

**COMPOSITION OF BENTHIC INVERTEBRATES ALONG RIVER MPANGA IN
RELATION TO ANTHROPOGENIC DISTURBANCE**

BY

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DECLARATION

This dissertation is my original work and has not been presented for any Master's degree in any other University.

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APPROVAL

This research report has been submitted for examination with the approval of the following supervisors;

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DEDICATION

I dedicate this dissertation to my mother Mrs. Kasolo Racheal Namuhose, and to my best friends Christopher Mugalu and Chrystal Tendo Mugalu

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I wish to thank the Almighty God who has enabled me to come this far in my studies; I will always serve you GOD amidst all circumstances. I extend my sincere appreciation to my supervisors Dr.Sanyu Grace Asiyo and Dr.Dumba Robinah for sparing their precious time and providing constructive criticism with professional guidance before, during and after the study. Special thanks go to the staff and management of the Kyambogo University, Department of Biological Sciences, the Directorate of Research and Graduate Training and the National Agricultural Research Laboratories for the technical and educational information rendered to me during the study. Most of the information has been incorporated in this research. Thank you so much. I am grateful to my mother Mrs. Kasolo Racheal Namuhose who has been of great help and continually supported me in every aspect towards my studies. All support cannot go unrecognised and I will always be grateful for the love and devotion accorded to me during the challenging times of study. I thank you so much mother. I would be a great cheat if I do not recognise my best friends' support; mostly Christopher Mugalu, Kevin Oratungye, and Chrystal Tendo Mugalu. May God bless you abundantly!

LIST OF ACRONYMS

AWMZ	Albert Water Management Zone
BMWP	Biological Monitoring Working Party
BOD	biochemical oxygen demand
BWQI	Biological Water quality index
CMO	Catchment Management Organisation
COD	chemical oxygen demand
DFP	Sampling area 'downstream Fort Portal'
DO	dissolved oxygen
DWRM	Directorate of Water Resources Management
EC(25)	electric conductivity (standardised to 25°C)
GoU	Government of Uganda
GPS	Global Positioning System
IFP	Sampling area 'in Fort Portal'
IUC	Institutional University Cooperation
m a.s.l.	metres above sea level
MMIF	Multimetric Macroinvertebrate Index Flanders
MMU	Mountains of the Moon University
MW	megawatt
MWE	Ministry of Water and Environment
NGO	Non-governmental organisation
NO ₃	Nitrate
NTU	Nephelometric turbidity units
NWSC	National Water and Sewerage Corporation
RM-CMP	River Mpanga - Catchment Management Plan
TN	Total nitrogen
TP	Total phosphorus
UFP	Sampling area 'upstream Fort Portal'
μS	Micro-Siemens

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ABSTRACT

Research on the assemblages of benthic macro faunal community in the River Mpanga catchment was conducted during the period November 2019 - January 2020 following the standard methods to assess the status of environmental pollution. Good ecological water quality is needed to maintain the integrity of the river system and depends on the preservation of natural conditions of the water and the surrounding environment. Unsustainable and improper use and pollution through various human activities can impair and destroy the ecological state of a natural system by changing its chemical composition and the biological communities that are naturally occurring. To assess the benthic invertebrates' composition in relation to anthropogenic disturbance along river Mpanga, chemical, physio-chemical and biological data were collected along the different sections of the river. The study area includes upstream of Mpanga river, the midstream in Fort Portal, the tea estates area downstream of Fort Portal. Results from the upstream area confirm that human activities have a large influence on the physical and chemical water quality. While the impact on the general biodiversity of benthic invertebrates is less pronounced at present, the continuation of these human activities threatens the habitat availability for benthic invertebrates that depend on natural river banks and unpolluted water. Chemical and biological water quality were further lowered by certain urban pressures, which can be mainly linked to improper waste and sewage disposal, as to the absence of natural bank environments. Downstream of the urban area in Fort portal, where human pressure is less intense and where banks are less modified and protected from surrounding land use practices by a protection zone of natural vegetation, both chemical and biological quality improve. The river system recovers further as it passes through Kibale Forest Natural Park, which leaves time for suspended solids (turbidity) to settle and allows chemical and biological processes to lower the water's mineral, salt and nutrient-load.

CHAPTER ONE: INTRODUCTION

1.1 Background

Globally, water systems especially rivers are particularly susceptible to land use change and ubiquitous exploitation and thus the deterioration of river water quality because of unsustainable human activities has become a key environmental concern (Chen, 2014; Ding et al., 2015). Concerns over the consequences of land use in terms of water quality aren't only restricted to local and national levels in temperate and tropical regions, but they're also found worldwide in both developed and developing countries (European commission,2003; Gyawali et al., 2013; Santhl et al.,2005).

The adverse effects increasing pollution have evidently attracted management attention and research interests in both developed and developing countries. This challenge consequently became the main target of research and studies worldwide (Huang et al., 2013, Kibena et al., 2013). Previous studies have indicated that different human influences – like dams, the introduction of alien non-native fish, and pollution – affect water security and biodiversity. Human development activities including agricultural operations, forestry, and expanding cities and towns also are affecting the river ecosystems (Gyawali et.al., 2013). However, even the world's great rivers, like the Yangtze, the Nile and therefore the Ganges, are suffering serious biodiversity and water security stress haven't been exhaustively studied (Vörösmartyet al.,2010).

Of the total area in Uganda, 15.3% is open water mainly for rivers and lakes (Nile Basin Initiative, 2010). Among these open waters is Lake Edward Basin which has numerous rivers originating from Rwenzori Mountains including Mpanga, Nyamugasani, Mubuku, and Chambura. These resources are facing pollution of the water caused by urban and rural discharges, and run-off from agricultural fields (Nile Basin Initiative, 2010).

The Mpanga watershed consists mainly of rural and urban settlements and valuable national parks such as Rwenzori National Park, Queen Elizabeth National Park and Kibaale National Park that depend on its waters for consumption, agriculture and fishing. Because the river flows into Lake George, Mpanga State also contributes to the quality of the lake and its fish stock. In recent years, the water quality of Mpanga has been affected by human activities (Butsel et.al., 2017).

Extraction of forests and river sediments in the catchment area may be providing economic advantages, but it affects water quality, flora and fauna downstream (Butsel et al., 2017).

Poor land use of water resources not only affects people's water use but their life support capacity and the integrity of all freshwater ecosystems that affect the future management of the ocean (Bagalwa et.al. 2013; Charles, 2011 Chu et al., 2013). Land use and land change mainly through human development can provide nutrients and sediments to surface waters (Banner et al., 2009; Seumaloisafi, 2015).

The abundances of most functional feeding groups of macro invertebrate in aquatic systems change over time due to change in hydrological conditions as a result of human activities (Ruhí et al., 2012). The unexpectedly high abundance of filter-feeders can be due to the consequence of the continuous input of nutrient-rich water (Ruhí et al., 2012).

Aquatic invertebrates are the most widely used biota for freshwater biomonitoring worldwide (Rosenberg and Resh, 1993). The data enables the assessment of whether the quality of the environment supports local organisms and is therefore useful in assessing potential damage to protected areas, such as water bodies in conservation areas.

Comparative studies have found that land use has a significant impact on river water quality and that the processes are complex. Deforestation, agriculture and urbanization in general change the surface quality, change the amount of precipitation, change the water temperature, cause pollution, increase the production of algal and reduce the amount of dissolved oxygen in 'water body (Kibena et. al, 2013)

This study therefore contributes to determining this information gap and qualifying these gaps through scientific evidence as well as assessing the changes in benthic invertebrate in relation to land use changes in the Mpanga catchment

1.2 Problem statement

The relevance of a water body for human use lies in the amount and quality of services it can provide, such as drinking and irrigation water provision, natural water purification, support of fishery and aquaculture, or recreational uses. The sustainable, long-term use of such services depends strongly on the health of the system and is linked to good management of the quantity and quality of the water and of the surrounding environment. Assessing the macro-invertebrate community composition in relation to water quality and anthropogenic disturbance along river Mpanga is one way to measure the health of the system and is done by an integrated analysis of biological, chemical and structural quality elements.

The entire community largely depends on this river as a source of water for domestic and commercial use. At present, the river water is very turbid and water levels have greatly reduced increa on the cost of treatment which is done by National Water and Sewerage Corporation (NWSC) which operates a drinking water plant that abstracts water from the Mpanga and after physical and chemical treatment distributes it to 7000 households, covering 95% of the population's water need.

Between 2010 and 2016, the chemical consumption at NWSC Fort Portal plant increased by 3.1 times, from 0.0120 units of water to 0.0375 units of water treated," Mr Muramuzi says. "And it's all thanks to the increasing pollution levels on the river, which is our source of raw water supplying Fort Portal and Kabarole District," he adds. (Daily Monitor Friday March 23rd 2018). Mr Tom Bwijana, an elder who has resided in Fort Portal town for many years, looks on in disbelief as he compares beauty past and also the ugliness of this flow of River Mpanga. "In the olden days, River Mpanga had much water and it could give beauty to our town. Unfortunately, it's now a narrow stream where all its tributaries like River Mugunu and Itara have now reduced their amount of water flow" he says. (Daily Monitor Friday March 23rd)

Complaints about dirty, turbid tap water and concerns about the increased risk of getting water-borne diseases are urging the Mpanga Catchment Management Committee, and local stakeholders to take action. To prevent the system from getting overexploited, it is essential to implement sustainable ways of rural and urban development, especially with regard to water resource management.

Therefore, the importance of this research is to investigate how the water quality changes along the different sections of the river. This is done by looking at how the ecological quality gradually evolves from source to mouth, by identifying relevant changes in chemical and macrobenthos composition between the areas upstream of Fort Portal, in Fort Portal, and downstream of Fort Portal.

Besides this general assessment, it is to investigate how the impact of certain human activities is reflected in the chemical and biological data, by comparing the surface water condition upstream and downstream of such pressures. The results help to locate areas under (high) pressure and allow to suggest focus areas and key impact factors and characteristics for future monitoring.

