HUMAN IMPACTS ON ECOSYSTEMS IN THE CHIBEFWE RIVER CATCHMENT AREA IN MKUSHI DISTRICT, ZAMBIA

By

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Lusaka

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A thesis submitted to the University of Zambia in fulfilment of the requirements for the award of the Degree of Master of Science in Integrated Water Resources Management

University of Zambia,

School of Mines, Department of Geology,

Integrated Water Resources Management Centre,

Lusaka

2020

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DECLARATION

I, **Namafe Namafe**, hereby declare that this thesis is my own original work and that it has not been presented to this or any other University for a degree award.

Signature: …………………………… **Date:** ……………………………….

APPROVAL

This thesis of **Namafe Namafe** is approved as fulfilling the requirements for the award of the Degree of Master of Science in Integrated Water Resources Management by the University of Zambia.

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DEDICATION

I dedicate this thesis to my parents, Charles and Mutumba Namafe, for giving me the best they could. I thank God for such parents. I also dedicate the thesis to my wife, Ethel M. Namafe, for the love, support and encouragement given during the study.

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ABBREVIATIONS AND ACRONYMS

AAS:	Atomic Adsorption Spectrophotometer
ANZECC:	Australian and New Zealand Environment Conservation Council
APHA:	American Public Health Association
ASPT:	Average Score Per Taxon
BOD:	Biological Oxygen Demand
COD:	Chemical Oxygen Demand
CSO:	Central Statistics Office
DO:	Dissolved Oxygen
DWAF:	Department of Water Affairs and Forestry
EC:	Electro-conductivity
FAO:	Food and Agricultural Organization
FFG:	Functional Feeding Group
FTU:	Formazin Turbidity Units
GSM:	Gravel, sand and mud
WHO:	World Health Organisation

IWRM: Integrated Water Resources Management

LHPC: Lunsemfwa Hydro Power Company

LWSC: Lukanga water and sewerage company

MACO: Ministry of Agriculture and Cooperatives

MWDSEP: Ministry of Water Development Sanitation & Environmental Protection

pH: Potential of Hydrogen Ions

SAFRASS: Southern African River Health Assessment Scheme

UNEP: United Nations Environmental Programme

WBF: World Bank Fellowship

WQI: Water Quality Index

ZABS: Zambia Bureau of Standards

ZISS: Zambia Invertebrate Scoring System

ZWRDP: Zambia Water Resources Development Project

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ABSTRACT

The main objective of the study was to assess the impacts of anthropogenic land use activities on river health conditions using aquatic macroinvertebrates as indicators of water quality in the Chibefwe River Catchment area in Mkushi district, Central Province, Zambia. Three study sites were selected on the Chibefwe River: One near the source of the Chibefwe River (this served as a reference site for the study); The second inside the built-up area of Mkushi town; and the third, just before the confluence of the Chibefwe River with the Lunsemfwa River. At each site the following physicochemical parameters were recorded; pH, water temperature, electro-conductivity, turbidity, dissolved oxygen content and total dissolved solids. The Zambia Invertebrate Scoring System (ZISS) was employed as a standard biomonitoring protocol. The sampling of aquatic macroinvertebrates was done using a one-millimetre kick-sized net, targeting three major biotopes namely; stones, aquatic vegetation and gravel (including sand, mud, silt and clay), if present at the site. Collected specimens were enumerated and identified to family level on-site using the ZISS photographic identification manual. Specimens that could not be identified in the field were preserved in 70% ethanol and taken to the lab for further study and subsequent identification. Data collected was analysed by computing the ZISS score, Average Score Per Taxon (ASPT) and the macroinvertebrate species diversity. To identify water and land-based habitats, the latest sentinel two image covering the study area was obtained from the open Copernicus portal and the dataset was subjected to a land cover classification for analysis. Generally, all water quality parameters except pH and Turbidity conformed to the required standards. Macroinvertebrate results in the wet season showed that sites one and three had moderate water quality conditions (with ASPT values of 6.66 and 7.75, respectively). In contrast, an ASPT value of 4.5 was recorded for site two suggesting an impaired environmental quality of river water at the site. A total of 26 specimens were collected at this site (C2). Sites one and three had macroinvertebrate species diversities of 1.12 and 1.34, respectively, suggesting moderate modifications to the environment. A species diversity value of 0.84 determined for site two indicated that the Chibefwe River inside Mkushi town was highly degraded with high levels of pollution. During the dry season, results showed that sites two and three indicated close to natural conditions with few impairments recording ASPT values of 6.18 and 6.63 respectively whereas an ASPT value of 5.08 was recorded at site one. Higher species diversity values were recorded across all the sites in the dry season than in the wet season. Land cover results showed that much of the area is predominantly covered by forests (90Km^2), followed by croplands (77.7 km^2), settlements (16.6 km^2), open shrublands (14 km^2) and finally wetlands (0.8 km^2). The study concluded that there were changes in water quality and ecosystem conditions across the Chibefwe river along a gradient of human disturbance. This was demonstrated from the presence of pollution sensitive (Ecnomidae) and semi-tolerant species to pollution (Coenagrionidae) for the first and second sites respectively. Deterioration of habitats near the township was due to variability in land use activities associated with settlements and croplands which resulted in the depletion of vegetation cover. The study recommended that the existing vegetation be conserved while reducing disposal of untreated wastes in rivers in the Chibefwe River Catchment area.

Key words: Land use, Aquatic macroinvertebrates, Water quality, Species diversity

CHAPTER 1: INTRODUCTION

1.1 Background

The availability of water resources in any given area is crucial for sustainable human development. According to Nhiwatiwa *et al*., (2017), river systems constitute areas of high population densities owing to their favourable conditions for agriculture, water supply and transport, among others. However, despite human dependence on river systems, anthropogenic activities such as those associated with rapid population growth, urbanisation or industrialization have resulted in severe degradation of water quality in river systems. The Chibefwe River Catchment area, in the Central Province of Zambia, provides a good example of this relationship because the catchment is notably characterized by such human activities as uncontrolled water abstractions and river water diversions, stream bank cultivation, uncontrolled spraying of pesticides such as herbicides, open defecation and unmanaged solid waste disposal, all of which cause instream habitat disturbances. Reports suggest that the Chibefwe River catchment has of recent been deteriorating in terms of river channel integrity, ecosystem health and water quality due to human activities and this is a river upon which Mkushi township depends upon for water supply (Malasha, 2018).

In recent years, the catchment has reportedly been affected by changes in land use patterns caused by the increasing population and lapses in catchment management and conservation practices and this has been a concern for the Mkushi District Management team. The catchment has further been experiencing uncontrolled water abstractions using furrows to irrigate vegetable gardens by small-scale farmers, a number of whom are also engaged in stream bank cultivation, open defecation, as well as uncontrolled solid waste disposal, situations which may lead to the river catchment becoming vulnerable to erosion and sedimentation, eutrophication and which may introduce risks of water contamination. Furthermore, according to the Mkushi District Management team, the Chibefwe River also gets additional pollution from the cleaning of pesticides from equipment such as herbicide spraying equipment in the river after use by the small-scale farmers and from the generally uncontrolled disposal of pesticide containers after use, a practice which threatens the integrity of aquatic ecosystems. The combined pressures due to human population growth, inadequate treatment of human wastes and ineffectively managed and treated industrial and agricultural wastes, in places like the Chibefwe River Catchment area, make it imperative that continuous monitoring of water quality is practised in order to provide clean and safe water for human consumption and provide optimal environmental integrity (Pullanikkatil *et al*., 2015).

This study focused on water quality of the Chibefwe River catchment and on land use in the area with the intent of identifying major land-based activities that cause changes in water quality, habitats and ecosystem conditions. The American Public Health Association (APHA) (2010) reveals that rivers are highly vulnerable to anthropogenic changes and are exposed to a number of these threats which are undeniably mostly as a result of man's own activities.

1.2 Statement of the Problem

Presently, there is limited information on impacts of land use on water quality in the Chibefwe River Catchment area, an important commercial agricultural region in Zambia. Very little is also known about impacts of multiple anthropogenic activities on biodiversity and ecosystem structures in the catchment area. According to Ollis *et al*., (2006), the ecological integrity of rivers reflects all activities and many catchments are subject to ecologically unsustainable land use which threaten human water security and river biodiversity. This may be the case the Chibefwe River catchment.

1.3 Objectives of the Study

The general objective of the study was to investigate impacts of multiple anthropogenic pressures observed in the Chibefwe Catchment area, on the river system and to assess the health of its ecosystems. The specific objectives of the study were to:

i. Identify existing aquatic macroinvertebrate fauna that can serve as indicators of water quality in the Chibefwe River Catchment area;
ii. Determine the diversity of benthic macroinvertebrates in the Chibefwe River Catchment area;
iii. Determine impacts of land use types on water quality in the Chibefwe River Catchment area; and
iv. Determine the water quality of the Chibefwe River.

1.4 Research Questions

The following research questions were addressed in this study:

i. What macro-invertebrate fauna exist in the Chibefwe River Catchment area and which of the species can be used as indicators of water quality in the area?
ii. What is the diversity of macro-invertebrate families in the Chibefwe River catchment area?
iii. How do the Zambia Invertebrate Scoring System (ZISS) results for the Chibefwe River Catchment area relate to the various land use activities in the area?
iv. What are the major land use activities in the Chibefwe River Catchment area and what is their spatial extents?
v. What are the water quality characteristics of the Chibefwe River catchment area?

1.5 Significance of the Study

Techniques and findings of this study can be used to assess river integrity anywhere else in Zambia and to monitor and control pollution occurring in Chibefwe River Catchment area. In addition, the findings can be used to set objectives for developing reserve flows and will assist policy makers and planners to communicate ecological river aspects with an ultimate aim to foster the integrated management of the catchment area and ecosystem benefits.

1.6 Organisation of the Thesis

This Thesis consists of six chapters. **Chapter 1** briefly introduces the background of the study by revealing the existing problem that necessitated the study. Additionally, it presents the objectives and outlines the accompanying research questions that guided the study. **Chapter 2** attempts to review the relevant literature that establishes the conceptual framework of the study. It describes the general relevance of river ecosystems, highlights both the type of stressors affecting rivers and their associated consequences. **Chapter 2** also introduces both the concept of river health and biomonitoring principles. A description of the study area which includes information about location, climate, population and livelihood characteristics, topography, flora, fauna and hydrology characteristics are presented in **Chapter 3**. This chapter also describes the selection criteria of the study sites and reveals the data collection and analyses techniques applied during the study in order to achieve the objectives. The main findings of the Thesis are presented and discussed in **Chapters 4 and 5** respectively whereas, **Chapter 6** synthesizes the main the conclusions of the study and proposes recommendations for appropriate action.

CHAPTER 2: LITERATURE REVIEW

2.1 General Significance of River Ecosystems

Riverine ecosystems play a key regulatory function in our environment, supporting biodiversity, transporting sediment and nutrients, diluting pollutants and waste, and regulating floods and droughts. Many of these services are intrinsically related to factors indicative of river health, such as water quality, ecological status and flows (Finlayson and D’Cruz, 2005). On the other hand, findings from a working paper by Parker and Oates (2016), reveal that rivers have the potential to provide a wide range of benefits to society, but are often exploited to deliver a narrow range of objectives, to the detriment of river health and other human needs. Among these benefits of rivers include social benefits (such as inland fisheries, cultural or aesthetic), economic benefits (such as those derived from commercial agriculture or hydropower), as well as environmental benefits such as reserve flows (Figure 1). All these benefits tend to rely on aspects of river health such as those associated with water quality and flow. Furthermore, Parker and Oates (2016), report that there are strategic benefits that are indirectly related to river health and that the causal relationships are more difficult to prove, for example, energy security through hydropower require flows and not high-water quality. In contrast, much as rivers provide services and benefits, these can also be detrimental to posing flood risks which have to be managed to deliver a wide range of benefits and account for potential trade-offs. To achieve this, Parker and Oates (2016) suggest that more research is required to understand spatial and temporal dimensions of river-society relationships and that the realization of benefits derived from rivers require human intervention, underpinned by infrastructure, institutions and other forms of capital.

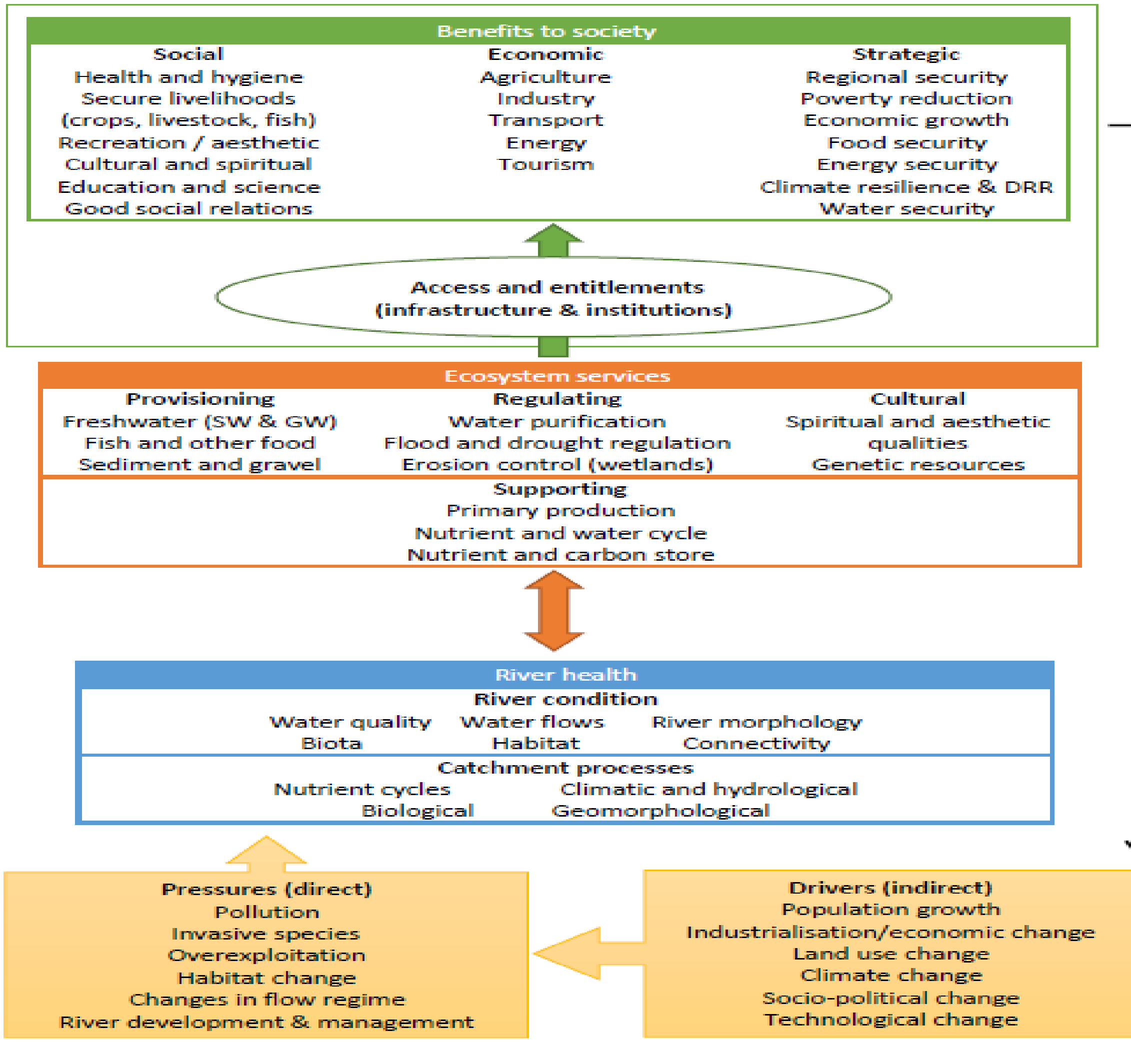

Figure 1. Adapted from Parker and Oates (2016) illustrating the relationships between river health and society benefits- A Conceptual Framework

2.2 Type of Stressors Affecting Rivers and their Consequences

Matthaei *et al*., (2010) define a stressor as a measurable variable that exceeds its range of normal variation and thereby adversely affects individual taxa, community composition or ecosystem functioning. When biological systems are exposed to various stressors, the biological or ecological response is difficult to predict, particularly when stressors interact (Townsend *et al*., 2008; Côté *et al*., 2016). Water is one of the most essential natural resources, and water-related services are major components of human well-being and key factors for socio-economic development

(United Nations Environmental Programme, (UNEP, 2007). Nowadays, freshwater ecosystems are under threat from the effects of multiple stressors, including organic and inorganic pollution, geomorphological alterations, land use changes, water abstraction, invasive species and pathogens (Vörösmarty *et al*., 2010). In fact, O'Keefe and Le Quesne (2009), reveal that on regional and global scales, freshwater biodiversity is more severely endangered than terrestrial or marine systems.

In addition to Nhiwatiwa *et al*., (2017) report of water quality deterioration due to human activities, a study by Ollis *et al.* (2006) indicate that most catchments are subject to an array of ecologically unsustainable land use and developing activities, which constantly threaten the ecological integrity of river systems. Further, these potential threats are most apparent in arid areas, being particularly severe in developing regions, where almost all of them are due to escalating demands (Ollis *et al.*, 2006). According to Vörösmarty *et al*., (2010), global rivers are generally exposed to a number of threats as they are being utilized to fulfil various developmental needs. This has led to alterations to their natural conditions, dynamics and the land use in their basins. Damage to these river systems, degradation of their quality and ability to perform important functions bring about major consequences, leading to long-term economic losses and affecting mankind's quality of life as a whole.

River pollution is one of the largest threats to rivers (Abel, 1996). The reduction in river water quality is a clear indicator of the decline in the environmental health of a river basin. Sources of pollution come from domestic and industrial sewerage, effluents from livestock farms, manufacturing and agro-based industries, suspended solids from mining, housing and road construction, logging and clearing of forest and heavy metals from factories.

