EFFECTS OF ANTHROPOGENIC ACTIVITIES ON AQUATIC MACRO-INVERTEBRATE COMPOSITION AND WATER QUALITY IN LUMEMO RIVER, MOROGORO TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ECOSYSTEMS SCIENCE AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Biodiversity of freshwater ecosystems is declining faster than any other ecosystems due to various anthropogenic activities which result in changes in land use and water quality. However, the effects thereof on aquatic ecosystems are not well quantified and understood especially where small holder agriculture is a major economic activity and driver of changes on the status of ecosystems. This study investigates the effects of anthropogenic activities on water quality and aquatic macro-invertebrates in the Lumemo River Morogoro Tanzania. Aquatic macro-invertebrates, physio-chemical water variables and the health of the riparian vegetation were assessed in the upper, middle and lower reach of the River. A total of 30 sampling points were established, ten in each river reach segment. The distance between sampling points was 500 m. The abundance of aquatic macro-invertebrate was determined as the sum of all individuals in each sampling point. The diversity of macro-invertebrates was calculated using Shannon-Wiener Index. Anthropogenic activities were assessed based on the health of the riparian ecosystem by measuring the width and height of the vegetation strip, the structure of the vegetation strip and the extent of human-induced degradation (uses, vegetation clearing, and cultivation). The extent of use was determined using a scale of 1-5 where 1 = no/low use 5 = extensive use. Non-metric Multidimensional Scaling (NMDS) was used to determine the association between macro-invertebrates, physicochemical variables and anthropogenic activities. Macro-invertebrate diversity was lowest in the lower reach segment (H’ = 0.6228), with notable dominance of high pollution tolerant species than the middle reach (H’ = 1.299) and upper reach (1.593). There was statistically significant difference in water conductivity and pH across longitudinal sections of the river reaches. The lower reach had higher conductivity which infer higher amounts of suspended solids, followed by middle reach and the upper reach. Higher pH value was recorded in the upper reach (pH = 9);

while the middle reach had almost similar pH values to the upper reach (pH = 8.83). The lower reaches recorded an acidic pH value of 4.23 an indication of potential pollution load from intensive human use. The health of the riparian vegetation as indicated by vegetation cover, vegetation width and height was highest in the upper reach of the river. Overall diversity and abundance of aquatic macro-invertebrates along the reaches of Lumemo River were negatively correlated with the physicochemical parameters (pH, conductivity and temperature). Minimizing anthropogenic activities is vital for maintaining the health, water quality and improving the diversity and stability of macro-invertebrate in the Lumemo River ecosystem. Maintenance of ecological integrity by controlling anthropogenic activities, protection of the river channel and its basin and increased public education and awareness on environmental integrity is recommended.

DECLARATION

I, JOEL FRANK MREMI, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work done within the period of registration and that it has neither been submitted nor is being concurrently submitted to any other institution.

________________________ ________________________

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The above declaration is confirmed by:

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Prof. Munishi P.K.T. Date

(Supervisor)

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LIST OF ABBREVIATIONS

EC	Electric Conductivity
GPS	Geographical Position System
NMDS	Non-metric Multidimensional Scaling
PAST	Paleontological Statistics
TEEB	The Economics of Ecosystems and Biodiversity
UMNP	Udzungwa Mountain National Park
URT	United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

River ecosystems are important natural resource that provides a variety of valuable functions to the environment, national economies and human wellbeing (Gichana *et al*., 2014). However, these ecosystems are unable to provide basic functions to the rapidly growing population because they are threatened by pollution from various anthropogenic activities (Yillia *et al*., 2008; Raburu, 2003). Anthropogenic activities, such as land-use changes due to intensified agriculture, increasing urbanization and industrialization have had impact on natural river flow regimes (Dudgeon, 2000; Pringle *et al*., 2000; Ramírez *et al*., 2008). As a result, this affects water quality and hence living organism within aquatic ecosystems.

Effects of these anthropogenic activities are manifested in changes in biotic communities, as the patterns of this biota are responsive to the nature of the prevailing physical and chemical conditions (Sponseller *et al*., 2001). For example, land clearance for agriculture is known to increase surface runoff leading to loss of riparian complexity and in-stream habitats, changes in hydrology and increased inputs of herbicides/pesticides and fine sediments into the river (Zhang *et al*., 2012). Subsequently, these alter the functional feeding group composition of macro-invertebrates and other organisms such as fish by modifying the supply of food resources and producing changes in habitat structure and quality (Dudgeon, 2006; Wantzen and Wagner, 2006). In Tanzania, few studies have examined the effects of anthropogenic activities on water quality and aquatic macro-invertebrate at the regional or local scale.

The Lumemo River contributes substantially to the development of the Kilombero Valley. Lumemo River is the main source of freshwater supply and irrigation for many residents in the rural and urban settlements of the neighboring districts (Malinyi, Ulanga, Kilombero). Nonetheless, Anthropogenic activities; such as washing, irrigation, fishing, brick making, use of agro-chemicals (Alavaisha *et al*., 2019) and degradation of riparian ecosystems affects stream flow and water quality in the Lumemo River but also destroys the habitats for macro-invertebrate. Mangadze *et al*., 2015 argue that knowledge on the relationship between anthropogenic activities, water quality and macro-invertebrate composition in riverine ecosystems provides a starting point for establishing stream water quality control regulations, conservation goals, ecological restoration efforts and necessary research hypotheses for management of river ecosystems in Tanzania.

1.2 Problem statement and justification

Biodiversity of freshwater ecosystems is declining faster than any other ecosystems (Sala *et al*., 2000) due to various anthropogenic activities, which results in changes in land use, water quality and quantity. Anthropogenic influences, such as agricultural activities, deforestation, land-use changes can degrade surface water quality and make it unsuitable for drinking, sustainable agricultural use and sustaining biodiversity (Kartikasari *et al*., 2013; Selemani *et al*., 2018).

The expansion from small-scale rain-fed farming to medium and large-scale irrigation farming though has contributed to global food security, it has often been associated with land and water degradation problems (Mateo *et al*., 2017) with consequences on aquatic life. Specifically, surface water and wetlands are susceptible to contamination from agricultural use of chemicals and fertilizers and removal of riparian vegetation that allows increased input of harmful chemicals to the streams, increased light input to the stream which in turn supports greater primary productivity rates in the stream, as well as increased water temperature (Snyder *et al*., 2003). These changes have drastic effects on the water quality and macro-invertebrate community present in the stream (Buss *et al*., 2002). Therefore, monitoring of water quality and macro-invertebrate is consequently essential to institute appropriate management decisions (Mbaruku, 2016) especially for controlling negative impacts of anthropogenic activities. Such monitoring require baseline information on the status of relevant aquatic ecosystems.

The Lumemo River is an important source of water for the ecology of Udzungwa Mountains National Park but also surrounding communities who depend on it for their livelihood through fishing, irrigation, domestic use and several other economic activities. It is also important for the supply of water to the Kilombero Valley along its course and maintenance of aquatic biodiversity and related ecosystem services in the Kilombero Valley Floodplains Ramsar Site.