1.3 General Objective

To determine the Composition of benthic invertebrates along River Mpanga in relation to anthropogenic disturbance

1.3.1 Specific objectives

1. To determine the variation in land use at the different points along R. Mpanga from upstream of the river to downstream the river.
2. To determine the abundance and distribution of macro-benthos taxa at the different points along Mpanga river.
3. To determine the water quality at the different points along the River Mpanga.

1.3.2 Research questions

1. What are the different land use variations at the different points along the river from upstream, of the river to downstream the river?
2. What are the variations in abundance of benthic invertebrates at the different types of land use along R. Mpanga?
3. What is the water quality status of the different points along the river?

1.4 Scope of the study

1.4.1 General information

The Mpanga catchment is found within the south-west of Uganda along the border with Democratic Republic of the Congo and is an element of the Lake George and Lake Albert sub-basin, situated within the Nile basin. It covers a surface of roughly 4700 km², with its waters flowing over a distance of roughly 200 km through the districts of Kabarole, Kyenjojo and Kamwenge, before discharging into Lake George

Sampling locations were chosen to include both the diversity of the catchment's environment as well as potentially relevant impact areas. Twelve sampling sites were selected, spread over three areas further referred to as 'upstream of Fort Portal' (FPU), 'in Fort Portal' (IFP), 'downstream Fort Portal' (FPD). The study area includes upstream of R. Mpanga at the foothills of the Rwenzori Mountains, mid-stream which is the Urbanized area of Fort Portal, the Kibaale forest area downstream of the river in Fort Portal

Selection of these sites is based on the main surrounding land use (anthropogenic activities) and of particular impact factors in proximity of the sampling sites.

CHAPTER TWO: LITERATURE REVIEW

2.1 River Mpanga

Freshwater ecosystems including lakes, ponds, rivers, streams, springs and wetlands are home to approximately 126,000 species. Additionally, to being a very important home for biodiversity, these aquatic ecosystems provide provisioning, supporting, regulating and cultural ecosystem services that underpin the health, livelihoods and wellbeing of billions of individuals (Aylward et al., 2005). Despite their importance, freshwater ecosystems are a number of the foremost heavily altered ecosystems on earth (Carpenter et al., 2011). The shift to the Anthropocene, a rising population and temperature change have all increased the threats to and demands on ecosystems (Vörösmarty et al., 2010; Russel et al., 2013).

Most of the biodiversity are often found in natural forests, but a substantial amount is additionally found in other natural ecosystems like mountains, savannahs, wetlands, lakes and rivers. However, the biodiversity has over the years been subjected to varied threats and current estimates show that the country is losing its biodiversity at the speed of 1% p.a. due these threats. Since the first 1990s, Uganda has made tremendous effort to handle these threats through national initiatives and also through international cooperation including ratification of the Convention on Biological Diversity (CBD) on 8th September 1993 (Fourth National report back to the Convention on Biological Diversity NEMA, MWE 2009).

The Mpanga River system is that the main water resource for the communities that live along its banks, who depend on clean water for consumption, agriculture and fishery (New Vision 2019). River Mpanga's headwaters originate from the slopes of the northern a part of the Rwenzori chain of mountains (around 1700 m a.s.l.) and join at the eastern foothills to create the River Mpanga. The river then flows east, crossing the town of Fort Portal and a section of tea estates before entering Kibale Forest parkland and turning south-east. Within the downstream area of river Mpanga in Kamwenge, Rushagwe River joins Mpanga as a very important tributary from the east, and therefore the river continues west to discharge into Lake George (Butsel et al. 2017)

It is this protected dam area, metres outside Queen Elizabeth parkland, where you discover the forest canopy and what's believed to be the world's largest colony of rare young and old cycads (Daily Monitor Friday March 2018)

2.2 Impact of land use on river water quality

The impacts of those threats are already being felt, and at increasing scales. Over 200 river basins, which are home to over 2.67 billion people, are experiencing annual states of severe water scarcity. Globally, wetlands are estimated to own declined by between 64 per cent and 71 per cent within the 20th century alone, with degradation continuing (Gardner et al., 2015). Freshwater species have decreased by 50 per centsince1970andriversareoftendeprivedof flows or are heavily polluted (Gleick and Palaniappan, 2010).

The Colorado, a principal river of the us, suffers from invasive species, beginning pollution and over-extraction (Kennedyetal.,2013; Jones-Leppetetal.,2012). In China, the Chinese Academy of Sciences estimates that 43 per cent of surface water is polluted beyond use (Liu and Yang, 2012) with one study finding that roughly 28,000 rivers have disappeared across the country within the previous few decades – due partly to uncontrolled and unsustainable

In China, the Chinese Academy of Sciences estimates that 43 per cent of surface water is polluted beyond use (Liu and Yang, 2012) with one study finding that roughly 28,000 rivers have disappeared across the country within the previous few decades – due partially to uncontrolled and unsustainable water extraction for industry and agriculture (Hsu andMiao, 2013). water extraction for industry and agriculture (Hsu and Miao, 2013)

2.3 Macro zoo benthos in along Rivers

Structure of macrobenthos community has been accustomed determine various environmental disturbances both in farming (Sapto, 2007; Gonzalez and Jerez, 2011; Yokoyama et al., 2007) and industrial activities (Wijayanti, 2007; Mooraki, 2009; Amin et al., 2012). Macrobenthos are organisms that sleep in the mud, sand, gravel, stone or organic waste either on the idea of the aquatic environment which is capable to settle and persist with the underside of aquatic environment (Lind, 1979).

Therefore, macrobenthos is an organism which is difficult to flee from environmental disturbance. Macrobenthos animals have a spread of roles including as a part of the food cycle of aquatic ecosystems and improve the structure of the sediment through the activity of digging, drilling, bioturbation and excretion. Through their roles macrobenthos can determine the standard of the waters between space and time to seem at the structure or dominance of a taxa (Sapto, 2014). Macrobenthos can respond quickly to changes within the environment occurred through the structure and abundance changes

Owing to their short lifecycle and high environmental adaptability (e.g., body shape, annual cycles, resistance and distribution), macrobenthos constitute highly valuable study material within the group of freshwater organisms. Some macrobenthos species lead an open lifestyle, and their presence is typically an indicator of a clean environment. For this reason, they're considered bio indicators of condition, and that they are accustomed monitor the standard of aqueous ecosystems in many countries (Bonn, 1988; Obolewskiet al.,2009a,b). Selected macrobenthos groups periodically reach optimal levels of abundance and variety relative to spatial and environmental variables, although the above is scantily documented within the available literature (e.g. Heino, 2000; Griffith et al., 2001; Arscott et al., 2005; Moñaghan et al., 2005)

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

River Mpanga originates from the slopes of the northern a part of the Rwenzori geological formation (around 1700 m a.s.l.) and join at the eastern foothills to make the River Mpanga. The river then flows east, crossing the town of Fort Portal and a region of tea estates before entering Kibale Forest park and turning south-east. within the downstream area of river Mpanga in Kamwenge, Rushago River joins Mpanga as a crucial tributary from the east, and also the river continues west to discharge into Lake George (920 m a.s.l.)

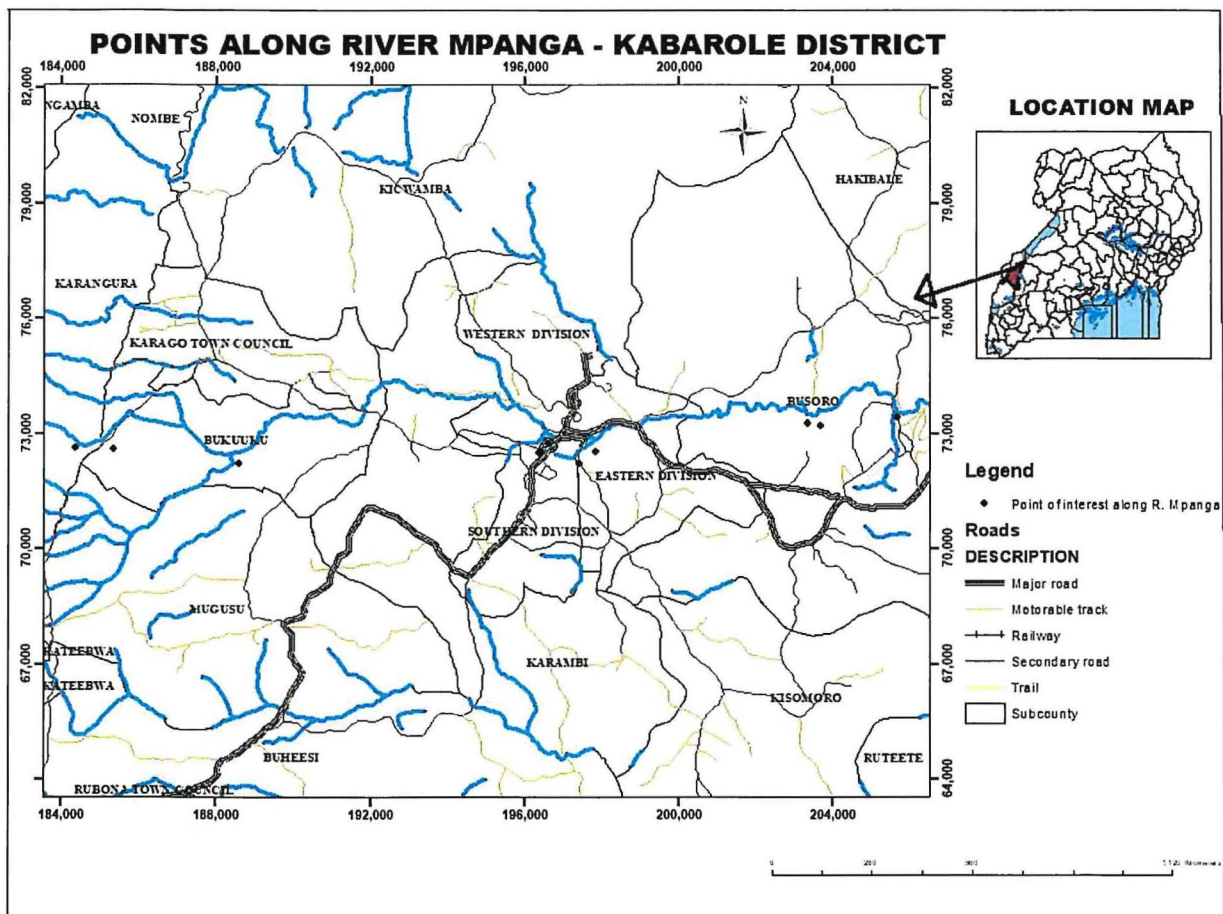


Figure 3. 1: Map Showing R. Mpanga Catchment in Relation to the Map of Uganda

3.2 Study sites selection

Three study sites were selected, that is Fort portal upstream (FPU), Fort portal Midstream (FPM) and Fort portal downstream (DFP) of R. Mpanga.