Another threat to rivers has to do with physical alterations of the river systems. Leibenthal (2009) reveals that infrastructure projects implemented in river basins for the purpose of flood control, storage of water or to generate power, such as dams, normally involve channelization of rivers running through urban areas, river diversion, deepening, straightening and widening, and clearing of riparian vegetation. These activities cause shifts in flow regimes, changes in river water chemistry and processes, and sediment deposition resulting in alteration of the natural river ecology and hydrology. Normally, aquatic life is the most significantly and directly affected (Leibenthal, 2009).

These threats to river systems, underscore the need by man to understand the concepts of river health and/or river condition and how they can be used to achieve sustainable water resources utilization, management, and development.

2.3 Concept of River Health

Environmental impacts resulting from flow regulation are linked to the concept of river health and condition (Xuezhong, 2017). Rivers possess a delicate ecology that depends on a regular cycle of disturbance within certain tolerances (Baruah *et al*., 2011). The concept of river health originates from river ecosystem health, but it is not confined to river ecosystem health alone because a river has both, natural and social attributes (Yadav *et al*., 2015). Ecosystem health is an important component of river health because it is formed by the interaction between river biota and their hydro-geochemical environment (Yadav *et al*. 2015). Davies *et al*., (2010) highlights that generally, a healthy river is a river that can satisfy and sustain the needs of humans, and maintain the health of the river ecological environment. A healthy river is an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations (Meyer, 1997). So, a healthy river supports all the organisms that should be there, all the ecological processes that should occur and all the goods and services that people obtain and value (Davies *et al*., 2010). Further, Davies *et al*., (2010) outline the key indicators to assessing river health as water quantity, water quality, biotic components (such as fish, macroinvertebrates or macrophytes), functional indicators (such as leaf decomposition rates or primary production rate) and habitat conditions. In addition, Gippel and Speed (2010) state that the term "river health" is often equated to "biological integrity," defined by Karr and Dudley (1981) as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region." Karr and Dudley (1981); Schofield and Davies (1996); and Davies *et al*., (2010), also rephrased this definition as ecosystem integrity. Ollis *et al.*, (2006) defined ecosystem integrity as a measure of how intact or complete an ecosystem is and that freshwater ecosystems provide a host of critical life-supporting services and these have an irreplaceable essential value (Figure 1). Furthermore, the ecological integrity of rivers and other freshwater ecosystems is a direct reflection of the activities in the catchments they drain (Ollis *et al.* 2006; Mbaruku, 2016). Gippel and Speed (2010) indicate that practically, river health is measured using indices that are intentionally selected to vary along a gradient of environmental disturbance, so that there is a scale of deviation from the healthy state. To avoid confusion, it may be preferable to use the term 'river condition' when describing the degree of deviation from a healthy state, rather than using 'condition' and 'health' synonymously.

River condition reflects the overall state or character of a river and can be described using various indices that apply to certain attributes of rivers. River condition is measured relative to an arbitrary benchmark or reference condition (Gippel and Speed, 2010). The benchmark condition can be the pristine state i.e. ecosystem integrity intact, using the definition of Dallas (2013), or an ecological state that represents a known departure from this ideal.

2.3.1 Significance of Measuring River Health

Measuring River Health is vital because healthy rivers provide**:** water for drinking, agriculture, and industry; fish and other produce for consumption; buffers against flooding; electricity generation; and transport and recreational opportunities (Cullen, 2001). As rivers become unhealthy, they lose their capacity to provide these valuable goods and services. Maintaining and improving river health requires an accurate assessment of the current ecological state of river ecosystems. Ideally, this assessment should involve monitoring and assessment that can:

i. Identify rivers or river reaches that are in poor health, or at risk of poor health;
ii. Identify the likely causes of poor river health, such as sources of pollution;
iii. Help prioritize funding for river restoration, including catchments that are most in need, and guide effective and efficient management actions;
iv. Assess the effectiveness of management actions, which is important if significant public funds are invested in improving river health; and
v. Allow for reporting on river health to improve awareness within both government and the broader community of the current condition of a waterway.

River health monitoring can involve all elements of a river ecosystem that respond at different spatial and temporal scales. These elements include water quality; the structure, abundance, and condition of aquatic flora and fauna; hydrology; levels of catchment disturbance; and the physical form of the channel system (Department of Water Affairs and Forestry, DWAF, 2008). Importantly, no single variable can indicate ecological condition unequivocally and a suite of complementary variables is typically required to provide an accurate picture of river health (Cullen, 2001). Therefore, water quality monitoring programs alone may be inadequate for a thorough understanding of the condition of a river over time. Norris and Thoms (1999) agree to this and recommend for increased examination of relationships among various environmental variables affecting aquatic biota, such as habitat structure, flow regime, energy sources, water quality, biological conditions, and biotic interactions.

2.3.2 Overview of various techniques and indicators used to characterize river health

Historically, environmental assessment of streams was based on physicochemical measures of water quality (Gippel and Speed, 2010). Physicochemical profiling may identify situations where biotic communities are at risk, but provides no information on the actual damage, if any, to the biota. Even where the tolerances of organisms to individual pollutant concentrations are known, this information has limited application to the common situation of streams being affected by multiple pollutants, as well as habitat disturbance, and hydrological alteration.

Rather than measuring the physical and chemical factors that give rise to stream health, bioassessment methods directly measure the condition of the aquatic biota (Norris and Thoms, 1999). Compared with full physicochemical characterisation, targeted bioassessment requires less equipment and a large area can be surveyed intensively in a short time. According to Arundel *et al*., (2008), bioassessment originally focused on benthic macroinvertebrate assessment, but these approaches now also include periphyton, vegetation, fish and other components of the aquatic system. The weakness of undertaking bioassessment alone is that it provides only indirect information on the potential causes of any observed biological effects.

Holistic methods of measuring river health include a range of indicators (Australian and New Zealand Environment Conservation Council, ANZECC, 2010). River condition can be expressed as a string of sub-index values, or as a single integrated index, without concern for mixing cause (abiotic drivers or pressures) and effect (biotic response) attributes. Common driver/pressure variables include physical habitat availability, hydrology, riparian vegetation, physical form and process, and water quality (ANZECC, 2010). These driver/pressure variables enhance the capacity to diagnose the cause of river health problems and to identify the issues that require management action.

Norris and Thoms (1999), have since indicated that despite physicochemical characteristics being efficient for regulating effluent discharges and protecting humans, they are not very useful for large-scale management of catchment or for assessing whether river ecosystems are well preserved or not. This study, therefore, focusses on assessing river health using macroinvertebrates and selected physicochemical water quality parameters to reduce further degradation on aquatic and terrestrial ecosystems as well as complement biodiversity conservation efforts. Addy *et al*., (2016) define biodiversity as **“**the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.” Examples of these are macroinvertebrates (invertebrates), fish (vertebrates) and macrophytes (plants).

Quantifying biodiversity has been reportedly done by means of diversity indices (Gippel and Speed, 2010). A diversity index is a mathematical measure of species diversity in a community (Vishwakarma *et al*., 2017). Diversity indices provide more information about community composition such as species richness (i.e., the number of species present); they also take the relative abundances of different species into account (Mengistu and Asfaw, 2016). These provide information about rarity and commonness of species in a community. The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure (Beals *et al*., 2000). One example of a commonly used index is the Shannon-Weiner diversity index. The Shannon-Weiner diversity is an information statistic index that is widely used to characterize species diversity and examine overall community structure (Beals *et al*., 2000). It takes into account both abundance and evenness of species present in an ecological community (Beals *et al*., 2000). It assumes all species are represented in a sample and that they are randomly sampled. Both measures are important; in a high diversity community, one would expect to see different types of organisms. At the same time, if one abundant species dominate the community, we would not call that ecosystem diverse. The Shannon-Weiner diversity index is useful in the sense that the function considers both the richness and evenness of a given ecosystem.

Studies for example from Turkmen and Kazanci (2010) have demonstrated that the Shannon-Weiner Index and other non-parametric diversity indices can be particularly useful for diversity ordering i.e. comparing diversity among different communities.

For example, according to Turkmen and Kazanci (2010), values of the Shannon-Weiner Index for aquatic systems are generally between 1.5 and 3.5 but do occasionally exceed 4.5. Calculated values that are above 3 potentially indicate that habitat structure conditions are stable and balanced whereas values below 1 indicate pollution and degradation to habitat structure conditions. In a more recent study by Kochelani (2015), habitat structure conditions were devised from the calculated Shannon-Weiner Indices with the highest (3.896) and lowest (0.257) values suggesting stable and potentially impaired habitat conditions respectively. As such three classes of habitat structure can be devised from Table 1.

Table 1. Classes of habitat structure devised from the Shannon-Weiner Index Range (Türkmen and Kazanci, 2010)

Shannon-Weiner Index Range	**Habitat structure**
Below 1	Disturbed: habitat degradation and high levels of pollution
Between 1.1- 2.9	Fairly good: Habitat moderately modified to natural, with moderate levels of pollution
Above 3	Natural: habitat stable and balanced; low pollution

Kochelani (2015) describes parametric indices as being based on measurable values or parameters in a population whereas, on the other hand, non-parametric diversity indices are ‘distribution free’ and are useful where exact measurements or counts are difficult to set.

2.3.2.1 Macro invertebrates

Aquatic macroinvertebrates are small organisms that lack backbones (Li *et al.*, 2009). Nhiwatiwa *et al*., (2017) indicated that benthic (bottom-dwelling) macroinvertebrates are the most widely used biological indicators of water quality assessments because of the following reasons:

i. Their sedentary nature makes them suitable tools to ascertain the effects in various lotic environments;
ii. They constitute the majority of species present in streams;
iii. The numerous species present often show a wide range of sensitivity to pollution;
iv. They are relatively easy to sample and identify;
v. Their methods for analyses are well developed; therefore, qualitative sampling is achievable with the use of inexpensive and simple equipment;
vi. Readily-available documentation on macroinvertebrate response to various common pollutants and a rich inventory on their data analyses make them suitable tools for management of lotic systems; and
vii. The short-lived cycles and high movement of many species may provide reliable and rapid evidence of the return of favourable water quality after a pollution event.

Their presence or absence can reflect a stream's general condition and this is because certain species respond differently to physical, chemical and biological conditions within an aquatic environment (Li *et al.*, 2009). Community structure of the macroinvertebrate assemblages frequently changes in response to environmental disturbances in predictable ways, which is the basis for the development of biocriteria to evaluate anthropogenic influences. These responses have been summarized by Li *et al.*, (2009) into three categories, including a reduction in diversity, retrogression to dominance by opportunistic (e.g. shorter life-cycle, faster reproducing) species and reduction in the 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 the direct and indirect impact of contaminants; Chironomidae, Simuliidae, Crabs, Oligochaeta, Tipulidae and Corixidae commonly possess the dominant status at the expense of other more sensitive groups, such as stoneflies (Plecoptera), caddisflies (Trichoptera) and mayflies (Ephemeroptera) (Mphande, 2008 un pub).

According to Mphande (2008 un pub), benthic macroinvertebrates can either be of the insect group or non-insect groups. The insect groups i.e. Class Insecta comprise the following orders:

i. Plecoptera (Stoneflies)
ii. Ephemeroptera (Mayflies)
iii. Trichoptera (Caddisflies)
iv. Odonata (Dragonflies and Damselflies)
v. Diptera (Crane flies, Black flies, Midges, and Water snipe flies etc)
vi. Coleoptera (Beetles and Water pennies)
vii. Megaloptera (Fishfly and Alderfly)

The non-insect groups include the following classes and orders

i. Class Crustacea; Orders Decapoda (Crayfish), Isopoda and Amphipoda
ii. Class Gastropoda (Snails and Mussels)
iii. Class Oligochaeta (aquatic worms)
iv. Class Hirudinea (Leeches)
v. Class Turbellaria (Flatworms)

2.4 Biomonitoring Principles and Approaches

Since streams and rivers are amongst the most endangered ecosystems worldwide (Saunders *et al*., (2006); Ollis *et al*., (2006), there are urgent demands for comprehensive methodological approaches to evaluate the actual state of these ecosystems and to monitor their rate of changes (Li *et al*., 2009). Currently, there are two basic approaches to water quality assessments within river ecosystem health assessments and these include measuring physico-chemical variables and biomonitoring (Bere and Tundisi, 2010). According to Metcalfe (1989), physical, chemical and bacteriological measurements commonly form the basis of monitoring because they provide a complete spectrum of information for effective water management. Li *et al*., (2009), however, argue that in running water where changes in hydrology are rapid, these physicochemical and bacteriological based measurements cannot reflect the integration of numerous environmental factors and long-term sustainability for their instantaneous nature. Chikodzi *et al*., (2017), also agree to this argument such that they explain that physicochemical assessments cannot alone form the basis of biodiversity conservation because the synergistic effects of pollution on aquatic biotic communities may not be fully and easily accessed through physicochemical measurements and hence generation of adequate ecological information may be unsuccessful.

The shortcomings of physical and chemical water assessments have therefore necessitated the adoption of biological organisms to assess the impacts of anthropogenic activities on water quality in aquatic ecosystems and have given rise to a branch of ecology called biological monitoring (biomonitoring) (Utete *et al*., 2013). Day (2000), describes biomonitoring as a collective term for all the techniques that use living organisms to provide information about both abiotic (non-living) and biotic (living) components of an environment. Oertel and Salánki (2003) define biomonitoring or biological monitoring as the "systematic use of living organisms or their responses to determine the condition or changes of the environment." This approach has, however, both advantages and disadvantages according to Palmer *et al*., (2004) outlined below:

2.4.1 Advantages of Biomonitoring

i. It provides information on environmental conditions that must have prevailed in the river at the beginning;

ii. It also provides a long-term integrated view of biotic integrity and quality of water in the river system;
iii. Resident aquatic organisms will reflect pollution events through changes in their biology and ecology;
iv. The activity is cost-effective and is scientifically recognized;
v. It provides for multiple site investigations in a field season and there is quick turn-around of results for management decisions.

2.4.2 Disadvantages of Biomonitoring

i. The existence of a large spread of results between very good conditions and fair/poor;
ii. It is not precise;
iii. Biomonitoring cannot be used to identify a specific pollutant; it merely provides an indication that there is something wrong with the water quality;
iv. Monitoring cannot be done very successfully during high flow periods;
v. There is a danger that the classification of sampling points and habitat types may be subjective. It is therefore vital that experienced personnel are involved in the determination of sampling points.

Biomonitoring of stream conditions is one of the most credible sources of freshwater ecological assessments since it provides an integrated and comprehensive assessment of the health of water bodies over time (Chikodzi *et al*., 2017). In Zambia, for example, the Zambia Invertebrate Scoring System (ZISS) has been recently developed to help determine the quality of tropical freshwater systems by sampling macroinvertebrate communities in Zambian rivers (Lowe *et al*.,2012). However, despite developing this biomonitoring protocol in 2012, the only information and data currently available for characterizing river health in the Luangwa River Basin to which the study area is a part of, is the unpublished datasets relating to aquatic macroinvertebrates collected in 2010 and 2011 as part of the Southern African River Assessment Scheme (SAFRASS). Lowe *et al*., (2012) have indicated that despite the SAFRASS dataset being the most spatially comprehensive, samples were only collected once at the end of the dry season and therefore, do not provide information on seasonality variability which the present study attempted to accomplish to fill the existing knowledge gaps. Mehari *et al*., (2014), as well as Li *et al*., (2009) both, reveal that aquatic organisms such as diatoms and benthic macroinvertebrates respectively can serve as bioindicators to integrate their total environment and their responses to complex sets of environmental conditions. Li *et al*., (2009) report that these offer the possibility to obtain an ecological overview of the current status of streams or rivers.

Li *et al*., (2009) observes that there are several biomonitoring techniques currently employed in river ecosystems and that the selection of the appropriate technique depends on the issues being addressed and the availability of resources. Potential biomonitoring methods include diversity indices, biotic indices, multimetric approaches, multivariate approaches, functional feeding groups (FFGs) and multiple biological traits. The diversity and biotic index approaches were applied in this study.

2.5 Biomonitoring efforts in the Southern African Region

Munyika *et al*., (2014) states that anthropogenic activities in catchments where rivers drain have in most cases, been linked to the deterioration of water quality and ecological integrity of rivers. In relation to this, Ollis *et al*., (2006) have revealed that this is usually because of unsustainable land use and development activities which constantly threaten the ecological integrity of rivers, and these are most apparent in arid areas, and particularly severe in developing countries. Integrated Water Resources Management (IWRM) requires that water resources and other natural resources are utilized in a sustainable manner and that aquatic ecosystem health is preserved. Hence, studies conducted to assess river health are critical. Biological assessment of stream conditions provides information required for the conservation of biodiversity (Simaika and Samways, 2009). Several approaches worldwide make use of river biota, and this is described as bioassessment.

CHAPTER 3: MATERIALS AND METHODS

3.1 The Study Area

This study was conducted in the Chibefwe River catchment area, which is part of or a sub-catchment of the larger Lunsemfwa River catchment area in eastern Zambia. The latter is found within an even larger Luangwa River catchment region shown in blue in the overview map of Zambia (Figure 2). The study area is located between Latitudes 6 and 14^0 South & Longitudes 4 and 15^0 East. The source of the Chibefwe River is in the Illume Hills northeast of Mkushi town, in Central Province.