Anthropogenic activities such as irrigation, deforestation, degradation of the riparian buffer strips, inappropriate farming practices, brick making, washing and bathing compromise rivers water quality (Mbungu and Kashaigili, 2017) and related biodiversity and ecosystem services. Most of the above-mentioned anthropogenic activities occur within sixty meters of the river banks and thus adversely affect conservation and/or the protection of the Lumemo River (URT, 2002). Riparian forests protect water quality by reducing the amount of sediment, nutrients, and other pollutants that enter streams, lakes, and other surface waters and the design of riparian forest buffers to improve water quality must take into account the area's hydrology, soils, pollutant loadings, and adjoining land use. Effects of these activities on water quality and macro-invertebrates found in this area are not well analyzed, understood and documented and especially the role of the riparian ecosystem (riparian filter strip).

Studies that have been conducted in Tanzania to assess the influence of anthropogenic activities on aquatic macro-invertebrate and water quality in river systems are few. Mbaruku (2016) assessed river health using physicochemical parameters and macro-invertebrates case study of Mungonya River in Kigoma. Alavaisha *et al.* (2019) assessed water quality across Irrigation Schemes and agricultural impacts in Kilombero Valley, Tanzania, but also, Kaaya (2015) carried out a study on the biological assessment of tropical riverine systems using aquatic macro-invertebrates as indicators in Tanzania. The studies concluded that macro-invertebrate indices can be successfully used as a guide in assessment of water quality. Further future changes in land use land cover might cause deterioration of water quality.

The lack of information on the water quality and aquatic macro-invertebrates in most of the rivers impairs decisions on the wise use and management of water resources (LTBWB, 2015). To date, there has been no study conducted to determine the health of the Lumemo River as influenced by anthropogenic activities. Further, the use of aquatic macro-invertebrates as a measure of the health of aquatic ecosystems in Tanzania is inadequate.

1.3 Justification of the study

The findings in this study will provide baseline information on the water quality and aquatic macro-invertebrate status of Lumemo River as influenced by anthropogenic activities. The study will farther suggest positive changes towards conservation of aquatic ecosystems especially the riparian filter strips while sustaining socio-economic activities that sustain livelihoods across river catchments in the Lumemo River with wider implication on other rivers across Tanzania. This is contribution to policy and decision making by providing guidelines on the appropriate conservation of aquatic ecosystems amid sustainable human use for livelihoods. Furthermore, as macro-invertebrates can be good indicators of water quality in river systems and can easily be identified, such assessments are important and can easily be used as among the citizen science approaches to monitoring the health of aquatic ecosystems and prompting for changes in the ecosystem for immediate corrective action(s).

1.4 Objectives

1.4.1 General objective

The main objective is to assess the influence of anthropogenic activities on aquatic macro-invertebrates and water quality in the Lumemo River, Tanzania.

1.4.2 Specific objective

i. To determine the major anthropogenic activities with influence on aquatic ecosystems and their relationship with water quality in the Lumemo River
ii. To determine the diversity and abundance of aquatic macro-invertebrates across the longitudinal reaches of the Lumemo River
iii. To determine the relationship between water quality, the health of the riparian ecosystems and macro-invertebrates' abundance

1.5 Research questions

i. What are the major anthropogenic activities and their relationship with water quality in the Lumemo River?

ii. What is the diversity and abundance of macro-invertebrate along the different reaches of the Lumemo River?

iii. What is the relationship between water quality, the health of riparian ecosystems and macro-invertebrate abundance?

CHAPTER TWO

2.0 LITERATURE REVIEW

River ecosystems provide a range of resources that can be exploited for the benefit of human wellbeing and other organisms. These ecosystems have the potential to provide freshwater for domestic consumption, livelihoods and commercial production (agriculture, livestock and fisheries), industry and energy, and are used for transport and tourism, all contributing to national economic growth and poverty reduction (TEEB, 2013). Riverine ecosystems can also play a key regulatory function in the 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).

The majority of aquatic macro-invertebrates are organisms that live in water with size more than 1mm, are visible with the naked eye, and lack skeleton (invertebrate) (Agouridis *et al*., 2015). These includes but not limited to insects, worms, snails, mollusks and crustaceans. Aquatic macro-invertebrates may also be found under rocks or logs, sediments, debris or living in aquatic plants during some period of their life. They are an integral part of the food chain and without these creatures, a stream's entire aquatic food web would collapse (Agouridis *et al*., 2015). Many macro-invertebrates feed on organic material such as leaves and algae, they constitute a critical component to the life of the stream. Aquatic macro-invertebrate may act as indicators of stream health and water quality monitoring (Zaimes and Emanuel, 2006).

Water quality is a term used to describe the physical, chemical and biological characteristics of particular water for the intended use (Bhateria and Abdullah, 2015). Global environmental change induced by natural variability and anthropogenic activities influences both water quantity and quality at local and regional scales as well as at the global scale (Chang, 2004). Natural factors such as lithology, topography and climate, surface water quality are influenced largely by anthropogenic impacts such as irrigation, inappropriate farming practices, deforestation. Physico-chemical variables such as temperature, pH, electrical conductivity (EC) are the most commonly used indicators of water quality (Chang, 2004). These variables, however, differ in their responsiveness to heterogeneity in anthropogenic activities at multiple spatio-temporal scales. For instance, evidence indicate that the area where agricultural and irrigation activities influences water quality variables such as nitrogen and phosphorus (Chang, 2004).

Moreover macro-invertebrates are often used for bio-assessment as they are relatively easy and quick to sample and offer a biodiverse and responsive group of species inhabiting waters with different quality from clean to highly polluted (Hauer, 2017; Mathuriau *et al*., 2012). Some macro-invertebrates have relatively low mobility and long lifecycles hence ensure that the presence of a given taxon also reflects past conditions. Norris and Thoms (1999), suggest that the effect on macro-invertebrates is usually the final point of environmental degradation and thus an important indicator of overall ecosystem health. Physical-chemical parameters can only show water quality at the moment of measurement and can change rapidly over time in response to numerous conditions. With this in mind, rivers are increasingly investigated from an ecosystem perspective, estimations of water quality are done by assessing the influence of pollutants on aquatic organisms and the environment. According to Shilla (2011), Ephemeroptera, Plecoptera and Trichoptera (EPT) are pollution sensitive groups and can be used to determine the condition of aquatic habitat. EPT assemblages are mostly considered to be a good indicator of water quality (Johson *et al*., 2011).

Anthropogenic activities in river drainage basins greatly influence the river's physical, chemical and biotic characteristics (Mokaya *et al*., 2004). Several rivers and streams flow through urbanized areas across the world and are profoundly impacted by changes associated with urbanization (Bernhardt and Palmer, 2007). Such urban flowing rivers, often occurring at low lying points of the landscape are particularly sensitive and prone to pollution from urban development and other anthropogenic activities, which result in increased pollutant load through surface runoff (Bernhardt and Palmer, 2007). Excessive loading of domestic waste into rivers can alter the physical, chemical and biological characteristics of the aquatic system beyond their natural self-purification capacity. Higher levels of turbidity, nutrients, suspended and dissolved solids as well as coliform bacteria in rivers, are all indicative of compromised systems attributed to increased pollutant loading, resulting largely from anthropogenic activities (Adams and Papa, 2001).

