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ASSESSMENT OF RIVER HEALTH USING PHYSICO-CHEMICAL PARAMETERS AND MACROINVERTEBRATES: A CASE STUDY OF MUNGONYA RIVER IN KIGOMA, TANZANIA

BY

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In collaboration with

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Integrated Water Resources Management of the University of Zimbabwe.

11th July, 2016

DECLARATION

I, **Stephano Mbaruku**, declare that this thesis is my own original work (except where acknowledged) and that it has not been presented to any other University for any other degree award.

Signature: ……………………………..

Date: …………………………………..

DISCLAIMER

The findings of this research, interpretations and all the conclusions expressed in this study do neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor of the individual members of the MSc Examination Committee, nor of their respective employers.

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DEDICATION

To my lovely son ***Arvin Stephen*** and my lovely wife ***Leandra Mbogoni***.

ABSTRACT

Mungonya River is subjected to anthropogenic activities impacts from upstream to downstream, because of rapid population increases in the basin. The main pollution sources include irrigation, washing, bathing, brick making, sand mining and grazing. This study was conducted from December 2015 to March 2016 at six selected sampling points from the upper reaches of the river. The main aim was to assess water quality for river health using selected physico-chemical, biological parameters and macroinvertebrates using the TARISS scoring system in relation to land use and land cover changes. The National Sanitation Foundation Water Quality Index (NSFWQI) and TARISS scoring system methods were used to assess the water quality of the river. Eleven water quality parameters were analyzed and only two were tested in-situ, namely temperature and DO, and four were tested on-site namely, pH, EC, TDS and turbidity, while five were tested in the laboratory (BOD_5, PO_4^{-3}, NO_3^-, TSS and FC). The physico-chemical and biological results were within acceptable standards, except for turbidity (202.5-413.2 NTU) and FC (270.0-616.5 cfu/100ml). It was concluded that the significant increases in irrigation and settlements Land Use Land Cover from 2013 to 2016 were correlated to changes in water quality parameters. The current water quality status of the river was within acceptable standards, except for turbidity and faecal coliforms, with the NSFWQI confirming that the water quality status was medium or average. The TARISS rapid bioassessment method also showed that the river health was fair and there was a weak significant correlation between NSFWQI and TARISS, suggesting complimentarity of the two indices. It was recommended that there should be means of control and mitigation of further pollution of the river and that further studies should be carried out along the river, covering different seasons, in order to establish the status of water quality of the entire river and to establish proper means of managing the river as proposed in the Integrated Water Resources Management and Development Plan (2015) for LTBWB. It is also recommended that the LTBWB should develop a water quality database in order to facilitate improved water quality monitoring.

ACRONYMS AND ABBREVIATIONS

ANOVA…………………………	One Way of Analysis of Variance
APHA……………………………	American Public Health Association
ASPT……………………………..	Average Score Per Taxon
BOD_5……………………………..	5-day Biochemical Oxygen Demand
DID………………………………	Department of Irrigation and Drainage
DO………………………………..	Dissolved Oxygen
EC………………………………...	Electrical Conductivity
EMA……………………………...	Environmental Management Act (Tanzania)
FC………………………………...	Faecal Coliforms
IWRM……………………………	Integrated Water Resources Management
LTBWB…………………………..	Lake Tanganyika Basin Water Board
MASL…………………………….	Mean Above Sea Level
LULC…………………………….	Land Use Land Cover
NASS…………………………….	Namibian Scoring System
NSFWQI…………………………	National Sanitation Foundation Water Quality Index
OKAS…………………………….	Okavango Assessment System
PBWO……………………………	Pangani Basin Water Office
SASS……………………………...	South African Scoring System
SD………………………………...	Standard Deviation
S..………………………….……………...	Sampling Point
TARISS…………………………..	Tanzania River Scoring System
TDS……………………………....	Total Dissolved Solids
TSS……………………………….	Total Suspended Solids
TWQS…………………………....	Tanzania Water Quality Standards
URT……………………………....	United Republic of Tanzania
WHO………………………….…...	World Health Organization
WQI………………………………	Water Quality Index
WRBWO…………………………	Wami Ruvu Basin Water Office
ZISS………………………………	Zambia Invertebrate Scoring System

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CHAPTER ONE: INTRODUCTION

1.1 Water Quality

Water quality is a term used to describe the physical, chemical and biological characteristics of a particular water for the intended use (Bhateria and Abdullah, 2015). Global environmental change induced by natural variability and human activities influences both water quantity and quality at regional and local scales as well as at the global scale (Chang, 2004). Attua *et al.*, (2014) stated that water quality is influenced by both seasonality and geographical location. Besides natural factors such as lithology, topography and climate, surface water quality is influenced largely by anthropogenic impacts including land use. Chang (2004) further stated that physico-chemical variables such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO) concentrations are the most commonly used indicators of water quality. These variables, however, differ in their responsiveness to heterogeneity in land use and land cover (LULC) at multiple spatio-temporal scales. For example, there is some evidence that the area of agricultural land cover influences water quality variables such as nitrogen and phosphorus (Chang, 2004). In this study Land use land cover changes were used to determine how it influenced the water quality of Mungonya river.

1.2 Land Use Land Cover Changes

Mungonya River flows through Kigoma District in Kigoma region, Tanzania where the growth rate is 2.4% and the population is approximately 2,127,930 (URT, 2012). The predominant human activities and/or uses of the river are irrigation, grazing, brick making, sand mining, washing and bathing. The main socio-economic activities in the study area are irrigation or agriculture and fishing as well as brick making. There are several factors that contribute to the decline in water quality such as agricultural practices and population growth which increases the demand for domestic water supply and waste water disposal, This has affected aquatic life and impacted much on other socio-economic uses of water (LTBWB, 2015). The land use along the river causes water quality deterioration in the sense that, the river might be at risk of being polluted

(LTBWB, 2015). The water resources within the basin have been negatively impacted. Lake Tanganyika basin which is under the Ministry of Water is still putting efforts to manage the water resources' quantity and quality in all the basins including Kigoma District (LTBWB, 2015). Apart from land use activities mainly irrigation and settlement contributing to poor water quality. According to Kibena *et al.,* (2013) land use is the primary factor causing environmental degradation and consequently water quality deterioration. Land Use Land Cover (LULC) changes assessed using Landsat satellite images during the period 2013-2016. In order to determine how it could have influenced water quality deterioration, this was based on the premise that water quality in the basin is suspected to be deteriorating due to poor land-use practices, effluent and solid waste pollution (PBWO, 2007).

A few studies have examined the combined effects of land use on water quality at the regional or local scales. Understanding the linkage between water quality indicators and landscape transformation, particularly anthropogenic LULC variability, can be a useful tool in land management decision for effective integrated water resource management (Attua *et al.,* 2014).

1.3 National Sanitation Water Quality Index

The study used the National Sanitation Water Quality Index (NSFWQI) to evaluate the status of the Mungonya River. The NSFWQI gives a single value to the water quality of a source, thereby reducing the large amount of parameters into a simpler expression. This enables easy interpretation of the water quality monitoring data (Chowdhury *et al.,* 2007). The NSFWQI is used to check the water quality status of a water body while other water quality indices, like the Dinius Water Quality Index (DWQI) is used to check the water quality status for a specific water use. So the NSFWQI gives the overall status of water quality of a specific area (Poonam *et al.,* 2013). The NSFWQI uses nine water quality parameters to come up with a classification of the status to which the water body belongs (Bash, 2015). During this study biomonitoring was also used to assess the water quality of Mungonya river.

1.4 Biomonitoring

Todd *et al.,* (2000) defines biomonitoring as the use of a biological community to provide information on the quality or "health" of an ecosystem. The ecological integrity of a river is its ability to support and maintain a balanced, integrated and adaptive composition of physico-chemical characteristics with a biological diversity, composition, and functional organization on a temporal and spatial scale that is comparable to those characteristics of a natural aquatic ecosystem in the region (Todd *et al.,* 2000). The main advantage of a biological approach is that it examines organisms (macroinvertebrates) whose exposure to pollutants is continuous. Thus, species present in riverine ecosystems reflect both the present and past history of the water quality in the river, allowing detection of disturbances that might otherwise be missed (Todd *et al.,* 2000).

1.5 River Health

In river health assessment, the use of macroinvertebrates must be combined with the analysis of water quality parameters (Bwalya, 2015). In order to assess the river health of Mungonya River both on particular physico-chemical water quality parameters and macroinvertebrates, were used in order to provide fundamental information needed in decision-making and to contribute to the management of water quality in Mungonya River in an effective manner. Macroinvertebrates are organisms that can be seen with a naked eye and lack a backbone (Norris and Thoms, 1999). The abundant existence of these organisms in water indicates that the water quality is good. River health is applied to the assessment of river condition (Norris and Thoms, 1999).

The River Health Programme (Norris & Thoms, 1999) was initiated in South Africa in order to determine the ecological status of river systems, as a basis towards supporting the rational management of river ecosystems (Todd *et al.,* 2000).