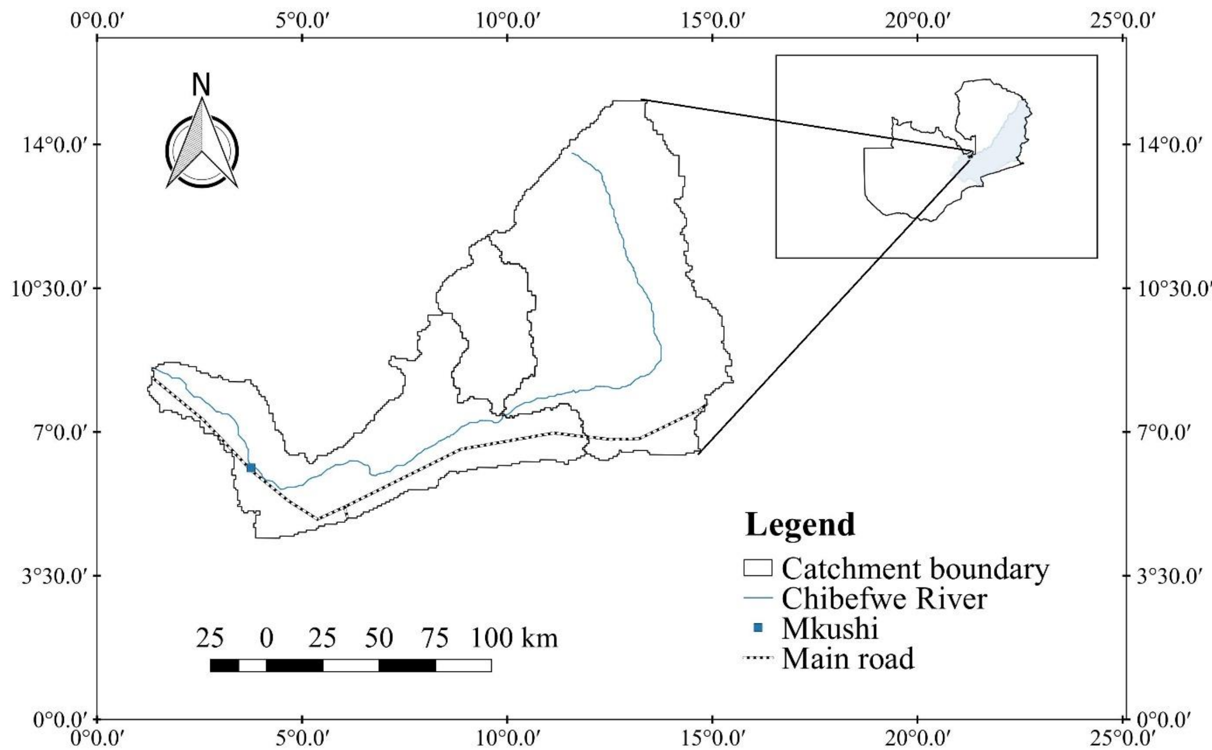

Figure 2. Study area map of the Chibefwe River Catchment

3.1.1 Climate

According to the Ministry of Agriculture and Cooperatives (MACO) and the Food and Agricultural Organization (FAO) (MACO and FAO, 2004), the country Zambia, is divided into three Agro-ecological regions. MACO and FAO (2004), categorize the Lunsemfwa catchment in which the Chibefwe River catchment falls, to be under region I which includes major valleys of Gwembe and Luangwa, and the southern parts of Western and Southern Provinces. This Agro-ecological region is a drought-prone area characterized by low-rainfall (less than 800 millimetres of rainfall per year (mm/yr)) and a short, hot growing season. MACO and FAO (2004) reveal that the study area experiences distinct dry (May to October) and wet (November to April) seasons. Rainfall frequently occurs in heavy thunderstorms producing precipitation events ranging from 20 to 40 millimetres (mm) per precipitation event. The annual mean rainfall averages 877 mm with the lowest being 603mm, recorded in 1998 and highest, 1444mm recorded in 1978. The daily evaporation rate in the area ranges from 3 to 10 mm. Mean monthly wind speeds vary from a low value of 1.2 meters per second (m/sec) in February and March to a high value of 3.4 m/sec in July through to December. Mean humidity levels vary from a minimum of 29 percent (%) in the cool dry season to a maximum of 89 % in the wet season. Annual sunshine in the area is about 4.5 to 7.9 hours per day with more sunshine during the dry season than the wet season. The sunshine hour decreases from December to March and afterwards start to increase in April to May. The predominant wind direction in the area is from the northeast, east and southeast directions. The average annual wind speed in Mkushi is around 1.7 m/sec reaching its maximum of 2.1 – 2.2 m/sec during the period (August to October). The monthly minimum wind speed measured from January to February ranges between 1.1 and 1.2m/sec. Temperatures in Mkushi District are defined by the two seasons, cool and dry (May-September) and warm and wet (October – April). The mean annual temperature of Mkushi is 21 degrees Celsius (^{0}C), and October being the hottest month with an average temperature of 23.8 ^{o} C. June characterises the coldest month with an average temperature 16.9 ^{0}C.

3.1.2 Population

The study area solely lies within Mkushi District, and according to Central Statistics Office (CSO, 2014), during the 2000-2010 inter-censual period, the district experienced the fastest growing population growth rate at an average annual rate of 3.7 % in the whole of Central Province. The CSO (2014) further reveals that the population of Mkushi District increased from 107, 438 in 2000 to 154, 534 in 2010 with approximately 87.6% of the total population living in the rural parts of the district and with only 12.4% residing in the urban areas. In addition, it has a total of 29, 128 households, with an average household size of 5.2 people and nearly 45 % of the total population is composed of a population of less than 18 years (CSO, 2014).

3.1.3 Topography

Surface elevations in the catchment area range from 1200 to 1600 metres above sea level (Figure 3). The highest elevation is close to the source of the Chibefwe River near the Illume Hills and the lowest being near the confluence of the Chibefwe River with the Lunsemfwa River at Kamwendo, in Mkushi District, Zambia.

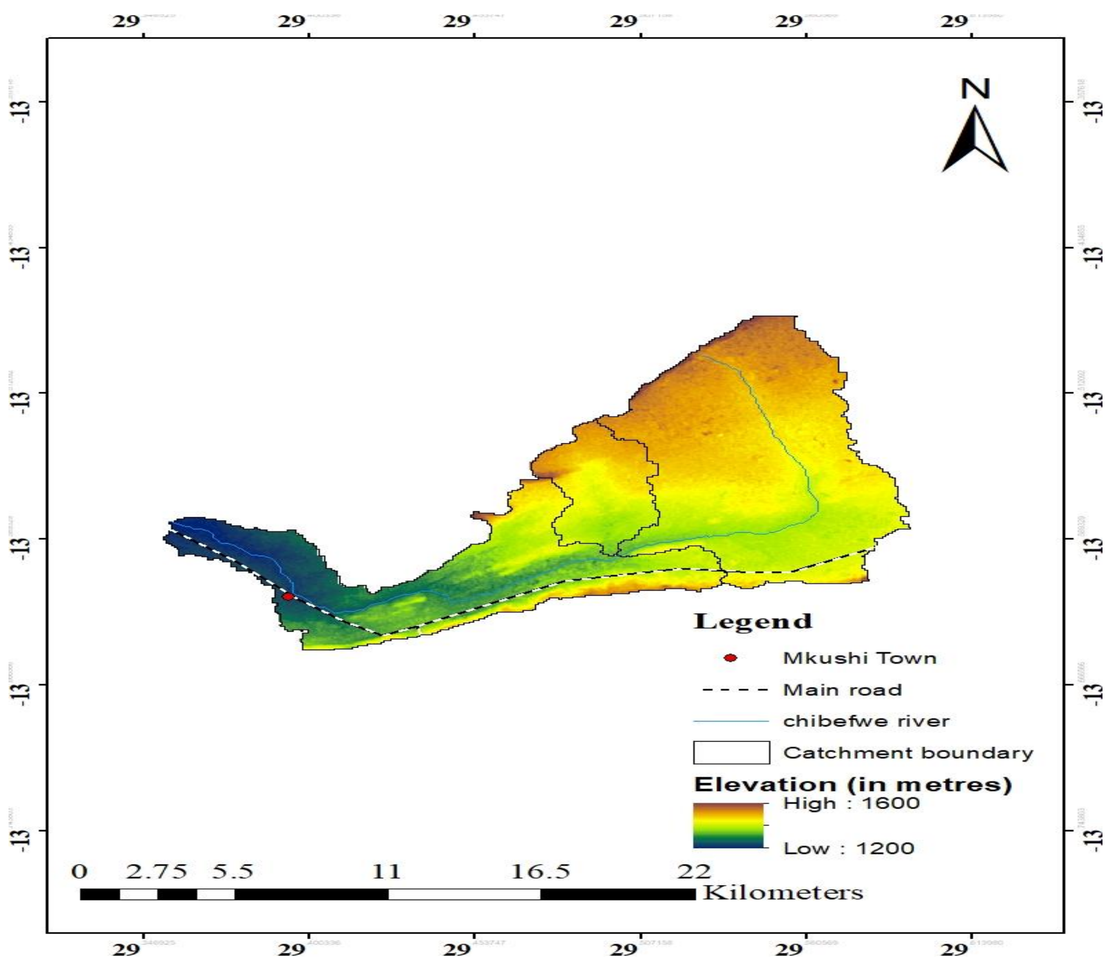

Figure 3. Elevation variations within the Chibefwe River Catchment

3.1.4 Livelihood Activities

The major economic activity in Mkushi district is agriculture (MACO and FAO, 2004). Commercial farming is an activity that has significantly influenced Mkushi's economic set-up and growth and is the principal economic activity and the source of employment for the majority of Mkushi residents. The other source of livelihood for the people in the area is subsistence farming (i.e. both crop and livestock production). The most predominant soils in the area are classified as Acrisols which is described as being acidic. Much of the land cover is degraded disturbed woodland (Lunsemfwa Hydro Power Company; LHPC, 2014). The area has been affected by shifting cultivation practices, deliberately started bushfires and charcoal burning activities.

3.1.5 Flora and Fauna

Edmonds (1976) describes the vegetation of Mkushi District generally as miombo with *Brachystegia*, *Julbernardia,* and *Isoberlina* as common dominant tree species. According to the Lunsemfwa Hydro Power Company (LHPC, 2014), animals found in the district include mammals, birds, fish, and insects.

3.1.6 Hydrology

The main watercourse in the study area is the Chibefwe River whose source lies within the Illume Hills North-East of Mkushi town, upstream of Kundakabula village. It is approximately 40Km long and flows in a south-easterly direction (Figure 2) before draining across Mkushi town to the Lunsemfwa River in Kamwendo Village. The River has two perennial tributary streams namely Funda and Kabufumu. The estimated catchment area size is approximately 199.18 km^2.

3.2 Selection of sampling sites

Three sampling sites were purposively selected along the Chibefwe River (Figure 4). Sampling was conducted in both the wet (i.e. between 1st and 12th February 2018) and the dry (1st and 12 July 2018) seasons. The sites included the source of the Chibefwe River site (site C1) approximately 7 km downstream of the Illume Hills where the

Chibefwe River begins; the Chibefwe River site (site C2) within Mkushi township, approximately 200 meters upstream of the water treatment plant and half a kilometre downstream of a weir owned by the Lukanga Water Sewerage Company (LWSC) the utility company mandated to supply domestic water for Mkushi township; and finally the Chibefwe River site (site C3) at Kamwendo Village which is approximately 2.5 km upstream to the confluence of the Chibefwe River with the Lunsemfwa River.

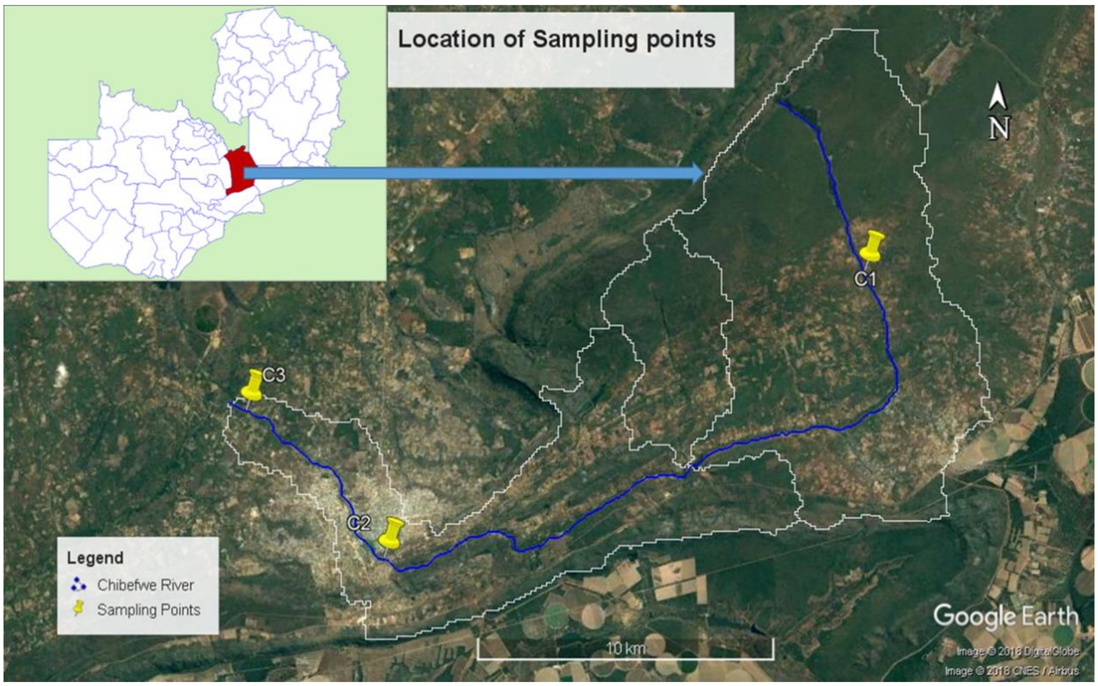

Figure 4. Study sites along the Chibefwe River

The geographical locations of the sites in Figure 4 are presented in Table 2

Table 2: Physical characteristics of sampling sites along the Chibefwe River

Sampling site	Elevation (m)	Latitude	Longitude
C1	1414	-13.5409	29.5538
C2	1268	-13.6262	29.40585
C3	1205	-13.5823	29.36062

3.3 Data Collection and Analyses

This section presents data collection and analyses techniques applied during the study.

3.3.1 Macroinvertebrate Sampling

Macroinvertebrate sampling followed the Zambia Invertebrate Scoring System (ZISS) method developed during the Southern African River Assessment Scheme (SAFRASS) project in 2012 as a standard biomonitoring protocol (Lowe *et al*., 2012). At each site, sampling was primarily done using the kick net sampling technique (Figure 5).

Figure 5. Kick net sampling near the source of the Chibefwe River

The kick net with dimensions 30 X 30 centimetres (cm) frame and 1-millimetre (mm) mesh size was used throughout the sampling campaign. In line with the ZISS biomonitoring protocols, at each sampling locality, three major biotopes (habitats) based on sand grain size were targeted if present at the site namely: stones (including bedrock or any solid substrate), vegetation (marginal, floating and submerged) as well as gravel, sand and mud (GSM). Sampling effort applied for each biotope involved kick sampling of loose stones for two minutes, sweeping marginal aquatic vegetation for two minutes for a total length of two metres and sweeping aquatic vegetation (submerged or emergent) for one minute as well as stirring and sweeping the GSM biotope for one minute (Lowe *et al*., 2012). Besides, hand picking and visual observations were made for five minutes (Figure 6). Specimen present were recorded on the ZISS score sheet. Abundances were also estimated using the scale: 1 = 1, A = 2-10, B = 10-100, C =100-1000 and D >1000 (Lowe *et al*., 2012).

Figure 6. Screening for macroinvertebrate specimen through hand picking and visual observations

Collected samples were then placed on a white tray for sorting and screening of aquatic insects, and approximately 15 minutes was spent on examining the tray contents of each biotope sampled. Specimens were counted and identified to family level on-site using a hand lens, as well as with the aid of photographic identification manual developed specifically for the ZISS, which lists all commonly found invertebrate families in Zambian rivers (Lowe, 2012; Moore and Murphy, 2015). Macroinvertebrate specimens that were not identified in the field, were immediately preserved in 10% formalin in polythene bottles and transported to the laboratory for subsequent identification and confirmation.

3.3.1.1 Analysis of Macroinvertebrate Data

The study summarized the biological metrics of Shannon–Wiener diversity indices, taxa richness, ZISS score, and ASPT. Macroinvertebrate data collected was used to compute the ZISS diversity (S: number of taxa present), and Average Score per Taxon (ASPT) scores (Moore and Murphy, 2015). Besides macroinvertebrate diversity and taxa, richness was determined by applying the Shannon-Weiner Diversity Index (Hammer *et al*., 2012) (equation 1). These computations were made using Microsoft Excel.

$$H = -\sum^{s}_{i} (pi).\ \ln(pi) \ldots\ldots\ldots\ldots (1)$$

Where, pi = proportion of species i represented by each taxon in the community, S is the total number of species in the community.

3.3.2 Mapping land use types in the Chibefwe River Catchment Area

To identify water and land-based habitats, a Sentinel two satellite image of spatial resolution 10 X 10 metres covering the study area was acquired from the Copernicus Open Access Hub (Congedo, 2016). The acquisition date of the image was 28th August 2016. Apart from that, drone imagery was used for some sites to visually assess human impacts that might have water quality implications.

3.3.2.1 Land cover classification

Lee *et al*., (2009) have indicated that strong ties exist between land use/land cover and water quality of adjacent aquatic systems. Bearing this in mind, the spatial configuration of land use of the study area was used as a proxy to infer to certain processes occurring on the ground. An August 2016 Sentinel two image of spatial resolution 10 X 10 metres was acquired from the sci-hub Copernicus portal and subjected to a supervised land cover classification in QGIS (version 2.14) using the semi-automatic classification version 5 plugin. The study applied the classification approach proposed by Congedo (2016) (Figure 7).

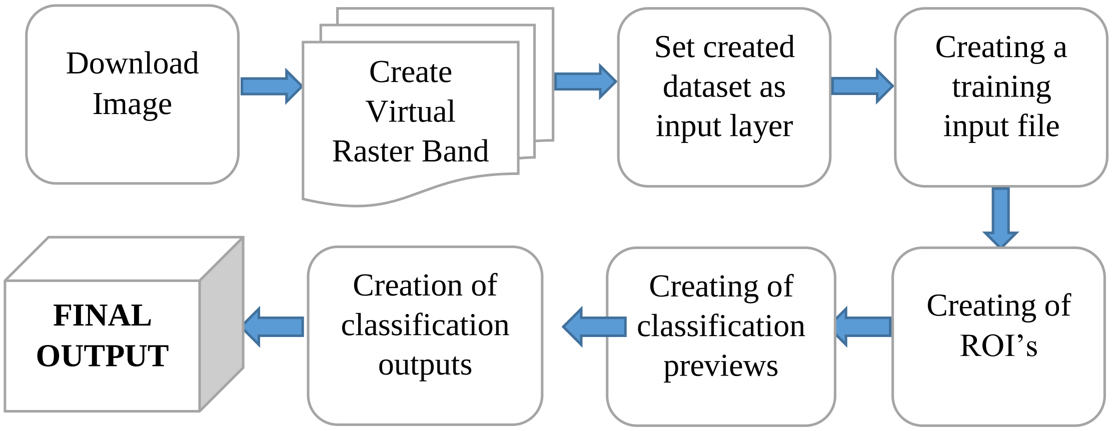

Figure 7: Land cover classification flow chart

In addition, to acquire site-specific land use characteristics, satellite imagery was acquired from google earth and this image was imported to ArcGIS (Version 10.3). A training file was created and spectral signatures for each land use was defined. The maximum likelihood algorithm was selected and a supervised classification approach for each of the sites was applied.