Table 3. 1: Sampling site information

Code	Name		Type	Land use	Description
FPU 1	Mpanga		Main channel	Agriculture	Mpanga, downstream of joint with Dunga
FPU 2	Dunga		Head water	Agriculture	Dunga, upstream of joint with Mpanga.
FPU 3	Mpanga		Head water	Agriculture	Upstream of river sediment mining
FPU 4	Mpanga		Head water	Agriculture	Downstream of river sediment mining
MFP 5	Mpanga		Main channel	Urban	Upstream of urban area
MFP 6	Mpanga		Main channel	Urban	Downstream NWSC drinking water plant
MFP 7	Mugunu		Tributary	Urban	Upstream effluent of sewage treatment ponds (lagoons)
MFP 8	Mugunu		Tributary	Urban	Downstream effluent of sewage treatment ponds (lagoons), pours into Mpanga.
FPD 9	Mpanga		Main channel	Natural Forest	4 km downstream of Fort Portal town border
FPD 10	Mpanga		Main channel	Natural Forest	Broad forested protection zone
FPD 11	Nyakanuka		Tributary	Natural forest	Broad reed protection zone
FPD 12	Mpanga		Main channel	Natural Forest	Entrance of Kibale Forest at Kibale bridge
	Code = sampling site label;				

	<p>Name = name of the stream or river;</p> <p>Type =functional role of the stream/river with regard to Mpanga;</p> <p>Land use = main land use in the sampling location;</p> <p>Description = additional information on the sampling location area</p>
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3.3 Data Collection Methods

3.3.1 Assessment of the land use variation at the different selected points along R. Mpanga

Variation of land use at the different selected points along R. Mpanga from upstream of the river to downstream the river was done through observations, satellite imagery and mapping of the study area using GIS. Vegetation cover change was determined using Landsat8 and sentinel 2. Landsat enabled the acquisition of old satellite images of 2006, whereas sentinel facilitated the acquisition of satellite images of 2016 and 2021. A hand held GPS receiver was used for ground verification in determining the land use/cover classes

3.3.2 Determination of abundance and distribution of macro-benthos taxa at the different selected points

A total of 12 sampling sites were selected for macrobenthos sampling which were taken twice during the dry and rainy season. Likewise, Macro invertebrates samples are to be taken a moment before or shortly upstream avoid interference from whirled up material.

The sub-index values of each parameter are calculated to obtain water quality index. Besides that, there is alternative method conducted by using macro benthos as a bio indicator based on Biological Water Quality Index (BWQI). Macrobenthos obtained was analysed and the score was calculated to determine the status of river.

3.3.3 Basics Equipment Used in Macrobenthos Method

The equipment for this method was easy to use and perform. This is listed in the table shown below. A macrobenthos sampling was taken using large square dip net. Samples were collected and rinsed using 300µm sieve to remove the sediments and leaving behind any invertebrates and kept in a bottles filled with 70% ethanol for temporary preservation before being analysed in laboratory

Table 3. 2: Equipment used for BWQI Method

Equipment	Function
Large	Square Net Taking a sample of macrobenthos
Universal Bottles	Placing the macrobenthos
Forceps	Taking a sample of macrobenthos from square net and put into another bottles or tray Brochure Identify a sample of macrobenthos
Lens	Larger and clear an image of macrobenthos
Spoon	Transfer sample from another bottles or tray
Stick	Current Meter Digital Measuring River current and height of river water level
Pipette	Sucking/ Inhaling tiny objects

Sample Analysis.

Macro benthos

Macrobenthos analysis is a biological analysis method that is used to determine the water quality using Biological Water Quality Index (BWQI). It is easy to be conducted compared to conventional method. Furthermore, it does not need any chemicals and does not harm or pollute the ecosystem of the river while study is being carried out. This method is an alternative method to determine the quality of water or level of water pollutant despite using the conventional method which is costly, take a long time, required a skilled person to using high technology equipment and dangerous chemicals.

Macro benthos were placed in universal bottles in certain duration for the process of recognition and identification based on guidelines given by Department of Irrigation and Drainage. A macrobenthos sampling was taken using large square dip net. A dip net was placed on the shallow running water substrate against the water flow. Then, the substrate was disturbed and boulders in that area were rubbed gently to dislodge the organisms into the net. Samples collected were rinsed using 300µm sieve to remove the sediments and leaving behind any invertebrates and kept in a bottle filled with 70% ethanol for temporary preservation before being analysed in laboratory

$$\text{Biological Water Quality Index (BWQI)} = \frac{\text{Score of macro benthos}}{\text{Type of Macro benthos}}$$

3.3.4 Determination of water quality at the selected points along the River Mpanga

Water quality data collection

Water samples were taken from the different points along the river. These were taken at upstream, Midstream and downstream of the river and tested at the laboratory. There were several factors that need to be considered while sampling. The bottle for the sampling need to be rinsed to avoid any reaction from particle or contamination from previous work and need to be marked to avoid any mistake or confusion. Sample taken need to be tested and analysed at the laboratory.

Schedule

Sample collection took place during the rainy and dry season and was preceded by a week of preparative work during which all sampling locations were visited to check accessibility. Coordinates of the sampling locations were registered with a GPS device. Field work was alternated with laboratory work to ensure that both chemical and macro benthic invertebrate samples could be processed within maximum one day after sampling. This is important to prevent samples from degrading, i.e., chemical concentrations to change from true field concentrations, and macro invertebrates to die and decompose. Within the same day, and when at short distance from each other (< 3 km), downstream locations were sampled before upstream

locations to prevent those downstream measurements get influenced by prior sampling activities upstream (i.e., by whirling up sediment and nutrients and dislodging macro invertebrates that flush downstream).

Water Samples

Sample collection and preservation procedures were based on the Standard Methods for the Examination of Water and Wastewater (APHA, 2008).

On-site measurements were done with Horiba multi parameter probes (U-50 series), equipped with sensors for Temperature, Electric conductivity (EC), Ph and turbidity. The sensors were calibrated weekly with commercially available standard solutions. Measurements were done onsite.

For parameters that might not be measured within the field, water samples were collected and brought to the laboratory for analysis at the regional water quality laboratory within the Albert Water Management Zone, Fort portal. This was in hot water ammonium (NH₄), nitrite (NO₂), nitrate (NO₃), total nitrogen (TotN), total phosphate (TP), dissolved orthophosphates (o-PO₄), chemical oxygen demand (COD), and biochemical oxygen demand (BOD). The tests which were dispensed on each of the chosen samples were physical and Chemical tests. The physical tests distributed include colour, temperature, total dissolved solids, turbidity and total hardness. While the chemical tests administrated are contents of calcium, phosphate, total alkalinity (TA), dissolved oxygen and biochemical oxygen demand (BOD) levels of the water samples of the study area. The results obtained were compared with the globe Health Organization's (WHO) (2011) water quality standard values and former studies.

Stream water was collected in a well-rinsed bucket, from an undisturbed spot (no upwelling sediment or floating debris), where water is flowing (not stagnant) and well homogenised (e.g., not immediately downstream of an effluent discharge point). From this general sample, separate sampling recipients were filled by means of a measuring jug and stored in a cooling box containing sufficient frozen cooling elements to keep samples cool until they were returned to the laboratory. The samples were analyzed spectrophotometrically, using Hach Lange® cuvette tests within 24h of sampling.

Samples were collected from three different locations representing upstream, midstream and downstream of R.Mpanga. the gathering was done using sterilized plastic containers of 1.5 L capacity. The containers were dipped into the river at about 0.3 m below the water surface. The mouths of the containers were directed to the direction of flow (current) and when enough water (2 L) has entered, it absolutely was immediately corked. The temperature, total Temperature, Turbidity and pH were determined with a transportable in place pH meter. Sampling containers were labelled immediately using different identification marks. Water samples were temporarily stored in a veryn ice-packed cooler and transported to the laboratory before stored in a refrigerator at about 4°C before analysis. These samples were collected on a monthly basis consecutively for a period of three months (November to January 2019).

3.4 Data Analysis

3.4.1 Assessment of the land use variation at the different selected points along R. Mpanga

Image acquisition

Re-classification process and alter detection analysis of the various Land Use Land Cover (LULC) classes were performed using Landsat satellite images. The satellite imagery data were all sourced from us Geological Survey (USGS) (<ftp://ftp.glcg.umd.edu/glcg/Landsat/WRS2and> <https://earthexplorer.usgs.gov/>).After downloading, the photographs were all geo-referenced to the WGS 84 datum with the UTM Zone 36N of the organization. All satellite data were analyzed by assigning per-pixel signatures and differentiating the land uses to 5 classes supported different landscape elements. The delineated classes were; forestry, grassland, wetland, settlement, and little scale farming. for every of those, predetermined land cover/use type was assigned training samples by delimiting polygons within representative sites, and signatures files created for the respective land cover types derived from the satellite imagery recorded by using pixels enclosed by polygons. All classification processes were performed using ArcGIS 10.2

Land use/cover change detection and classification analysis

As formerly described and presented in Table 1, the study area is defined to categorically have eight land uses which are: Built up Areas, Grassland, Farmland, Bushland, Wetlands, Woodland, Open Water, and Forests respectively.