While worldwide progress has been made in controlling the acute effects of point sources of water pollution, it has become increasingly clear that non-point-source pollution from agriculture, mining and urban land uses has caused long-term cumulative harm to stream ecosystems (Waite *et al*., 2000). Numerous land-use changes in the farming areas following the fast track land reform program of 2000 (Matsa and Muringaniza, 2011). This has had serious implications on water quality as it is impossible to separate land-use activities from the water resources (Dube and Swatuk, 2002). Land-use change, from natural forest to urban developed, mining or agriculture, is now a major concern in developing countries because of the associated disturbances that lead to soil erosion, sedimentation, nutrient enrichment and input of toxic substances to aquatic habitats and biological communities (Stewart *et al*., 2001; Jun *et al*., 2011). For example, agriculture is known to increase landscape vulnerability to surface runoff leading to loss of riparian complexity and in-stream habitats, changes in hydrology and increased inputs of herbicides/pesticides and fine sediments into the river (Zhang *et al*., 2012).

Organic matter derived from riparian sources provides habitat and food to the macro-invertebrate community (Flory and Milner, 1999; Hession *et al*., 2003). Shade provided by riparian vegetation can influence stream macro-invertebrate communities by reducing water temperature, which can impact sensitive species by limiting their biological functions, or eliminate them entirely from the ecosystem (Davies and Nelson, 1994; Rutherford *et al*., 2004). Vegetation on stream sides remove excess nutrients and sediments from surface runoff and shallow ground water, shade streams to optimize light and temperature conditions for aquatic plants and animals, ameliorate the effects of some pesticides, and directly provide dissolved and particulate organic food needed to maintain high biological productivity and diversity in the associated stream (Mathuriau *et al*., 2012). Riparian vegetation function often simultaneously as filters, sources, transformers and sink for different materials in the stream ecosystem.

Research data suggest that riparian buffers (linear vegetated areas along rivers, streams and other water bodies) are a cost effective tool in mitigating water quality problems (Buffler, 2005). Information on riparian ecosystem conditions is important on assessing the functional condition of existing riparian buffers and the off-site conditions to be buffered, determining the applicability of buffers to address these conditions, determining buffer appropriateness, general buffer design guidelines and management strategies, buffer configuration and structural characteristics to meet water quality and aquatic ecosystem conservation objectives. Riparian areas function in maintaining ecological processes such as: regulating stream temperature, stream flow, cycling nutrients, providing organic matter, filtering chemicals and other pollutants, trapping and redistributing sediments, stabilizing stream channels and banks, absorbing and detaining floodwaters, maintaining fish habitats, and supporting the food web for a variety of biota, and regulating stream temperature (Buffler, 2005). Although riparian buffers have been shown to be effective in improving water quality and regulations exist to govern their management and conservation anthropogenic activities impose high degradation pressure on these buffers due to associated socio-economic activities on riparian ecosystems of aquatic systems.

There is currently poor understanding of aquatic community responses to changes in riparian condition within agricultural catchments occurring at river reach scale, despite grazing management practices having been shown to have a significant impact on riparian zone condition (Jansen and Robertson, 2001a), riparian bird communities (Jansen and Robertson, 2001b; Martin *et al*., 2006) and frog communities (Jansen and Healey, 2003).

Riparian areas are essential for diminishing negative impacts of land use activities on rivers (Mitsch & Day, 2006; Enanga et al., 2011).

However, the riparian areas in SWMFC are experiencing diverse development initiatives likely to have also considerably reduced the biodiversity and increased threats to these river systems (GoK, 2009). This study set out to determine how land use activities have affected riparian structure, water and soil qualities along Chemosit and Kipsonoi rivers in South West Mau Forest Complex

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

Lumemo River is one of the tributaries of the Kilombero River originating from Udzungwa Mountains catchments (Fig. 1). The climate in the watershed is highly variable, at both spatial and temporal scales, there are two rain seasons, long rain (March to May) and the short rain season (November to January) with the annual average rains between 1200 and 1400 mm (RAMSAR, 2002). The mean annual temperature varies from about 18˚C at higher altitudes to about 28˚C. Elevation ranges from 698 to over 2300 m, above mean sea level (m. asl).

Major pollution and potential environmental impacts in the river include excess nutrients, agrochemical runoff and diversion by irrigation and sedimentation (Alavaisha *et al*., 2019). However, in recent years, communities neighboring the River have increased commercial medium-scale farming coupled with the use of agrochemicals, where rice, maize, peas and bananas are food and cash crops and sugarcane, sunflowers, are grown for commercial purposes. Encroachment to the riparian ecosystem associated with valley bottom cultivation and irrigated smallholder agriculture has increased overtime reducing the capacity of the system to buffer the water body against excessive pollutant loading (Mariana *et al*., 2016).

