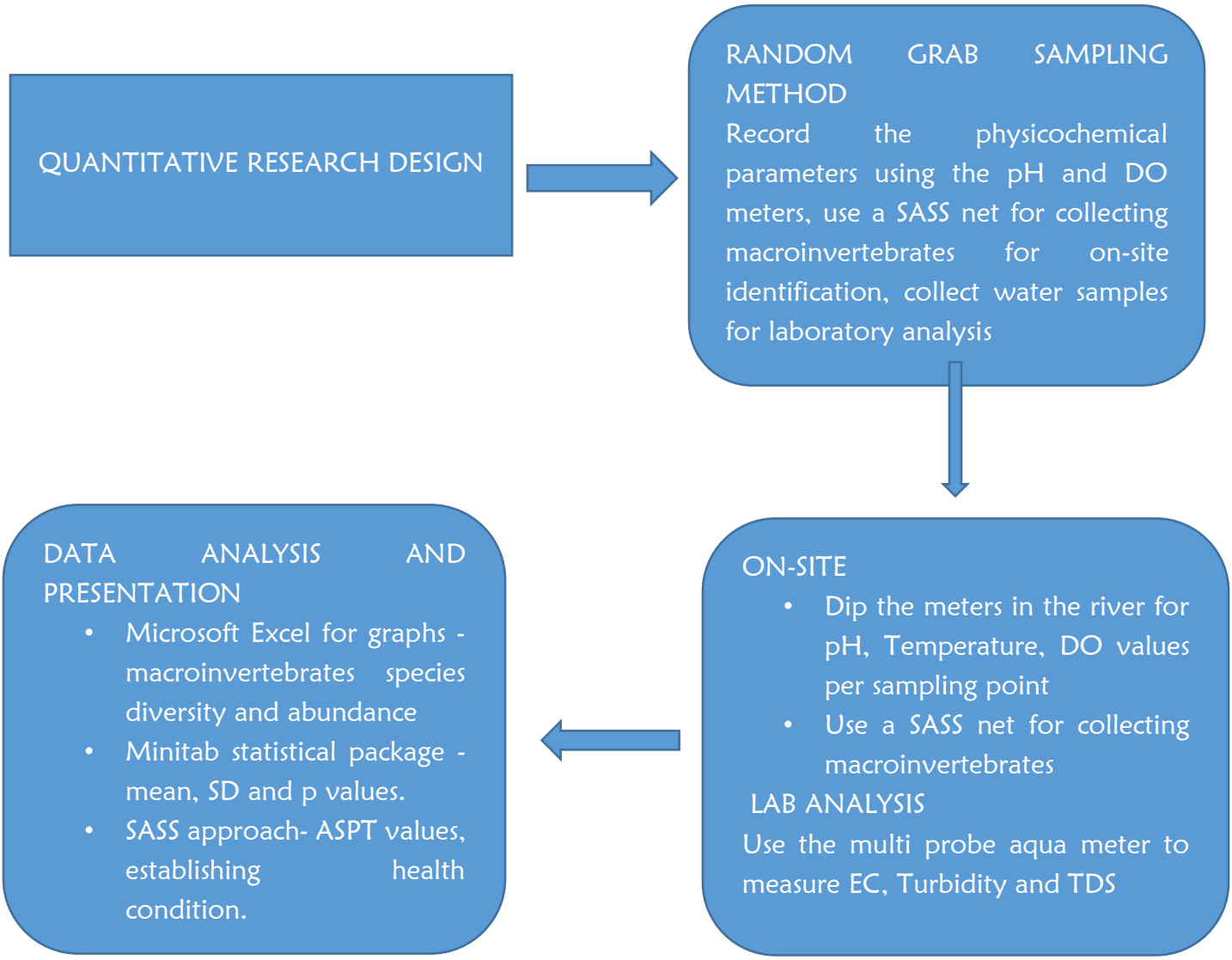


Figure 2: Workflow of the quantitative research design

4.4. Sample collection

For onsite measurement of physicochemical parameters the pH and DO meters were used for pH, temperature, and DO measurements. Using the grab sampling methods 3 Water samples were collected from random points in the sampling sites and were placed in pre-acid-washed plastic sample bottles for further identification in the laboratory. The macroinvertebrates were collected using a SASS approach and were placed in white trays for sample identification. After identification, the macroinvertebrates were returned to the rivers.