According to Todd *et al.,* (2000) the River Health Programme (RHP) is a management information system, that produces information for a specific objective. The primary focus of the RHP is to determine the health of aquatic ecosystems. River health is assessed by studying the fauna and flora that exists in the river. Macroinvertebrates are good short to medium term indicators of ecosystem health, while fish and riparian vegetation are good long-term indicators of river health (Todd *et al.,* 2000). By using these biological indicators the status of the rivers' health can be monitored and if necessary, corrective action taken. The integration of biological indicators with chemical and physical indicators can be used to assess the river health of a river. The aim is to ensure public health protection and to protect the desirable water quality (Todd *et al.*, 2000).

The River Health Programme focuses on qualitative and quantitative information requirements and the ability of the programme to deliver the information (Todd *et al.*, 2000). In the past, water resources in Tanzania were managed administratively but nowadays, they are all managed in basins after observing unnecessary conflicts in administrative management. At present, there are nine river basins (URT, 2002), and Mungonya River is one of the rivers under Luiche catchment in Lake Tanganyika Basin (LTBWB,2015).

1.6 TARISS

Tanzania River Scoring System (TARISS) rapid bioassessment index was used in this study to assess the water quality status of Mungonya River. TARISS was developed in 2012 basing on the principles of South African Scoring System (SASS) (Kaaya *et al.*, 2015). Tanzania River Scoring System (TARISS) has been conducted only in three rivers basins namely; Rufiji Basin, Wami-Ruvu Basin and Pangani Basin (Kaaya *et al.*, 2015). TARISS has been validated and tested for the East African Countries conditions. TARISS was developed to fit with the East African country's conditions such as Kenya, Uganda, Burundi and Rwanda in order to cater for the differences due to climate, geology, longitude and latitude. Biomonitoring studies have been conducted and published for the purpose of river health monitoring on only three river basins out of nine basins in Tanzania (Kaaya *et al.,* 2015). There is lack of expertise in biomonitoring in Tanzania. The government is making effort to facilitate education to ensure that the biomonitoring personnel are available for assessing river ecosystems (URT, 2002).

The Tanzania River Scoring System (TARISS) index was developed to assess the rivers but currently, it is not effectively used due to lack of expertise (Kaaya *et al.,* 2015). According to URT (2009) there is a need for managing water resources because water is a fugitive resource and for protecting biological diversity in aquatic ecosystems. This study contributes towards generating information on water quality and indicating the river health challenges that are being faced in Tanzania. River health assessment through using SASS or TARISS indices is cheaper, easy to use and less time consuming (Kaaya *et al.,* 2015). The decline in the water quality as well as river ecosystems is one of the major Tanzania.

1.7 Statement of the Problem

The human activities within the catchment of Mungonya River such as irrigation, sand mining, brick making, washing and bathing are compromising the river water quality (LTBWB, 2015b). The public could be exposed to health risks as unabated deterioration of water quality in Mungonya River might eventually affect the water quality of Lake Tanganyika (URT, 2002). To date no studies have been conducted to determine the health of Mungonya River. The lack of information on the water quality of Mungonya river impairs decisions on the wise use of water and management (LTBWB, 2015b). Most of the above-mentioned human activities occur within sixty metres of the river banks and thus adversely affect conservation and/or the protection of Mungonya River (URT, 2004).

1.8 Research Objectives

1.8.1 General Objective

To assess the water quality and health status of Mungonya river using selected physico-chemical parameters and macroinvertebrates from December, 2015 to March, 2016, in relation to land use and land cover changes.

1.8.2 Specific Objectives

(i) To assess land use land cover changes within the catchment of Mungonya River in relationship with the water quality status using Landsat Satellite Images for 2013, 2015 and 2016.

(ii) To assess the physical, chemical and biological characteristics water quality of Mungonya River.

(iii) To assess the water quality status of Mungonya River using the US National Sanitation Foundation Water Quality Index.

(iv) To assess the water quality of Mungonya River using the Tanzania River Scoring System (TARISS) rapid bioassessment index and correlate it with National Foundation Water Quality Index (NSFWQI).

1.8.3 Research questions

(i) What is the relationship between land use change and water quality status of Mungonya River for 2013, 2015 and 2016?

(ii) What is the current water quality status of Mungonya River with respect to physico-chemical and biological parameters from December, 2015 to March, 2016?

(iii) What is the National Sanitation Foundation Water Quality Index of Mungonya River from December, 2015 to March, 2016?

(iv) What is the relationship between TARISS rapid bioassessment index and National Sanitation Foundation Water Quality Index of Mungonya River from December, 2015 to March, 2016, and which of the two is a more reliable indicator?

1.9 Justification

Mungonya River is an important source of water for the surrounding communities who depend on it for their livelihood through fishing, domestic use and several other activities. However, the river is threatened by pollution from human activities. The human activities are negatively impacting on the water quality of the river. This is leading to escalation of water supply cost and an increase in water resource scarcity, especially to those communities using water from the river. Unsustainable irrigation along the river is the major human activity affecting the river (LTBWB, 2015). According to Kimirei *et al.,* (2015) the demand for animal protein in Kigoma region is high and the importance of fish, especially clupeids, is reduced due to the poor water quality caused by unsustainable human activities.

In Tanzania, the studies that have been conducted to assess the river health assessment status are limited. According to Kaaya *et al.,* (2015), assessment has been done only in three river basins out of nine basins namely Rufiji Basin, Wami-Ruvu Basin and Pangani Basin. The loss of biodiversity is increasing significantly to the extent that the Convention on Biological Diversity (CBD) considers inland waters as one of the most threatened ecosystem types (Carr and Rickwood, 2008). Biodiversity of freshwater ecosystems is declining faster than for any other ecosystems. Monitoring of water quality is consequently essential in order to institute appropriate management decisions.

A nation's water resources require protection, usage, development, conservation, management and control in ways which take into account the need to protect the biological diversity especially the aquatic ecosystems, this study contributes towards this (URT, 2009). The challenges that are faced by the Tanzanian water sector it include lack of water quality data and adequate number of highly skilled professionals in biomonitoring (URT, 2002).

The study assists in reinforcing Integrated Water Resources Management Dublin Principle 1 "Ecological": Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Pertaining Sustainable Development Goals (SDGs), the study will also assist to ensure availability and sustainable management of water and sanitation for all. The study will assist addressing SDGs Target 6.3 by 2030; improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Water is an essential resource for human life. However, most of the surface water sources have been depleted due to pollution, climate change and poor solid waste management (Todd *et al.,* 2000). There is extensive recognition that water resources are under pressure from increasing demand and declining yields (Todd *et al.,* 2000). Water supply systems have often been developed in an unsustainable way, threatening vital social and economic development. Water quality is one of the key parameters to be considered in ensuring the safety of water for human consumption. Water quantity and water quality are both important and need to be considered to ensure that the users use clean and safe water (Todd *et al*., 2000).

Human activities have had a series of progressively worsening impacts on water resources and ecosystems. Therefore, for its sustainability, water needs to be properly managed (Zhou *et al.,* 2015). According to Valeriani *et al.,* (2015), in order to prevent possible adverse effects on human health and the environment, a correct approach to water quality assessment and management is needed. In the past, water quality assessment was essentially centered on the evaluation of physical and chemical parameters of water itself, focusing on sources of pollution only (Dladla, 2009).

However, the study carried out by Kibena *et al.,* (2013) showed that land use is the primary factor causing environmental degradation and water quality deteriorations. Unsustainable irrigation means the use of water within sixty meters from the river banks for the purpose of improving productivity of agricultural crops per unit of land per of water and thereby contributing to increased food security (URT, 2009). The unsustainable land uses such as unsustainable irrigation is one of the land uses that result in land degradation which further degrades the water quality.

The realization of the biological effects of water pollution has resulted in the development of a number of methods through which water quality is assessed by analyzing the indigenous aquatic community (Valeriani *et al.,* 2015). Also Valeriani *et al.,* (2015) noted that the method of assessing the health of the river commonly used organisms such as macroinvertebrates. These organisms are stable within a wide range of environmental fluctuations, and form interrelated populations whose structure and function reflect the underlying abiotic and biotic conditions in stream ecosystems (Valeriani *et al.,* 2015). Score systems using macroinvertebrates have been developed to enable the interpretation of large quantities of data that are may be obtained from the biological monitoring of water quality (Phiri, 2000).

De Moor *et al.,* (2000) described the use of macroinvertebrates abundance and diversity to provide information on the status or 'environmental health' of a river ecosystem. The community structure of aquatic invertebrates can provide a time-integrated measure of prevailing conditions (De Moor *et al.,* 2000).

According to De Moor *et al.,* (2000) the presence or absence and relative abundance of macroinvertebrate species can be used to assess disturbance events which occurred prior to sampling to determine the health of the river. Aquatic macroinvertebrates are sedentary and thus vulnerable to ecological disturbances, unlike fish which can move away from unfavourable areas and return once temporary disturbances have passed (De Moor *et al.,* 2000).