The statistical analysis of the land use/land cover maps of Kabarole District wetlands reveal that significant changes have taken place from 2006, 2016 and 2021, the total area of the study area is 1314.94Km²; The overall classification accuracy was 88.8%

3.4.2 Determination of abundance and distribution of macro-benthos taxa at the different points

Data for comparison of the macrobenthic invertebrates was analyzed using diversity indices. A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simply species richness (i.e., the number of species present); they also take the relative abundances of different species into account. Diversity indices provide important 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. In this study, Shannon-Wiener index was used. It is one of the most commonly used species diversity indices due to its robustness and simplicity. The index because it gives more weight to common or dominant species. It is defined and given by the following function:

$$\text{Shannon Wiener Index } (H) = - \sum_{i=1}^s p_i (\ln p_i)$$

Where;

H is Shannon-Wiener Index, a measure of the diversity of species

p is the proportion of total sample represented by species

i obtained by dividing the number of individuals of species i by total number of samples

Σ is the sum of the calculations

S is the total number of unique species, also known as species richness

From Shannon Diversity Index, the evenness of a species is then measured using Shannon Equitability Index denoted by E_H . The term “evenness” simply refers to how similar the abundances of different species are in the community, and is calculated as follows:

$$\text{Evenness } (E_H) = H / H_{\max}$$

Where

E_H = Evenness

$H_{\max} = \ln(S)$ = Maximum diversity possible

H is the Shannon Diversity Index

3.4.3 Determination of water quality at the different points along the River Mpanga

Descriptive statistics including mean, median, standard deviation and skewness were obtained for the physical-chemical parameters of the water samples collected from selected points along River Mpanga. The obtained averages were evaluated against the national portable water standards. Box and Whisker plots were used to explore the distribution (variability) of the water quality variables. The averages of the water quality parameters were then compared across selected river points by subjecting the data to a non-parametric test known as Kruskal-Wallis H -test. The test compares medians among k independent groups ($k > 2$) and is formulated based on ranks rather than actual observations (Daniel, 1990). The test is suitable for small sample sizes and is generally robust to departures from normality and homoscedasticity and less sensitive to outliers or extreme values.

Kruskal-Wallis tested the null hypothesis that: the medians of the water quality parameters were equal across the selected river points against the alternative that the medians differed for at least one river point. By setting the level of significance at α , the null hypothesis was rejected on the condition that the probability value (p) associated with the test-statistic (H) was less than α . The test however only tells you that at least two groups are significantly different. It cannot tell you which specific groups of the independent variable are statistically different from each other. So, following the rejection of the null hypothesis of equal medians, a post-hoc test was carried out using the Dunn's test to determine which specific river points were statistically different from each other. Dunn's test investigated the hypothesis that medians of the water quality parameters from any two selected river points were equal.

Similarly, Kruskal-Wallis H -test was used to compare averages of the water quality parameters across the different land-use types. Following the rejection of the null hypothesis, a post-hoc test was carried out using Dunn's test. The analyses were run using the SPSS version 20.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

Chapter four presents the findings of the research in terms of the water quality, macro benthos and the different land use types along river Mpanga. The main aim of the research was to assess the effects of land use effects on water quality using biotic index of the macro benthos of river Mpanga. The specific research questions that were used to achieve this aim were; What is the water quality status of the different points along the river? What are the variations in abundance of benthic invertebrates at the different types of land use along R. Mpanga? What are the different land use variations at the different points along the river from upstream, of the river to downstream the river?

4.1 Land use variations at the different points along River Mpanga

The study area was defined to have eight major land use and land cover categories, rather; Built Up Areas, Grassland, Farmland, Bush land, Wet lands, Wood land, Open Water, and Forests respectively. The land use land cover classification and analysis were from 2006, 2016 to 2021 in obtaining accurate results for land use land cover change. The essential outputs of this study were the land cover maps for 2006, 2016 and 2021. The area increases and decrease of the major LULC classes as well as the driving forces of land use land cover change in along River Mpanga in Kabarole District. From the table below, the following sections elucidate on these aspects of the output.

Table 4. 1: Land Use Land Cover Classes with the total areas and percentage change totals

LULC	2006		2016		2021		% Change
	Area Sq.Kms	Percent age	Area Sq.Kms	Percent age	Area Sq.Kms	Percent age	
Agriculture	217.31	16.53	272.78	20.74	416.11	31.65	15.12
Built Up Areas	47.29	3.60	149.53	11.37	228.93	17.41	13.81
Bush land	138.59	10.54	79.95	6.08	52.00	3.95	-6.59
Forests	402.20	30.59	351.66	26.74	301.72	22.95	-7.64
Grassland	173.16	13.17	162.41	12.35	153.91	11.70	-1.46
Open Water	13.34	1.01	9.85	0.75	10.52	0.80	-0.21
Wetland	183.29	13.94	164.74	12.53	72.41	5.51	-8.43
Woodland	139.76	10.63	124.03	9.43	79.34	6.03	-4.60
TOTAL	1314.94	100.00	1314.94	100.00	1314.94	100.00	0.00

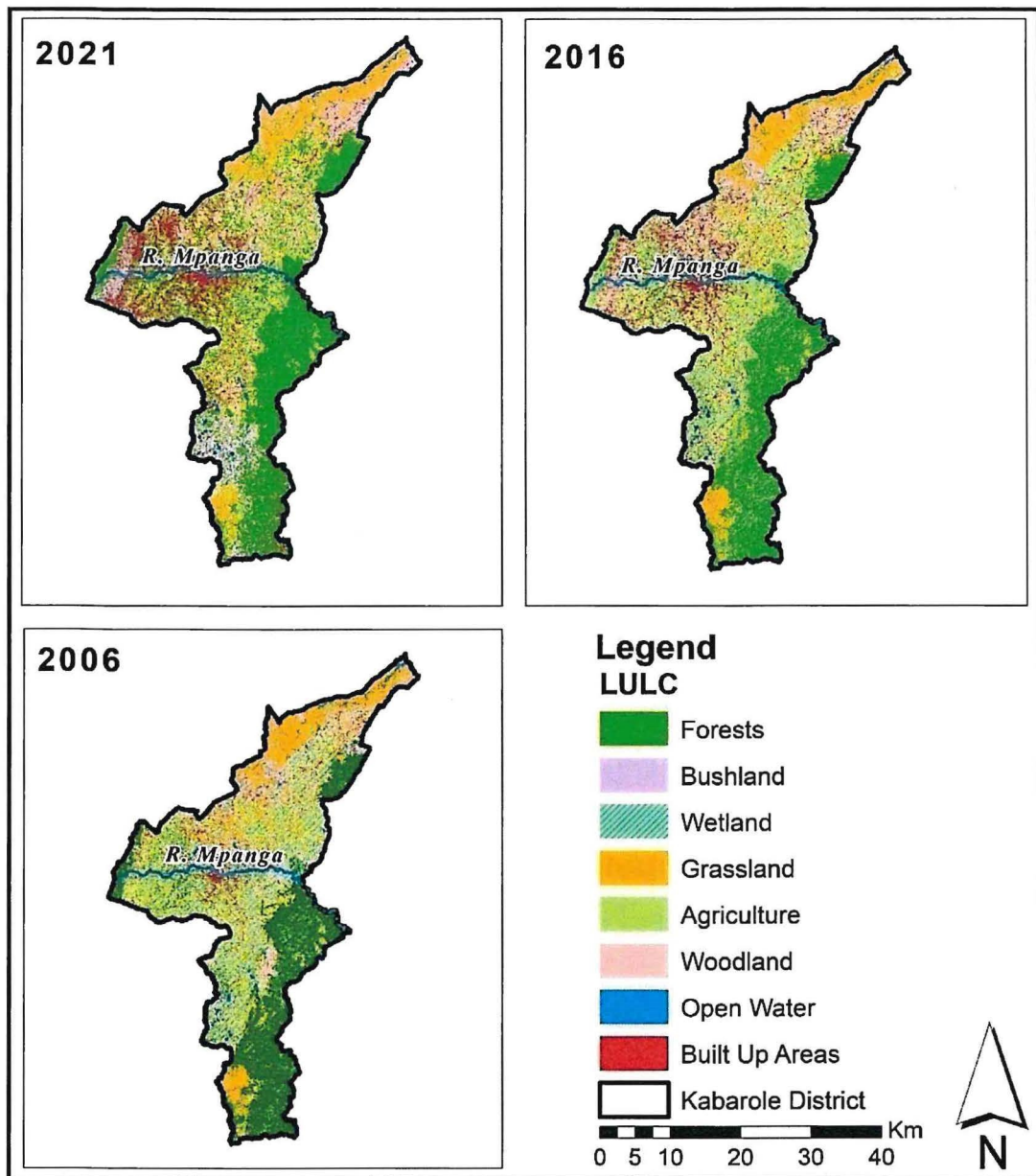


Figure 4. 1: Land Use Land Cover change of the study area from 2006-2021

In 2006, Forests as dominant land use indicated $402.20\text{Km}^2(30.59\%)$, this was followed by agriculture at $217.31\text{Km}^2(16.53\%)$, wetland $183.29\text{Km}^2 (13.94\%)$, grassland at $173.16\text{Km}^2 (13.17\%)$ as well as woodland $139.76 \text{ Km}^2 (76\%)$, Bush land at $138.59 \text{ Km}^2 (10.54\%)$, Built up Areas at $47.29 \text{ Km}^2 (13.29\%)$, and open water at $13.34 \text{ Km}^2 (1.01\%)$, of the total land cover area respectively.

In 2016 Over the previous years with the effect of land use land cover change could be attributed to destruction of the green vegetation cover categorically forests, bush land, grassland and permanent wetlands, from the above analysis of results, it the moderate decline in Forests and other natural land uses led to an increase in agriculture and built up areas. Forests slightly reduced by 351.66 km² (26.74%), followed by a decline in wetlands 164.74 km² (12.53%) and grassland at 162.41 km² (12.31%), woodland at 124.03 km² (9.43%), and open water at 9.85 km² (0.75%). This could have led to an increase in agriculture 272.78 km² (20.74%), and built up at 149.53 km² (11.37%) respectively.