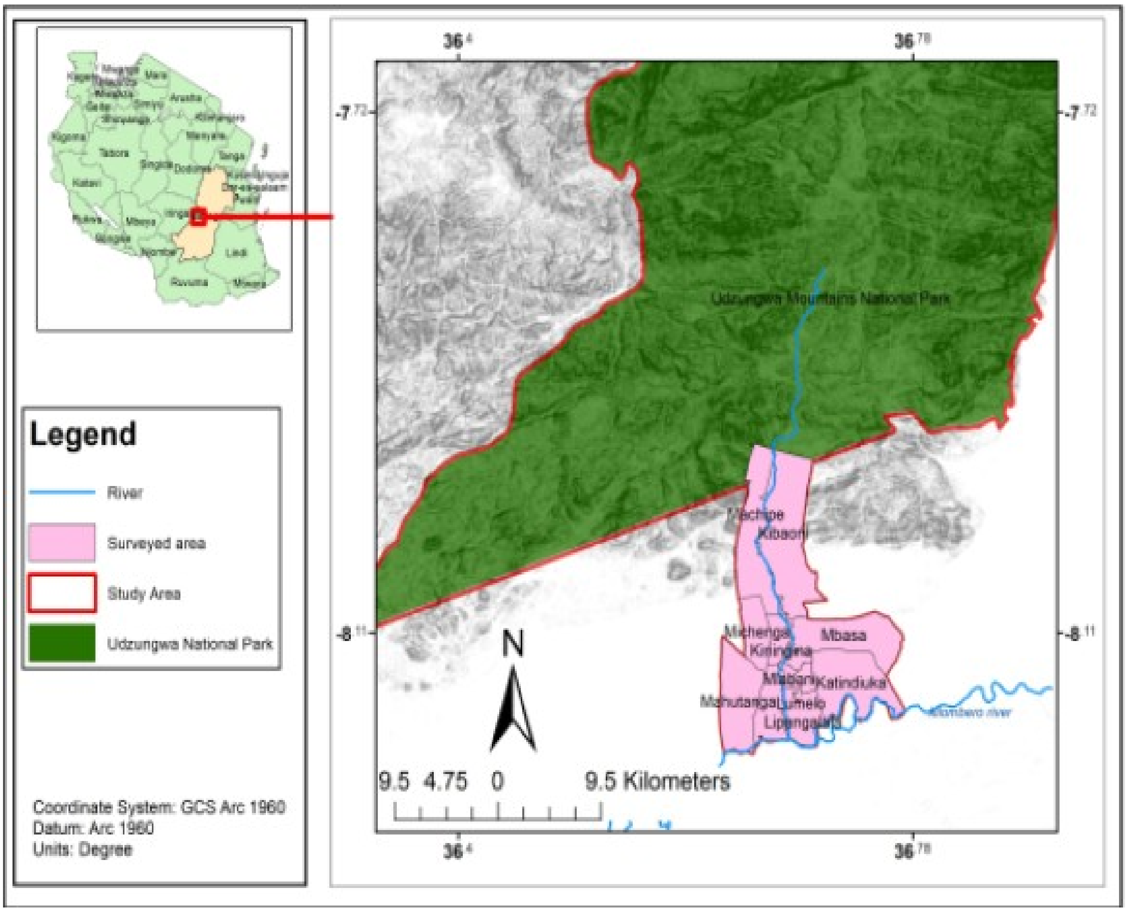

Figure 1: Map showing Lumemo River emerging from Udzungwa Mountain National Park towards Kilombero District and ends in the Kilombero River

3.2 Research methods

3.2.1 Sampling design

A stratified sampling method was used to divide the river into three reaches along its longitudinal section based on elevation; the upper reach (>1500 m, asl), middle reach (945-1500m, asl) and lower reach (< 945m, asl) (Fig. 2). A river reach is defined as the section of river along which boundary conditions are sufficiently uniform that the river maintains a near consistent internal set of process-form interactions. (A river segment can contain one to several reaches).

As a general rule, the length of a reach should not be smaller than 20 times the mean channel width, although shorter reaches can be defined where local circumstances are particularly complex. For the Lumemo River the upper reach is characterized by a consistent cover of forest vegetation within the Udzungwa National Park, the middle reach is characterized by extensive human induced activities of various forms especially agriculture with potential for pollutant and sediment release transport and delivery into the river, while the lower reach is characterized by human induced activities with potential sediment release, transport but more specific sediment deposition. All these sections will have different influences on the water quality and aquatic life depending on the extent and potential of sediment loading.

It is assumed that human activities with potential for influencing the water quality in the river increase downstream with the middle and lower reach associated with higher impacts. It is also agreed that the riparian ecosystems will tend to play major role in buffering the effects of human activities with regards to sediment loading and thus the condition of the riparian buffer strips in terms of the width and height of vegetation is a good indicator of the condition of the riparian ecosystem. The first sampling point was randomly selected whereas other sampling points were systematically aligned in each reaches (river section). Ten sampling points were established in each reach and the distance from one sampling point to another was 500m making a total of 30 sampling points across the whole catchment. The design focused on trying to cover all anthropogenic activities carried out along the river, the study area has a maximum length of approximately 55 km and the sampling points spanned over 25 km. The focus of anthropogenic influence was more on the riparian ecosystem and its condition/health. Riparian ecosystem health was assessed as the extent of its degradation in terms of the width and height (depth) of the riparian vegetation at each river reach.

Figure 2: 3-D map showing location of sampling points in the Lumemo River. Lower reach between 500 and 1000m asl, middle reach between 1,200m asl and upper reach 1,800m asl and above. (The Upper Reach was located entirely in the protected area characterized by low human activities and high protection (Udzungwa National Park), Middle Reach was in the middle of the catchment with high influence of anthropogenic activities potentially high sediment delivery and transport and the Lower Reach is characterized by high anthropogenic activities and sediment/pollutant deposition).

3.3 Data Collection

Data were collected for three months from October to December 2019, five consecutive days per month in each reach. The study site was visited in the morning (08:00-12:00) every day for data collection. The information recorded at each sampling point in the field included; location (GPS), anthropogenic activities with high potential to influence the aquatic ecosystem especially pollution loading, physicochemical water parameters, macro-invertebrates species identity (presence/absence), riparian ecosystem health assessment (vegetation buffer width and height).

3.3.1 Anthropogenic activities and the health of riparian ecosystems

At each sampling point, adjacent anthropogenic activities were assessed through direct observation and recording of all human activities with potential for influencing the aquatic ecosystem. The local anthropogenic activities in every sampling site was recorded focusing more on the use of the riparian ecosystems. Observed anthropogenic activities in Lumemo River included agriculture, domestic activities, urbanization and associated pollution, urban surface runoffs and commercial activities. The health of the riparian ecosystem was determined by assessing the width and height of the vegetation filter strip, the percentage cover of the vegetation strip and the extent of human-induced degradation (uses, vegetation clearing and cultivation). The extent of use was determined using a scale of 1-5 where 1 = no/low use 5 = extensive use.

3.3.2 Assessment of aquatic macro-invertebrates

Macro-invertebrate sampling was adopted and modified from the South African Scoring System (SASS) version 5 protocol (Dickens and Graham, 2002). At each sampling point, a handheld net (mesh size 500 µm) was used to collect macro-invertebrates within a 20–30 m reach comprising a relatively homogenous riffle section. Riffle sections were selected because they are relatively shallow and they are vulnerable to physicochemical impacts (Carter *et al*., 2006). Where available, the three major habitats identified by Dickens and Graham (2002) were sampled. These habitats include stones (including bedrock or any solid object), aquatic plants (marginal, floating and submerged) and gravel (including sand mud, silt and clay). Stones were sampled by kicking, dislodging and collecting the invertebrates into the net for approximately 2 min. A total length of approximately 2m of aquatic plants spread over more locations was sampled by pushing the net vigorously into the plants. Samples that may have been missed by the sampling procedure were hand-picked for approximately 1 min. Snails and fast-moving pond skaters were noted. The three subsamples from the three habitats were pooled and macro-invertebrates were identified using taxonomic keys by Geber and Gabriel (2002) and recorded. Macro-invertebrate families that could be identified in the field were returned to the stream, while those that could not be identified immediately were preserved in 10% formalin in polythene bottles for further identification by a specialist.

3.3.3 Physicochemical variables

Water samples were collected at each sampling point from both edges of the river and in the middle following standard methods (APHA, 2012). The following water parameters were measured for each site: water temperature (°C), acidity (pH) and electric conductivity (CE, µS. cm–1). Electric Conductivity is a measure of both suspended and dissolved sediment load in the water. Macro-invertebrates have different tolerances to water pollution in terms of temperature, acidity/alkalinity and sediments. These parameters were selected because they are common water quality assessment parameters globally and their ease of measurement in the field under rough conditions (Alavaisha *et al*., 2019). The water temperature, pH values and electric conductivity were measured by using a portable pH and conductivity meter (HANNA HI-8424).

3.4 Data analysis

Data on anthropogenic activities with potential influence on the aquatic ecosystem were listed, summarized and described to indicate the extent at which they are likely to influence the water quality in the river in terms of pollutant generation and delivery (sediments, agrochemicals, nutrients and other chemicals of potential adverse impacts). Macro-invertebrate abundance was expressed as the number of individuals in each River reach. Kruskal-Wallis test was used to determine variation in aquatic macro-invertebrates' abundance across the longitudinal section of the River using the three reaches as groups for comparison. The Kruskal-Wallis test is a non-parametric (distribution free) test, used when the assumptions of one-way ANOVA are not met. Both the Kruskal-Wallis test and one-way ANOVA assess for significant differences on a continuous dependent variable by a categorical independent variable (with two or more groups).