2.2 Land Use Land Cover Changes

Anthropogenic activities such as agriculture, washing, forestry, brick making and industries often lead to more intensive land use which in turn increases runoff (Kibena *et al.,* 2013). As anthropogenic land disturbance continues to increase worldwide, aquatic scientists are faced with the challenge of determining how human activities influence the structure and function of aquatic (Attua *et al.,* 2014). For example, in sub-

Saharan Africa, tropical forests are threatened by accelerating rates of forest conversion and degradation. The situation is severe in East Africa, where many remaining forests are islands of forest surrounded largely by converted land. It is estimated that only 28% of the original rain forests that covered East Africa remain, with the majority of land clearing associated with subsistence farming and fuelwood harvest (Kasangaki *et al.,* 2007). The evidence has been drawn from the study conducted by Attua *et al.,* (2014), the nature of land cover changes could alter the water quality dynamics.

2.3 Water Quality

Water quality is the term used to portray the physical, chemical and biological characteristics of particular water for the intended use (Bhateria & Abdullah, 2015). The quality of water resources is deteriorating dramatically in many places on a daily basis and this is one of the major problems faced by people (Bhateria & Abdullah, 2015). The causes of the deteriorations are both natural (for example, changes in precipitation and erosion) and anthropogenic (for example, urban, industrial and agricultural activities and excessive human exploitation of water resources) reasons for this continuing degradation of water on our planet (Bhateria & Abdullah, 2015). Therefore on the basis of water quality the study is going to look on physical, chemical and biological parameters.

2.4 Water Quality Parameter Selection

Rangeti *et al.,*(2015) explains that the first step in water quality parameter selection is to choose an appropriate set of variables. Since it is generally impossible to monitor all water quality variables due to time constraints and lack of resources, the most important variables should be considered. The selection of chemical and physical analysis to be performed on each sample is based on the purpose of the study, the data quality objectives and available resources (Agency *et al.,* 2001).

2.5 Physical Parameters

The physical parameters selected should give information on the water quality trends and should provide information on the quality of the water resource (Carr and Rickwood, 2008). The following physical parameters were considered:

2.5.1 Temperature

Temperature is one of the important factors in the aquatic environment, because it regulates the various physicochemical and biological processes. The temperature of surface waters is influenced by latitude, altitude, season, air circulation, tree cover, flow and depth of a water body (Bhateria and Abdullah, 2015). Carr and Rickwood (2008) explained that the identification for water temperature is difficult because natural variations occur with climate and season. An increase in temperature which may occur due to climate change has the potential to result in shifts in species composition and loss of endemic species (Carr and Rickwood, 2008). Temperature of water varies throughout the day and year. A change in temperature can alter the chemical properties of a wide range of parameters (David *et al.,* 2007).

2.5.2 Turbidity

Turbidity is a measure of how clear the water is. A turbidity meter is used to measure turbidity in Nephelometric Turbidity Units (NTU). The turbidity is influenced either naturally by rainfall runoff or by anthropogenic activities. Wastes from industries influences turbidity. Turbid water affects for photosynthesis by limiting the penetration of light (Carr and Rickwood, 2008).

2.5.3 Total Suspended Solids (TSS)

Fine particles are often carried as suspended materials by stormwater runoff (Shammaa and Zhu, 2016). Sources of TSS include erosion in construction points and landfill areas, combined sewer overflow systems, dust in the air, erosion in stream channels by stormwater flows, and fine metals and other particles from roads and vehicles

(Shammaa and Zhu, 2016). The contribution of each source to TSS loading is not well known (Shammaa and Zhu, 2016). However TSS loading is directly related to the degree of urbanization (Shammaa and Zhu, 2016). TSS are important pollutants in stormwater runoff which degrade the quality of the receiving water by making it turbid, inhibiting plant growth and reducing species diversity (Shammaa and Zhu, 2016). On settling at the bottom, excess sediment destroys fish spawning beds and the habitats of bottom, dwelling biota that depends on the small cracks or space of sand and gravel particles for their habitat. Stormwater runoff is the major source of the TSS released to aquatic systems. High levels of suspended solids in water are an indication of water pollution (Shammaa and Zhu, 2016).

2.5.4 Total Dissolved Solids (TDS)

TDS is the ability of water to dissolve various inorganic and some organic minerals or salts like potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulfates (Bwalya, 2015). There is no consensus on the negative or positive effects of water that exceeds the WHO standard limit of 1,000 mg/l (Bwalya, 2015). In urban areas the increase in the amount of TDS in water bodies mainly originates from sewage and urban industrial wastewater discharges (Bwalya, 2015). TDS test is an indicator of the quality of water in a water body. High levels of TDS reduce algal productivity and growth. High TDS depicts the poor water quality (Bwalya, 2015).

2.5.5 Electrical conductivity (EC)

Electrical conductivity is a measure of the ability of a sample of water to conduct an electrical current (Carr and Rickwood, 2008). The increase in land use practices in the catchment influences higher TDS which contributes high EC. High EC indicates that the water is salty which is not acceptable for macroinvertebrates because some they cannot tolerate in that condition (Carr and Rickwood, 2008).

2.5.6 Dissolved Oxygen (DO)

Dissolved oxygen is the amount of gaseous oxygen dissolved in an aqueous solution (Carr and Rickwood, 2008). Adequate dissolve oxygen is necessary to sustain aquatic biota. Oxygen content is important for the direct need of many organisms and affects the solubility of many nutrients and the periodicity of aquatic ecosystem. In summer, dissolved oxygen decreases due to increase in temperature and increased microbial activity (Carr and Rickwood, 2008).

The lowest acceptable dissolved oxygen concentration for aquatic life, ranges from 6 mg/l in warm water to 9.5 mg/l in cold water (Carr and Rickwood, 2008). DO is vital to the aquatic organisms as they use it for survival (David *et al.,* 2007). Low DO depicts that the aquatic ecosystem is degraded and some organisms that use aerobic conditions will not manage to survive due to lack of oxygen (David *et al.,* 2007).

2.6 Chemical Parameters

2.6.1 pH

The pH indicates the intensity of acidity and alkalinity and measure hydrogen ions in water. Water which has a pH value of more than 9 or less than 4.5 becomes unsuitable for domestic use like drinking (Bhateria and Abdullah, 2015). The pH is most important in determining the corrosive nature of water. The lower the pH value higher is the corrosive nature of water. Various factors bring about changes in the pH of water. Low pH increases the solubility of metals and nutrients such as phosphates and nitrates making them available for uptake by plants and animals (Mero, 2011). pH is temperature dependent, thus newer pH meters have been designed to automatically measure temperature and adjust to give a correct pH reading (David *et al.,* 2007).

2.6.2 Biochemical Oxygen Demand (BOD)

According to Bhateria and Abdullah (2015) BOD is the measures of the amount of oxygen that is required by microorganism for aerobic decomposition of organic matter present in water. BOD is an important parameter in aquatic ecosystem since it indicates the status of pollution (Bhateria and Abdullah, 2015). BOD can be affected by human activities in the riparian areas, which destroy the buffering capacity of the river against pollutants emanating from the catchment. The greater the BOD, the more rapidly oxygen is depleted in the water body, because microorganisms are using up the DO (Masese *et al.*, 2015). The consequences of high BOD are the same as those for low dissolved oxygen; whereby aquatic organisms become stressed, suffocate, and die (Masese *et al.*, 2015).

2.6.3 Nitrate (NO_3^-)

Nitatre is an important nutrient in aquatic ecosystem for plants growth and it limits algal growth (Bwalya, 2015). According to Bwalya (2015) nitrogen containing elements are essential for all biotic processes in the aquatic environment. The increase of nitrate concentration in watercourses is due to the anthropogenic activities. When it rains, the runoff from agricultural activities carries fertilizers to the watercourses causes pollution of water bodies. The increase of nitrate cause excessive algal growth, upon decomposition excessive algal growth lowers oxygen levels thereby some aquatic organisms that cannot tolerate anaerobic condition (Mwangi (2014). High nitrate levels recorded in surface waters originate from human activities and differ with land use (Mwangi (2014). High nitrate concentrations observed in many river systems may be due to diffuse source from urban and agricultural runoff and to point discharge from sewage treatment plants (Mwangi (2014).

2.6.4 Phosphate (PO_4^{-3})

Major nutrient for the plants growth, in aquatic ecosystems if phosphorus exceeds the acceptable limit affects aquatic ecosystem by decreasing the oxygen after excess algal growth (Bwalya, 2015). Fertilizers, after being used for agricultural activities, are washed down to the water bodies bringing in high loads of phosphorus (Bwalya, 2015). Phosphorus can exist in a variety of forms in aquatic ecosystem namely: as mineral phosphorus, inorganic phosphorus and organic phosphorus (phosphorus bound up with carbon and oxygen in plant matter) and as dissolved soluble reactive orthophosphate (PO_4^{-3}) (Kihampa *et al.,* 2013).

2.7 Biological Parameters

2.7.1 Faecal Coliforms (FC)

Coliforms bacteria originate in the intestines of warm-blooded animals. Fecal coliforms are capable of growth in the presence of bile salts or similar surface agents (Bhateria and Abdullah, 2015). The assay is an indicator of fecal contamination *E. coli* is an indicator microorganism for other pathogens that may be present in feces. The presence of fecal coliforms in water may not be directly harmful, and does not necessarily indicate the presence of feces (Bhateria and Abdullah, 2015).