3.3.3 Water Quality and Quantity Assessment

Both in-situ measurements and standard laboratory analyses were used to determine water quality physico-chemical conditions in the Chibefwe catchment area (APHA, 2010). Seven (7) physico-chemical parameters and 19 physico-chemical parameters were determined in-situ and the laboratory, respectively. The in-situ parameters were: pH and Redox potential (mV) determined by a potable cyber scan eutech pH 110 series metre; conductivity (µS/cm) and total dissolved solids (mg/l) both determined by a Wagtech international potable conductivity metre; dissolved oxygen (DO) (mg/l and percentage saturation) and water temperature (^{0}C); determined by a potable waterproof eutech instrument cyber scan DO 300 series metre; and Turbidity (FTU) determined by Hanna potable Turbidimeter. These measurements were made during both the wet and dry seasons.

Twenty physico-chemical parameters were measured in the laboratory (see Appendix C). Water samples were collected in plastic bottles at depths of 6-10 cm at the sampling sites. Each water sample was preserved at approximately 4^0C in a cooler box filled with ice packs prior to laboratory analysis for physico-chemical properties. The physico-chemical properties analysed were; nitrates, nitrites, phosphates, potassium, sodium, magnesium and chloride concentrations. Others were biochemical oxygen demand, bicarbonates and heavy metals (arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, nickel and zinc). Except for pH, all the parameters were measured in milligrams per litre (mg/l). Water samples for heavy metal–analyses were preserved in nitric acid and the measurements for these parameters were determined in mg/l using the Atomic Adsorption Spectrophotometer (AAS) standard laboratory methods (APHA, 2010).

For water quality analyses, the Water Quality Index (WQI) developed by Brown *et al*., (1970) was used. The WQI computations were done for both the wet and dry seasons for all the sites sampled using an automated electronic excel spreadsheet.

According to Pullanikkatil *et al*. (2015), the WQI index is the most comprehensive, available and widely used physico-chemical index worldwide. It numerically summarizes various water quality variables into one value and provides an indication of the health of the water source. Seven variables used to compute the WQI in this study were; pH, change in temperature (^{0}C), dissolved oxygen (% saturation), biological oxygen demand (mg/l), turbidity (FTU), phosphorus (mg/l P) and nitrates (mg/l N). The mathematical expression of the WQI is:

$$\mathrm{WQI} = \sum_{i=0}^{n} QiWi \ldots\ldots (2)$$

where

Qi = sub-index for *i*-th water quality parameter;

Wi = weight associated with *i*-th water quality parameter;

n = number of water quality variables.

To interpret, the calculated WQI, reference was made to Table 3.

Table 3: Water Quality Index Rating

Water Quality Range	**Quality of water**	**Class**
91–100	excellent water quality	I
71–90	good water quality	II
51–70	medium water quality (fair)	III
26–50	bad water quality (polluted)	IV
0–25	very bad water quality (highly polluted/poor water quality)	V

Source : (Brown *et al*., 1970; Pullanikkatil *et al*., 2015)

Apart from water quality measurements, water flow assessments were also made using a current metre and a Q-liner. For each site, discharge estimates were determined.

CHAPTER 4: RESULTS

4.1 Aquatic macroinvertebrates

4.1.1 Aquatic macroinvertebrates identified along the Chibefwe River in the wet season

A total of 75 macroinvertebrate specimens belonging to six orders (Figure 8) and 13 families (Table 4) were identified during the wet season. The macroinvertebrate specimens comprised 31 Trichoptera, 27 Odonata, 8 Ephemeroptera, 6 Hemiptera, 2 Crustacea, and 1 Coleoptera. The relative percentage composition of the orders identified is presented in Figure 8.

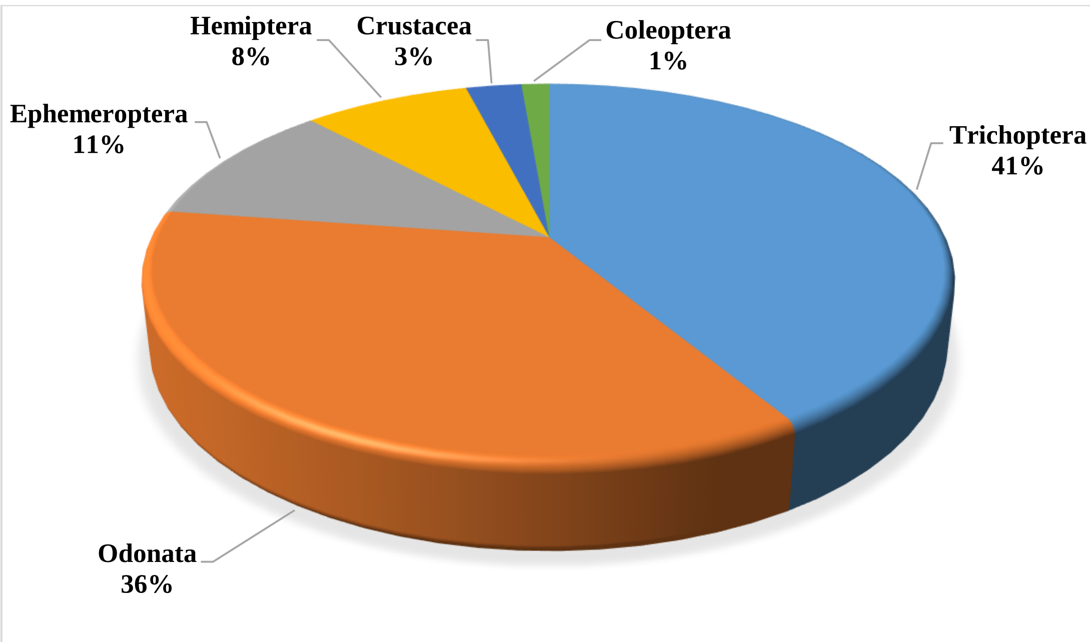

Figure 8. Abundance of macroinvertebrate orders identified in the wet season along the Chibefwe River

Table 4 shows all the macroinvertebrate families identified during the wet season across all the site

Table 4: Identified macroinvertebrate families during the wet season along the Chibefwe River

Site	Identified macroinvertebrate Families
C1 (Source Site)	Hydropsychidae, Ecnomidae, Libellulidae, Aeshinidae, Chlorolestidae (Synlestidae), Elmidae
C2 (Urban Site)	Libellulidae, Baetidae, Coenagrionidae, Hydrometridae
C3 (Confluence Site)	Heptageniidae, Veliidae, Atyidae, Gerridae,

A total of 38 macroinvertebrate specimens, were identified at site C1 during the wet season, whereas a total of 26 and 11 specimens were identified for sites C2 and C3, respectively, during the same season. The dominant family at site C1 was Ecnomidae which had 19 specimens, followed by the Hydropsychidae (12 specimens), Libellulidae (3 specimens), Chlorolestidae (Synlestidae) (2 specimens) and finally the Elmidae and Aeshinidae with one specimen each (Figure 9).

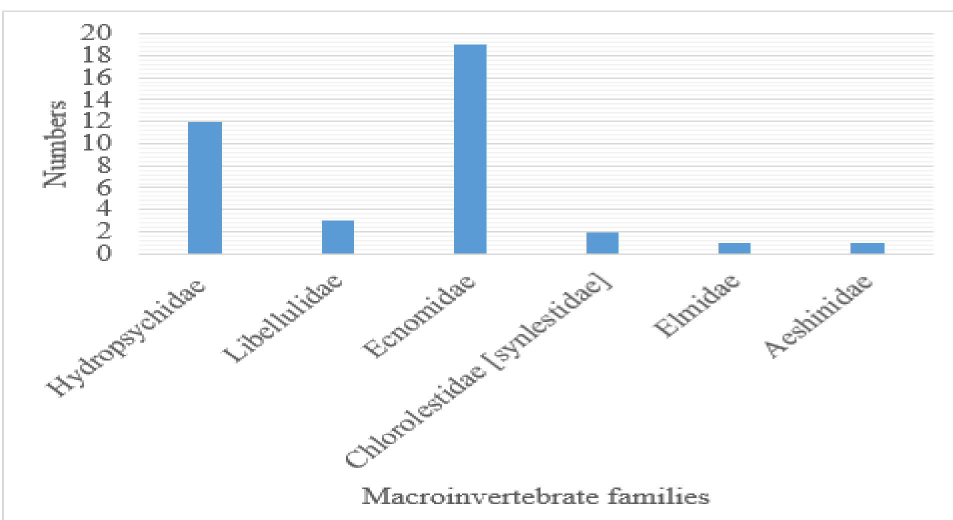

Figure 9. Proportions of macroinvertebrate specimen families found at site C1 during the wet season

The percentage composition of the families in Figure 9 are presented in Figure 10.

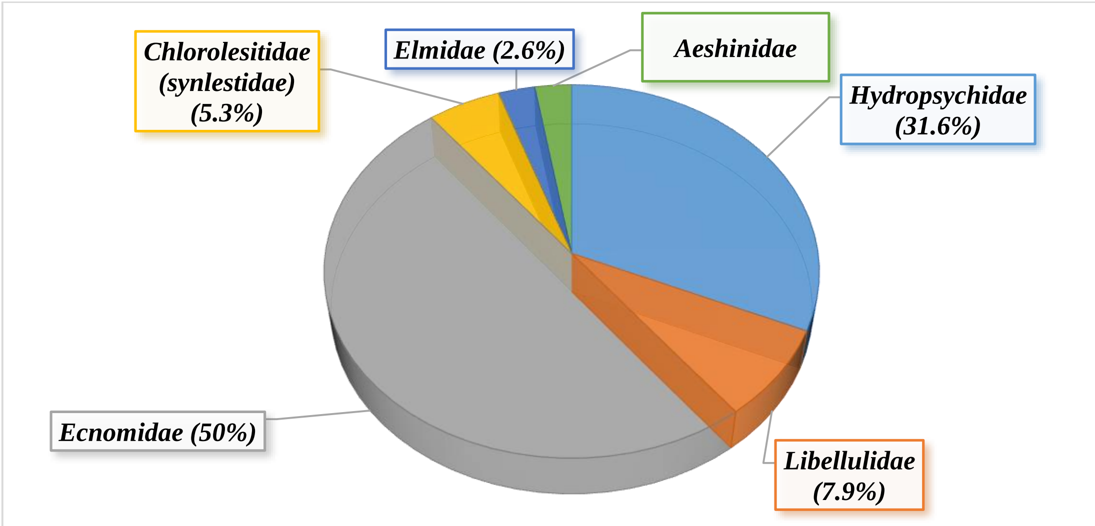

Figure 10. Abundance of macroinvertebrate families found at site C1 during the wet season

At sampling site C2, two macroinvertebrate specimens were Libellulidae, 19 were Coenagrionidae, four were Baetidae and one belonged to the Hydrometridae family (Figure 11).

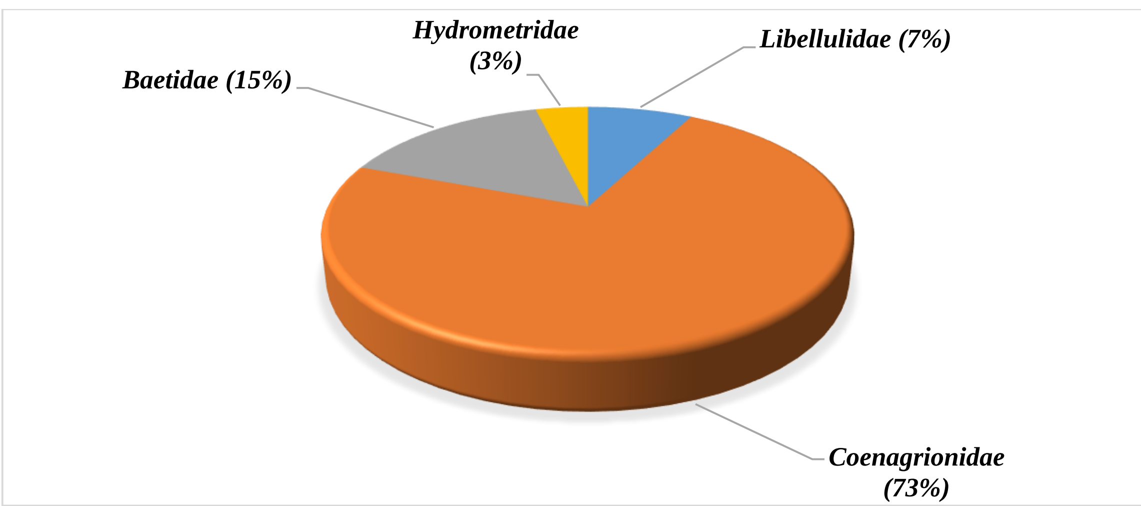

Figure 11. Abundance of macroinvertebrate families found at study site C2 during the wet season

Finally, the dominant family at site C3 was Heptageniidae with four specimens, three belonged to the family Geriidae and two each to Vellidae and Atyidae (Figure 12).

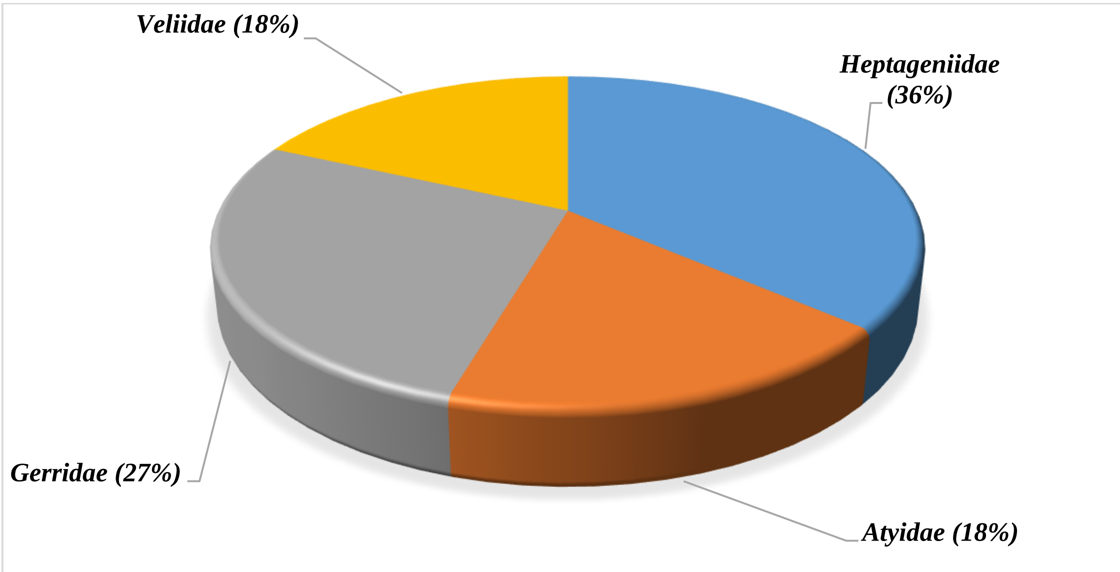

Figure 12. Abundance of macroinvertebrate families found at site C3 during the wet season

4.1.2 Aquatic macroinvertebrates identified along the Chibefwe River in the dry season.

Unlike the wet season, a total of 170 macroinvertebrate specimens belonging to 10 orders (Figure 13) and 21 families (Table 5) were identified in the dry period season. This included 35 specimens of Odonata, 15 of Annelida, 42 of Diptera, 16 of Coleoptera, 12 of Crustacea, 30 of Trichoptera, 7 of Ephemeroptera, 3 each of Hemiptera and Turbellaria, and 7 of Lepidoptera. The relative percentage composition of the orders is presented in Figure 13.

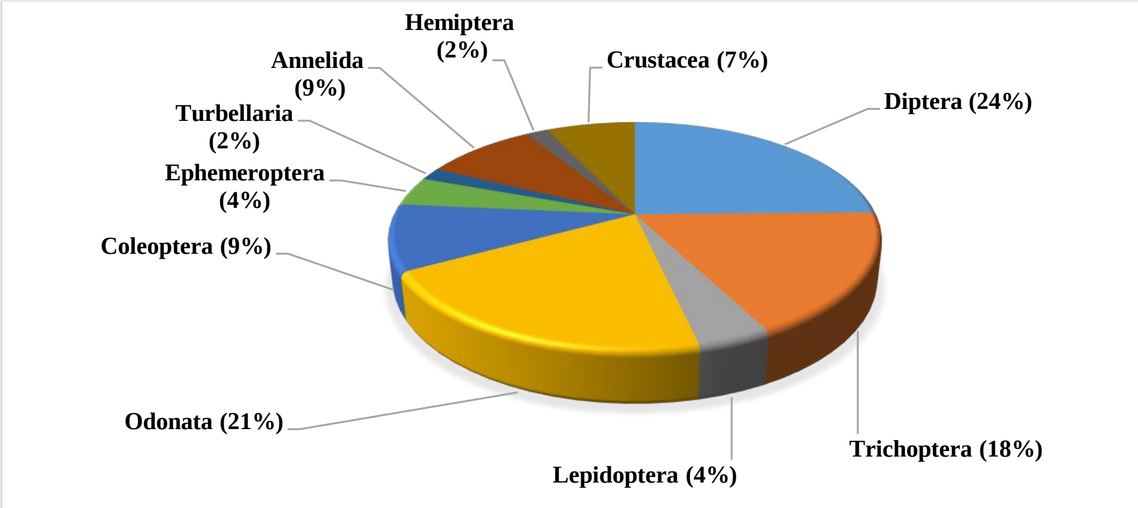

Figure 13. Abundance of macroinvertebrate orders identified in the dry season along the Chibefwe River

As shown in Figure 13, Diptera had the highest proportion among the ten orders identified during the dry season. Additionally, Table 5 shows the macroinvertebrate families identified at all the sites during the dry season.