4.5. Sampling procedure

4.5.1. Physicochemical parameters

Physio-chemical parameters sampling was performed for 3 days in November 2020. Physical variables including temperature, dissolved oxygen, pH were measured on-site using a portable Dissolved Oxygen meter and pH meter respectively. These meters were dipped into the river where the values were obtained and recorded. There was an analysis of Total Dissolved Solids, Turbidity, Electric Conductivity using the multi-parameter probe in the laboratory.



Figure 3: In situ measurement of physicochemical parameters using the multi-parameter probe

4.5.2. Macroinvertebrates sampling

Aquatic organisms were collected using a SASS net which was positioned in a direction against the flow of the river in all biotypes. The samples collected were rinsed to remove mud and have clear and clean samples collected. The collected samples from the net were put into the white plastic trays with water and each white tray was identified by the biotope the samples belonged to. The macroinvertebrates were identified using the South African Identification Book. After identification, the samples were returned to the river. An average score of aquatic invertebrates was calculated by summing up the sensitivity score of different groups of organisms and then divide with the number of groups of the organisms present at that station. The average score was then compared to the ecological conditions of the rivers to establish the condition of the river. In the past, water quality was assessed using only physicochemical parameters, but these variables only reflect punctual pollution. The use of biological indicators is more adequate to detect long-term changes in water

quality since aquatic organisms are adapted to specific environmental conditions. If these conditions change, some organisms can disappear (intolerant) and be replaced by others (tolerant). Therefore, variations in the composition and structure of aquatic organism assemblages in running waters can indicate possible pollution (Benetti et al., 2012). The assessment of biota in rivers is a widely recognized means of determining the condition or 'health' of rivers.



Figure 4: Collection of Benthic invertebrates using a SASS net

4.5.3. Materials and equipment

A Stream Assessment Scoring System (SASS) net, 3 white trays, buckets, life jacket, waders, booklet of the Aquatic Invertebrates of South African Rivers and a SASS sensitivity score sheet, forceps, soft plastic wide-mouth pipettes, magnifying lens, and SASS scoring sheets, GPS, antiseptic soap, clean water, funnel, gloves, sample collection bottles, pH meter, DO meter and conductivity meter was used.

4.6. Data analysis

The macroinvertebrates were analyzed using the Stream Assessment Scoring System (SASS) to obtain the Average Score Per Taxa. Microsoft Excel was used for the production of graphs and tables. Minitab Statistical package was used to calculate the mean, standard deviation, and p-value.

4.7. Data presentation

Results of the physiochemical parameters were presented in tables and biomonitoring data was displayed through graphs.

4.8. Limitations of the study

Lack of financial resources for conducting the research for the whole river systems which only made it possible to conduct the study in the upstream areas.

5. RESULTS AND DISCUSSIONS

5.1. Introduction

This section presents the results of the physicochemical parameters of the water samples which were measured on-site and collected for laboratory analysis which are. The specific objectives for this study were to explore the diversity of macroinvertebrates species in these rivers, to profile the physicochemical parameters of these rivers, and determining the relationship between the macroinvertebrates species and the river health conditions. The biomonitoring results indicating the diversity of macroinvertebrates were presented using a graph of diversity. In addition to that, there was a presentation of the measured physicochemical parameters of these rivers which were presented through tables and analyzed using ANOVA and the Average Score Per Taxa was calculated to establish the health conditions of these rivers using the SASS approach using the different sensitivity scores of these invertebrates. Pictures of the study sites were also used to attach to display the various activities being done.

5.1.1. SASS Scoring Table

GROUPS	SENSITIVITY SCORE
Flatworms	3

Worms	2
Leeches	2
Crabs or Shrimps	6
Stoneflies	17
Minnow Mayflies	5
Other Mayflies	11
Damselflies	4
Dragonflies	6
Bugs or Beetles	5
Caddisflies	9
True flies	2
Snails	4
TOTAL SCORE	
NUMBER OF GROUPS	
AVERAGE SCORE (SASS SCORE)	
Average score= Total score/number of groups	

Table 1: SASS Score Table

5.1.2. Ecological condition table

Ecological category(conditions)	**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 CONDITIONS (some modifications_Orange)	5.4 to 5.8	5.7 to 6.1
POOR CONDITIONS (Lots of modifications_Red)	4.8 to 5.3	5.3 to 5.3

VERY POOR CONDITIONS (Critically modified_Purple)	≤4.8	≤5.3

Table 2: Ecological condition table (based on the SASS 5 method)