2.8 Water Quality Index

According to Mustapha and Aris, (2011) the water quality index was developed in order to integrate the composite influence of various physical, chemical and biological parameters measured. This enables comparison of different samples for quality on the basis of the index value for each sample. The assessment of water quality can be defined as the analysis of physical, chemical and biological characteristics of water (Bharti and Katyal, 2011). Water quality indices aim at giving a single value to the water quality of a source reducing great amount of parameters into a simpler expression and enabling easy interpretation of monitoring data (Bharti and Katyal, 2011).

Water Quality Index is a scale used to estimate an overall quality of water based on the values of individual water quality parameters (Bash, 2015). It is a mathematical expression used to transform large quantities of water quality data into a single number and it is a measure of how the water quality parameters compare to the water quality guidelines or objectives for a specific area (Bash, 2015). Sometimes referred to as water quality information communicator, it is considered the most powerful tool in communicating useful information to decision makers and the general public (Bash, 2015).

To analyze the water quality, different methods can be used such as statistical analysis of individual parameters, multi-stressors water quality indices (Bharti and Katyal, 2011). There are different water quality indices like Weighted Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Dinius Water Quality Index (DWQI) and the Oregon Water Quality Index (OWQI) whose selection depends on the status of water to be assessed and selected parameters (Bwalya, 2015).

Numerous water quality indices have been formulated all over the world which can easily determine the overall water quality within a particular area promptly and efficiently (Bharti and Katyal, 2011). Some of these water quality indices are limited to only one specific use like recreational so the use of water quality index depends on the use under consideration. Water quality indices are tools to determine conditions of water quality and, like any other tool require knowledge about principles and basic concepts of water and related issues (Poonam *et al.,* 2013).

2.8.1 Categories of WQI

According to Poonam *et al.,* (2013) water quality indices are categorized into four main groups namely; Public indices: do not consider the type of water consumption within the analysis method and are used for the analysis of general water quality eg National Sanitation Foundation Water Quality Index (NSFWQI), specific consumption indices: are based on the premise of the type of consumption and application such as drinking, industrial and ecosystem preservation examples include the Dinius, Oregon and British Columbia indices. Designing or planning indices: act as an instruments in planning water quality management projects and aiding decision making. Statistical indices: are based on statistical methods. The essential part of statistical approach is relevance bound assumptions of water quality observations.

2.8.2 Relevance of National Sanitation Water Quality Index to this study

According to Curve (2006) water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of a stream with a single number. That number is placed on a relative scale or benchmark classification that rates the water quality in categories ranging from very bad to excellent. This study used NSFWQI because it assesses the status of general water uses of the river and not specific water use like irrigation or recreation. Nine physico-chemical and biological water quality parameters were used. NSFWQI is used as a tool to protect and promote human health by providing a clean environment, and it is more sensitive than the Weighted Average Water Quality Index to show changes in the individual variables (Mustapha and Aris, 2011).

Due to its exposure to pollution surface water quality has been a subject of study in many parts of the world (Mustapha and Aris, 2011). Water Quality Index (WQI) was developed at the National Sanitation Foundation (NSF) during 1970's in United States of America. Calculation of the water quality index is based on nine physico-chemical and bacteriological water quality parameters. NSFWQI calculation is based upon temperature, pH, turbidity, faecal coliform, dissolved oxygen, biochemical oxygen demand, phosphates, nitrates and total solids (Bash, 2015). The mathematical expression for NSFWQI is:

$$NSFWQI = \sum_{i=1}^{n} I_i W_i \qquad \text{Equation (1)}$$

Where, I_i is sub-index for **i**th water quality parameter;

W_i is weight associated with **i**th water quality parameter;

n is number of water quality parameters.

The conventional methods for evaluating the quality of water are based on the comparison of experimentally determined parameter values with the existing guidelines (Poonam *et al.,* 2013). Water quality indices are an example of such an approach. They minimize the data volume and simplifies the expression of water quality status. Bash (2015) observed that water resources professionals generally evaluated water quality variables individually and presented this information in terms of values or figures. While this technical language is understood within the water resources community, it does not readily translate into meaningful information to those communities having profound influence on water resources policy, the lay public and policy makers. Bash (2015) observed that it is difficult to determine the water quality from a large number of samples, each with values for many parameters. Water quality index turn complex water quality data into information that is understandable and user friendly to the public. Any water quality index should be based on some very important water quality parameters that could be used to provide a single indicator of water quality (Bash, 2015).

The NSFWQI classifies water quality into five (5) categories starting from 0 to 100 as shown in Table 2.1. Excellent water is suitable for drinking and aquatic life. Table 2.1 classification of water quality status based on NSFWQI of the River (Mnisi, 2010).

Table 2.1: Classification of water quality status based on NSFWQI

Numerical Range	Category	Descriptor Word
91-100	A	Excellent Water Quality
71-90	B	Good Water Quality
51-70	C	Medium/Average Water Quality
26-50	D	Bad/Fair Water Quality
0-25	E	Very Bad/Poor Water Quality

2.8.3 Limitations of Water Quality Indices

There are limitations in the use of WQIs which include;- loss of information by combining several variables to a single index value; the sensitivity of the results to the formulation of the index; the loss of information on interactions between variables and the lack of portability of the index to different ecosystems (Bash, 2015). The NSFWQI has advantages and disadvantages. According to the study conducted by (Bash, 2015) the following are the advantages and disadvantages of the NSFWQI;-

2.8.4 Advantages of NSFWQI

The major advantage is that it summarizes data in a single index value in an objective, rapid and reproducible manner. Additionally, it evaluates between areas and identifies changes in water quality. Index value relates to a potential water use and it facilitates communication with lay person.

2.8.5 Disadvantages of NSFWQI

The maojor disadvantage is that it represents general water quality and not represents specific use of the water. It does not give the causative effect of the status of the river. Its calculation is specific for only nine water quality parameters while some index uses more than nine parameters which are not cost effective.

This study used NSFWQI to come up with a single value to classify different sampling points as well as the condition of Mungonya River. The major limitation is that Bash (2015) a single number cannot provide a comprehensive status of the water quality of a river because many other water quality parameters are not included in the index. However WQI based on very important parameters can provide a simple indicator of water quality for a particular resource. Besides the NSFWQI, the study used TARISS rapid bioassessment index to assess the health status of the river.

2.9 The importance of assessing the ecological integrity of rivers

Ecological or biological integrity is a measure of how intact or complete an ecosystem is (Ollis *et al.,* 2006). Freshwater ecosystems provide a host of critical life support services and have an irreplaceable essential value (Ollis *et al.,* 2006). There is widespread evidence that freshwater ecosystems, and rivers in particular, are amongst the most threatened ecosystems (Ollis *et al.,* 2006). The ecological integrity of rivers and other freshwater ecosystems is a direct reflection of the activities in the catchments they drain. Most catchments are subject to an array of ecologically unsustainable land-use and development activities (Ollis *et al.,* 2006). The threats to the ecological integrity of river systems are most apparent in arid areas, being particularly severe in developing regions, where almost all of them are due to escalating water demands (Ollis *et al.,* 2006).

2.10 Biomonitoring

Biomonitoring is a collective term for all the techniques that use living organisms to provide information about both abiotic (non-living) and biotic (living) components of an environment (Day, 2000). The study conducted by Palmer *et al.,* (2004) explains the advantages and disadvantages of biomonitoring; although, the disadvantages do not outweigh the advantages. These are as listed below;-

2.10.1 Advantages of biomonitoring

According to Palmer *et al.,* (2004) the advantages for biomonitoring are: (1) It provides information on environmental conditions that must have prevailed in the river at the beginning. (2) It also provides a long-term integrated view of biotic integrity and quality of water in the river system. (3) Resident aquatic organisms will reflect pollution events through changes in their biology and ecology. (4) The activity is cost-effective and is scientifically recognized. (5) It provides for multiple site investigations in a field season and there is quick turn-around of results for management decisions

2.10.2 Disadvantages of biomonitoring

Biomonitoring has some disadvantages, (1) The existence of a large spread of results between very good conditions and fair/poor. (2) It is not precise. (3) Biomonitoring cannot be used to identify a specific pollutant; it merely provides an indication that there is something wrong with the water quality. (4) Monitoring cannot be done very successfully during high flow periods. (5) There is a danger that classification of sampling points and habitat types may be subjective. It is therefore vital that experienced personnel are involved in the determination of sampling points.

2.11 South African Scoring System (SASS)

The South African Scoring System is a biotic index developed by Chutter in 1998. It has been tested and refined over several years and the current version is SASS5 (Dickens and Graham, 2002). The biomonitoring technique is based on a British biotic index called Biological Monitoring Working Party (BMWP) scoring system and has been modified to suit South African fauna and conditions. SASS is a rapid biological assessment method developed to evaluate the impact of changes in water quality using aquatic macroinvertebrates as indicator organisms (Dickens and Graham, 2002). The biological assessment of the river by using macroinvertebrates is internationally recognized and accepted. The United Kingdom was the first nation which started using rapid biomonitoring method for river health assessment in 1970s (Elias *et al.,* 2014). Biomonitoring assessment started in South Africa then spread to different countries within the southern region.