Table 5: Identified macroinvertebrate families during the dry season along the Chibefwe River, in Mkushi district, Zambia

Site	Identified macroinvertebrate Families
C1 (Source Site)	Hirudinea, Hydrophilidae, Oligochaeta, Elmidae, Athericidae, Libellulidae, Hydropsychidae, Gyrinidae.
C2 (Urban Site)	Coenagrionidae, Calopterygidae, Athericidae, Chironomidae, Nepidae, Pisulidae, Helodidae, Lestidae, Baetidae, Turbellaria, Hydrophilidae, Oligochaeta.
C3 (Confluence Site)	Atyidae, Tipulidae, Heptageniidae, Chironomidae, Libellulidae, Baetidae, Lepidoptera, Veliidae, Coenagrionidae.

A total of 105 macroinvertebrate specimens were collected at site C1 during the dry season, whereas a total of 45 and 20 were collected from sites C2 and C3, respectively. The dominant families at site C1 (Figure 14), were the Hydropsychidae and Chironomidae.

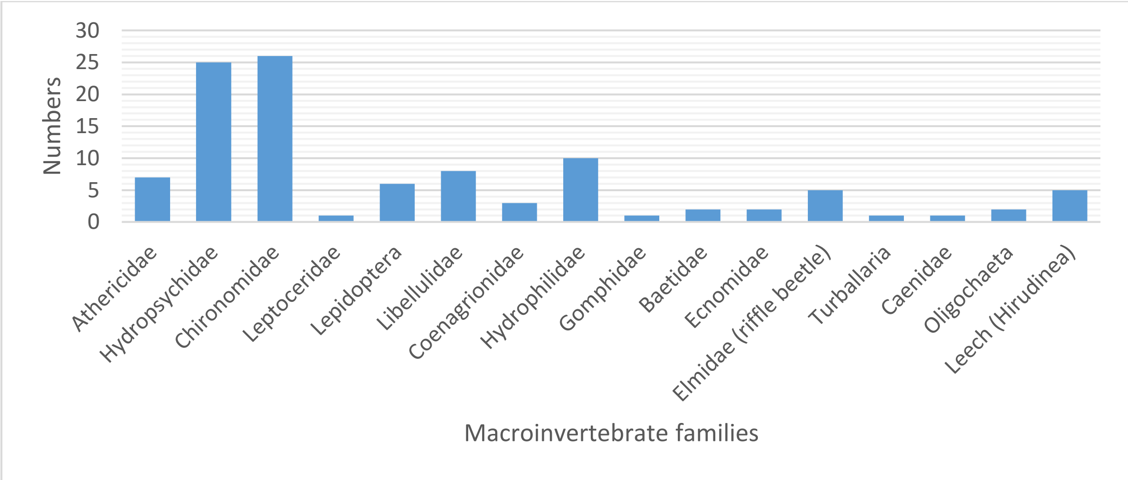

Figure 14. Macroinvertebrate families identified during the dry season at study site C1.

According to Umar *et al*., (2013), the Hydropsychidae species (figure 15) are recognised by the presence of branched gills on their ventral surfaces of abdominal segments 7 or 8, and a prominent brush extending from the base of each anal claw.

Figure 15. Hydropsychidae specimens showing branched respiratory gills on the ventral side of the abdomen (left picture) and the pattern of the sclerotized head from the dorsal view (right picture). (Source: Umar *et al*., 2013)

The urban site (C2) was dominated by the macroinvertebrate family Coenagrionidae followed by the families Annelida and Chironomidae in that order (Figure 16).

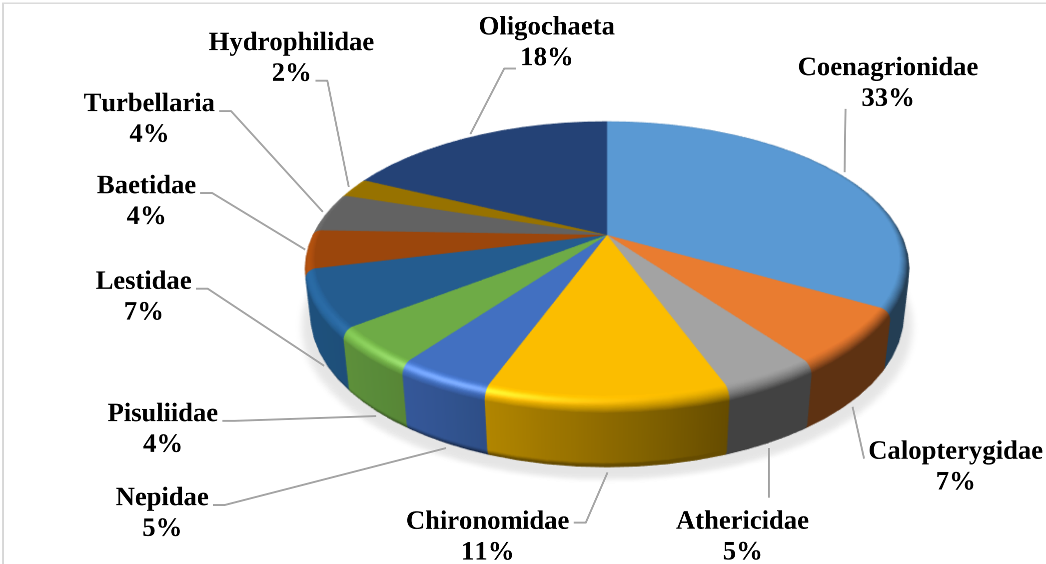

Figure 16. Abundance of macroinvertebrate families found at the urban site (C2) during the dry season.

Finally, the confluence site (C3) was dominated by the family Atyidae (shrimps) (Figure 17).

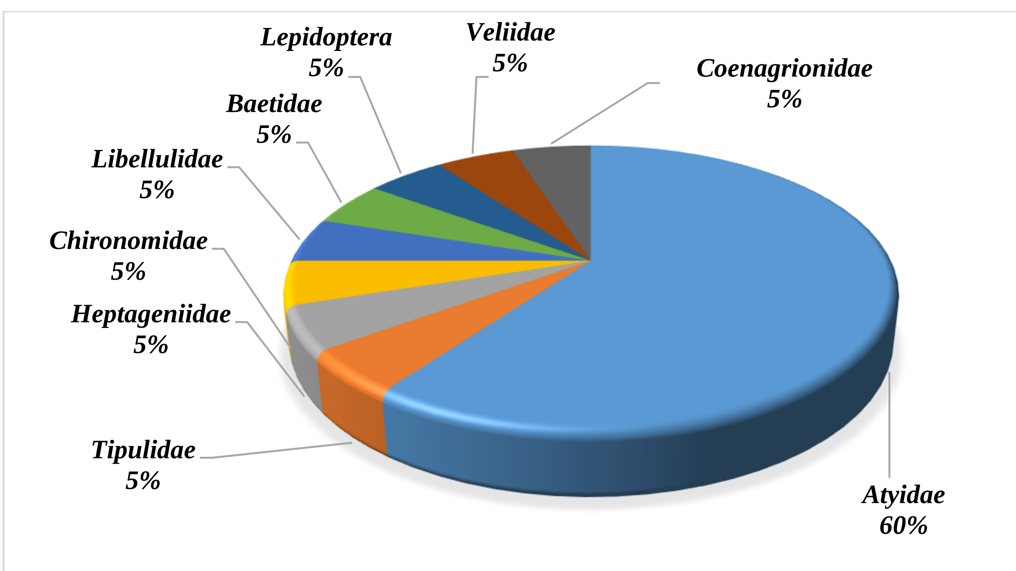

Figure 17. Abundance of macroinvertebrates found at the confluence site during the dry season.

The wet season was mainly dominated by the somewhat tolerant macroinvertebrate order to pollution, the Trichoptera, whereas the dry season was dominated by the semi-tolerant species, the Diptera, as well as the Odonata. Figure 18 presents the dissolved oxygen levels across the sites.

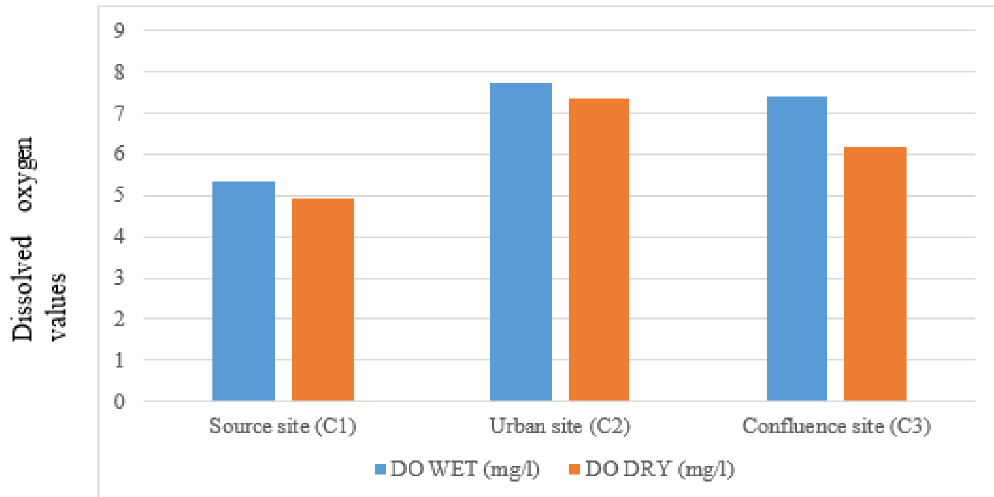

Figure 18. Dissolved oxygen levels across sites along the Chibefwe River.

4.2 Calculated Species Diversities, ZISS and ASPT

Findings in Figure 19 show that the confluence site (C3) had the highest species diversity (1.34) during the wet season, whereas the source site recorded the highest species diversity (2.25) in the dry season.

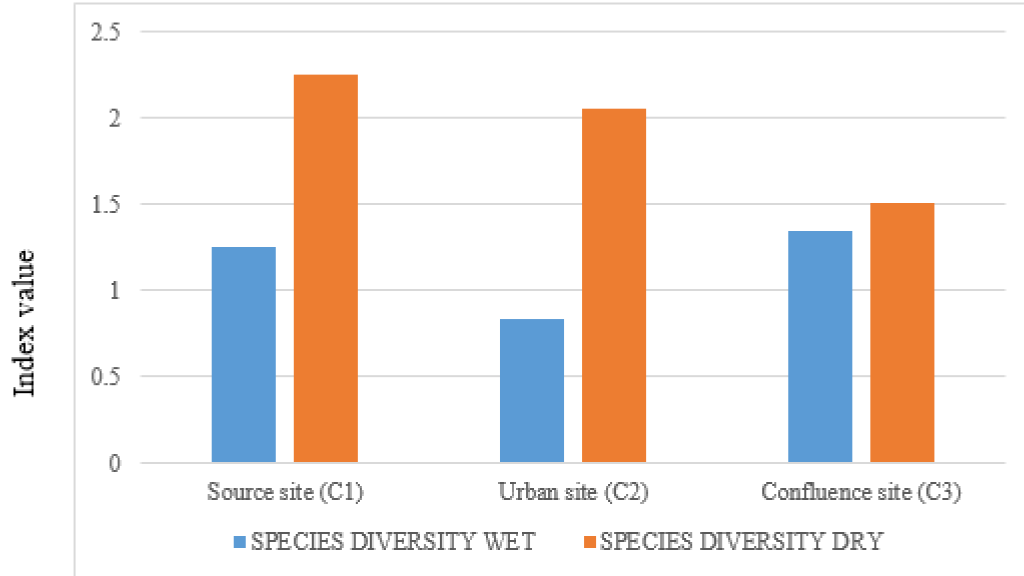

Figure 19. Species Diversities in both the wet and dry season

The results showed that species richness correlated positively with species diversity (r = 0.77) (Figure 20), i.e. the higher the species richness exhibited by a study site, the higher the species diversity is. A declining trend in species diversity was observed from up to downstream during the dry season (Figure 19).

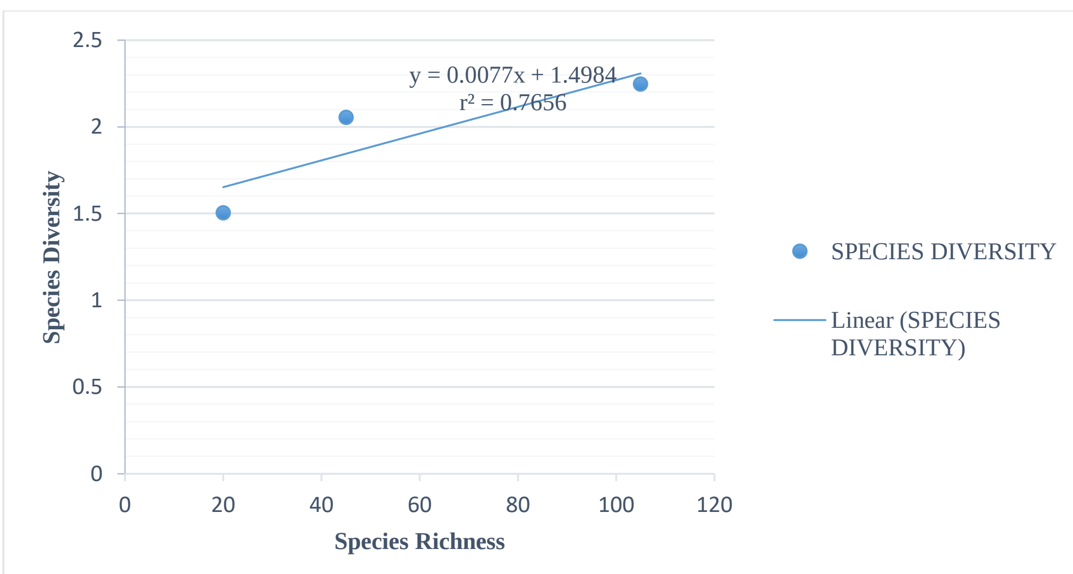

Figure 20. Correlation of Species Richness and Species Diversity at Study Sites.

Table 6 presents the Zambia Invertebrate Scoring System (ZISS) and Average Score Per Taxon (ASPT) results for all study sites during both the wet and dry sampling seasons.

Table 6: Summary of ZISS results in both wet and dry periods along the Chibefwe River.

Season	Description	C1	C2	C3
Wet	ZISS Score	40	18	31
	Taxa Present	6	4	4
	ASPT	6.67	4.5	7.75
	Category	B	E	B
Dry	ZISS Score	66	68	53
	Taxa Present	13	11	8
	ASPT	5.08	6.18	6.63
	Category	D	B	B

A study by Wen *et al*., (2017) recommended using in-stream Biochemical Oxygen Demand (BOD) as an overall indicator of organic river pollution. In this study, despite having higher BOD values in the wet than during the dry seasons (Figure 21), BOD values observed in the dry season were still much higher than the benchmark threshold of 5mg/l (Wen *et al*., 2017).

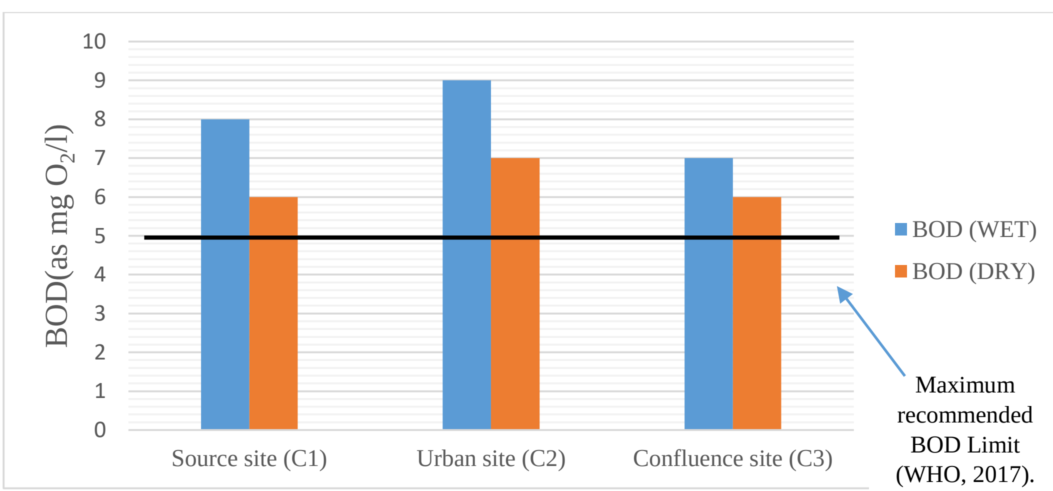

Figure 21. BOD values across the three sites on the Chibefwe River

Site C1 was observed to have a rocky river bed (i.e. consisting of cobbles, boulders, and pebbles) substrate covered with aquatic algae (Figure 22).

Figure 22. Aquatic algae observed on the river bed at the source site of the Chibefwe River

Conditions observed during the dry season were that the turbidity levels were relatively higher in the wet (25.92 FTU) than in the dry season (0.00 FTU) (Table 7).

Table 7: Turbidity levels in both the wet and dry seasons across sites along the Chibefwe River

Sampling site	Turbidity during the wet period (FTU)	Turbidity during the dry period (FTU)
Source site (C1)	0	0
Urban site (C2)	25.92	0
Confluence site (C3)	52	0

Table 8: Guide for interpreting scores calculated and ecological categories. Source: (Dallas, 2007)

Category	**Total Score**	**ASPT**	**Description of Water Quality**	**Colour**
A	>110	>5.8	Unmodified natural	
B	<110	>5.8	Largely natural with few modifications	
C	>110	<5.8	Moderately modified	
D	40–110	<5.8	Largely modified	
E/F	<40	Variable	Seriously modified	

4.3 Land Use Types in the Chibefwe River Catchment Area

To infer to contemporary anthropogenic factors which may pose water quality threats in the study area, a land use map for the whole catchment was developed (Figure 23).