Macro-invertebrate diversity and evenness was computed using the Shannon-Weiner Diversity Index.

$$\mathrm{H} = \sum_{i=1}^{S} (\mathrm{P}i \ln pi)$$

Where;

H′ – Shannon-Wiener diversity index

Pi - the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

Species Evenness was computed as H/ln S where

H' = the Shannon Index for the diversity of macro-invertebrates

S = the number of species of macro-invertebrates enumerated

Data on the health of the riparian ecosystems were summarized in terms of average tree/ vegetation cover at each reach, average width and height of the riparian strip at different points within each reach. Further, correlation between the different parameters measured for riparian health (vegetation cover, width and height of the riparian strip, extent of human use of the riparian ecosystem) were correlated using correlation analysis with macro-invertebrate abundance and water quality being the dependent variables and the vegetation width, height and cover of the riparian ecosystem being the independent variables.

Non-metric multidimensional scaling (NMDS) was used to determine the association between water quality, the health of riparian vegetation and macro-invertebrate abundance. It was used to group the samples based on the abundance of benthic macro-invertebrates across the river reaches. NMDS ordination is a robust ordination technique for exploring similarities or dissimilarities in biological data as it does not require any assumptions of multivariate normality and yields good results even when large numbers of data sets have zero values (Nesemann, 2011). Statistical analyses were performed using R-software (version 3.3.5) and PAST (Version 3.21) software.

CHAPTER FOUR

4.0 RESULTS

4.1 Anthropogenic activities with potential influence on the water quality and macro-invertebrate abundance/diversity in the Lumemo River

Anthropogenic activities such as agriculture, commercial use (fishing, brick making, car-washing) and domestic use (bathing, washing clothings, swimming, water for cooking) occurred more intensively in the middle and lower reaches. The upper reach which crosses the forest vegetation within the Udzungwa National Park had minimum anthropogenic activities. Cultivation near the river bank was recorded in the middle and lower reaches (44%, 42% respectively) while domestic use increased downstream with middle reach (38%) and lower reach (58%). Commercial uses were observed only in the lower reach and forest vegetation decreased downstream from upper reach (81%), middle reach (15%) and lower reach (0%) (Fig. 3). Furthermore, the extent of use of riparian ecosystem showed a significant difference across the river reaches ($\chi2$= 327.92, df= 2, p= <.0001) where the lower and middle reaches had higher extent of use (45%, 38% respectively) compared to the upper reach (5%) as shown in Figure 3.

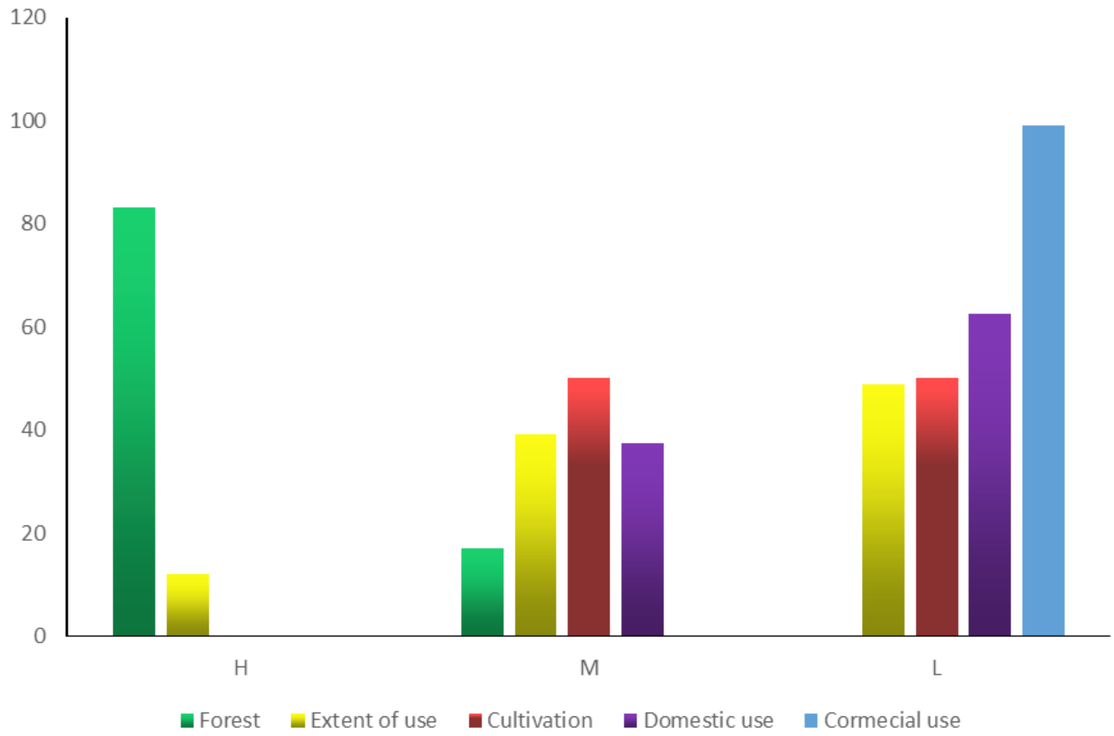

Figure 3: Anthropogenic activities along Lumemo River

(H = upper reach, M = middle reach and L = lower reach)

There was statistically significant difference in water conductivity and pH across the river reaches ($F_{2, 27}$ = 4.758, p = 0.017, $F_{2, 27}$ = 66.77, p = 0.0001 respectively). The lower reach had higher conductivity (150.64 µS/cm) followed by middle reach (96.65.65 µS/cm) and the upper reach (95.36 µS/cm). Higher pH values were recorded in the upper reach (pH = 9) while the mid and lower reaches recorded pH values of 8.83 and 4.23 respectively. There was no statistically significant difference in temperature across the river reaches ($F_{2, 27}$ = 20.028, p = 0.1). However, temperature in the upper reach (25ºC) was relative high compare to lower and middle reaches (T = 23ºC and 22ºC, respectively) (Table 1).

Table 1: Mean and standard deviations of various water quality parameters for Lumemo River in Morogoro, Tanzania

Elevation	pH	Temperature (^{0}C)	Conductivity (µS/cm)
Upper	9.07±0.39a	25.02±1.45ab	95.36±12.54b
Middle	8.83±1.56a	22.57±0.441ab	96.65±65.17b
Lower	4.23±0.84b	23.35±0.133ab	150.64±43.25c

4.2 Diversity and abundance of macro-invertebrates along the different reaches of the Lumemo River

4.2.1 Aquatic micro-invertebrates abundance

Fourteen (14) macro-invertebrate families comprising of 1997 individuals were encountered and enumerated. Moreover, one class, not classified to class level (Oligochaeta) was recorded. Kruskal-Wallis Test showed statistically significant differences in aquatic macro-invertebrate species abundance ($\chi2$ = 14.199, p = 0.0008) along the river reaches. Macro-invertebrate abundance in the lower reach (n = 1043, 51%) was higher compared to the middle (n = 180, 10%) and upper (n = 774, 39%) reach (Table 2). Family Gerridae was the most dominant of all macro-invertebrate taxa contributing to 86%, 66% and 44% of total macro-invertebrate in the lower, mid and upper reaches respectively (Fig. 4). This family seem to have a wide distribution along the river reaches an indication of possible adaptation to different levels of water quality and disturbance.