In Africa four biotic indices based on aquatic macroinvertebrates have been developed in the southern region namely; the South African Scoring System (SASS) in South Africa, the Namibian Scoring System (NASS) in Namibia, the Okavango Assessment System (OKAS) in the Okavango Delta and the Zambia Invertebrate Scoring System (ZISS) in Zambia (Kaaya *et al.,* 2015). NASS, OKAS and ZISS have been modified from SASS, which has been extensively tested in South Africa and has proven its capability and reliability as an index for the assessment of water quality and general river condition. Tanzania has got its own rapid bioassessment index (TARISS) that originates from SASS. The study used TARISS rapid bioassessment index for assessing the health of Mungonya River in Kigoma, Tanzania.

2.12 TARISS in Tanzania

The Tanzania River Scoring System (TARISS) was developed in 2012 basing on the South African Scoring System (SASS) (Kaaya *et al.,* 2015). Additionally Kaaya *et al.,* (2015) explained that in Tanzania, the study showed that river assessment by using aquatic macroinvertebrates provides positive results due to its advantages over disadvantages.

SASS is applicable to South African due to differences in climate, geology and longitude and latitude. TARISS has been designed and tested for perennial lotic waters. There are three principal indices that has to be calculated in TARISS assessment namely; TARISS Total Score, No. of Taxa and Average Score per Taxa (ASPT) (Kaaya *et al.,* 2015). A quality score based on its susceptibility to pollution is allocated for each taxon per sample. High score is attributed to greater sensitive organisms and the low score correspond to tolerant organisms (Mwangi, 2014). The lower ASPT indicates that there area might be highly utilized and highest ASPT not highly utilized (Mwangi, 2014).

2.12.1 Limitations of SASS and TARISS

SASS does not distinguish the types of pollutants that cause poor health of the river (Bwalya, 2015). SASS does not determine the extent or concentrations of the pollutants. It only provides an indicator that the river is not healthy so further investigation have to be done to determine with the approximate figures that depict the concentrations of the pollutants. These limitations applies to TARISS. Table 2.2; shows benchmark category boundaries for TARISS (Town, 2004).

Table 2.2: Benchmark category boundaries for TARISS

Class boundary (River Category)	Range of ASPT scores
Natural	7
Good	6-6.9
Fair	5-5.9
Poor	Less than 5

2.13 Benthic macroinvertebrates

In assessing the Mungonya River health benthic macroinvertebrates were used. Benthic macroinvertebrates are the organisms without backborne or those organisms that could be seen with the naked eyes and are retained in the mesh sizes greater than or equal to 200 to 500 micrometers (Rajele, 2004). The following are the advantages and disadvantages of using benthic macroinvertebrates in water quality monitoring (Rajele, 2004).

2.13.1 Advantages of using benthic macroinvertebrates in water quality monitoring

Rosenberg and Rajele (2004), identified some advantages and disadvantages of using macroinvertebrates in water quality biomonitoring. Benthic macroinvertebrates occur in all lotic system habitats, and are therefore affected by virtually any disturbance that takes place in the streams or rivers that they inhabit. Many macroinvertebrates are sensitive to various chemical and physical disturbances, and their ubiquitous nature makes them suitable tools for monitoring the effects of such perturbations. Their sedentary nature makes them suitable tools to ascertain the effects on various lotic environments. Their life cycles are relatively long and this makes them suitable tools to determine regular disturbances, intermittent perturbations and variable concentrations to be examined temporally. The methods for analyses are well developed; therefore qualitative sampling is achievable with the use of inexpensive and simple equipment. Most of the macroinvertebrates can be identified with ease and their identification keys are available. Readily-available documentation on macroinvertebrate response to various common pollutants and a rich inventory on their data analyses make them suitable tools for management of lotic systems. They are responsive to research activities undertaken either in the laboratory, or *in-situ*. Although the advantages of biological monitoring of the aquatic ecosystem outweigh those of the chemical-based methods, it may not be practical to rely on biomonitoring as the sole monitoring technique. More research on the interaction of the environmental variables (physical and chemical) and biota still needs to be conducted.

2.13.2 Disadvantages of using benthic macroinvertebrates in water quality monitoring

There are disadvantages associated with the use of benthic macroinvertebrates (Rajele, 2004). Qualitative sampling requires large numbers of samples and this can be costly. Macroinvertebrates such as dragonflies and mosquitoes are susceptible to factors other than water quality, which equally influences their distribution and abundance. Seasonal variations may complicate interpretations and comparisons. Other organisms have the tendency to drift, and that may offset the advantages gained by the sedentary nature of many species. They are not sensitive to all perturbations. Certain organisms are taxonomically not well known.

CHAPTER THREE: STUDY AREA

3.1 Location

The study site was Mungonya River which is located in Kigoma District in Tanzania. Kigoma Region is located in the western part of Tanzania between latitudes 2° 45″ and 8° 45′ and longitudes 29° 35′and 34° 00′ (Figure 3.1). The district has a population growth rate of 2.4% and a population of 211,566 according to census 2012. The Mungonya River is used by approximately 41,300 people (URT, 2012). Kigoma Region has six districts namely Kigoma, Uvinza, Buhigwe, Kakonko, Kasulu and Kibondo. Lake Tanganyika forms the western and southern borders of the district. To the North and East, the municipality is bordered by Kigoma District (Mbuligwe, 2010). Tanzania mainland has nine river basins which includes the Lake Tanganyika Basin. The basin authority is responsible for to collecting, processing and analyzing data for water resources management (URT, 2009). Figure 3.1 shows the administrative map showing the location of the study area.

3.2 Climate

The climate in the basin is a semi-humid tropical climate with two main seasons that is the dry season from June to October and the wet season from November to May. Air mass movement along the steep slope or cliff produces frequent intense rainfall in highly localized heavy thunderstorms particularly in areas north of Kigoma (LTBWB, 2011).

3.3 Temperature

Temperatures in the basin range from 18 °C to 30 °C, average temperature around Mungonya River is 25 °C. The variation in mean monthly temperature is small, while the spatial variation is much larger and is related to altitudinal differences (LTBWB, 2015a).