In 2021 as shown in table above, Forests continuously declined by 301.52 km² (22.95%) as well as a continuous reduction in grassland 153.59 km² (11.70%). The uniform decline in woodland 79.34 km², wetlands 72.41 km² (5.51%), bush land 52.00 km² (3.95%), and open water by 10.52 km²(0.08%) proportionately gave rise to the increase of agriculture and built up Areas to 416.11 km²(31.65%), 228.93 km²(17.41%) Agriculture and rising levels of urbanization activities could have been attributed to the continuous decline in wetlands, woodland, forest, and grassland and bush land thus impacting on water quality along R. Mpanga respectively.

4.2 Abundance and distribution of benthic invertebrates at the different points along Mpanga river

Results from Shannon Wiener Diversity Index indicate that Trichoptera was the most abundant species in the downstream section of R. Mpanga (Table 4.3.0).

Table 4. 2: Shannon Wiener Index for macro-benthos taxa downstream

Species (<i>i</i>)	<i>n</i>	<i>p_i</i>	ln(<i>p_i</i>)	<i>p_i</i> x ln(<i>p_i</i>)	Index	
Trichoptera	43	0.222	-1.507	-0.334		
Ephemeroptera	38	0.196	-1.630	-0.319	<i>H</i>	1.760
Diptera	32	0.165	-1.802	-0.297	<i>H_{max}</i>	1.792
Plecoptera	26	0.134	-2.010	-0.269	<i>E_H</i>	0.982
Odonata	36	0.186	-1.684	-0.313		
Coleoptera	19	0.098	-2.323	-0.228		
<i>S = 6</i>	194			-1.760		

In the midstream section of R. Mpanga, Coleoptera were found to be the most dominant species of Macro-benthos (Table 4.3.1).

Table 4. 3: Shannon Wiener Index for macro-benthos taxa midstream

Species (<i>i</i>)	<i>n</i>	<i>p_i</i>	ln(<i>p_i</i>)	<i>p_i</i> x ln(<i>p_i</i>)	Index	
Trichoptera	0	0.000	Null	Null		
Ephemeroptera	4	0.056	-2.876	-0.162	<i>H</i>	1.437
Diptera	21	0.296	-1.218	-0.360	<i>H_{max}</i>	1.609
Plecoptera	8	0.113	-2.183	-0.246	<i>E_H</i>	0.893
Odonata	12	0.169	-1.778	-0.300		
Coleoptera	26	0.366	-1.005	-0.368		
<i>S</i> = 6	71			-1.437		

In the upstream section of R. Mpanga, Diptera were found to be the most dominant species of Macro-benthos (Table 4.3.2).

Table 4. 4: Shannon Wiener Index for macro-benthos taxa upstream

Species (<i>i</i>)	<i>n</i>	<i>p_i</i>	ln(<i>p_i</i>)	<i>p_i</i> x ln(<i>p_i</i>)	Index	
Trichoptera	26	0.154	-1.872	-0.288		
Ephemeroptera	29	0.172	-1.763	-0.302	<i>H</i>	1.741
Diptera	45	0.266	-1.323	-0.352	<i>H_{max}</i>	1.792
Plecoptera	17	0.101	-2.297	-0.231	<i>E_H</i>	0.972
Odonata	32	0.189	-1.664	-0.315		
Coleoptera	20	0.118	-2.134	-0.253		
<i>S</i> = 6	169			-1.741		

The findings indicate that the downstream section of R. Mpanga had a higher species diversity ($H = 1.76$) compared to the midstream ($H = 1.44$) and the upstream ($H = 1.74$) sections of the river. Similarly, the downstream end had greater species evenness ($E_H = 0.98$) than both the midstream ($E_H = 0.89$) and the upstream sections of R. Mpanga ($E_H = 0.97$).

4.3 Water quality at the different points along Mpanga river

The water parameters considered in this study included pH, EC ($\mu\text{S/cm}$), Turbidity (NTU), Nitrites (mg/l), Total Phosphates (mg/l), Nitrates (mg/l), Ammonia (mg/l), Total Nitrogen(mg/l) and BOD (mg/l) as shown in the tables below

Table 4. 5: Mean and standard deviation of physical-chemical parameters of R. Mpanga water

Parameter	Overall skewness	National standard	Mean \pm Standard Deviation (Number of observations per site, $n = 3$)								
			FPU1	FPU2	FPU3	FPM4	FPM5	FPM6	FPD7	FPD8	FPD9
pH (pH Units)	0.77	6.5 – 8.5	7.37 \pm 0.15	7.57 \pm 0.06	7.47 \pm 0.06	7.87 \pm 0.15	8.30 \pm 0.20	8.20 \pm 0.26	7.87 \pm 0.15	7.53 \pm 0.15	7.57 \pm 0.12
Electrical Conductivity (μ S/cm)	-0.23	2500	226 \pm 7	197 \pm 2	209 \pm 6	368 \pm 5	559.33 \pm 14	566 \pm 3	452 \pm 6	450 \pm 4	461 \pm 6
Turbidity (NTU)	0.27	1200.	155 \pm 0.61	136 \pm 1.99	140 \pm 0.93	25.4 \pm 0.46	21 \pm 1.89	41 \pm 1.24	319 \pm 2.52	315 \pm 0.44	109 \pm 1.36
Total Phosphates as P (mg/l)	1.28	1.00	0.22 \pm 0.01	0.22 \pm 0.01	0.20 \pm 0.02	0.15 \pm 0.01	0.84 \pm 0.01	0.68 \pm 0.01	0.09 \pm 0.01	0.10 \pm 0.00	0.23 \pm 0.15
Nitrites as N (mg/l)	0.14	400.	4.00 \pm 0.00	2.00 \pm 1.00	3.23 \pm 0.12	5.67 \pm 0.06	0.02 \pm 0.01	0.05 \pm 0.01	9.60 \pm 0.10	9.67 \pm 0.58	9.63 \pm 0.06
Nitrates as N (mg/l)	1.39	200	0.00 \pm 0.00	0.10 \pm 0.01	0.00 \pm 0.00	0.02 \pm 0.03	0.69 \pm 0.01	0.67 \pm 0.06	0.02 \pm 0.01	0.00 \pm 0.00	0.00 \pm 0.00
Ammonia as N (mg/l)	-0.06	20	0.77 \pm 0.01	0.86 \pm 0.01	0.37 \pm 0.46	0.49 \pm 0.01	0.24 \pm 0.01	0.88 \pm 0.01	0.45 \pm 0.01	0.49 \pm 0.00	0.42 \pm 0.01
Total Nitrogen as N (mg/l)	1.55	10	0.11 \pm 0.00	0.22 \pm 0.01	0.09 \pm 0.01	0.06 \pm 0.00	2.49 \pm 0.01	1.78 \pm 0.01	0.19 \pm 0.01	0.07 \pm 0.00	0.13 \pm 0.00
Biological Oxygen Demand (mg/l)	0.65	50	6.67 \pm 0.58	4.67 \pm 0.58	2.00 \pm 0.00	11.67 \pm 0.58	14.67 \pm 0.58	16.33 \pm 0.58	3.00 \pm 0.00	1.67 \pm 0.58	1.67 \pm 0.58

FPU: Fort Portal Upstream

FPM:Fort Portal Midstream

FPD: Fort Portal Downstream

The pH in River Mpanga was highest at midstream (8.30) and lowest at upstream (7.37). Overall, average pH along the river was within the national portable water standards. Similarly, the highest mean value for electrical conductivity was recorded along midstream (566.67 μ S/cm) whereas the lowest was observed upstream (197.00 μ S/cm). All averages for electrical conductivity were within the national standard. On average, the lowest turbidity was observed midstream (21.97 NTU) while the highest was recorded downstream (319.67 NTU).

Turbidity for River Mpanga was found to be within the national standard. For total phosphates, midstream area had the highest concentration on average (0.84 mg/l) while downstream recorded the lowest (0.09 mg/l). The highest concentration of Nitrites was found downstream (9.67 mg/l) whereas the lowest was obtained midstream (0.02 mg/l). For Nitrates, the midstream area had highest nitrites concentration (0.69 mg/l) while the lowest was found upstream. The concentration of Nitrates along all river points was below the national standard. On average, both the highest (0.88 mg/l) and the lowest (0.24 mg/l) concentrations of ammonia were recorded midstream. Total Nitrogen concentration was both highest (2.49 mg/l) and lowest (0.06 mg/l) in the midstream area.

For biological oxygen demand, the highest and lowest concentration was found midstream (16.33 mg/l) and downstream (1.67 mg/l) respectively. With regard to variability, about one-third of the parameters were found to be highly skewed to the right (skewness > 1). These were phosphates, nitrates, and nitrogen. The high positive skewness is an indication of presence of abnormally large values (outliers) within the data, which implies that parametric tests are not suitable for carrying out further analysis.

The average concentrations for pH, electro conductivity, total phosphates, nitrates, total nitrogen and biological oxygen demand were higher at midstream points FPM5 and FPM6 as compared to other points of River Mpanga. A reverse pattern was observed for turbidity and nitrites whose concentration was lowest at these midstream points.