Table 2: Abundance of macro-invertebrates along the Lumemo River Reaches

River reaches	Abundance	Percent (%)
Upper	774	39
Middle	180	10
Lower	1043	51

$\chi2$ = 14.199, p = 0.0008

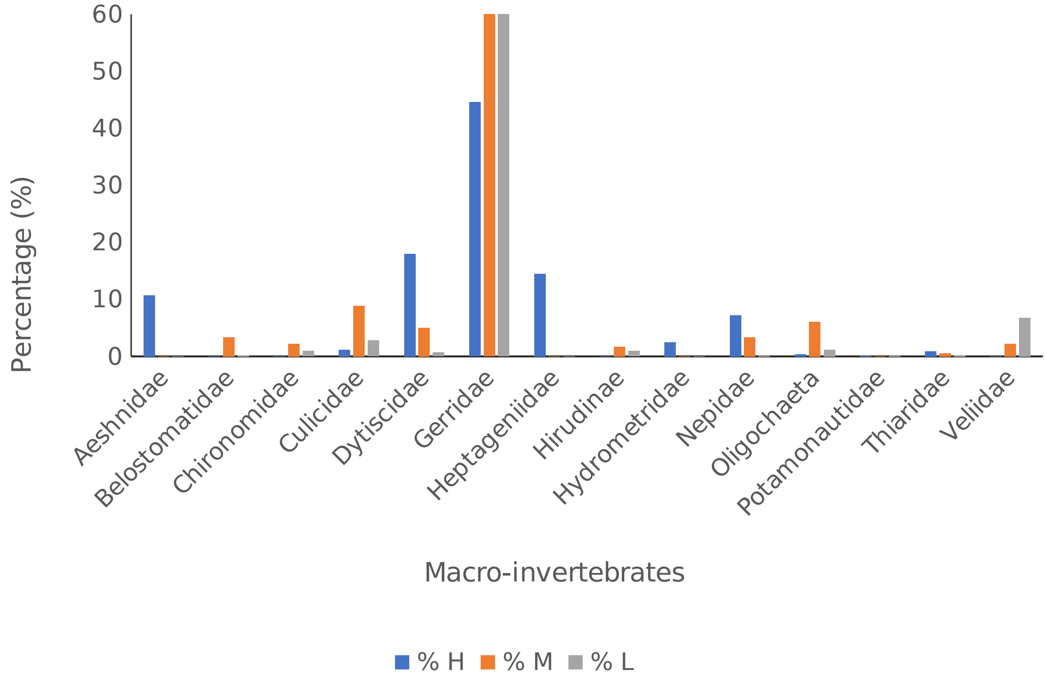

Figure 4: Percentage composition of benthic macro-invertebrate taxa along Lumemo River (H = upper reach, M = middle reach and L = lower reach)

4.2.2 Aquatic macro-invertebrate diversity

Although the diversity of macro-invertebrates was not so high in the Lumemo river I observed slightly higher diversity in the upper reach (elevation) (Shannon-Wiener(H') Index of 1.59) compared to the mid-reach; (H' = 1.29) and lower reach (H' = 0.62). Shannon evenness index was also relatively higher 0.4919 for the upper reach compared to mid (0.366637) and lower (0.169) reaches (Table 3).

Table 3: Diversity and Evenness of macro-invertebrates across Lumemo River

		River Reach	
Parameters	**Upper**	**Middle**	**Lower**
Simpson Index (1-D)	0.7306	0.5379	0.2529
Shannon Index (H)	1.593	1.299	0.6228
Evenness (H/lnS	0.4919	0.3666	0.1695

4.3 Relationship between water quality, the health of riparian ecosystems and Macro-invertebrate abundance

There was significant negative correlation between pH and the riparian cover within the river reaches (r = -0.318 **) while temperature was positively correlated with riparian height and cover (r = 0.133* and 0.261* respectively). The water conductivity showed significant negative correlation with the width of the riparian vegetation (-0.397*) and significant positive correlation with height of riparian vegetation (0.335*) (Table 4).

Table 4: Relationship between water quality variables and riparian vegetation

	pH		**Temperature**		**Conductivity**	
Use of the Riparian	**coefficient**	**p-value**	**coefficient**	**p-value**	**Coefficient**	**p-value**
Riparian Width	-0.023	0.901	0.297	0.111	-0.397*	0.03
Riparian height	-0.165	0.901	0.133*	0.006	0.335*	0.029
Riparian cover	-0.318**	0.001	0.261*	0.002	-0.304	0.448

** Correlation is significant at the 0.001 and * at the 0.05 level.

Similarly, pH had significant negative correlation with the extent of land use, domestic, commercial and agriculture use within the river reaches (r = -.558**, 0.769**, -0.664**,-0.491** respectively) but also pH correlated positively with forest cover (r = 0.647**). Temperature had significant positive correlation with extent of land use, agriculture and domestic use but correlated negatively with forest cover (0.462*, 0.735**, 0.543**) (Table 5).

Table 5: Relationship between water quality variable and anthropogenic activities

	pH		Temperature		Conductivity	
Anthropogenic activities	**coefficient**	**p-value**	**coefficient**	**p-value**	**Coefficient**	**p-value**
Extent of use	-0.558**	0.001	0.462*	0.010	0.114	0.548
Forest cover	0.647**	0.0001	-0.642	0.0001	-0.021	0.910
Agriculture	-0.491*	0.006	0.735**	0.0001	0.174	0.357
Domestic	-0.769**	0.0001	0.549**	0.002	-0.027	0.885
Commercial	-0.664**	0.0001	0.105	0.578	0.237	0.206

** Correlation is significant at the 0.001 and * at the 0.05 level.

4.3.1 Aquatic macro-invertebrates assemblage in relation with water quality variables and anthropogenic activities

Aquatic macro-invertebrate assemblage associated positively and negatively with physico-chemical properties and anthropogenic activities (Fig. 5). The ordination produced two clusters of aquatic macro-invertebrates where cluster one was dominated by seven families Heptageniidae, Potamonautidae, Hydrometridae, Aeshnidae, Dytiscidae, Thiaridae and Nepidae. These species were positively associated with forest cover, pH and riparian width (r =0.945, 0.649 and 0.446 respectively) but negatively associated with temperature, domestic use and cultivation (r = -0.509, -0.839, -0.671 respectively). Seven families co-occurred in the second cluster: Hirudinae, Hirudinae, Gerridae, Culicidae, Chironomidae, Belostomatidae and Veliidae. The species were positively associated with temperature, domestic use, agriculture and commercial uses (r = 0.509, 0.839, 0.671 and 0.5 respectively) but negatively associated with riparian width, forest cover and pH. The mid and lower reaches had lower diversity and richness of macro-invertebrates in comparison with native forested sites in the upper reach. The different groupings therefore show the extent of macro-invertebrate sensitivity to different anthropogenic activities.