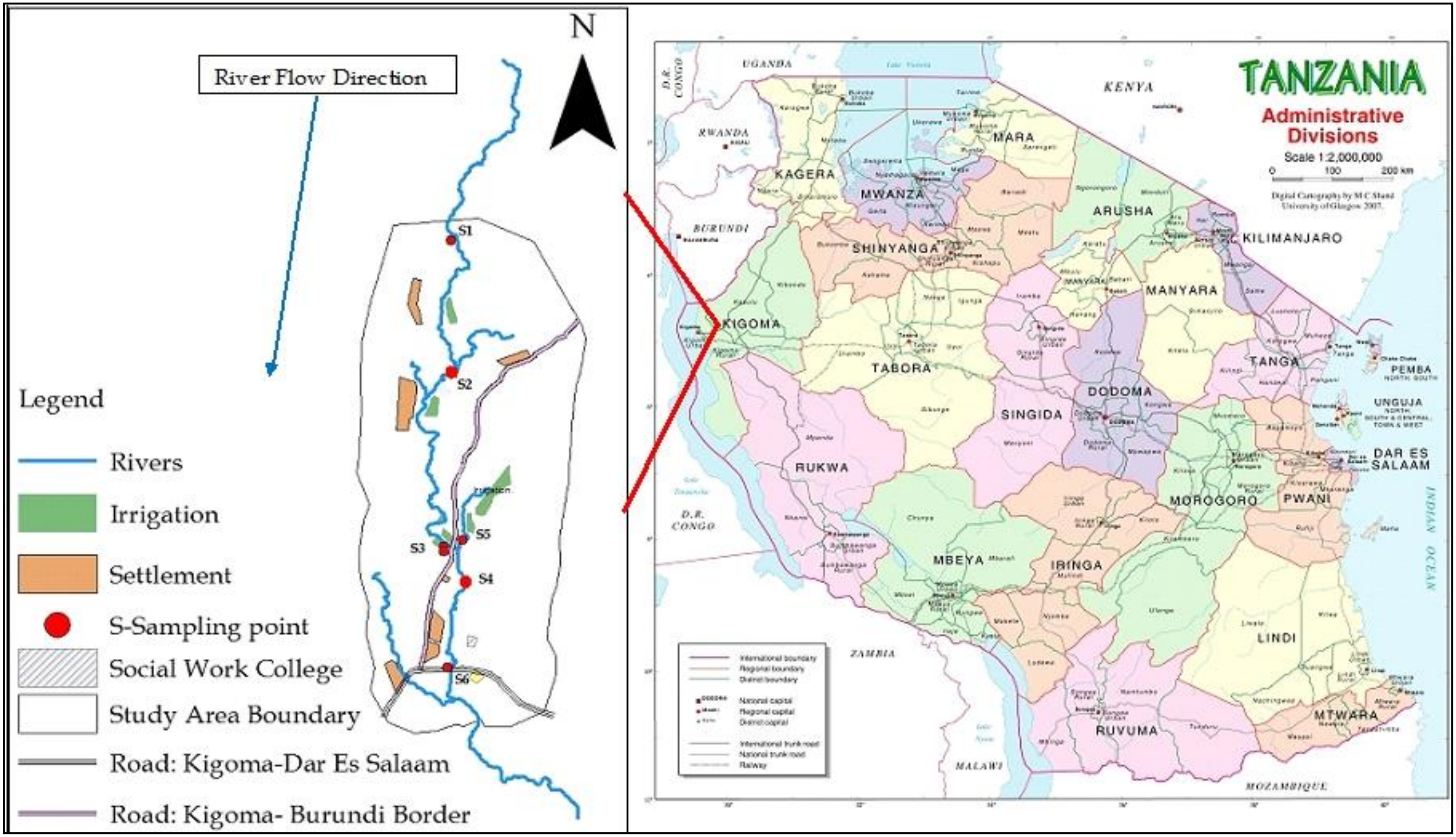

Figure 3.1: The administrative map showing the location of the study area

3.4 Hydrology of Mungonya River

Mungonya River is a perennial river, its source is in Mgazo village in Luiche catchment which is 2600 km^2 (LTBWB, 2015). The Mungonya river area spans over 128 km^2. The rainfall in the area ranges from about 980mm/year in the south to 1250 mm/year in the north, with an average of 1125 mm/year (LTBWB, 2015). Mungonya River is a tributary of Luiche River, Mungonya River flows into Luiche catchment in the western part of Tanzania where the Lake Tanganyika Basin is located. Lake Tanganyika Basin has a catchment area of about 223,000 km^2, it covers seven catchments and Luiche is one of the seven catchments. Mungonya River drains into Luiche River which then discharges directly into Lake Tanganyika. Mungonya river originates in Kigoma district and flows Kigoma Ujiji Municipality before it drains into Luiche River and finally into Lake Tanganyika. Mungonya River passes through villages who depends on it as a water source (LTBWB, 2015).

3.5 Topography of Mungonya River

The Basin is a gently inclined plateau with steep hills rising very sharply from 773 MASL to altitudes of 1,800 MASL. The fall leads to river valleys at 1000 MASL, and swampy and flat delta area at 800 MASL where the rivers join the lake. Topography or elevation of the sampling points ranged from 807 MASL to 999 MASL. The human activities in all the six sampling points are similar but differ in terms of coverage (LTBWB, 2015). Figure 3.2 is a the schematic diagram showing the Sampling Points; Table 3.1 shows the sampling points, coordinates, elevation and characteristics of the selected sampling points.

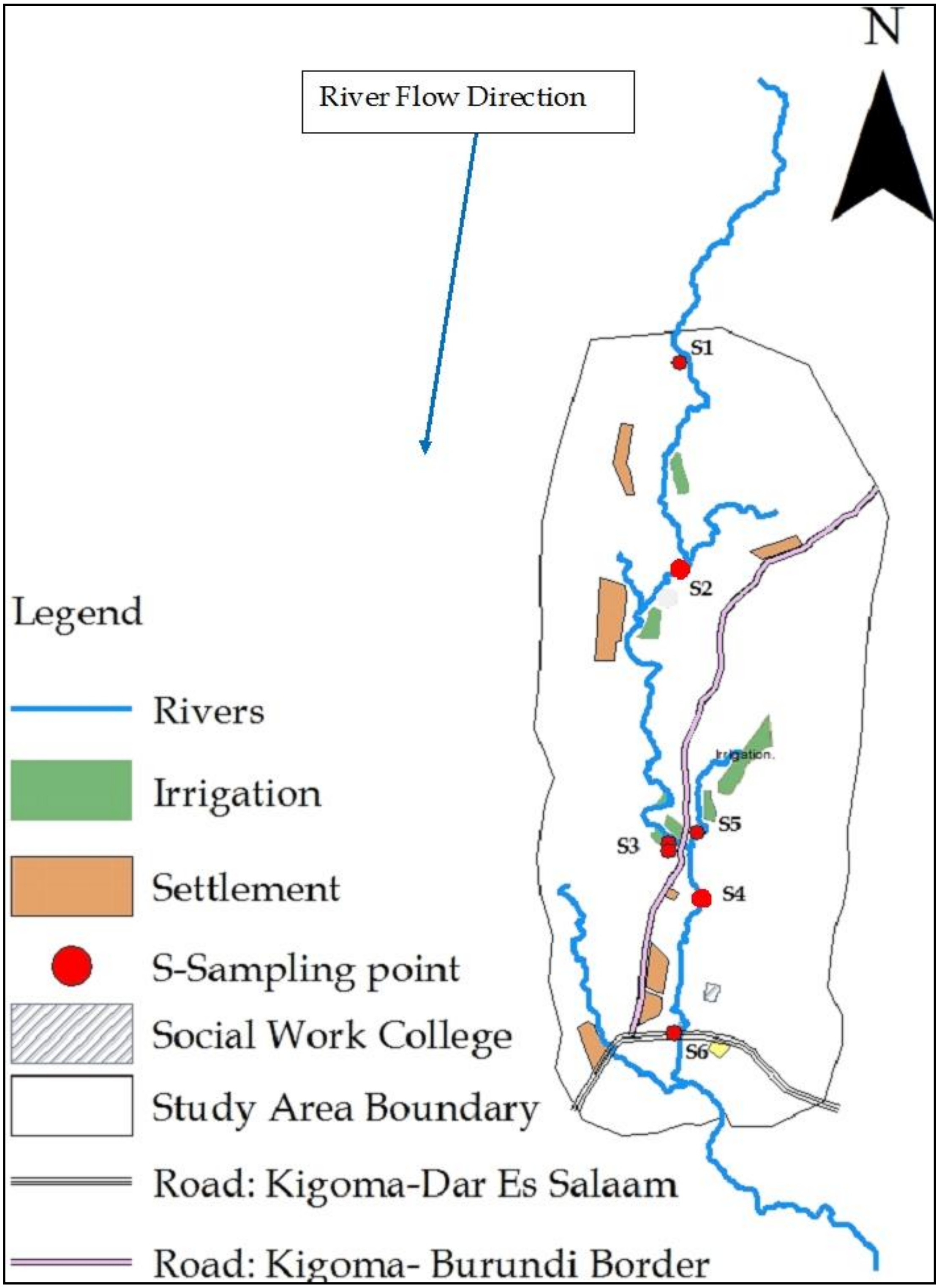

Figure 3.2: Schematic diagram showing Sampling Points

Table 3.1: Coordinates, elevation, sampling points and characteristics

Sampling Point	Coordinates	Elevation (MASL)	Description of sampling points	Sampling points characteristics
S1	S0443.302 E029 40.087	999	Bubango-Chankele bridge	Irrigation, bathing and washing
S2	S0445.329 E029 40.124	943	Bitale K'koo bridge on the way to Mgaraganza/Bubango	Irrigation, brick making, bathing, washing and sand mining
S3	S0448.348 E029 40.048	847	Kibingo Bridge on the way to Burundi border	Irrigation, bathing and washing
S4	S0448.403 E029 40.173	838	Confluence of the tributary and the Mungonya river	Irrigation and bathing
S5	S0448.306 E029 40.174	839	Tributary that drain to Mungonya river	Irrigation
S6	S0450.344 E029 39.944	807	The last point before the river drain to Luiche river	Irrigation, brick making, bathing, washing and sand mining

3.6 Soils

The soil in the low relief areas are dark reddish clay loams with fairly good internal drainage. Black and brown alluvial soils are mostly found in areas of high relief. The river banks are weak due to the type of the soil and the nature of the flow of the river itself. The weak banks of the river sometimes fall into the river resulting in high turbidity and total suspended solids. Figure 3.3 banks of the Mungonya River at Sampling Point 6.

Figure 3.3: Banks of the Mungonya River at Sampling Point 6

3.7 Geology

The geology of Mungonya River comprises of quartzite which is the typical rock in the Basin. Outcrops are found in the study area especially at sampling site two. The geology of the river consists almost entirely of coarse-to-medium grained sandstones (LTBWB, 2015). Figure 3.4 shows outcrops at Sampling Point 5.

3.8 Land Use Land Cover Changes

The vegetation in the area consists of upland vegetation which includes closed and open woodland, bush land, bushy grassland and lowland vegetation consisting of wooded grassland. Woodland is the man vegetation type along the river (LTBWB, 2015). The predominant land uses along Mungonya River were irrigation, settlement, grazing, brick making, washing and bathing (LTBWB, 2015).

3.9 Water Pollution Sources and their Effects on Water Quality

Pollution from non point and point sources of water resources is the major cause of the deterioration of water quality. Point source discharges in the area are minimal since the basin has few industries. Agrochemicals such as nitrate, phosphates are commonly used to increase agricultural yield in the basin. Agricultural activities carried out along

Mungonya river may affect the quality of water as well as the present macroinvertebrates that were living in the biotopes (LTBWB, 2015).

Figure 3.4: Outcrops at Sampling Point 5

3.10 Socio-economic activities

Humans receive multiple goods and services from freshwater ecosystems and the availability and quality of these services is influenced by river (WRBWO, 2011). The water from Mungonya River is used for domestic, irrigation, fish farming, washing, bathing and brick making sand is also mined from the river. Irrigation uses take a high percentage of water use from the river because the community depends primarily on irrigation. The river has a high risk of being polluted due to the unsustainable use. Figure 3.5 depicts an example of the washing activities taking place along the river.