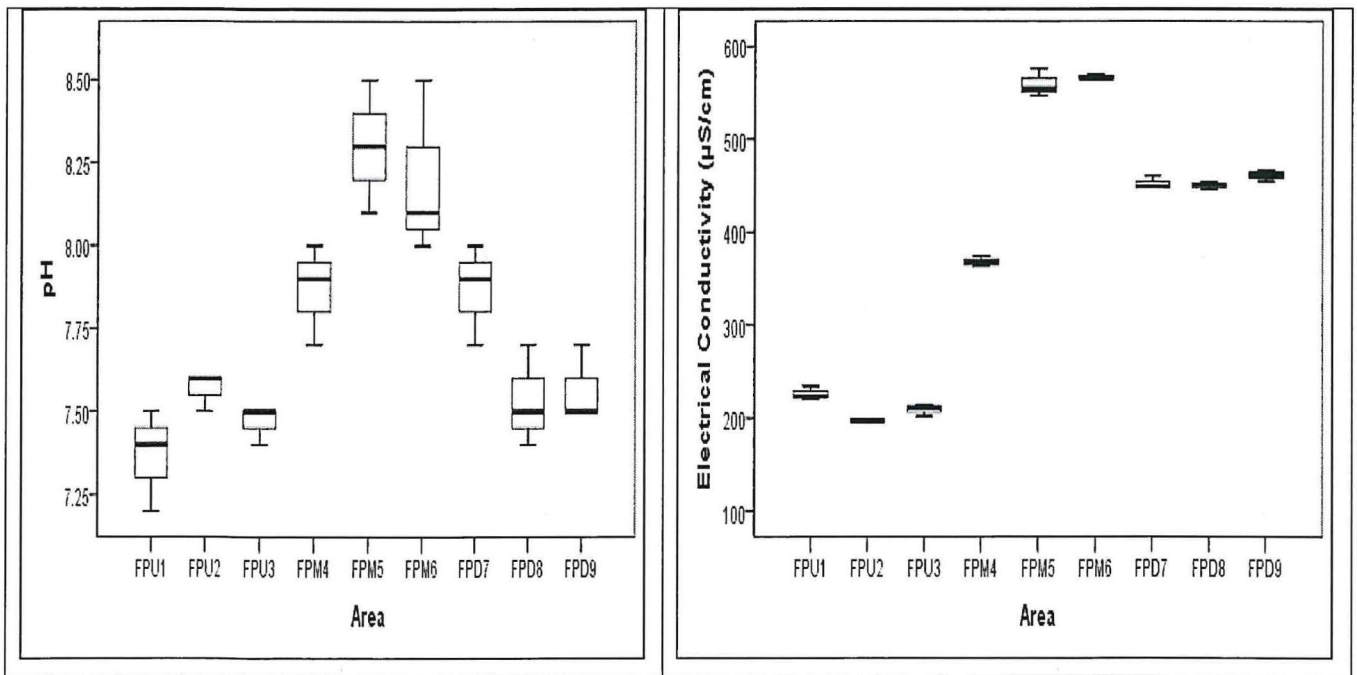


Figure 4. 2: Graphs of pH and EC measured at different points along River Mpanga

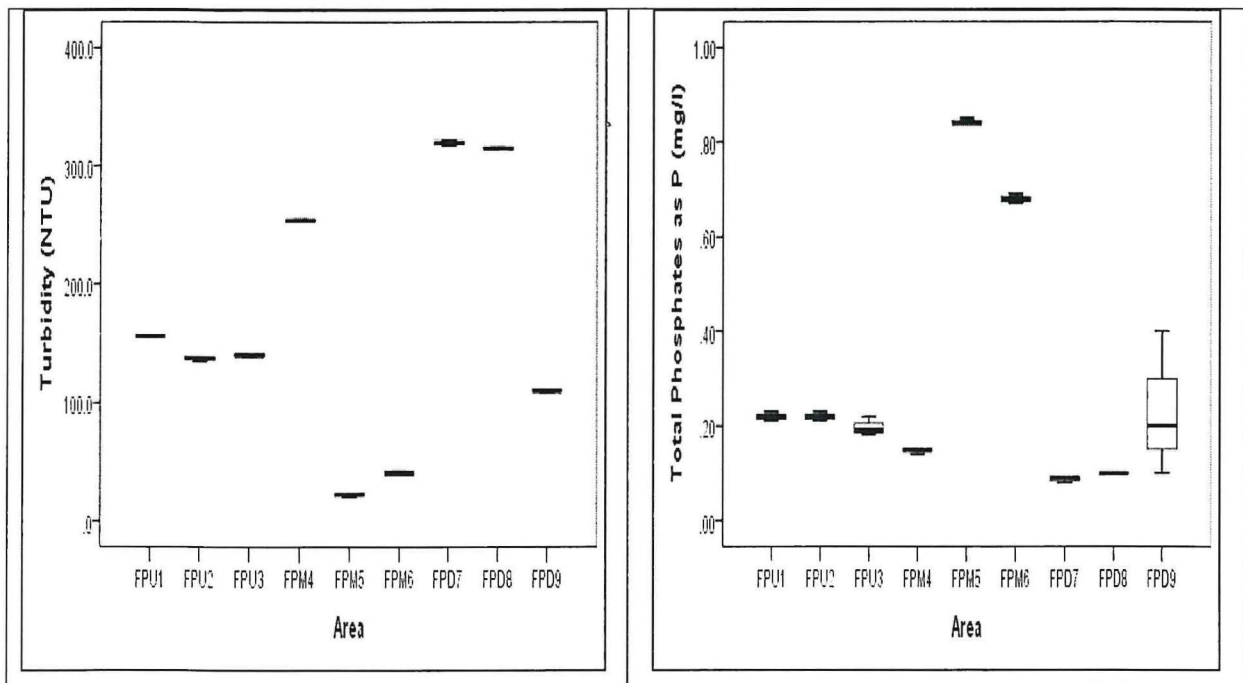


Figure 4. 3: Graph of turbidity and total phosphates measured at different points along River Mpanga

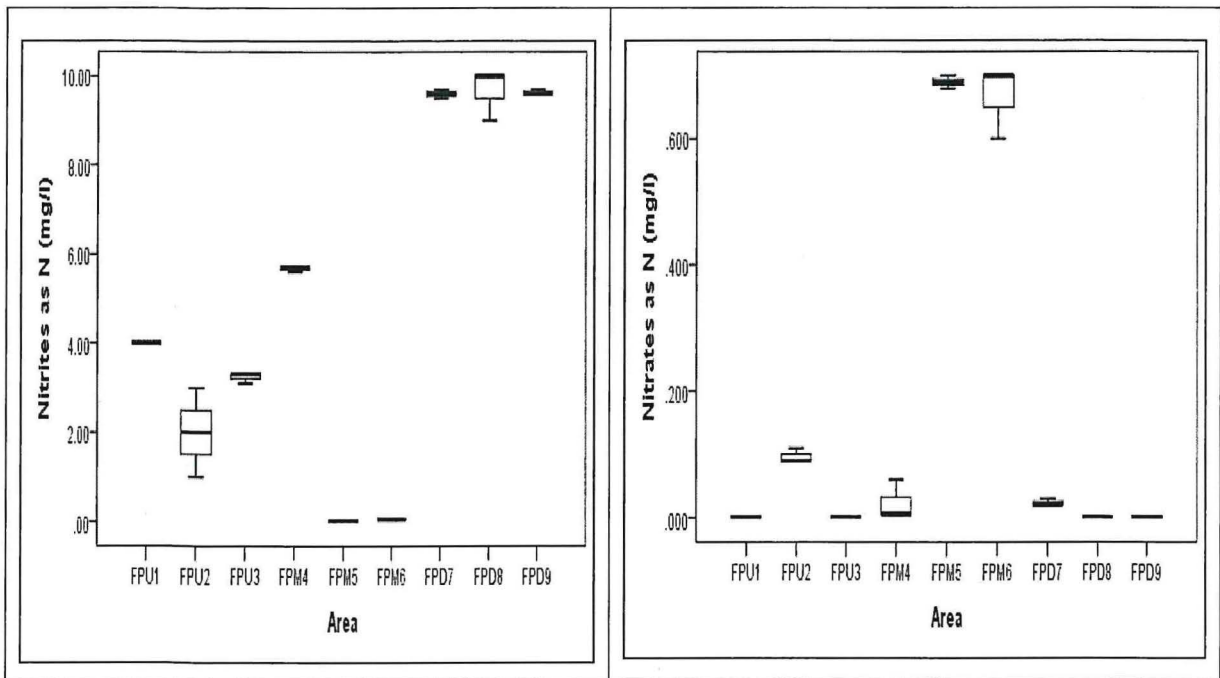


Figure 4. 4: Graph of Nitrites and Nitrates concentration measured at different points along River Mpanga

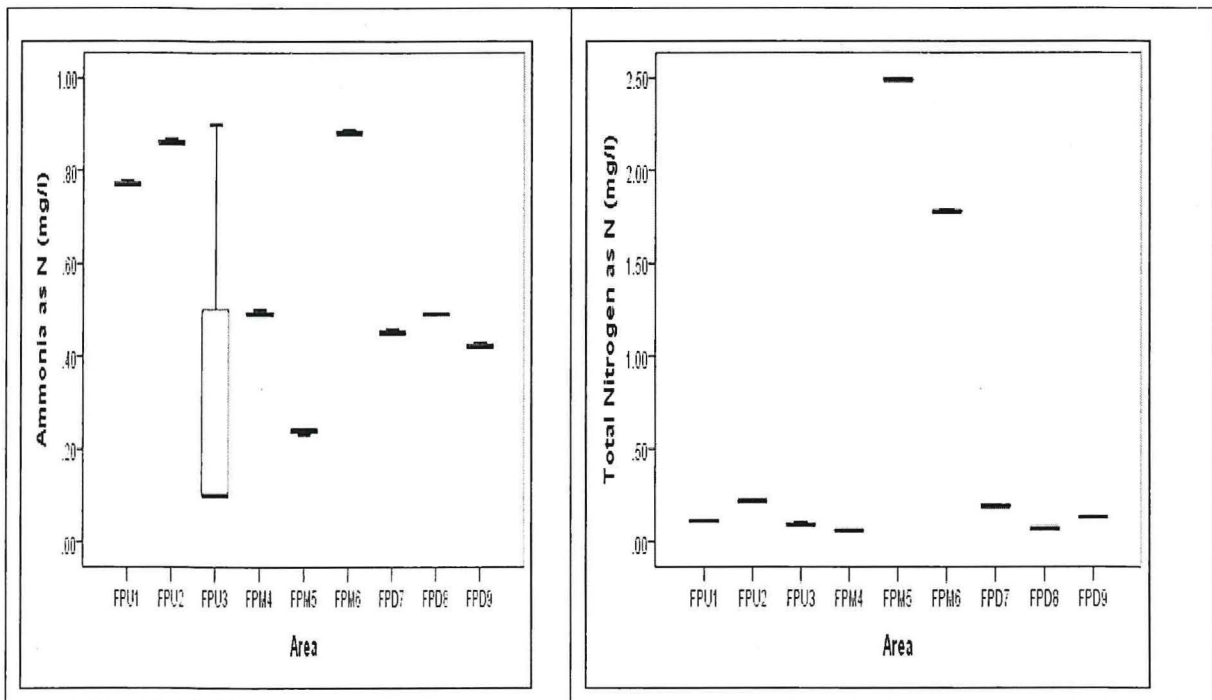


Figure 4. 5: Graphs of Ammonia and Total nitrogen concentration measured at different points along River Mpanga