5.2. Results and discussion for Species diversity

During sampling of fauna from the 4 rivers, different groups and families were recorded as displayed in the tables for each site in the species diversity for each river. Ephemeroptera, Hemiptera, Odonata, Diptera, Mollusca, and Coleoptera were the most diverse groups. From figure 3 it was observed that there was a diversity of species per site. According to Li et al., (2010), there is an assumption that the undisturbed environments are characterized by high diversity or richness, an even distribution of individuals among the species, and moderate to high counts of individuals. The best use of diversity-related indices in the river and stream monitoring is probably as an indicator of changes in species composition when comparing impacted and reference assemblages (Li et al., 2010). Due to the different activities that were done per site, it was observed that some species that were dominant in some sampling sites were extinct in other sites. For example, according to figure 5, there was only Baetidae as a dominant species and Likhubula had at least 4 dominant species including Baetidae, Dytiscidae, Libellulidae, and Corixidae. A study was conducted in the Republic of Macedonia where there was a significant disturbance of the water ecosystems as water ecosystems were under the influence of three of the most significant pressures: municipal and industrial wastewater discharge and water runoff from agricultural areas, but also hydro morphological alteration. With regard to the status of the aquatic ecosystem in the Republic of Macedonia, the most alarming situation was recorded in the rivers. It was observed that there was a decrease recorded in the number of families present along the watercourse in the downstream direction, which indicated environmental stress leading to diversity of species. The observed change in the community structure indicates the presence of pollution, but also a change of the type of watercourse (Valentina et al., 2011). Below are the detailed explanations of the species diversity for each river that was assessed.