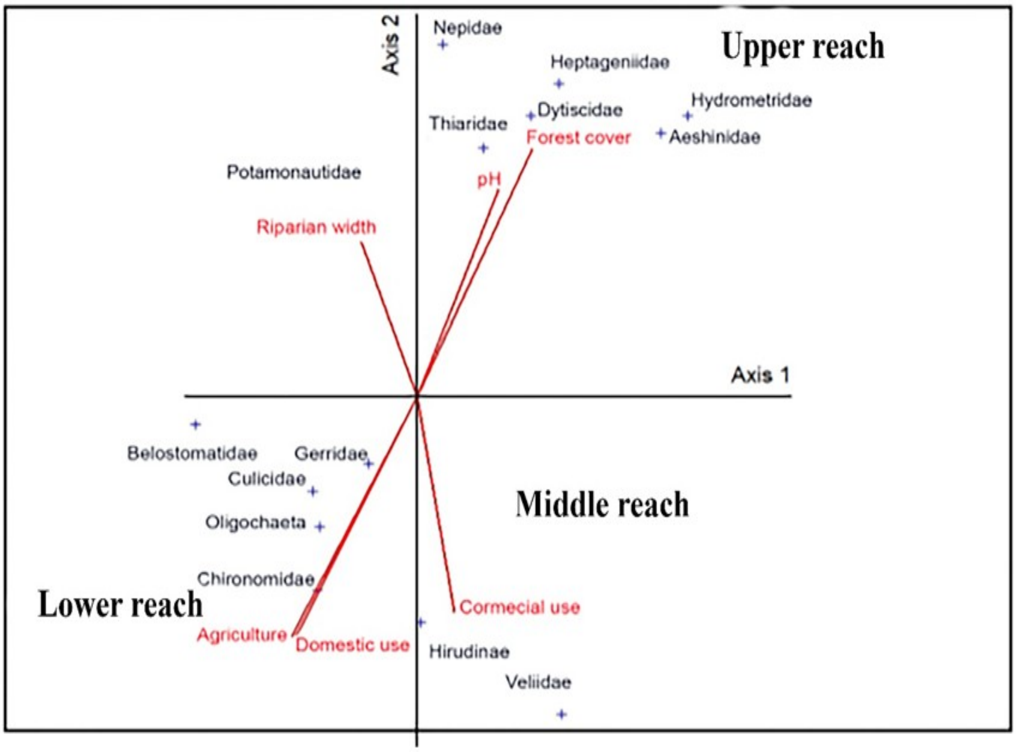

Figure 5: Multidimensional scaling (NMDS) plot showing aquatic macro-invertebrate assemblage in relation to water quality, anthropogenic variables and riparian vegetation. (+indicates species, red lines indicate factors that influence distribution of macro-invertebrates, water quality variables and anthropogenic activities)

4.4 Discussion

4.4.1 Anthropogenic activities with influence on aquatic ecosystems and their relationship with water quality in the Lumemo River

Anthropogenic activities such as agriculture, bathing, fishing, washing clothing, car washing, brick making, water collection using donkeys for domestic purposes, swimming were on-going at the time of sampling in the middle and lower reaches of Lumemo River. Sunil *et al*. (2011) reported that anthropogenic activities such firewood collection, cultivation near river banks and urbanization contributes to clearance of riparian vegetation which may result to macro-invertebrates and water quality degradation.

The fact that the quality of water and macro-invertebrates diversity at a relatively protected area located in the upper reach remain relatively good in comparison to all other sites sampled was a further indication of the increased role of anthropogenic activities in water quality degradation along the Lumemo River. Most contaminants affecting water quality in areas with human activities comprise simple inorganic ions, more complex organic molecules or particulates. These can be derived from various sources, including soils and decomposing vegetation, but also from animal manure and pesticides (Goss *et al.*, 2000). Agricultural run-off is one of the non-point sources of pollution that affects water quality. Agricultural activities that can cause pollution include poor animal husbandry practices; overgrazed grassland (Valiela and Bowen, 2002) excessive use of pesticides and application of fertilizers. The middle and lower reaches of Lumemo River which are adjacent to anthropogenic activities were the most impacted, supporting previous studies showing that anthropogenic activities such as agriculture, urbanization are among the land uses that have more severe consequences for riparian vegetation (Kutschker *et al*., 2009).

The growing of crops in the river banks strongly influences the presence of chemicals in water such as pesticides, herbicides and fungicides just to mention a few which on the other hand impacts the quality of water in the aquatic systems (Holden *et al*., 2015) as these chemicals are carried by surface flowing water into the rivers. The cultivation along the river banks also influences the presence of plant organic matter in rivers which results into a reduced amount of dissolved oxygen (DO) in water (Weiner, 2007) as this is the case the presence of aquatic animals is also affected as these animals can survive at DO levels not less than 3-4 ppm (Lee and Lwiza, 2008). Therefore the cultivation of crops along the river banks should be strongly avoided, not just because it influences the decreased amount of dissolved oxygen and loading of organic matter but the practice also encourages the siltation of rivers (Tundu *et al*., 2018) leading to degradation of streams ecosystem.

Similarly, from the ordination diagram (Fig. 5) forest cover and pH correlated positively with Herpartoniideae, Thiaridae Hydrometridae Dytiscidae and Aesthinidae, this implies that you will find these orders in areas with high forest cover and high pH. Any anthropogenic activities that reduce forest cover and pH will have negative impacts on these orders. Likewise agricultural use and domestic activities (fetching water, bathing and washing clothing in the river) had negative correlation with Herpartoniideae, Thiaridae Hydrometridae Dytiscidae and Aesthinidae thus increasing their intensity decrease their abundance.

4.4.2 Diversity and abundance of aquatic macro-invertebrates across the longitudinal reaches of the Lumemo River

The abundance and diversity of aquatic macro-invertebrates in the study area differed significantly between the three river reaches (longitudinal gradients) in the Lumemo River. Aquatic macro-invertebrate abundance in the lower reach was high compared to upper and middle reaches while the diversity of aquatic macro-invertebrates in the upper reach was higher compared to mid and lower reaches. The low species diversity and the dominance by few species could have been due to poor water quality resulting from changes in physicochemical parameters as well as nutrient levels contributed by increased anthropogenic activities into the river channel. Similarly, the difference observed was probably due to reasons that Lumemo River originates in the UMNP catchments, unlike its mid and lower parts which pass in highly impacted habitats by anthropogenic activities such as agriculture, domestic uses, sewage discharges, urban surface runoffs and commercial uses.

As a result, pollution tolerant groups such as Veliidae, Gerridae, Culicidae, Oligochaeta and Chrinomidae dominated the mid and lower reaches reflecting its poor water quality. These findings demonstrate a pattern similar to the study by Elias *et al*. (2014) which found the benthic communities of Pangani Basin streams to be dominated by macro-invertebrates of family Hydrometridae (order Hemiptera), Aeshnidae (order Odonata), indicating good to slightly polluted water categories. These findings were also consistent with those of Kibichi *et al*. (2007) who reported that benthic macro-invertebrate diversity and abundance of River Njoro watershed, from the upper reaches to lower reaches were highly dependent on anthropogenic activities along the river, more sensitive species were only recorded upstream. Moreover Sharma *et al*. (2008) found a similar result as an effect of flushing upstream and less human activities. Also, Jowett *et al*. (1991) found that less sensitive species (Chironomidae and Oligochaeta) which were more abundant in lower and mid reaches are generally known to prefer smaller low dissolved oxygen, high conductivity, salinity and high temperature.