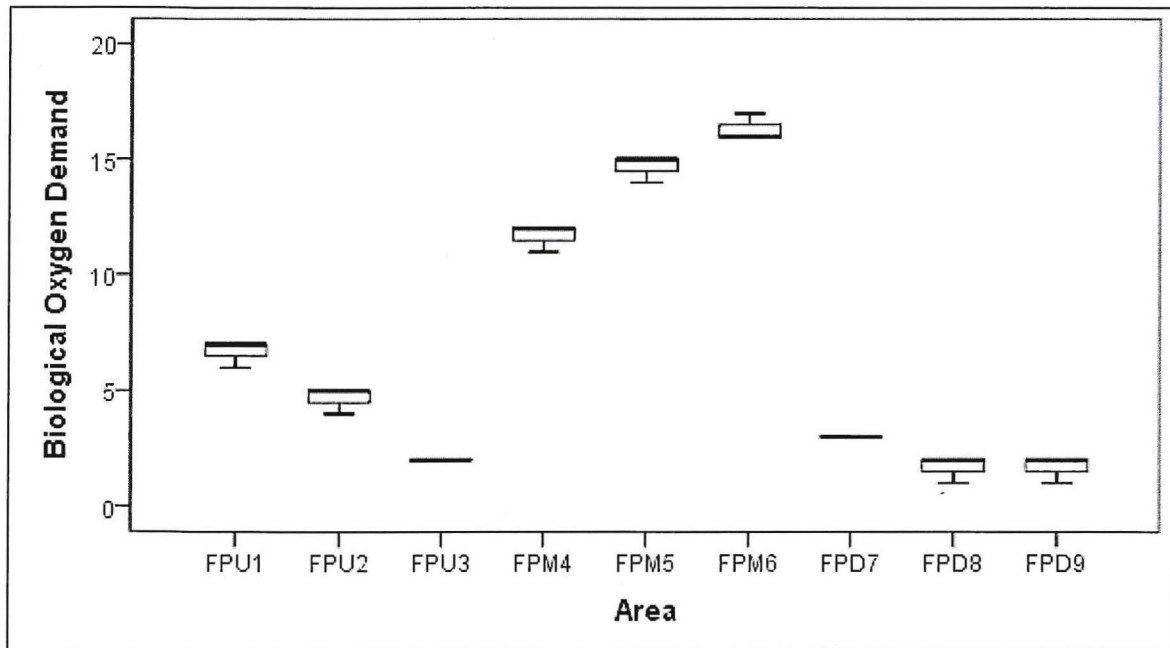


Figure 4.1: Biological oxygen demand measured at different points along River Mpanga

pH (FPM5) was significantly higher than that at upstream (FPU1). More so, electrical conductivity at midstream points (FPM 5-6) was significantly greater than that at upstream (FPU2). For turbidity, there values downstream at FPD7-8 were notably higher compared to those at midstream points FPM5-6. Concentration of total phosphates at midstream points FPM5-6 was significantly higher than that at downstream point FP7. For nitrites, the concentration at downstream FP8-9 was substantially greater compared to that at midstream FPM5. For the case of ammonia and total nitrogen, significant differences in concentration were observed only at midstream points. With regard to biological oxygen demand, the average concentration of was significantly higher for midstream (FPM6) as compared to downstream ends (FP8-9).

Table 4. 6: Median concentrations of water quality parameters along River Mpanga

River point	pH	Electrical Conductivity (µS/cm)	Turbidity (NTU)	Total Phosphates (mg/l)	Nitrites (mg/l)	Nitrates (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	BOD (mg/l)
FPU1	7.40 ^b	223.00 ^{ab}	156.00 ^{ab}	0.22 ^{ab}	4.00 ^{ab}	0.00 ^a	0.77 ^{ab}	0.11 ^{ab}	7.00 ^{ab}
FPU2	7.60 ^{ab}	197.00 ^b	137.90 ^{ab}	0.22 ^{ab}	2.00 ^{ab}	0.09 ^a	0.86^a	0.22 ^{ab}	5.00 ^{ab}
FPU3	7.50 ^{ab}	211.00 ^{ab}	140.10 ^{ab}	0.19 ^{ab}	3.30 ^{ab}	0.00 ^a	0.10 ^b	0.09 ^{ab}	2.00 ^b
FPM4	7.90 ^{ab}	367.00 ^{ab}	254.40 ^{ab}	0.15 ^{ab}	5.70 ^{ab}	0.01 ^a	0.49 ^{ab}	0.06 ^b	12.00 ^{ab}
FPM5	8.30^a	555.00^a	22.40 ^b	0.84^a	0.02 ^b	0.69 ^a	0.24 ^b	2.49^a	15.00^a
FPM6	8.10 ^{ab}	566.00^a	40.50 ^b	0.68^a	0.05 ^b	0.70 ^a	0.88^a	1.78^a	16.00^a
FPD7	7.90 ^{ab}	449.00 ^{ab}	320.00^a	0.09 ^b	9.60^a	0.02 ^a	0.45 ^{ab}	0.19 ^{ab}	3.00 ^{ab}
FPD8	7.50 ^{ab}	451.00 ^{ab}	315.00^a	0.10 ^{ab}	10.00^a	0.00 ^a	0.49 ^{ab}	0.07 ^b	2.00 ^b
FPD9	7.50 ^{ab}	462.00 ^{ab}	110.00 ^{ab}	0.20 ^{ab}	9.60^a	0.00 ^a	0.42 ^{ab}	0.13 ^{ab}	2.00 ^b

* Post-hoc results from Dunn's test: Medians with the same superscript letter are not significantly different from each another at 5% level; Number of observations per site (n) = 3

The built-up areas had significantly higher concentration levels of pH (8.1), electrical conductivity (555µS/cm), total phosphates (0.68mg/l), nitrates (0.68 mg/l) and biological oxygen demand (15.0 mg/l) when compared with other land uses. On a similar note, natural forests had significantly greater turbidity levels (315 NTU) and nitrite concentration (9.6 mg/l) in comparison with other land uses. However, the results found no sufficient evidence to suggest that the concentrations for ammonia and total nitrogen differed by land use type ($p > 0.05$). It was also observed that with the exception of pH, the concentrations for all other water quality parameters were below the national standards for portable water. The results imply that the midstream points of River Mpanga where the dominant land use was built-up area had higher levels of concentrations for most of the physical – chemical parameters as compared to other land use types.

Table 4. 7: Means and standard deviations of water quality parameters at different land-use types along Mpanga River

Parameter	Land use	Mean±Std Dev	Median*	National standard
pH	Agriculture	7.47 ± 0.12	7.50 ^b	6.00 – 8.50
	Built-up area	8.12 ± 0.27	8.10 ^a	
	Natural forest	7.66 ± 0.20	7.70 ^b	
Electrical Conductivity (µS/cm)	Agriculture	210.67 ± 13.50	211.00 ^b	2500.00
	Built-up area	498.00 ± 97.89	555.00 ^a	
	Natural forest	454.67 ± 7.07	454.00 ^a	
Turbidity (NTU)	Agriculture	144.29 ± 8.77	140.10 ^{ab}	1200.00
	Built-up area	105.88 ± 111.78	40.50 ^b	
	Natural forest	248.13 ± 103.98	315.00 ^a	
Total Phosphates as P (mg/l)	Agriculture	0.21 ± 0.02	0.22 ^{ab}	1.00
	Built-up area	0.56 ± 0.32	0.68 ^a	
	Natural forest	0.14 ± 0.10	0.10 ^b	
Nitrites as N (mg/l)	Agriculture	3.08 ± 1.01	3.30 ^b	400.00
	Built-up area	1.91 ± 2.82	0.05 ^b	
	Natural forest	9.63 ± 0.30	9.60 ^a	
Nitrates as N (mg/l)	Agriculture	0.03 ± 0.05	0.00 ^b	200.00
	Built-up area	0.46 ± 0.33	0.68 ^a	
	Natural forest	0.01 ± 0.01	0.00 ^b	
Ammonia as N (mg/l)	Agriculture	0.67 ± 0.33	0.78 ^a	20.00
	Built-up area	0.54 ± 0.28	0.49 ^a	
	Natural forest	0.46 ± 0.03	0.45 ^a	
Total Nitrogen as N (mg/l)	Agriculture	0.14 ± 0.06	0.11 ^a	10.00
	Built-up area	1.45 ± 1.08	1.78 ^a	
	Natural forest	0.13 ± 0.05	0.13 ^a	
Biological Oxygen Demand (mg/l)	Agriculture	4.44 ± 2.07	5.00 ^b	50.00
	Built-up area	14.22 ± 2.11	15.00 ^a	
	Natural forest	2.11 ± 0.78	2.00 ^b	

**Post-hoc results from Dunn's test: Medians with the same superscript letter are not significantly different from each another at 5% level; Number of observations per land-use type (n) = 9*

4.4 Discussion

This chapter presents the discussion of the findings on the benthic invertebrates composition in relation to anthropogenic disturbance in the study area. The main objective of the study and specific objectives are discussed in details in this chapter

The high levels of pollution in urban areas affect nutrient cycling (Pickett et al., 2011). Increased concentrations and loads of chemical pollutants in streams appear to be universal in river systems (Walsh et al., 2005; Walsh et al., 2005).