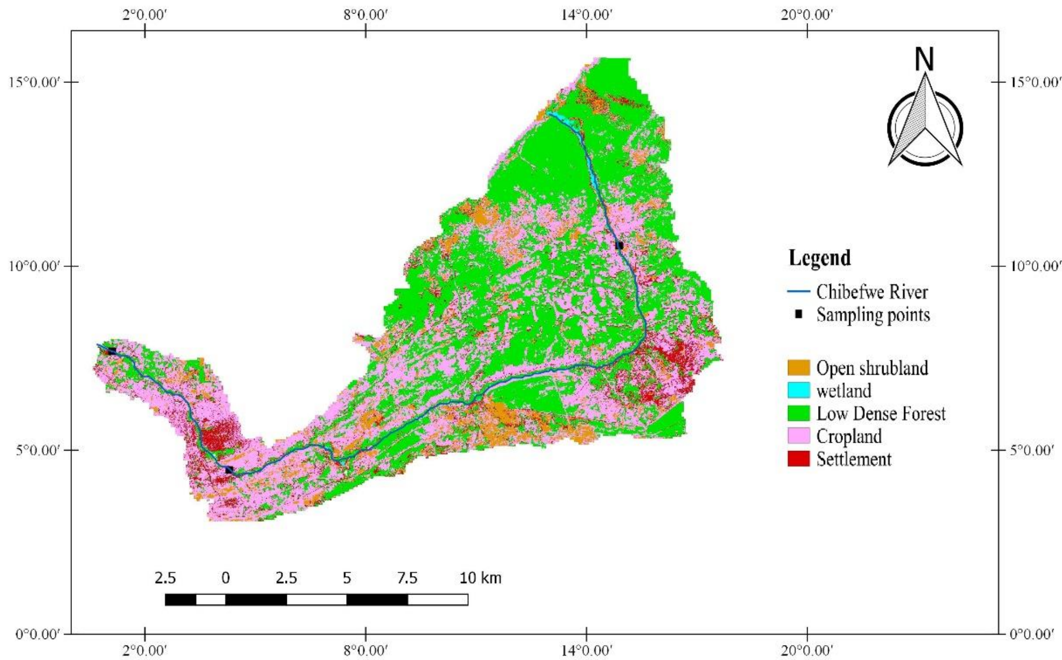

Figure 23. Spatial distribution of Land Use in the Chibefwe Catchment.

Each land use type was estimated showing the distribution of anthropogenic factors with respect to the three sampling sites selected (Table 9).

Table 9: Estimated land cover and land use in the Chibefwe Catchment

LAND COVER	**AREA (Sq. Km)**	**(%) Coverage**
Open shrubland	13.9855	7.02151
Wetland	0.8167	0.410029
Low dense forest	90.0759	45.22318
Cropland	77.656	38.98769
Settlement	16.6467	8.357583
TOTAL	**199.1808**	**100**

Figure 24 shows a drone image taken to illustrate adjacent anthropogenic activities that could potentially affect water quality.

Figure 24. Drone image showing the Chibefwe River used to flood croplands.

4.3.1 Study Site Specific Land Use Characteristics.

Figure 25 shows the site specific land use characteristics at C1. The Chibefwe River upstream of the source site drains through wetlands before flowing near croplands.

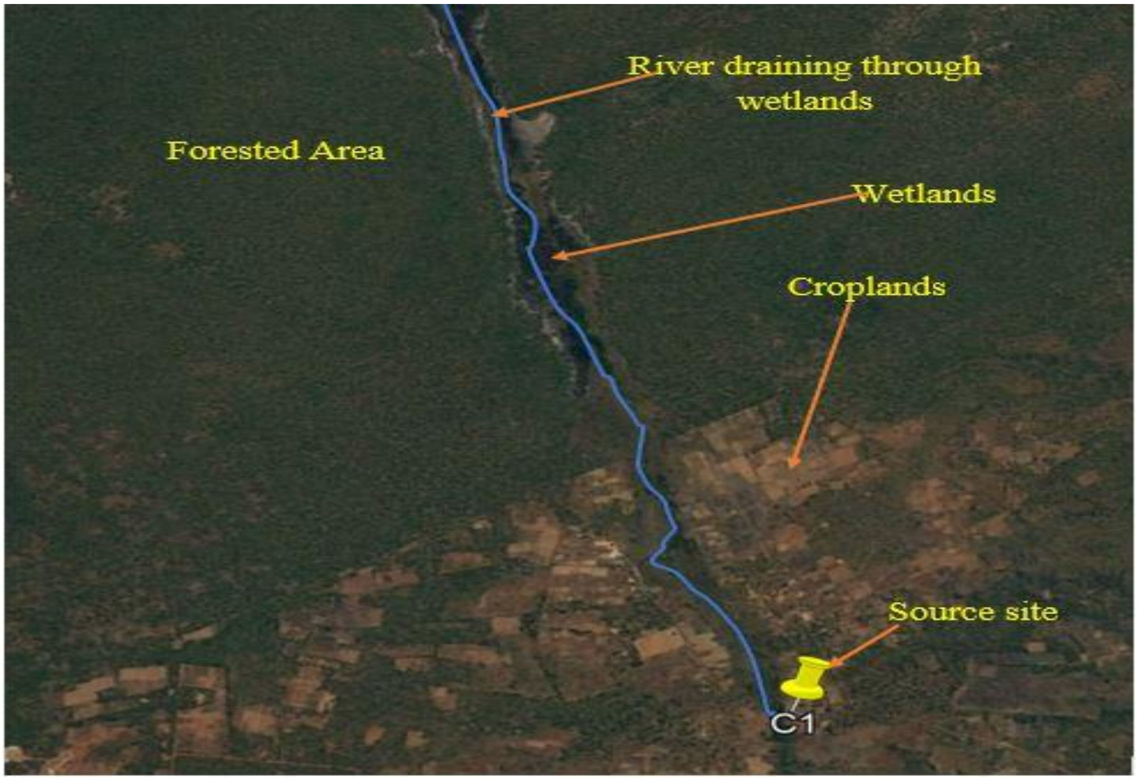

Figure 25. Google Image of surroundings near source site C1.

Three main land use land cover categories were identified within the surroundings of the source site (C1) (Figure 26). Observations revealed that the highest land use/land cover category was that of low dense forest (0.64Km^2) representing 91.61%. This was followed by that of cropland (0.05184Km^2) and wetlands (0.00675Km^2) both representing 7.42% and 0.97% respectively.

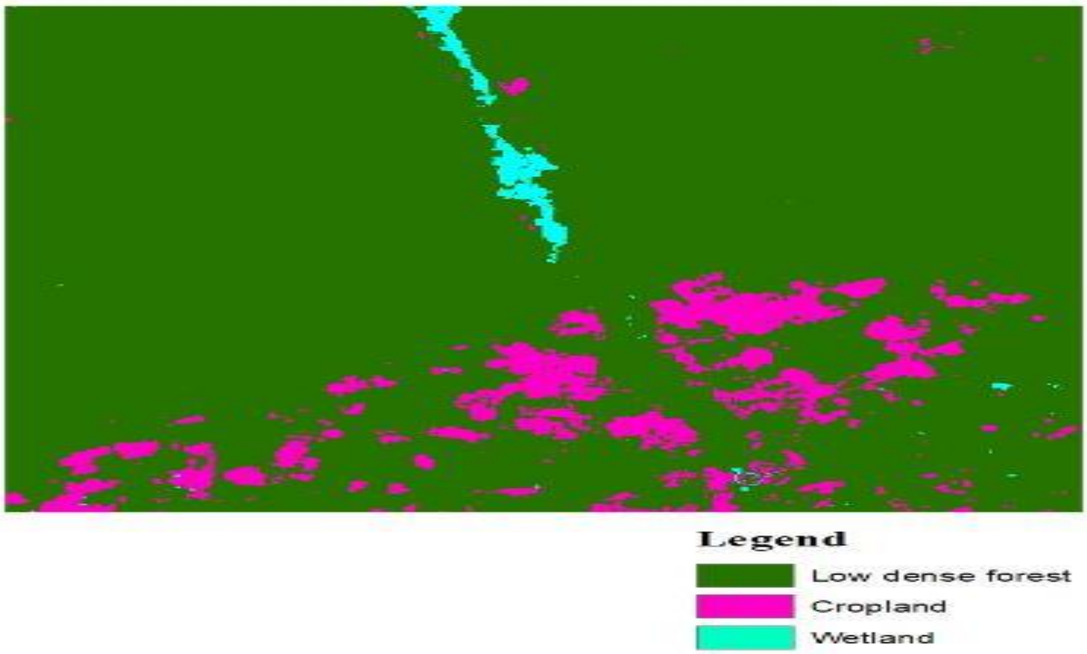

Figure 26. Spatial distribution of land use land cover at source site C1.

Figure 27 shows the location of the urban sampling site with respect to the surrounding land use.

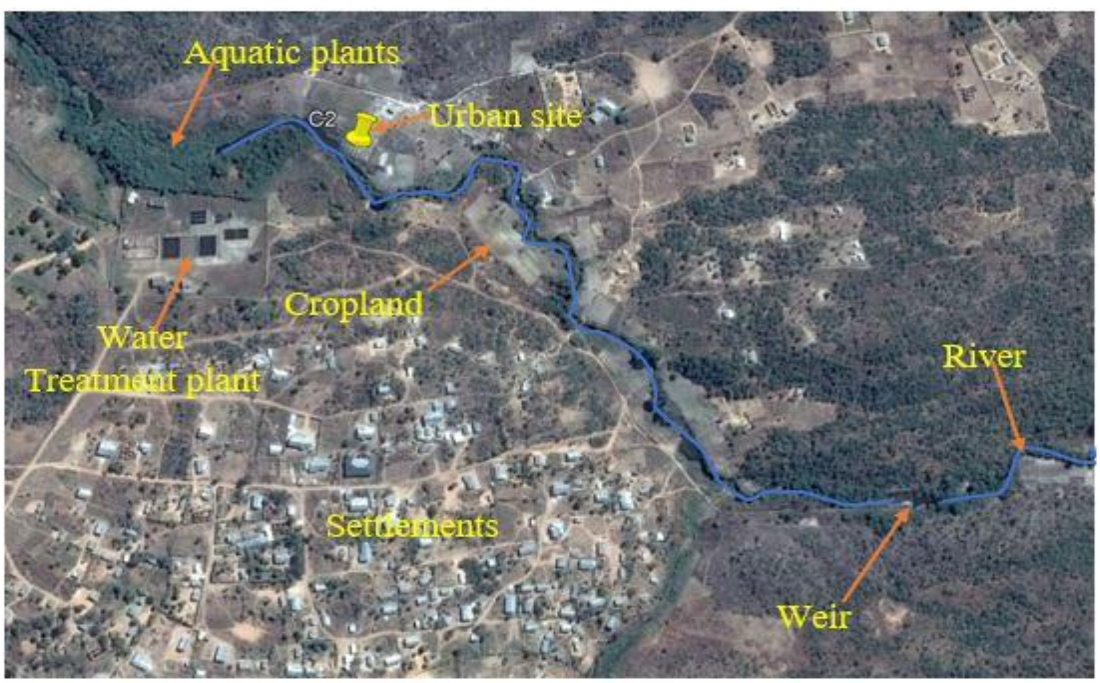

Figure 27. Surrounding Human activities near the urban sampling site (C2) on the Chibefwe River.

Unlike the source site (C1), the dominant land use categories at the urban site (C2) as shown in Figure 28 was that of open shrublands (bare land) (0.631898Km^2) representing 58.93%. Compared to the source site (C1) which had an estimated low dense forest cover of 0.64Km^2, the urban site had an estimated 0.285684Km^2 low dense forest coverage representing 26.65%. The other land use categories observed within the vicinity of the urban site were croplands (0.132962Km^2), settlements (0.02091Km^2) and water bodies (0.00069Km^2) all representing 12.40%, 2%, and 0.06% respectively.

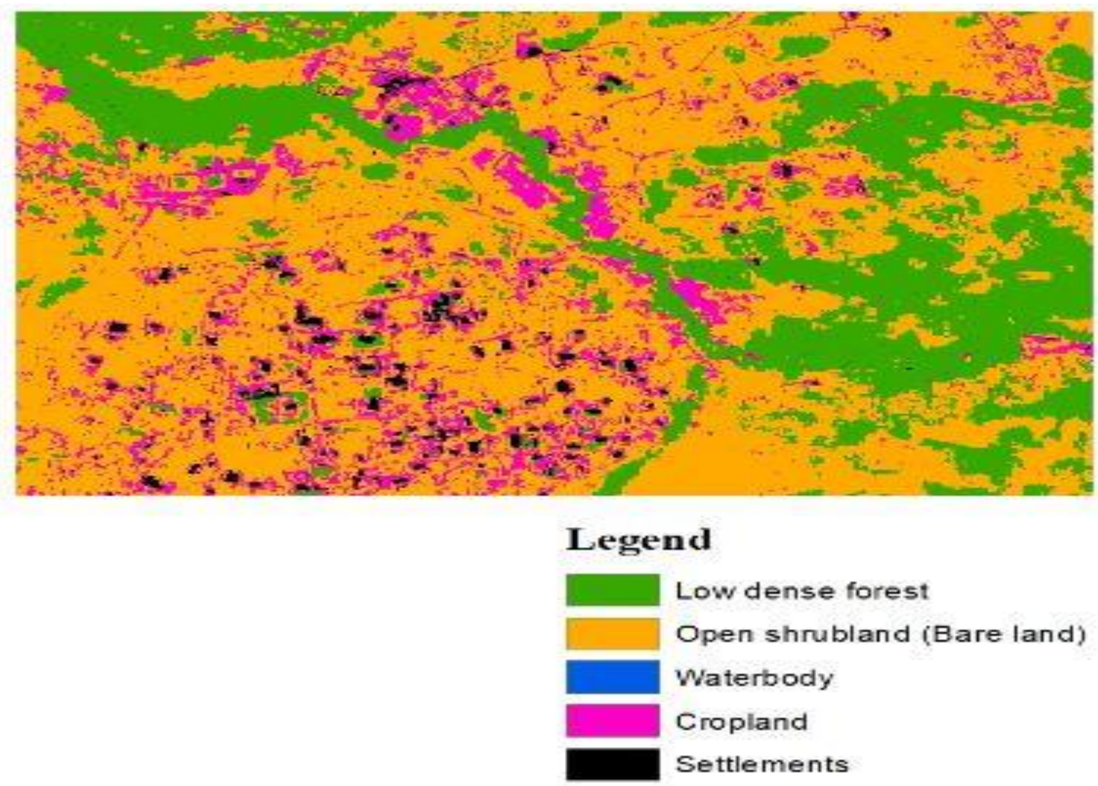

Figure 28. Spatial distribution of land use/land cover at urban site C2.

Site C3 was observed to be surrounded by croplands with less vegetation cover (Figure 29).

Figure 29. Surrounding environment near confluence site C3

The dominant land use category at this site as shown in Figure 30, was that of croplands (0.332834 km^2) representing approximately 53.75%. This was followed by low dense forest covering an estimated area of 0.28637 km^2 representing 46.25%.

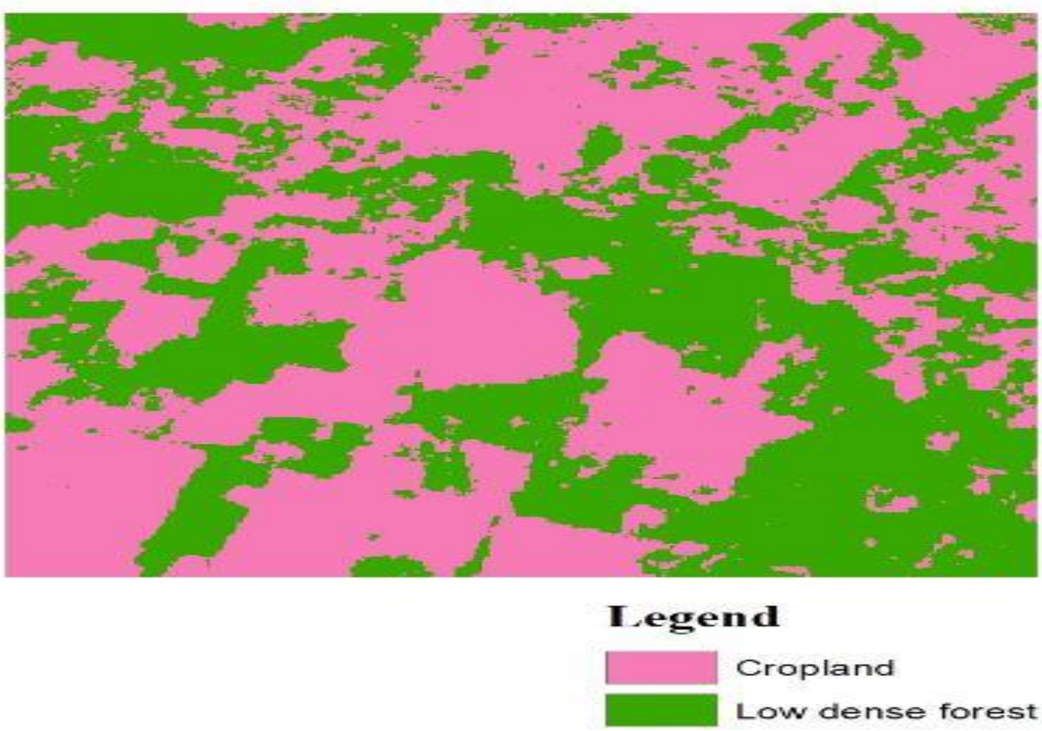

Figure 30. Spatial distribution of land use/land cover at confluence site C3.

4.4 Flow water quality characteristics.

Table 10 shows findings of physico-chemical parameters along the Chibefwe River measured in both the wet and dry seasons.