Figure 3.5: An example of washing activities taking place along the river

CHAPTER FOUR: MATERIALS AND METHODS

4.1 Study Design

The design focused on trying to cover all anthropogenic activities although accessibility also influenced selection of sampling points. Sampling was carried out from December, 2015 to March, 2016. The land use/land cover data were collected from Landsat Satellites Images. The water quality and macroinvertebrates primary data were collected at the six sampling points. Secondary water quality data were collected by reviewing the relevant documents from Lake Tanganyika Basin Water Board and Zonal Water Laboratory Office.

4.2 Land Use Land Cover Changes of Mungonya River

Landsat satellite images for 2013, 2015 and 2016 were downloaded from US Glovis website (http://glovis.usgs.gov/). The maximum likelihood method was used to classify the land use. Maximum Likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Kibena *et al.,* 2013). During classification only five land use were selected. This was based on the existing anthropogenic activities that are conducted along the Mungonya. These land use were irrigation, grassland, settlement, water & marshy and forest & shrub. Fifty two (52) control ground points were collected to validate the land use land cover classified maps and 63% accuracy was obtained which indicates that the classification done was acceptable. Historical water quality data for FC, pH, EC, turbidity and nitrates was used. The historical and current water quality data were correlated with the land use in respectively years. Table 4.1 shows landsat satellite images from US Glovis website that were used to classify the study area.

Table 4.1: Landsat satellite images from US Glovis website

Image acquisition date		Landsat version	Maximum Cloud
Year	**Month**	**landsat Archive**	
2013	April	Landsat 8 OLI	20%
2015	September	Landsat 4 present	20%
2016	June	Landsat 4 present	20%

4.3 Physico-chemical and biological water quality parameters

4.3.1 Selection of water quality parameters

Eleven water quality parameters which included pH, DO, Electrical Conductivity (EC), Total Suspended Solids (TSS), Turbidity, Temperature, Nitrates (NO_3^-), Phosphates (PO_4^{-3}), Total Dissolve Solids (TDS), BOD_5, and Faecal Coliforms (FC) were used to assess the health status of Mungonya River. Table 4.2 depicts the Standard Methods used for analysis of physico-chemical and biological water quality parameters (APHA, 2012).

4.3.2 Selection of Sampling Points

Selection of sampling points in a way that encompasses the human activities that are carried out along the river as well as accessibility. The study area has a maximum length of approximately 16 km. The sampling points spanned over 13 km. A total of 8 field surveys were done at each sampling point.

4.3.3 Sampling Times and Frequency

Eight sampling surveys were carried between 29th December, 2015 to 09th March, 2016 at six selected sampling points. The samples were collected between 10:00 hrs to 16:00 hrs started from S6 to S1. Sampling was carried out in the same day and repeated after 10 days. Table 4.3 shows the sampling dates and duration.

Table 4.2: Standard Methods for physico-chemical and biological analysis

WQ Parameter	Method for analysis	Standard method No.
pH	Portable Multi-Meter (Model HNNA HI 9812)	APHA 2510B
DO	Membrane Electrode (Model HNNA HI 9145)	APHA 4500-OG
EC	Portable Multi-Meter (Model HNNA HI 9812)	APHA 4500-OG
Turbidity	Nephelometric Method	APHA 2130 B
Temp	Membrane Electrode (Model HNNA HI 9145)	APHA 4500-OG
NO_3^-	UV Spectrophotometric Method (HATCH DR/3000)	APHA 4500-NH3C
PO_4^{-3}	UV Spectrophotometric Method (HATCH DR/3000)	APHA 4500-P E
FC	Membrane Filter Method	APHA 3500-Pb B
TSS	Gravimetric Glass Fibre Method	APHA 2540 D
TDS	Portable Multi-Meter (Model HNNA HI 9812)	APHA 4500-OG
BOD_5	BOD_5 Test	APHA 10B52

Table 4.3: Sampling dates and duration of sampling

Sampling dates	Duration of sampling
29-Dec-2015	1
9-Jan-2016	11
19-Jan-2016	21
29-Jan-2016	31
8-Feb-2016	41
18-Feb-2016	51
28-Feb-2016	61
9-Mar-2016	71

4.3.4 Water sample collection and analysis

Water samples were collected at each sampling point from both edges of the river and at the middle. A plastic water sampler was immersed to about 0.3 m from the surface at both edges of the river and to approximately 0.6 m in the middle of the river. The water was then mixed to get a composite sample. Temperature and dissolved oxygen were measured in-situ using dissolved oxygen meter. On site measurements were done for pH, electrical conductivity, total dissolved solids and turbidity using pH meter, conductivity meter and turbidity meter respectively. The lab tests were carried out for biochemical oxygen demand, phosphates, nitrates, total suspended solids and faecal coliform. Materials that were used for water quality sample collection were 1L plastic container, a 10L bucket, 1L polythene bottles and 0.5L glass bottles as well as cooler box for handling and transportation.

Materials that were used for macroinvertebrates collection were TARISS scoring sheet, hand-net (mesh size 250µm), macroinvertebrate guide book and white tray. The method that was used for macroinvertebrates sampling was kicking the biotopes in the opposite water current to capture macroinvertebrates.

4.3.5 Sample preservation and Storage

Sulphuric acid was used to preserve BOD samples. Equipments for sterilization and bacteriological (faecal coliforms) were well used for ensuring there's no any interference of external factors. The water sample using glass bottle for bacteriological analysis were collected and analyzed using membrane filtration method. In faecal coliforms the analysis was done on the same day and the samples were incubated for 18-24 hours at 44 ^{o}C, after which the colony forming units per 100 mls were counted. At the laboratory, the samples were refrigerated until laboratory analysis was done.

4.4 Determination of National Sanitation Foundation Water Quality Index

The NSFWQI calculation was done by using online calculator to come up with all the NSFWQI results as shown in appendix 10. During calculating NSFWQI the units for dissolved oxygen parameter was converted to % saturation instead of mg/l. The assumption made was that at 100% saturation dissolved oxygen is approximately to 8.5 mg/l (100% ≈8.5 mg/l). Finally all the parameters were inserted in the online calculator to obtain the NSFWQI values and status of a particular sampling point.

According to Chowdhury *et al.,* (2007), Table 4.4 shows the NSFWQI parameters and weights that were used in calculating NSFWQI .

Table 4.4: NSFWQI parameters and weights

Parameters	Weights
Dissolved Oxygen	0.17
Fecal Coliform	0.15
pH	0.12
BOD_5	0.10
Nitrates	0.10
Phosphates	0.10
Temperature	0.01
Turbidity	0.08
Total Solids	0.08

4.5 Biomonitoring

4.5.1 Macroinvertebrate sampling

Four biotopes were distinguished at each sampling points namely vegetation, gravel, sand and mud. A macroinvertebrates hand net with a 250 µm mesh size was used to collect the macroinvertebrates per site. In the vegetation biotopes, the net was used to sweep the underneath of the riparian vegetation over a distance of 2 m in order to capture the macroinvertebrates that are present in water. In each biotope sampling was carried out for two-five minutes to capture the present macroinvertebrates. The gravel, sand, and mud biotopes were disturbed by kicking whilst holding the hand net in opposite direction to the water current and continuously sweeping the net over the disturbed area to catch the free organisms for 2-5 minutes (Bwalya, 2015). The collected samples were washed down to the bottom of the net using clear water and the contents were tipped into a white sorting tray for on-site identification. The taxa were identified up to the lowest taxonomic level and recorded on the TARISS version 1 score sheet (Appendix 11). After completing the identification process, the identified taxa were returned into the river. Identification was done using the macroinvertebrate guide book for SASS (Appendix 12). Figure 4.1 shows macroinvertebrates being sampled.

Figure 4.1: Macroinvertebrate being sampled using a kick net

4.5.2 Macroinvertebrate identification

The macroinvertebrate taxa were identified to the lowest possible taxonomic level using macroinvertebrate guides (Bwalya, 2015; Fig. 4.2) and recorded on the TARISS 1 scoring sheet.

Figure 4.2: Macroinvertebrate identification

4.6 Data Analysis

4.6.1 Data Analysis for LULC

SPSS version 17.0 software was used to calculate the Pearson correlation coefficient between the LULC and water quality parameters. Pearson Correlation assumed that the land use and land cover were the independent variables and individual water quality parameters were the dependent variables. After obtaining the correlations values in SPSS, they are compared with ranges of -1 to +1 to come up with a conclusion on what are the correlations between the LULC and water quality parameters. The data were graphically presented in Microsoft Excel.

4.6.2 Data Analysis for Physico-chemical and Biological Parameters

The statistical software SPSS version 17.0 was used in the analysis of the physico-chemical and biological data, which were then plotted in Microsoft Excel. The values were compared with Tanzania Drinking Water Quality Standards (2008), Environmental Management Act 2004 (Water Quality Standards, 2007) and World Health Organization guidelines (2008) for drinking water. The comparison was done in order to check whether the measured values were within both national and international required standard limits. These standards were used to categorize the status of the river as to guide the allowable required standard limits of each selected parameters in the Mungonya River.