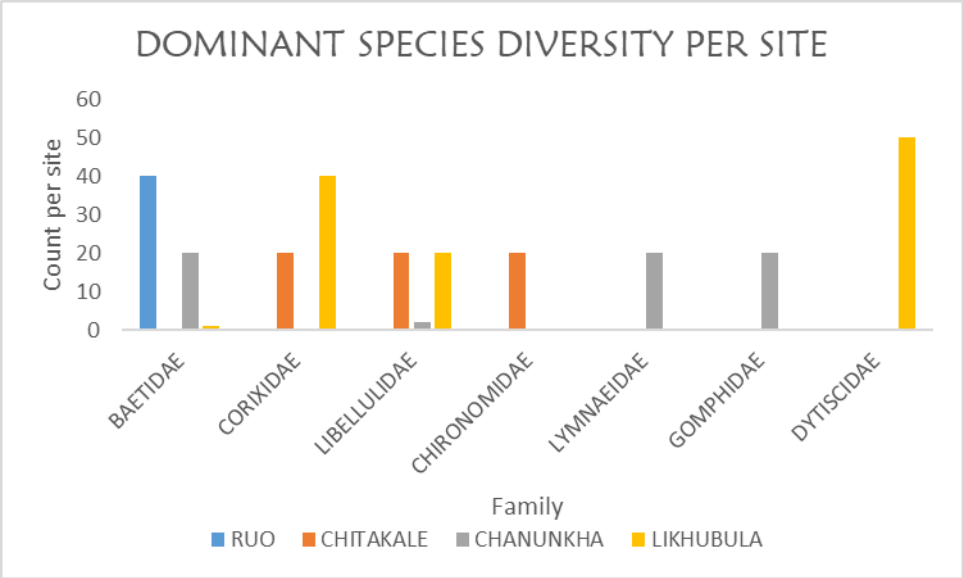


Figure 5: Graph of dominant species diversity per site

5.2.1. Ruo river

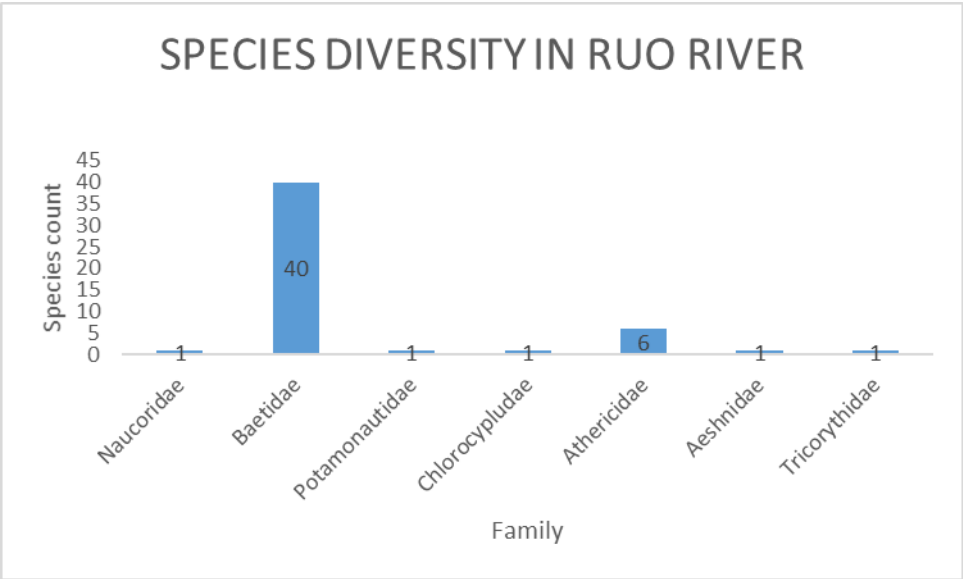


Figure 6: Species abundance and diversity for Ruo river

As seen in figure 6 the upstream section of the Ruo river is characterized by the Baetidae family under the order Ephemeroptera (minnow mayflies) which was a dominant family indicating that the river was in good condition. Baetidae has a high sensitivity score of 5 such that it can hardly be found in water that is polluted which showed that this section of Ruo river was in good condition. Due to the few modifications in this section, a few Aeshnidae (Dragonflies) and Potamonautidae (Crabs) from the orders of Odonata and Decapoda order with a sensitivity score of 6 were present as they can hardly be found in water that is not in a pristine condition and a polluted state. Together with the Baetidae (minnow mayflies), Tricorythidae (minnow mayflies), and Naucoridae (Bugs) were also present and these have a medium sensitivity of 5 indicating that the water was not polluted. The Chlorocypludae (Damselflies) and Athericidae (True flies) with sensitivity scores of 4 and 2 respectively and these recorded a low sensitivity amongst the other species in this stretch indicating this water accommodated pollution tolerant species. The diversity in the species was caused by different anthropogenic activities such as dishwashing and laundry causing some of the sensitive species to not be available.

5.2.2. Chitakale river

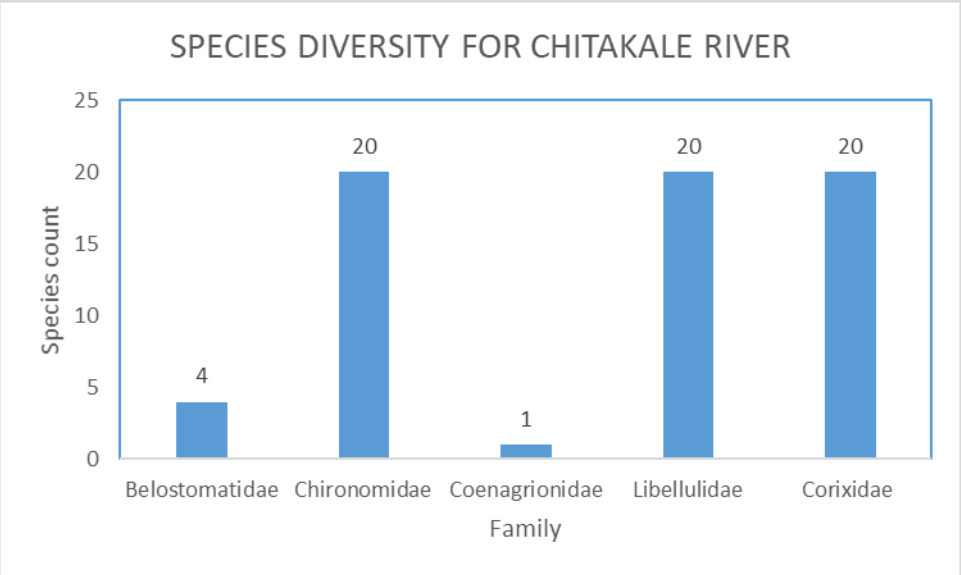


Figure 7: Species abundance and diversity for Chitakale river

According to figure 6, in this section of the Chitakale river, the most dominant species were the Corixidae (Bugs) from the order of Hemiptera with a sensitivity score of 5, Libellulidae (Dragonflies) from the Odonata order with a sensitivity score of 6, and Chironomidae (True flies) from the order of Diptera with a sensitivity score of 2, Belostomatidae (Bugs) from the order of Hemiptera with a sensitivity score of 5 and Coenagrionidae (Dragonflies) with a sensitivity score of 6. To begin with, Dragonflies from the Odonata order are sensitive species indicating that they can only be found in pristine and undisturbed conditions which indicates that the Chitakale river was not polluted. Another sensitive species Bugs with a score of 5. The Chironomidae with a score of 2 indicated that the less sensitive species were also present within this stretch. A few Coenagrionidae with a sensitivity score of 4 and Belostomatidae with a sensitivity score of 5 were also observed and these had a medium sensitivity. Along the Chitakale river, tea plantations where there were certain impacts from the pesticides and fertilizer use were observed that negatively affected the availability of highly sensitive species such as other mayflies.