Site	Temperature (^{0}C)		pH		Percentage saturation of DO (%)		Total Dissolved Solids (mg/l)		Total Suspended Solids (mg/l)		EC (µS/cm)		Bicarbonate (as mg $CaCO_3$/l)		COD (as mg O_2/l)	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
C1	22.2	17.9	3.15	4.07	60.9	53.05	6.2	6.5	2.1	0.9	9.43	10.96	52	8	12	13.5
C2	22.5	15.9	4.05	4.61	91.2	79.6	6.7	8.5	17.2	2.3	12.66	12.54	12	12	17	19
C3	21.9	15.9	4.74	5.37	84.6	62.8	6.3	8	18	2.4	25.5	16.87	28	16	13	18.5

The temperature was observed to be lower during the dry season than in the wet season and this was attributed to the fact that sampling in the dry season was conducted around July, and this is generally winter in the study area. Temperature ranged from 21.9 ^{0}C to 22.2 ^{0}C during the wet period season whereas temperatures ranged between 15.9 ^{0}C to 17.9 ^{0}C during the dry period season. In both the wet and dry periods seasons, findings suggest that pH conditions generally indicated acidic conditions (pH values <7) for all the sites, and consequently suggesting a low pH buffering capacity to the Chibefwe River (Figure 31).

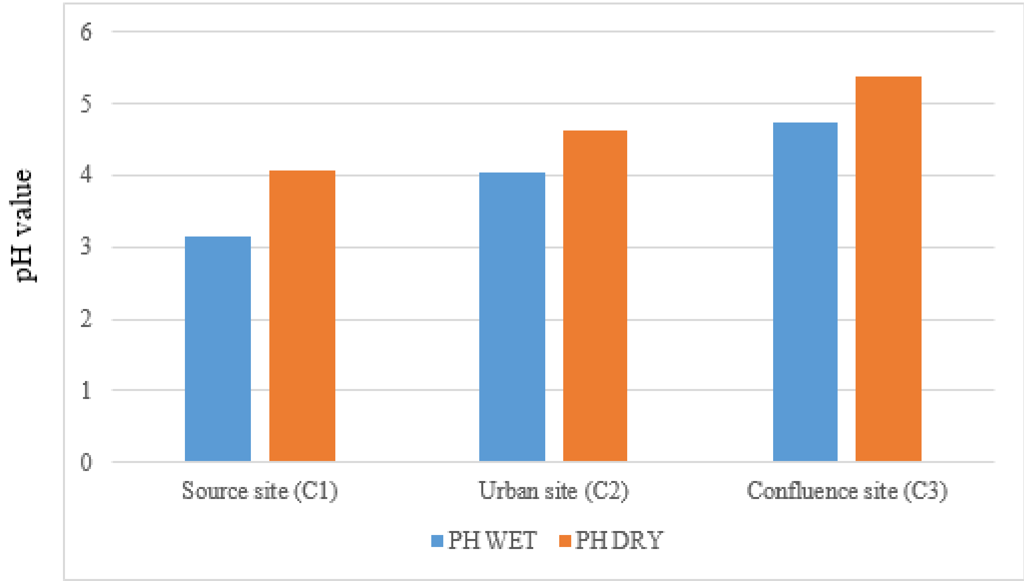

Figure 31. pH values of sampling sites along the Chibefwe River for both wet and dry seasons.

Total suspended solids were generally higher during the wet season due to high flows (Figure 32). The highest value of total suspended solids was recorded at the confluence site (18mg/l) and this was followed by that of the urban (17.2 mg/l) and the source (2.1 mg/l) sites all determined during the wet season in that order.

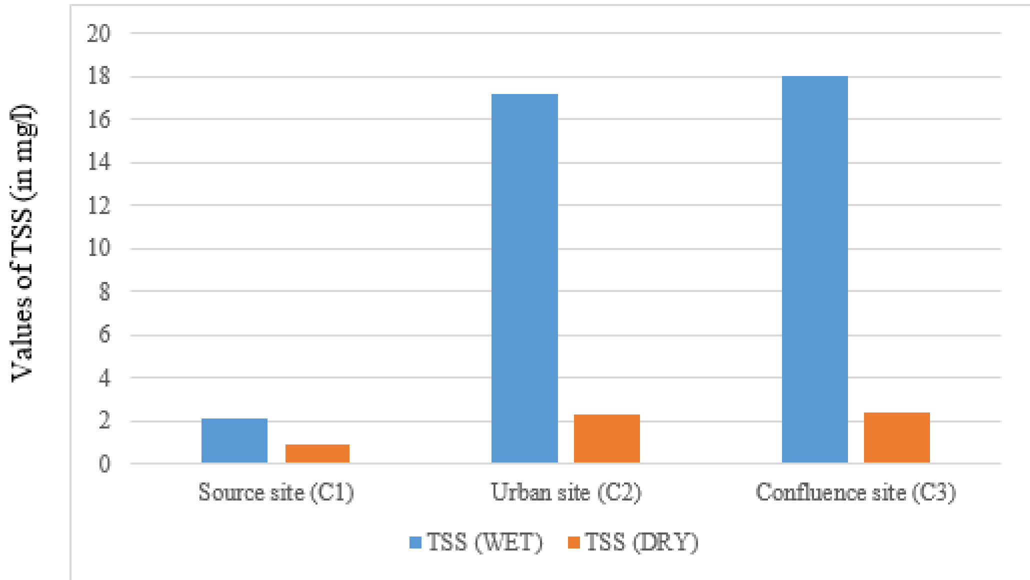

Figure 32. Total suspended solids for sampling sites along the Chibefwe River for both wet and dry seasons.

Findings suggest that turbidity was a function of total suspended solids (r=0.7862) (Figure 33), and the observation made here was that as total suspended solids increased from up to downstream, the turbidity levels also generally increased with the highest (52 FTU) recorded at the confluence site, followed by the urban site (25.92 FTU) and the source site (0 FTU).

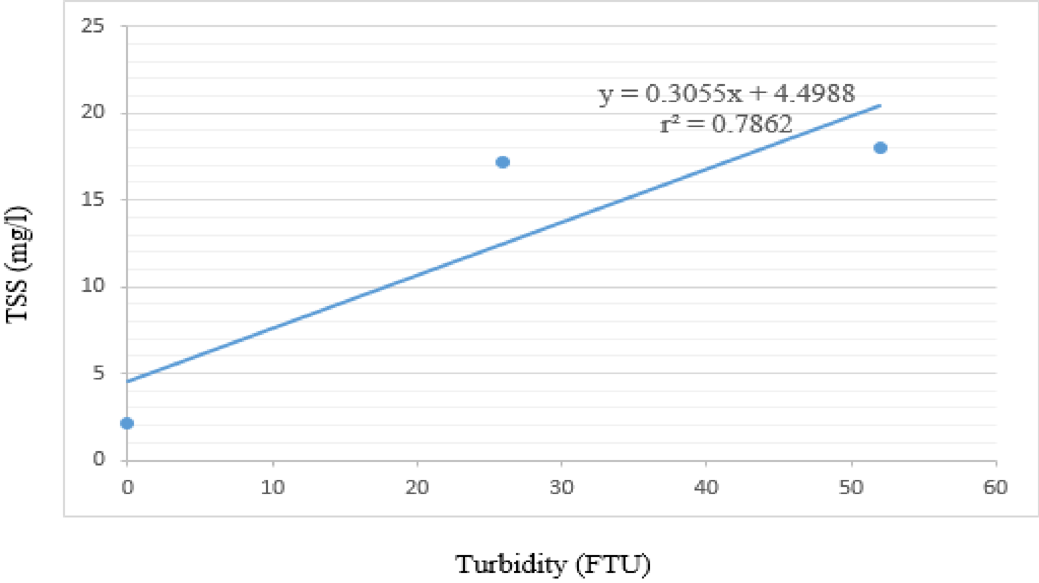

Figure 33. Correlation between Turbidity and TSS

4.4.1 Water Quality Index Calculations.

Water quality index (WQI) computations ranged from 57.87% to 60.14% and 57.32% to 64.91% during the wet and dry seasons, respectively (Figure 34).

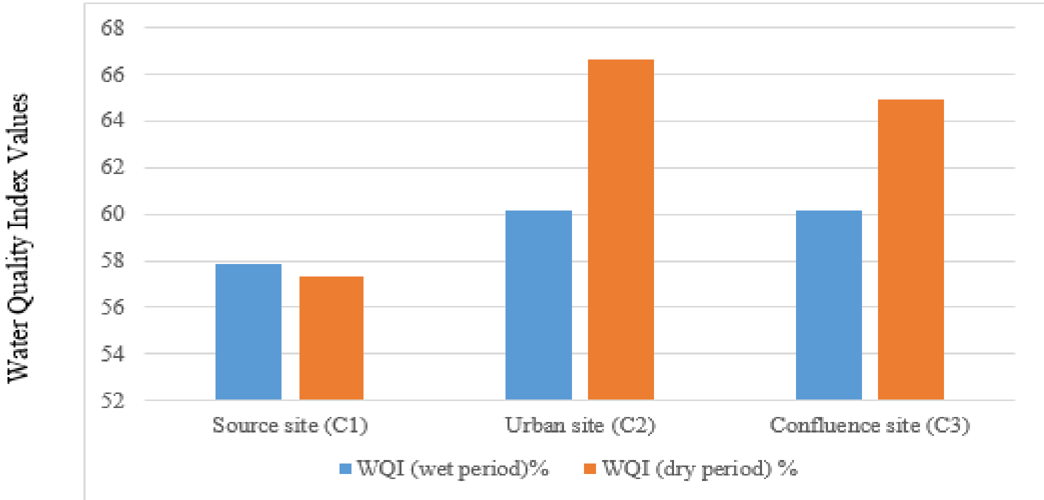

Figure 34. Water Quality Index computations of sites along the Chibefwe River

CHAPTER 5: DISCUSSION

5.1 The Diversity of Benthic Macroinvertebrates in the Chibefwe River Catchment Area

Generally, higher species diversity was recorded in the dry season than in the wet season across all the sites. However, despite having higher species diversities during the dry seasons (Figure 19), findings suggest that there was a decline of somewhat tolerant macroinvertebrate families for example at C1 such as a shift from the Ecnomidae to those of pollution tolerant (such as the Chironomidae) from the wet to dry period seasons. On the other hand, findings show that the dry periods had a variety in semi-tolerant orders (such as Odonata, and Diptera) and tolerant orders (such as the Oligochaeta). This clearly demonstrates that flow regimes play an important role in structuring the physical habitat and ultimately the macroinvertebrate community composition. These findings are consistent with the results of a study conducted by Righi-Cavallaro *et al*., (2010) which aimed at evaluating the effects of physical and chemical variables and seasonality on diversity and structure of the macroinvertebrate fauna in a Neotropical chalk stream. They found out that dry period seasons yielded more diversity in macroinvertebrate fauna organisms than the wet period seasons. Righi-Cavallaro *et al*., (2010) concluded that seasonality factors influence the temporal variation of communities of macroinvertebrates. Using the approach of Türkmen and Kazancı (2010), the results also suggest that there was some impairment to habitat conditions with indications of pollution at all the sites. The lowest species diversity was recorded in the wet season at the urban site (0.84).

According to (Umar *et al*., 2013), the order Trichoptera commonly called caddisflies, is usually associated with forest streams of moderate to excellent water quality conditions whereas, the Odonata order is composed of moderately tolerant species that can survive a wide range of water quality conditions. In this study, during the wet season, site C1 (source site) was dominated by both pollution-intolerant and mid-range tolerant macroinvertebrate families, i.e. Ecnomidae and Hydropsychidae, which are associated with excellent and moderate water quality conditions respectively (Umar *et al*., 2013). It is interesting to note that at the urban site (C2) both the wet (73%) and dry (33%) seasons were dominated by the

Coenagrionidae macroinvertebrate family commonly referred to as Damselflies. According to Camargo *et al*., (2004) Damselflies are capable of surviving a wide range of water quality conditions. Camargo *et al*., (2004) reveal that finding these macroinvertebrates generally indicate average stream water quality conditions. A study by Ojija and Laizer (2016) revealed that the Nzovwe stream in Mbeya city, Tanzania was dominated by damselflies which are moderately pollution-sensitive organisms and are associated with fair water quality conditions. The present study findings are consistent with those of Ojija and Laizer, (2016) and hence indicate that the aquatic environment of Chibefwe River at the urban site is moderately polluted and gives indications of moderate alterations to stream conditions. The Coenagrionidae is regarded as a semi-tolerant family to pollution and is usually associated with slow moving water (pools) of fair water quality and is predominantly found in the biotopes of aquatic vegetation found on the edges of rivers (Ojija and Laizer 2016; Gerber and Gabriel, 2002). Finally, the confluence site (C3) was dominated by the Heptageniidae macroinvertebrate family in the wet season. Umar *et al*., (2013) associates the Heptageniidae with high quality streams and are found in mostly river valley areas. This description coincides with the location where this family was found during the study, which is the confluence site.

In contrast, during the dry season, there were only two orders found at all the sites and these were Diptera and Odonata. According to Ojija and Laizer (2016), both these orders are considered semi-tolerant to pollution. During the dry season, two macroinvertebrate families namely the Hydropsychidae and Chironomidae dominated at site C1. Even though the Hydropsychidae are considered to be in the mid-range for tolerance of environmental stressors, they are actually slightly more tolerant to pollution, especially considering that they take in organic wastes or nutrients as food (Umar *et al*., 2013). Umar *et al.*, (2013) states that they are mainly herbivores and possibly scrapers as well as filter feeders. This explains the reason why most of them, were found in the vegetation biotope (24) (habitats) compared to the 1 that was found in the stones biotope. Results show that the other taxa that dominated at C1 during the dry season is that of the Chironomidae. The occurrence of the pollution tolerant family Chironomidae could be attributed to the reduced flows in the dry season ($0.347m^3/s$) compared to that of the wet period

(0.766 m^3/s). Additionally, the presence of Chironomidae could also indicate the occurrence of organic pollution at the site. These findings are consistent with those of a study by Harikumar *et al*., (2014) who also found this family and concluded that their presence showed a high degree of organic pollution. Griffiths *et al*., (2015)., describes the Chironomidae family as "blood worms," because they contain red-pigmented haemoglobin which enhances oxygen uptake, a feature that allows larvae to survive in organically enriched environments often subject to low oxygen concentrations. Observations made at C1 were that dissolved oxygen concentration levels had declined from 5.33mg/l in the wet season to 4.91mg/l in the dry season (Figure 18). This decline could have also caused a shift in the dominance of the (caddisfly) Ecnomidae family during the wet period season to that of the Chironomidae family (blood worms) in the dry season. The declining trend of dissolved oxygen levels could have been triggered by the reduction in flows from the wet (0.766m^3/s) and dry (0.347 m^3/s) seasons coupled with the possible occurrence of organic pollution which may have been associated with small farming activities (croplands) upstream of source sampling site (Figure 25).

Wen *et al*., (2017) have revealed that despite significant self-cleaning capacities of rivers, organic pollution (BOD > 5mg/l) of rivers affect both humans and ecosystems with developing countries such as Zambia where the present study was carried out being disproportionately affected. According to Wen *et al*., (2017), the number of people expected to be affected by organic pollution (BOD>5mg/l) was projected to increase from 1.1 billion in 2000 to 2.5 billion in 2050. According to Figure 21, the urban site (C2) recorded the highest BOD values in both the wet (9mg/l) and dry (7mg/l) seasons suggesting that the occurrence of organic pollution at this site was the highest compared to the other sites. This may be due to the accumulation of organic wastes associated with rapid urban growth of settlements and untreated urban wastes, inadequate sanitation around the urban as well as emerging small-scale farmers (croplands) along the Chibefwe River.
Additionally, Wen *et al*., (2017) suggest that the risk of river organic pollution is also due to water abstraction which in turn decreases a river's dilution capacities, a situation which increases risks to humans and ecosystems as a whole. A decline in pollution intolerant macroinvertebrate family Ecnomidae was observed in the wet season and replaced with the pollution tolerant family of the Chironomidae in

the dry season at the source site (C1). Additionally, the presence of Trichopterans (eg. Hydropsychidae) at site C1 during the dry season may indicate the presence of organic matter. These findings agreed with the findings of Stamenkovic-Slavevska *et al*., (2011) who reported the presence of Hydropschidae caddisflies that are associated with organically enriched environments. According to Wen *et al*., (2017), accumulation of organic pollution in rivers stimulate microbial growth, resulting in oxygen depletion and ultimately leading to disturbance of the entire river ecosystem. The present study findings at this site were consistent with suggestions of Wen *et al*., (2017). This was demonstrated by a reduction in dissolved oxygen concentration levels from 5.33mg/l during the wet season to 4.91mg/l during the dry season. Finally, during the dry season, the confluence site was dominated by the Atyidae (shrimps) macroinvertebrate family. According Umar *et al*., (2013) associates with moderate to high quality of stream water.

5.2 Aquatic Macroinvertebrates that can serve as Indicators of Water Quality in the Chibefwe River catchment area

According to Kenney *et al*., (2009), bioassessments are based on the premise that biotic communities respond to changes in habitat and water quality conditions mostly associated with anthropogenic influences. Kenney *et al*., (2009) further highlight that natural features of aquatic ecosystems such as instream habitat conditions affect macroinvertebrate assemblage structures. It is therefore vital to consider a spectrum of response macroinvertebrate taxa ranging from pollution sensitive taxa to pollution tolerant taxa. Kenney *et al*., (2009), identifies for example, measures of the presence of Ephemeroptera, Plecoptera and Trichoptera (EPT) as indicators of a healthy stream. Despite this, Kenney *et al*., (2009), reveals that not all species and families are sensitive to pollution, but that the abundance of taxa in these orders though not restricted to, gives a reasonable indication of stream health. In this regard, for this study, the identified aquatic macroinvertebrates that could potentially serve as indicators water quality in the study area included the Hydropyshidae and Chironomidae (from the source site), Coenagrionidae (from the urban site) and finally Atyidae and Heptageniidae (both from the Confluence site). These typically dominated sites, were identified in some seasons or both the wet and dry seasons and were assumed to be ubiquitous because of high abundances.