Aquatic ecosystems go through changes along with normal climatic fluctuation. These variations occur seasonally and in some systems over a period of 24 hrs. The climatic fluctuations influence the physical chemical parameters which then influence the essential ecosystem processes (DWAf 1966e)

4.4.1 Physical chemical characterisation of R. Mpanga water

Water composition was found to change substantially for some variables in the Mpanga main channels it flows from upstream to downstream. The panels in Figure 4.2 show the evolution of some of these variables in the R. Mpanga per sampling area.

4.4.1.1 Physical variables

A key variable in aquatic environments is Ammonia and Biological oxygen demand because like most other organisms, aquatic organisms need oxygen for respiration. Algae and plants produce oxygen through photosynthesis during the day and consume oxygen at night and on cloudy days, while all other organisms (fish, macro invertebrates, and microorganisms) only consume oxygen. This can lead to large day-night fluctuations in the dissolved oxygen content of a water body, and result in the disappearance of organisms that are sensitive to periodic or permanent oxygen depletion. Dissolved oxygen can be expressed as the absolute concentration (in milligrams of oxygen per litre water) or as percentage saturation, indicating how much oxygen the water

contains compared to its maximum oxygen dissolving capacity. The dissolved oxygen (DO) content in the Mpanga main channel remains above 85% saturation in most locations. It is lowest in the urban area (IFP), while it is at full saturation in the headwaters and gradually increases again downstream of Fort Portal.

The pH is a measure for the acidity of the water. It is a key variable because it influences other characteristics like the electric conductivity, and many chemical processes. Water of neutral acidity has a pH of 7, while lower pH values indicate more acid water. While the pH remains fairly neutral upstream in the main channel (pH 7-8), it shows a slight increase in the midstream area in the urban area and stabilizes again in the downstream area. pH in natural waters tends to fluctuate on a diurnal basis, but strong deviations from its natural average usually point to an external cause.

Electric conductivity is an indirect measure for the load of dissolved mineral salts in the water. As conductivity strongly varies with temperature, measurements are reported as the standardised conductivity at 25°C (EC25). A stream's natural conductivity is determined mainly by its hydrology and the mineral composition of the underlying geology and watershed soil. Sudden strong deviations are therefore unlikely to reflect a natural gradient, but can rather be ascribed to an external influence. The (natural) conductivity in most of the headwaters remains under 200 $\mu\text{S}/\text{cm}$, but rises in Fort Portal midstream, with the highest values of around 454 $\mu\text{S}/\text{cm}$ in the downstream fort portal in the natural forest. Downstream in fort portal, conductivity in the main channel is quite stable around 450 $\mu\text{S}/\text{cm}$.

Turbidity is an indirect measure for the content of suspended solids and light permeability of water. Despite the high variability, the waters downstream were the most turbid water (> 50 NTU), while from there on, turbidity decreases gradually midstream and then increases upstream the river course, to a minimum of less than 10 NTU.

The biochemical oxygen demand is the amount of oxygen consumed (typically in 5 days) by microorganisms to decompose the organic material in a water sample. If BOD is high (much oxygen consumed), this is indicative for organic pollution that can lower the oxygen content within the water body. Like COD, BOD is also typically measured to control the quality of

sewage treatment plant effluents. In the Mpanga main channel (and the entire catchment in general) BOD levels were low (<3mg O₂/L), with the highest level found in the midstream of Fort Portal (FPM6).

4.4.1.2 Chemical compounds and nutrients

Ammonium (NH₄⁺) is the ionised form of ammonia (NH₃), which is an extremely toxic compound to aquatic life. The ratio between ammonium and ammonia depends on temperature and the pH of the water and can be calculated. Low concentrations are present by nature, while elevated levels generally indicate pollution from sewage or manure. Nitrite is naturally only present in very low concentrations, as it is quickly oxidised to nitrate from ammonium in presence of sufficient oxygen. Its presence thus indicates recent pollution. In Mpanga's main channel, it was only detected midstream in fort portal, at the same locations where also elevated levels of ammonium were detected.

Nitrate (NO₃⁻) is the oxidised form of nitrogen that can be taken up as nutrient by microorganisms and plants. Natural nitrate concentrations in aquatic systems are usually very low, with elevated values mostly being the consequence of waste discharge or agricultural runoff from fertilisers and manure. Nitrate concentrations are elevated in the midstream. Impervious channels decrease the amount of infiltration due the hardened surfaces which allow nutrients to be easily transported downstream (Walsh et al., 2005).

Total Phosphates (TP) are important phosphorous-compounds that are used by microorganisms and algae and can, together with nitrates, lead to eutrophication and excessive growth of algae if present in high concentrations. Like nitrate, its concentrations are usually limited in natural systems. Phosphates are commonly found in fertilizers and domestic detergents, and thus elevated

concentrations usually point to agricultural runoff or (domestic) waste water discharge. Total phosphates are highest in the midstream stream and urban area, then decrease and remain constant downstream of Fort Portal.

4.4.2 Biological water quality

4.4.2.1 Indicators

In particular, biological biota respond well to nutrient content within river systems. Biological abundance is affected by the availability of certain nutrients in the river (Walsh et al., 2005). The headwaters are in general the most taxon-rich and also harbor the most sensitive communities. In Fort Portal, only about half as many taxa are found and some of the communities are reduced to only a few resistant taxa as indicated by the low ASPT. But biodiversity recovers again and some sensitive species return downstream of the urban area. The ASPT remains somewhat lower than in the UFP and DFP areas, suggesting that there is a lower share of very sensitive species compared to slightly more resistant taxa

The highest mean score of macro-benthos was obtained in natural forests (10.8) and that this was significantly greater than the average score recorded in urban areas (3.9). However, natural forests and agriculture did not differ significantly (Table 4.3.4).

Stream points and land-use types were both found to significantly influence the distribution and abundance of macro-benthos taxa in River Mpanga. The highest concentration of macro-benthos was found downstream in natural forest areas whereas the lowest was observed midstream in urban areas.

The trends observed in the different physical and chemical variables and land use are linked to each other and result from different impact sources along the Mpanga. The most drastic direct disturbance in the headwaters is the sediment extraction from the streams. As the river bed and banks are destabilised, fine particles and soil containing minerals, nutrients and organic matter are flushed downstream, the input of which is further enhanced by runoff from the deforested agricultural mountain slopes. As a consequence, the accumulating minerals and salts alter the pH of the water and cause conductivity to rise already before the river enters Fort Portal. This is also possibly the cause for the decline in DO, nutrients and COD in Fort Portal: microorganisms use oxygen for respiration during the breakdown of the organic matter, thereby using and retaining the nutrients that are supplied from the head waters. Minerals and salts, in contrast, are taken up in much smaller amounts, thus a similar decline in conductivity was not observed. In fact,

conductivity keeps rising until far downstream of Fort Portal due to accumulating effects of sewage, household waste and washing water being discharged into the Mpanga. This is also reflected in the concentration of phosphates which, unlike nitrates, does not decline, because there is additional input from household waste water (detergents) in the city. The concentration drops only downstream of Fort Portal, where the waste water input is less intense. The lower conductivity downstream of Kibale Forest could result from substances like humic acids forming complexes (colloids) in which ions like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and metals like iron (Fe^{2+}) and copper (Cu^{2+}). But to elucidate the exact processes that alter the water composition throughout Kibale Forest more specific monitoring and analyses are needed.

4.4.2.2 Field pictorials



Figure 4. 6: The field team sampling the different sections along the river Mpanga



Figure 4. 7: Some of the benthic invertebrates which have been sorted by the filed team in the laboratory as well as sorting of the benthic invertebrates ongoing

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter provides the summary of the analysis discussed in chapter five and the recommendations in relation to the findings. Future research study to be conducted is also presented.

5.1 Conclusions

The purpose of the study was to find out the benthic invertebrates composition in relation to anthropogenic disturbance along river Mpanga

In regards to water quality, the study revealed that the midstream of the river (in fort portal) was more contaminated than the other study sites along the river

Overall, the water quality parameters evaluated in R. Mpanga, in this study meet the World Health Organisation Standards for aquatic systems health

Although River Mpanga is relatively in good condition, the results in this study indicate that their areas along the river system which are slightly impacted thus care and focus must be given to the anthropogenic activities in the larger catchment in the future. River Mpanga is highly impacted by both the water quality results and diversity and abundance of benthic invertebrates as indicated in the study.

Thus, the river still receives important inputs of household discharges containing detergents and organic waste, both from washing (e.g., laundry, car washing bays) as from controlled and uncontrolled waste disposal. Rinsing water from the local slaughter house and waste disposal from Mpanga Market are additional sources of organic and inorganic (plastic) waste.

5.2 Recommendations

Based on the findings, it is therefore recommended that, although the river is in relatively good condition, the results in this study indicate that there some sections of the river system which are

slightly impacted, thus care and attention must be given to the anthropogenic activities to the larger catchment in the future.

It is recommended that legislative actions be taken by government to ensure compliance with environmental legislations by these industrial and domestic sources of effluents and pollutants. This is because the effect of these anthropogenic activities accumulates as the water flows downstream. It is thus vital to continuously monitor river systems through integrated water resources management plans and their implementation.

Government should allocate more funding to ensure the capacitation of government agencies and departments in terms of infrastructure and human resource to ensure compliance of facilities such as waste water treatment plants, abattoirs, and enforcement where needed for non-complaint factories

5.3 Further research

In line with the findings, A relevant additional analysis would be the determination of microorganisms in the water column, especially faecal coliforms (can cause diarrhoea and vomiting when taken in by drinking water), to identify the main input sources of municipal and industrial sewage in the urban and rural areas, and to map their general spread along the River Mpanga.

5.4 Challenges and lessons learned

Inaccessibility to some points along the river, this was mainly during the wet and rainy season since the road was slippery and the vegetation had overgrown and so sampling was not easy

The high-water volumes during the rainy season made it hard for the macrobenthos sampling since the high tide would push the hand net off the water and the surrounding vegetation

An additional sampling location could be included as most downstream location to represent the ecological quality of Mpanga shortly before it pours into Lake George

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