5.2.3. Results of Chanunkha river

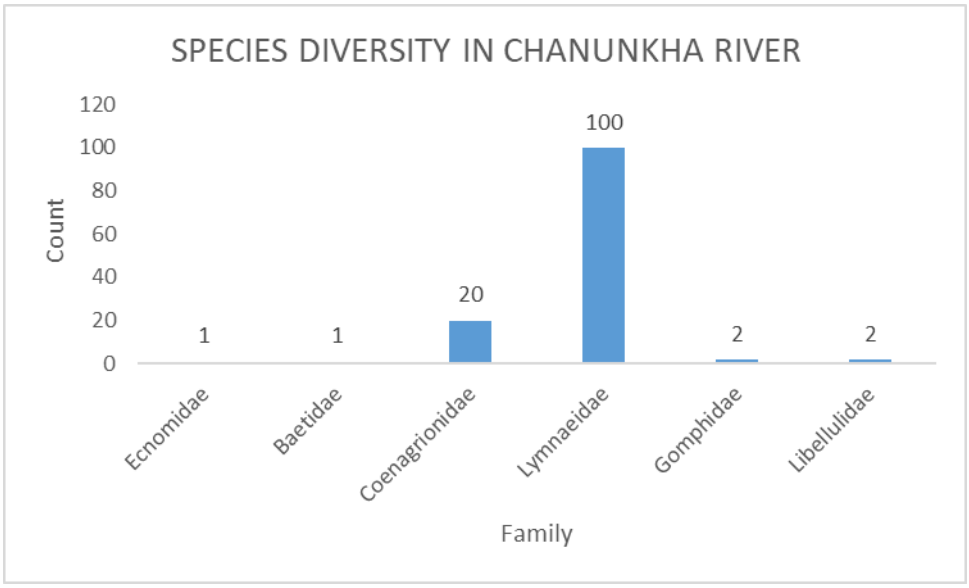


Figure 8: Species abundance and diversity for Chanunkha river

According to figure 7, the Chanunkha river is characterized by the domination of Lymnaeidae (Snails) with a sensitivity score of 4, Coenagrionidae (Damselflies) with a sensitivity score of 4, Gomphidae and Libelluliidae from the order of Dragonflies

with a sensitivity score of 6, followed by Baetidae (Minnow mayflies), sensitivity score of 5 which indicated medium sensitivity to pollution and Ecnomodae (Caddisflies) with a sensitivity score of 9 which was the most sensitive species observed. Even though they were not dominant, the presence of most species from the sensitive family of the dragonflies indicated that the water was in its pristine condition. However, human activities such as laundry and dishwashing may have negatively impacted the invertebrates causing only a few sensitive species to be available which also led to the diversity in terms of the invertebrates' families collected.