Overall, with reference to the ecological bands developed by Dallas (2007) in table 8, for site C1, results showed a change in environmental quality conditions from close to natural with few indications of impairment in class B during the wet season to largely modified environmental conditions in class D during the dry season. This could be attributed to reduced flows during the dry season thereby probably reducing the Chibefwe River's dilution capacity to flush organic matter present at this site. The urban site (C2) exhibited the worst ecological conditions in the wet than in the dry season in comparison to the ecological conditions of the other sites (table 6). The confluence site (C3) exhibited the best ecological conditions in both the wet (7.75) and the dry (6.63) seasons and had consistent ecological conditions in both wet and dry period seasons (table 6). This site was observed to be dominated by the families Heptageniidae and Atyidae (shrimps) in both the wet and dry seasons respectively. According to Umar *et al.*, (2013), shrimps are widespread in streams or rivers with medium to high water quality.

5.3 Impacts of Land Use Types on Water Quality in the Chibefwe River catchment area

With reference to the constructed land cover/ land use map, findings revealed that the highest land use category was that of low dense forest followed by croplands, settlements, open shrublands and wetlands, respectively (Table 9). One threat identified that could potentially affect water quality, relates to anthropogenic activities associated with croplands and settlements (Figure 24). For example, turbidity levels were observed to have increased from 0 to 52 FTU's from up to downstream sites during the wet period season (Table 7). This could be probably attributed to decreasing vegetation cover downstream. At the urban sampling site (C2), potential threats to the aquatic ecosystems of the Chibefwe river may have been associated with mainly settlements and croplands further upstream of the site (Figure 27). It is interesting to note that despite being surrounded by croplands

(Figure 30), the confluence site (C3) was dominated by the Atyidae macroinvertebrate family in both wet and dry periods seasons. According to Umar *et al*., (2013), these macroinvertebrates are associated with moderate to good water quality conditions. These ecological conditions should, however, be preserved especially considering the fact that forest cover is at risk of being converted to croplands. This site was observed to have had the highest turbidity (52 FTU) levels compared to all the other sites during the wet season and this may be attributed to less vegetation cover. Compared to the other sites, this site recorded relatively lower BOD values for both the wet (7 mg O_2/l)) and dry (6 mg O_2/l)) season. However, despite this, findings suggested that there are indications of organic pollution (BOD>5 mg of O_2/l) and this may also be attributed to the surrounding human activities associated with small scale farming. The occurrence and dominance of the Atyidae macroinvertebrate family in both wet and dry period season was due to favourable dissolved oxygen concentrations in both wet (7.41mg/l) and the dry (6.18mg/l) periods (Figure 18).

Findings in table 10 showed that the percentage saturation of dissolved oxygen was closely related to the flows. Hence having much higher values of percent saturation of dissolved oxygen in the wet (60.9% to 91.2%) than in the dry (53.05% to 79.6%) season for all the sites. Additionally, total dissolved solids ranged from 6.2 to 6.7mg/l in the wet season compared to the range of 6.5 to 8.5 in the dry season. These findings are congruent with those of Pullanikkatil *et al*., (2015) who concluded that total dissolved solids were higher in the dry than in wet season owing to less dilution effect due to reduced runoff during the dry season. The opposite trend was observed for total suspended solids where higher values were observed ranging from 2.1mg/l to 18mg/l in the wet season compared to a range of 0.9mg/l to 2.4mg/l in the dry season.

A steady increase in pH conditions was observed for both seasons with the wet season generally having relatively lower pH values than those of the dry season (Figure 31). This may be in line with findings by Saarinen *et al*., (2013) who observed that leaching of humic acids from organic deposits causes low pH (acidic conditions in rivers). Saarinen *et al*., (2013) further reported that there is large leaching to watercourses especially during high runoff periods, thereby causing severe chemical and ecological effects. The present study findings revealed that the lowest pH values for both the wet (3.15) and dry (4.07) seasons were observed at the source site (C1) which is dominated by low dense forest ($0.64km^2$) and areas used for small scale farming. Additionally, in line with the present findings, the study by Saarinen *et al*., (2013) demonstrated that areas consisting of organic deposits (peatlands) in highly forested areas are common in Finland, with a large proportion of Finnish rivers and streams being slightly acidic (median pH 5.9). Saarinen *et al*., (2013), had further revealed that "approximately 50% of Finnish peatlands have been drained for agriculture and forestry which may increase leaching of humic substances, metals, suspended solids, and nutrients." In their study, Saarinen *et al*., (2013), concluded that increased leaching causes organic acidification of watercourses, especially in areas with abundant forest (and peat) cover. According to present study findings, forest cover was highest at the source site ($0.64km^2$), compared to those of the urban ($0.285684km^2$) and confluence ($0.28637\ km^2$) sites. This could have triggered more deposits of organic debris at the source site compared to the other two sites. Lower pH values were generally observed during the wet season than that of the dry season, and this may have been due to leaching of humic acids stimulated by flows.

5.4 Water Quality of the Chibefwe River

Regarding water quality index (WQI) computations, findings suggested that the water quality generally exhibited fair conditions in both wet and dry seasons along the Chibefwe River. Results showed that the worst water quality for both wet (WQI 57.87%) and dry (WQI 57.32%) seasons was exhibited by the source site (C1) (Figure 34). Both the urban and confluence sites exhibited similar water quality conditions in the wet season (WQI 60.14%) with the latter having better water quality conditions in the dry period season (WQI 66.60%) than the former (WQI 64.91%). With an exception of the source site, the dry season generally registered better water quality conditions for the sites. These findings were congruent with the declining trend in ecological conditions from class B in the wet season to class D (Table 5) in the dry season at the source site. This may be attributed to possible causes of organic pollution occurring at the site. Although parameters such as phosphorus and nitrates were almost negligible (0.009 mg/l each), there is a likelihood that activities such as multiple diversions of water further upstream, could be a possible cause for a disturbance in instream habitat conditions due to flow alterations. For example, a study by James (2008), suggested that an alteration in flow adversely affects physical habitats, as reduced flow tends to decrease depth, velocity, and wetted width and increase fine sediment. Additionally, flow reduction stresses a number of macroinvertebrate taxa, causing them to drift as they redistribute themselves within the stream. This may have been the cause of the ecological class reducing from B class in the wet season to D class in the dry season at the source site (C1). A study by Pullanikkatil *et al*., (2015) revealed that the overall river water quality of Linkangala Catchment southern Malawi during both the wet and dry seasons was ranging between bad (WQI 34.13%) and medium (WQI 53.95%) water quality conditions. Unlike these findings, according to WQI computations of the present study, all the sites exhibited fair water quality ranging from 57.87% to 60.14% and 57.32% to 66.6% during the wet and dry seasons, respectively. The immediate land use surrounding the source site was a combination of agriculture (small scale farming) and forestry. Although the source site (C1), was forested, field observations revealed a number of diversions. Site C1 exhibited the highest pollution loads in both wet (57.87%) and dry periods (57.32%). This can be attributed to the occurrence of organic pollution and possible leaching processes of humic acids at the site. Field observations also revealed a number of small farming activities with some tags of various pesticides in their field used. Generally, the percentage saturation of dissolved oxygen reduced from 60.9% during the wet season to 53.05% in the dry season. This could also have ultimately led to the high occurrence of the pollution tolerant macroinvertebrate family (Chironomidae) at the site. In addition, turbidity levels during the wet period were observed to have increased from up (0FTU's) to downstream (52FTU's). Increased turbidity levels were attributed to river bank cultivation, increased runoff thereby carrying silt and organic matter. According to Pullankkatil *et al*., (2015), highly turbid water is unfit for domestic use and is aesthetically unappealing. Direct health effects depend on the precise composition of the turbidity-causing materials (Environmental Protection Agency (EPA, 2001).

In conclusion, a highly diverse aquatic macroinvertebrate community, is generally considered to be a healthy aquatic environment and biotic components are suitable indicators of water quality because they are indicative of various stressors including land use influences on aquatic environments. They are intended to complement physico-chemical techniques of monitoring water quality conditions.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings, the study concluded that:

i. Ecosystem conditions are influenced by seasons. For example, this was demonstrated at site C1 where ecological conditions changed from class B in the wet season where conditions were close to natural with few modifications to class D in the dry season indicating substantive impairment;

ii. Anthropogenic factors such as those of stream bank cultivation (or croplands) contribute to the deterioration of both water quality and ecosystem conditions;

iii. Water Quality Index (WQI) computations generally revealed that water quality registered as fair water quality conditions across the sites. This indicative of human impacts such as croplands or settlement; and

iv. Turbidity and organic pollution generally increase due to poor agricultural practices associated with river bank cultivation and leaching of humic acids in the Chibefwe River respectively.

6.2 Recommendations

The recommendations of the study were that:

i. Existing catchment vegetation be conserved especially considering the fact that the Chibefwe River drains through a forest reserve area while being mindful of a buffer zone to the river system;

ii. A deliberate programme for routine water quality monitoring should be put in place, and this should include the application of rapid bioassessment techniques such as the ZISS to preserve freshwater supplies. Acquired information could be useful in contributing towards the upcoming process of developing catchment management and development plan as well as conserving biodiversity; and

iii. It is also recommended that further studies be carried out along the Chibefwe River, covering both rainy and dry season in order to establish the status of water quality in the entire river in different seasons.

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APPENDICES

Appendix A: Site Photos at Sampling Points

Site C1

Figure A1: Discharge measurements at the source site

Site C2

Figure A2: Sampling of macroinvertebrates at the urban site

Site C3

Figure A3: Screening for macroinvertebrate specimen at the confluence site

Appendix B: ZISS Score Sheet

Date:	/ /		**OR dd.ddddd**	**Biotopes Sampled**	**Rating (1 - 5)**	**Time (min)**
Site Code:	-	**Geolocation (dd mm ss.s) Lat:**	**S**	**Stones In Current (SIC)**		
Collector/Sampler:		**Long:**	**E**	**Stones Out Of Current (SOOC)**		
River:				**Bedrock**		
Ecoregion:		**Altitude (m):**	**m**	**Aquatic Veg**		
Quaternary Catchment:		**Zonation:**		**MargVeg In Current**		
	Temp (°C):	**Cond (mS/m)**		**MargVeg Out Of Current**		
Site Description:	**pH:**	**Clarity (cm):**		**Gravel**		
	DO (mg/L):	**Turbidity:**		**Sand**		
	Flow:	**Colour:**		**Mud**		
	Riparian Disturbance:			**Hand picking/Visual observation**		
	Instream Disturbance:					

Taxon		**S**	**Veg**	**GSM**	**TOT**
PORIFERA (Sponges)	5				
TURBELLARIA (Flatworms)	3				
ANNELIDA					
Oligochaeta (Earthworms)	1				
Hirudinea (Leeches)	3				
CRUSTACEA					
Potamonautidae* (Crabs)	3				
Atyidae (Shrimps)	8				
HYDRACARINA (Water mite	8				
PLECOPTERA (Stoneflies)					
Perlidae	12				
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae (Squaregills/Cainfles)	6				
Dicercomyzidae	9				
Ephemeridae	15				
Ephemerythidae	10				
Heptageniidae (Flatheaded mayfl	13				
Leptophlebiidae (Prongills)	9				
Machadorythidae	8				
Oligoneuridae (Brushlegged may	15				
Polymitarcyidae (Pale Burrowers	10				
Prosopistomatidae (Water specs)	15				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae	10				
Chlorocyphidae	10				
Coenagrionidae (Sprites and blue	4				
Lestidae (Emerald Damselflies)	8				
Platycnemidae (Brook Damselfli	10				
Protoneuridae	8				
Aeshnidae (Hawkers & Emperors	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6				
Libellulidae (Darters)	4				

Taxon		**S**	**Veg**	**GSM**	**TOT**
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (=Pyralidae)	12				
HEMIPTERA (Bugs)					
Aphelocheiridae*	5				
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3				
Gerridae* (Pond skaters/Water stride	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7				
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Cased caddis:					
Calamoceratidae	11				
Hydroptilidae	6				
Lepidostomatidae	10				
Leptoceridae	6				
Pisuliidae					
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetle	5				
Elmidae/Dryopidae* (Riffle beetles)	8				
Gyrinidae* (Whirligig beetles)	5				
Haliplidae* (Crawling water beetles)	5				
Hydraenidae/Hydrochidae* (Minute r	8				
Hydrophilidae* (Water scavenger bee	5				
Limnichidae*	8				
Psephenidae (Water Pennies)	10				
Scirtidae (Marsh beetles-larvae only)	12				

Taxon		**S**	**Veg**	**GSM**	**TOT**
DIPTERA (Flies)					
Athericidae	10				
Ceratopogonidae (Biting midg	5				
Chironomidae (Midges)	2				
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggot	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ampularidae	5				
Ancylidae (Limpets)	6				
Bithyniidae*	3				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae*	5				
PELECYPODA (Bivalves)					
Corbiculidae	5				
Mutelidae	6				
Sphaeriidae (Pills clams)	3				
Unionidae (Perly mussels)	6				
ZISS Score					
No. of Taxa					
ASPT					

Other biota:

Comments/Observations:

Procedure:
Kick stones & bedrock in-current (IC) for 2 mins
(up to 5 mins. max if bedrock) Kick stones &
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated
abundance on score sheet). Score for 15 mins/biotope but stop if no
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity)

Figure B1: Shows Zambia Invertebrate Scoring Sheet (ZISS) with accompanied sampling protocols (Lowe *et al*., 2012)

Appendix C: Mapping of Land cover/use in the Chibefwe River Catchment

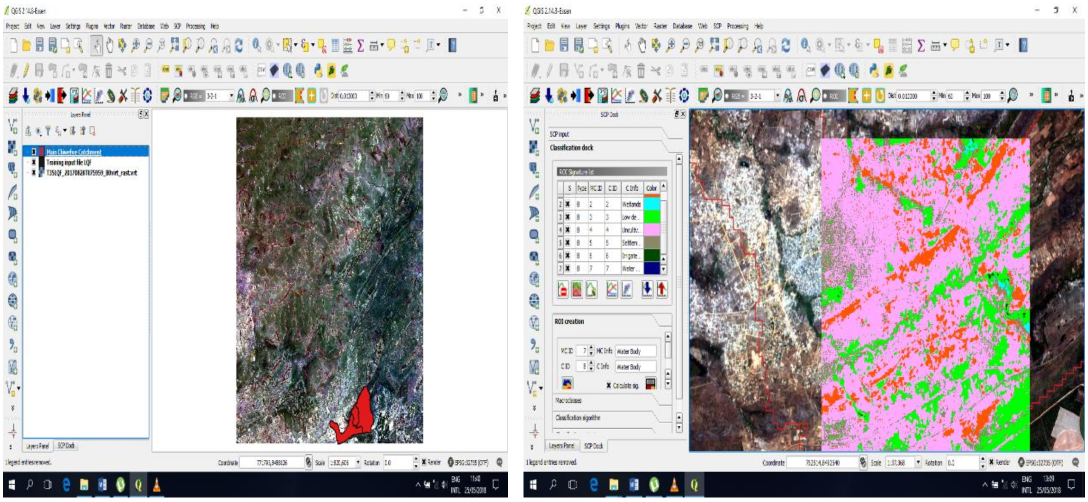

Figure C1: Land cover classification process of sentinel 2 image covering the Chibefwe River Catchment

Appendix D: Water Test Results

Table D1: Test results for laboratory analyses of water samples obtained from sites in the Chibefwe River Catchment

Category	**Parameter**	**Site C1**		**Site C2**		**Site C3**		**Maximum Permissible Limits**	
		Wet Season	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**WHO (mg/l)**	**ZABS (mg/l)**
Chemical characteristics	Nitrates(as NO3 –N mg/l)	0.009	0.009	0.009	0.009	0.009	0.009	50	10
	Nitrites (as NO2 –N mg/l)	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	3	1.0
	Phosphates(mg/l)	0.009	0.009	0.009	0.009	0.009	0.009	5.0	-
	Potassium(mg/l)	1.93	2.03	2.18	2.10	1.83	1.42	-	-
	Sodium(mg/l)	5.84	6.2	6.60	6.4	5.55	4.17	200	200
	Magnesium(mg/l)	5.28	0.46	1.44	1.44	3.84	2.64	-	150
	Chloride(mg/l)	9.0	9.5	10.0	9.5	9.0	6.5	-	250
	BOD(as mg O2/l)	8	6	9	7	7	6	5	5
	COD(as mg O2/l)	12	13.5	17	19	13	18.5	40	40

	Bicarbonates(as mg $CaCO_3$/l)	52	8	12	12	28	16	-	-
	Acidity(as mg $CaCO_3$/l)	18	13	0	8	0	0	-	-
Heavy metals	Arsenic(mg/l)	<0.002	< 0.3	<0.002	< 0.3	<0.002	< 0.3	0.01	0.01
	Cadmium(mg/l)	<0.002	< 0.002	<0.002	< 0.002	<0.002	< 0.002	0.003	0.003
	Cobalt(mg/l)	<0.005	< 0.005	<0.005	< 0.005	<0.005	< 0.005	-	0.5
	Copper(mg/l)	<0.003	< 0.03	<0.003	< 0.03	<0.003	< 0.03	2	1.0
	Iron(mg/l)	<0.01	0.10	0.39	1.20	0.46	1.70	0.3	0.3
	Lead(mg/l)	<0.01	< 0.01	<0.01	< 0.01	<0.01	< 0.01	0.01	0.01
	Manganese(mg/l)	<0.01	< 0.002	<0.01	< 0.002	<0.01	< 0.002	-	0.1
	Mercury(mg/l)	<0.002	< 0.2	<0.002	< 0.2	<0.002	< 0.2	0.006	0.001
	Zinc(mg/l)	<0.005	<0.001	<0.005	< 0.001	<0.005	0.026	3	3
Flow characteristics	Estimated flows (m^3/s)	0.766	0.3466	2.00	1.722	1.452	1.020	-	-

Lack of standards for drinking water in the above table for either WHO or ZABS maximum permissible limits implies no guidelines have been derived because of minimizing risks to health the parameters pose.

Appendix E: Laboratory Insights

Figure E1: Identifying macroinvertebrate specimen with the help of a compound microscope and pictorial guides.