4.4.3 Relationship between water quality, the health of riparian ecosystems and macro-invertebrate abundance

Among the anthropogenic activities studied forest cover and riparian width turned to be of greatest importance to explain the overall structure of aquatic macro-invertebrates. Areas covered by forest and with healthy riparian width supported high diversity of aquatic macro-invertebrates, these areas were dominated by pollution sensitive species such as the family Hydrometridae, Aeshnidae, Thiaridae indicating good water quality. Areas which were dominated by agricultural activities, domestic and commercial uses had low diversity of aquatic macro-invertebrates and they were dominated by pollution tolerant species such as Veliidae, Chironomidae, Culicidae, Oligochaeta indicating poor water quality.

Streams with forest or/and riparian vegetation experience more stabilized sediments loads and regulated nutrients despite mild human disturbances (Martin *et al*., 2006). Less clearance and increased abundance of forest and riparian vegetation could have contributed to higher macro-invertebrates richness and diversity at a mid and lower reaches. Forests and riparian vegetation provided organic matter for largely macro-invertebrate benthic organic feeders, e.g., dead leaves and plants debris, and a safe place to receive a considerable input of organic matter (Hauer, 2017). They are also the provider of shade and habitat for various fauna, ground protector from erosion, and as the filter of sediment and nutrient, so that the water quality is protected. Interestingly, riparian vegetation can regulate phosphorus and nitrogen, and filter pollutants that could adversely impact the biotic community and ecosystem functioning.

The water quality varied across the river reaches and sampling sites across selected points of Lumemo River. Conductivity and pH varied significantly along the River reaches while temperature had no significant difference except a slight increase in temperature in the upper reach. Low pH and high conductivity values observed in the mid and lower reaches might be due to in farm fertilizer use, urbanization, clearing of riparian vegetation and frequent irrigation which have contributed to increasing nutrient load into the river.

Conductivity is determined by the availability of organic and inorganic substrates in water environments (Manjare *et al*., 2010). Areas with high anthropogenic activities such as agriculture, domestic wastes, bathing and car washing have high electrical conductivity of water. The higher conductivities recorded in mid and lower reaches of this study reflects an increase in dissolved ions and therefore a reduction in water quality. High conductivity in mid and lower reaches of the Lumemo River is probably due to high surface run-off with resultant sediment loading, agricultural activities such as the application of fertilizer and frequent irrigation unlike in the upper gradient which is a conserved area which recorded low conductivity values. High levels of conductivity, suspended solids and nutrients have detrimental effects on aquatic life since they tend to deplete the amount of dissolved oxygen in the area (Ibemenuga, 2013). Mateo-Sagasta *et al.* (2017) showed that expansion of irrigation farming and use of fertilizer contributed to more nutrients, turbidity and lower DO level in surrounding water bodies.

The temperature in this study was almost similar though a slight variation along the river reaches. The observed similarity was probably due to the study was conducted in the single dry season of the year. The slightly higher readings were recorded in upper reach. Reduction of riparian vegetation due to cultivation and urbanization contributed to the elevation of water temperature in the study site since riparian vegetation reduces the amount of solar radiation and thermal currents reaching the stream channel. Higher temperature can adversely increase the rate of organic decomposition and thus influence the rate at which nutrients are released from suspended matter in water (Ollis *et al.*, 2006). The slightly higher temperature observed in the mid and lower reaches of Lumemo river can be associated with the removal of riparian vegetation due to unplanned cultivation along the river bank. Riparian vegetation performs important ecological functions such as provision of habitat and food for many species, regulation of shade and water temperature, control of nutrient and sediment input into streams, provision of corridors for the movement of biota, and stabilization of riverbanks (Naiman and Décamps, 1997). In addition, riparian zones provide spaces for recreational purposes (Naiman *et al.*, 2005). While riparian environments are among the most diverse and complex biophysical ecosystems (Naiman *et al.*, 1993), they are one of the most disturbed by land use change (Charron *et al.*, 2008). However, slight variations in temperature might also be due to the period of which samples were taken as studies have shown temperature to be a function of the weather and the extent of shade from direct exposure of sunlight (Ekhaise and Anyasi, 2005).

Several studies Shilla and Shilla (2012) in addition to present study, have reported that urbanization and agriculture had an effect of reducing shade which in turn increase temperature in Rivers. Also, Shilla and Shilla, 2011 found elevated temperature in urban and pasture streams compared to bushy streams with the corresponding decrease in macro-invertebrates assemblages in urban and pasture streams than bushy streams.

Higher pH value was recorded in the upper reach (pH = 9); the middle reach had almost similar pH values to the upper reach (pH = 8.83) while the lower reaches recorded an acidic pH value of 4.23. The value recorded in mid and lower gradient was consistent with the width of riparian vegetation, pollution tolerant macro-invertebrates. Extreme values of pH can cause shifts or death of aquatic macro-invertebrates (Ulimboka, 2014). A pH between 7 and 8.5 is ideal for biological productivity while pH < 4 is harmful to aquatic life (Deekae *et al*., 2010). Besides, Lumemo being close to Ifakara town as well agricultural-related factors, it is impacted by human activities along the River, such as washing clothes and discharge from untreated wastewater. A similar discussion was shared by Minaya *et al*. (2013) and Elias *et al*. (2014), who found most rivers located near towns to be more polluted compared to peripheral streams.

Sewage discharges, urban surface runoff, silt deposition resulting from river bank erosion are driven mainly by livestock activities especially at watering points, poor land-use practices among other anthropogenic activities contribute to water quality degradation thus alter the physico-chemical water quality parameters in the river (Anyona *et al*., 2014).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has examined effects of anthropogenic activities on aquatic macro-invertebrates composition and water quality in Lumemo River. The findings have revealed that aquatic macro-invertebrates assemblage and water quality variables vary across the river reaches of Lumemo River. Anthropogenic activities such as agriculture, clearing of riparian vegetation, domestic and commercial use along the River are the major factors influencing the diversity and abundance of aquatic macro-invertebrates and water quality in this River. There was significant differences in aquatic macro-invertebrate species diversity and abundance along the river reaches. The upper reach which had little disturbances has good water quality and supported high diversity of macro-invertebrates (pollution intolerant) unlike the middle and lower reaches which were dominated by agricultural activities, domestic and commercial uses had low diversity of aquatic macro-invertebrates dominated by pollution tolerant species. The conservation of quality riparian ecosystem conditions will sustain the ecological integrity of stream communities.

5.2 Recommendations

i. Development activities especially related to agricultural production should take into account the management of riparian vegetation as they serve to filter pollutants and sediment loading into the river.

ii. Maintenance of ecological integrity by controlling anthropogenic activities, protection of the river channel and its basin and increased public education and awareness concerning environmental integrity is recommended.

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