5.2.4. Results for Likhubula river

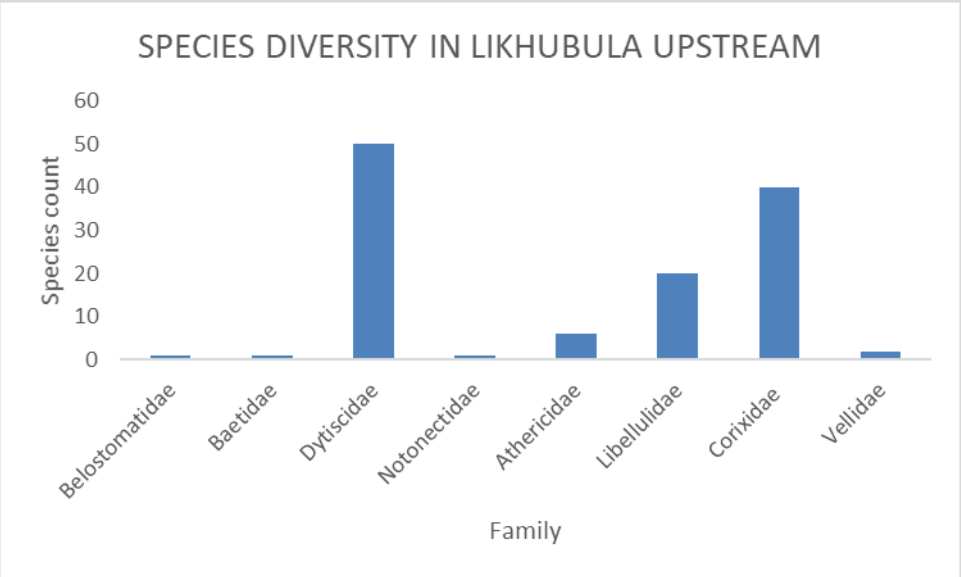


Figure 9: Species abundance and diversity of Likhubula river

According to figure 8, the most dominant species was the Dytiscidae family (beetles) under the order Coleoptera. Within this stretch, most species have a sensitivity score of 5 such as Corixidae (Bugs), Notonectidae (bugs), Baetidae (minnow mayflies), Vellidae (bugs), Belostomatidae (Bugs), and Dytiscidae (beetles) indicating that this stretch was in pristine condition. The high sensitive species amongst all the others in this stretch was the Libellulidae family under the Odonata order with a sensitivity score of 6. The athericidae (Trueflies) with a sensitivity score of 2 were also present in this stretch of the river which is less sensitive to pollution. The main human activity

that was done in this stretch was that the water was used for laundry and dishwashing which led to the diversity of the macroinvertebrates.

5.3. Results for Physiochemical parameters

	Ruo River		Chitakale		Chanunkha		Likhubula		
Parameters	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*p*-value
pH	7.35	0.280	7.35	0.1179	7.0	0.245	7.5	0.5190	0.031
Temp	21.175	0.443	23.75	0.873	30.750	1.893	25.138	0.763	0
DO	5.33	0.757	4.9	0.361	8.167	0.289	5.03	0.1528	0
EC	25	3	46	14.93	37.5	19.7	99	5.22	0
Turbidity	30.5	1.5	20.167	1.258	24.33	3.51	70.7	19.7	0.001
TDS	9	1	17	2	15	2	29	2	0

Table 3: Mean and standard deviation of the physicochemical parameters.

From table 1, all the parameters indicate that the *p* - values are <. 001 which shows that the results are statistically significant. This *p*-value indicates that at least one of the mean values for each parameter is different showing that there may be variations in the river health conditions. From the parameters recorded from all 4 rivers, the mean pH values were all almost neutral and thi s shows that the water was in a good condition. For the temperature, Chanunkha had the highest temperature value and this was the effect of the heat from the sun on one of the days during the field measurements, the other values however indicated that the temperature was good. The dissolved oxygen for Chitakale was highest. The EC was highest in likhubula river. Turbidity, TDS and EC was highest in Likhubula river.

5.4. Results indicating the relationship between macroinvertebrates and the river health condition

There is a direct relationship between macroinvertebrates and the river health condition in that if the river is in poor condition there hardly be sensitive

macroinvertebrates (Li et al., 2010). A biotic approach combines the relative abundance based on certain taxonomic groups with their sensitivities or tolerances into a single index or score. The sensitivity and tolerance of indicator assemblages to several environmental characteristics, such as organic pollution, heavy metals, pesticides, eutrophication, and pH, are known to differ among species (Turley et al., 2016). Therefore, these species-specific pollution indications can be used to infer environmental conditions in a habitat. To take benthic macroinvertebrates as an example, numerous biotic index and score systems have been developed. Commonly used biotic indices for macroinvertebrates include Trent Biotic Index (TBI) and Extended Biotic Index (EBI), Chandler's Score System, Biological Monitoring Working Party Score System (BMWP), and ASPT (Average Score per Taxon), Hilsenhoff's Biotic Index (HBI), etc. Among these indices, the ASPT was used.

5.4.1. Ruo river

Order	Family	Common name	Sensitivity score	Count
Hemiptera	Naucoridae	Bugs	5	1
Ephemeroptera	Baetidae	Minnow mayflies	5	40
Decapoda	Potamonautidae	Crabs	6	1
Odonata	Chlorocyphidae	Damselflies	4	1
Diptera	Athericidae	Trueflies	2	6
Odonata	Ashnidae	Dragonflies	6	1
Ephemeroptera	Tricorythidae	Minnow mayflies	5	1
		Total	**33**	**51**
		Number of groups	**5**	
		Average Score Per Taxa value	**6.6**	

Table 4: ASPT Value for Ruo river

The ASPT value was calculated by dividing the total score of the collected macroinvertebrates by the total number of groups that were identified. From table 4 for Ruo river, the total score was 33 and these were identified from 5 different groups. A value of 6.6 was obtained and in table 5 of the ecological condition, Ruo river is in a good condition where there are only a few modifications as also displayed in figure 10 below. The condition of the river was able to support the aquatic life that was discussed in section 4.2.1.



Figure 10: Ruo river

The few modifications that occurred in the upstream section of Ruo river included the laundry and dishwashing activities.

5.4.2. Chitakale river

Order	Family	Common name	Sensitivity Score	Count
Hemiptera	Belostomatidae	Bugs	5	4
Hemiptera	Corixidae	Bugs	5	20
Diptera	Chironomidae	Trueflies	2	20
Odonata	Coenagrionidae	Damselflies	4	1
Odonata	Libellulidae	Dragonflies	6	20
		Total	**22**	**65**

		Number of groups	3	
		Average Score per Taxa	7.3	

Table 5: ASPT value for Chitakale river

The ASPT values were calculated by dividing the total score of 22 by the number of groups that were 3 from which the invertebrates were identified. After calculating the ASPT the value of 7.3 was obtained and it indicated that the river was in a natural condition with an untouched or unchanged state, according to table 2 of ecological condition. From section 4.2.2's discussion and table 5 above, amongst the dominant species, there was the sensitive group of dragonflies that indicated that the river was indeed in pristine condition. The main human activity that occurred along this stretch was tea cultivation but it did not alter with the aquatic life availability. The main activities that occurred in this river were domestic activities such as laundry and dishwashing which somehow affected the quality of the water in this river as indicated by figure 11 below.



Figure 11: Laundry and dish washing along Chitakale river

Amongst the most abundant species, there were species with high sensitivity scores such as dragonflies indicating that the river was not polluted, it was able to assimilate

itself confirming that the water was in good condition according to table 2 of ecological condition. In this river, there are also more diverse species that showing that the species are well distributed which is an indicator for good quality water.

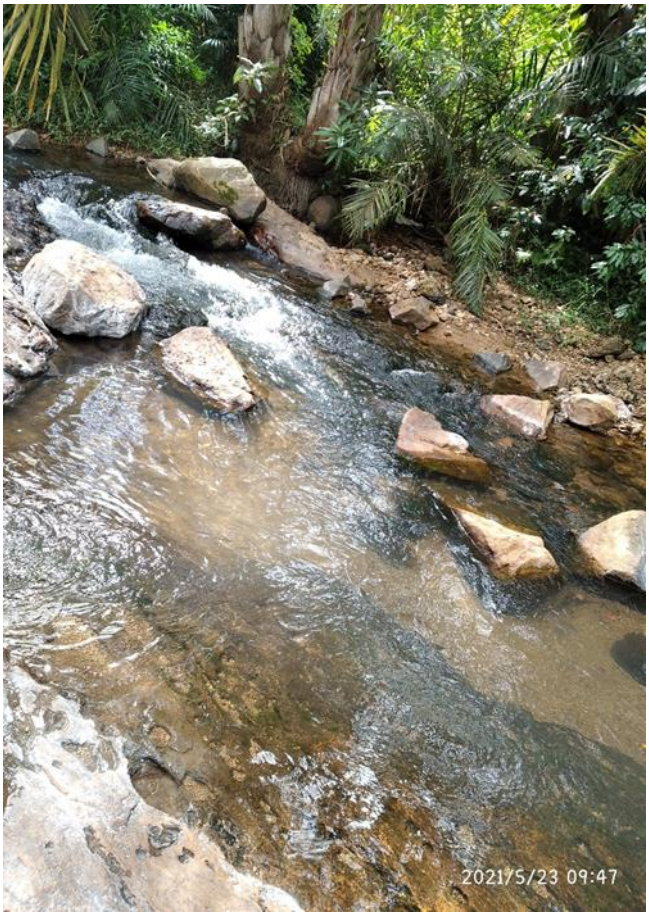


Figure 12: Chanunkha river

5.4.3. Chanunkha river

Order	Family	Common name	Sensitivity score	Count
Tricoptera	Ecnomidae	Caddisflies	9	1
Ephemeroptera	Baetidae	Minnow mayflies	5	1

Odonata	Coenagrionidae	Damselflies	4	20
Mollusca	Lymnaeidae	Snails	4	100
Odonata	Gomphidae	Dragonflies	6	2
Odonata	Libellulidae	Dragonflies	6	2
		Total	**36**	**126**
		Number of groups	**4**	
		Average Score Per Taxa	**9**	

Table 6: ASPT value calculation for Chanunkha river

According to table 6, for the ASPT calculation, the total score of 36 was divided by the number 4 groups that were identified and a value highest amongst all the other sampling sites was obtained, 9 was obtained and it indicated that the Chanunkha river was in a natural condition the natural state was untouched according to table 2 of ecological condition. Even though the most sensitive species in this study was only 1, the other dominant species were of high sensitivity. The general river health condition is excellent as also displayed in figure 10 above and discussion in 4.2.3.

5.4.4. Likhubula river

Order	Family	Common name	Sensitivity score	Count
Hemiptera	Belostomatidae	Bugs	5	1
Ephemeroptera	Baetidae	Minnow mayflies	5	1
Coleoptera	Dytiscidae	Beetles	5	50
Hemiptera	Notonectidae	Bugs	5	1
Diptera	Athericidae	True flies	2	6
Odonata	Libellulidae	Dragon flies	6	20
Hemiptera	Corixidae	Bugs	5	40
Hemiptera	Vellidae	Bugs	5	2
		Total	38	

		Number of groups	5	
		Average Score per Taxa	7.6	

Table 7: ASPT value for Likhubula river

The ASTP value of 7.6 was obtained after calculation by dividing total score of 38 by 5 which was the number of groups identified. 7.6 was obtained and according to table 2 of ecological condition twater was in natural condition as shown in section 4.2.4. The water in this stretch is the one from the Mulanje mountain and there are no interactions with human activities in this area which was also indicated by the physicochemical parameters.

	pH	*Temp*	*DO*	*EC*	*Turbidity*	*TDS*	*ASPT*
pH	1						
Temp	-0.75778	1					
DO	-0.94504	0.870304	1				
EC	0.583605	0.085949	-0.3457	1			
Turbidity	0.633798	-0.07738	-0.3478	0.899748	1		
TDS	0.487153	0.199908	-0.26471	0.987284	0.825819	1	
ASPT	-0.71187	0.929973	0.731121	0.045322	-0.25283	0.192068	1

Figure 13: Correlation between ASPT and physicochemical parameters

According to figure 13 above, it observed that there is a strong positive relationship between ASPT and Temperature where when the temperature is increasing there a conducive environment for macroinvertebrates to reproduce and grow. In addition to that, the table shows that there is a strong positive relationship between DO and ASPT values as the macroinvertebrates uses the oxygen for respiration. Furthermore, the table also shows that there is a weak positive relationship between TDS and EC and ASPT values. There is negative relationship between between pH in that when the pH was acidic and basic, macroinvertebrates cannot survive in such conditions but neutral one. Finally, turbidity has a negative relationship with the macroinvertebrates species that were found on this site in that when the turbidity is high there cannot be any macroinvertebrates secies available.

The correlation analysis however indicates that the physicochemical parameters are not enough to assess and establish the river health condition hence biomonitoring approach must be used.

6. CONCLUSION AND RECOMMENDATION

6.1. Introduction

This research was conducted in order to assess the river health condition of the Likhubula, Chitakale, Chanunnkha and Ruo river. The main environmental stressors that may affect the health conditions of these rivers include imacts from tea plantations where pesticides and fertilizers are used to increase cro yield. In addition to that there are isssues of deforestation in the Mulanje mountain and this study aimed at assessing whether the health condition of these rivers was affected by these factors. Acoording the biotic index developed from the biomonitoring approach, the Likhubula, Chitakale and Chanunkha river were in a natural condition with the ASPT values of 7.6, 8 and 9. Ruo river on the other hand had an ASPT value of 6.6 which indicated that the river was in good condition with a few modifications.

6.2. Recommmendations

i. It is recommeneded that further studies be conducted to assess all the sections of these rivers and to find out whay strategies can be used to manage these resources.

ii. The local community must be trained how to use a biomonitoring approach to assess the quality of the water bodies they have around them.

iii. The Mulanje Mountain Conservation Trust should enforce and be strict on the resources that are in the mountain and around.

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8. APPENDICES