To find out if there are significant differences between groups the One-Way ANOVA was used to determine whether there were significant difference between sampling points. The post hoc tests multiple comparisons, equal variances were assumed and used to be Student-Newman-Keaul (S-N-K). The statistical significance level used for all tests was 0.05 for two-tailed tests.

4.6.3 Data Analysis for NSFWQI

Bivariate correlations using Spearman's correlation coefficients were used to check if there was a correlation between the NSFWQI and TARISS.

4.6.4 Data Analysis for Biomonitoring

The TARISS version 1 scoring recorded the TARISS total score, number of taxa and average score per taxon (ASPT). The results from each sampling points were compared with the classification of the Benchmark category boundaries for TARISS that was developed by Town (2004) in order to state the status of water quality and the health of the river under study. Bivariate correlations using Spearman Correlation Coefficients (SPSS v17) was used to check the relationship between NSFWQI and TARISS.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Introduction

This chapter discusses the results for the water quality data and macroinvertebrate data that were collected from December, 2015 to March, 2016 at Mungonya River. In this study only eleven water quality parameters were used to assess the health of Mungonya River these were; pH, dissolved oxygen, temperature, electrical conductivity, turbidity, nitrates, phosphates, total suspended solids, faecal coliforms, total dissolved solids and biochemical oxygen demand. However, the NSFWQI, TARISS as well as LULC for 2013, 2015 and 2016 were also incorporated in the assessment of the river.

5.2 Land Use Land Cover Changes

Figure 5.1 shows the LULC classification maps for 2013, 2015 and 2016. The LULC for 2013, 2015 and 2016 showed significant variation. The forest and shrub decreased by 0.11% over the 3-year period while water and marshy, and grassland decreased by 0.01% and 0.17% respectively. Irrigation and settlement areas increased by 0.07%, 0.15% respectively over the 3-year period.

The decrease in forest and shrub, and grassland can be attributed to population increase which increases the demand for construction materials such as timber, firewood and charcoal. The increase of the Irrigation classification, settlements and water and marshy areas was probably due to population increase which also leads to increase in the demand of these land uses. Figure 5.2 depicts the Land Use variations around the catchment of the river.

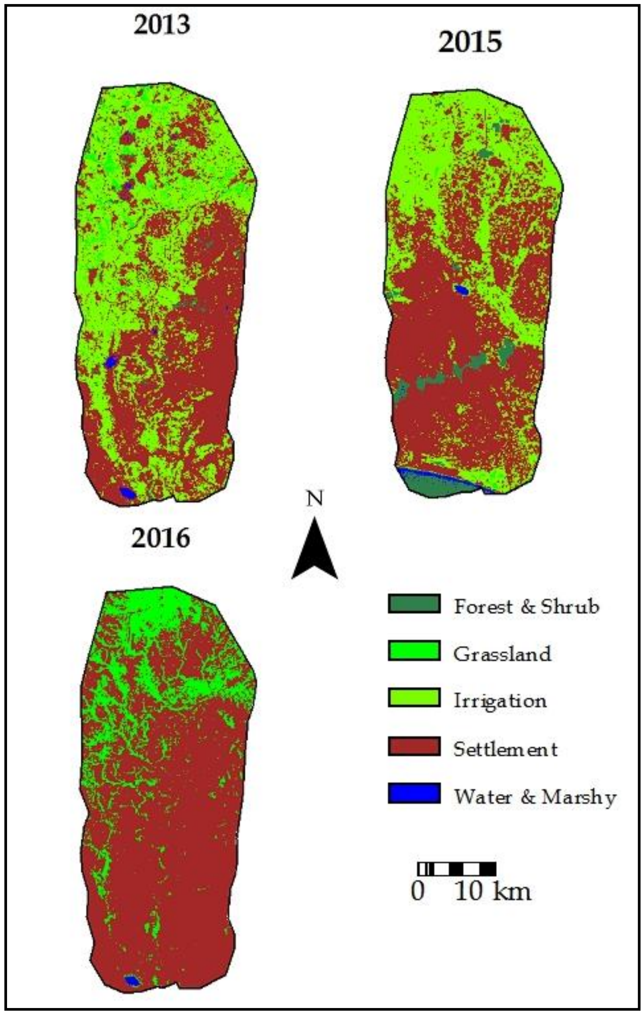

Figure 5.1 Land Use Land Cover Classification maps for 2013, 2015 and 2016

The increase in settlement in the river basin might result in an increase in faecal contamination that linked to the observed situation in the study area that throughout the entire river the faecal coliforms were below acceptable prescribed drinking water standards (0 cfu/100ml). Also irrigation and settlements were predominantly increasing over the 3-year (Figure 5.2).

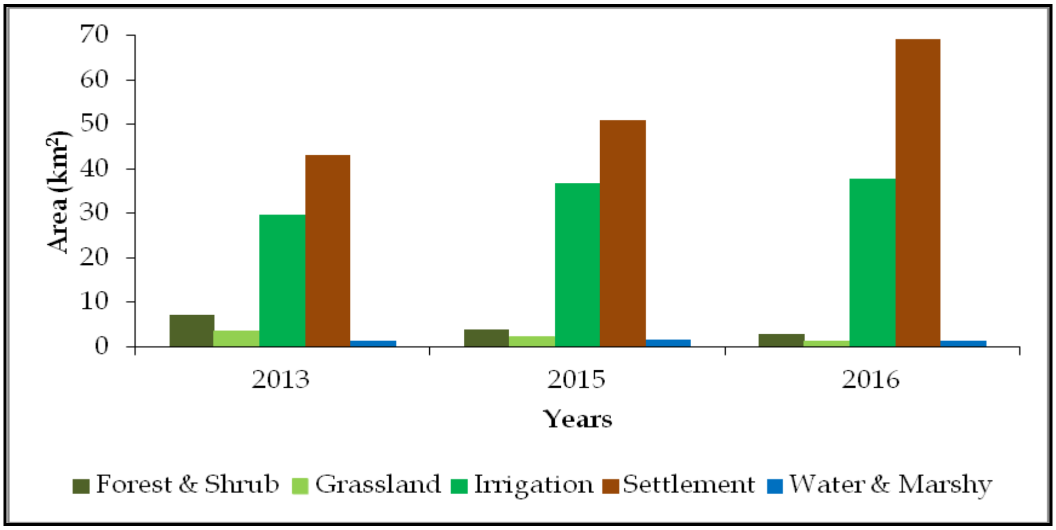

Figure 5.2: Land Use Land Cover variations

5.3 Physico-chemical and biological water quality parameters of Mungonya River

Table 5.1 depicts descriptive statistics of physical, chemical and biological water quality parameters for Mungonya River.

5.3.1 Temporal Variation of Temperature

The measured temperature values ranged from 24.08 ^{o}C to 26.73 ^{o}C and average was 25.41 ^{o}C during the study period. The highest temperature was recorded on Day 71 but it was found to increase from Day 61 to Day 71 even though there were some fluctuations between different sampling days. The temperature rise or fall might be attributed with several factors like sampling times and location of sampling points so on Day 51 it has been shown that there was a decrease in temperature as well, that could be due to the factors mentioned above. However, the temperature averages were within Tanzania Water Quality Standards (TWQS), 25-35 ^{o}C. Figure 5.3 shows the average temporal variation of temperature at Mungonya River.

Table 5.1: Descriptive statistics for Mungonya River water quality parameters

Sampling Points	Parameters	pH (Unit)	DO (mg/l)	EC (µS/cm)	Turbidity (NTU)	Temp (ºC)	NO_3^- (mg/l)	PO_4^{-3} (mg/l)	FC (cfu/100ml)	TSS (mg/l)	TDS (mg/l)	BOD_5 (mg/l)
S1	Mean	7.1	7.6	40.5	202.5	25.3	2.6	2.1	616.5	0.8	20.1	1.6
	SD	0.4	0.6	7.8	256.7	2.0	2.5	3.5	764.1	0.6	4.1	0.4
	Min	6.5	6.8	29.1	27.0	23.3	0.0	0.0	0.0	0.2	14.1	1.1
	Max	7.8	8.3	48.9	787.0	28.6	6.9	10.4	2400.0	2.2	24.5	2.2
S2	Mean	7.1	7.8	43.5	282.2	25.0	3.0	2.2	457.1	1.1	21.6	1.7
	SD	0.4	0.8	5.9	239.7	1.6	2.4	2.9	599.7	0.7	3.3	0.6
	Min	6.6	6.3	33.0	39.3	23.0	0.0	0.0	0.0	0.4	15.3	0.7
	Max	7.7	8.7	49.3	621.0	27.6	6.8	8.8	1800.0	2.3	24.6	2.8
S3	Mean	7.2	8.4	43.8	413.2	24.9	2.6	2.2	476.5	1.0	21.7	1.7
	SD	0.3	1.4	6.9	534.7	1.8	2.4	2.8	377.5	0.7	3.8	0.6
	Min	6.8	7.0	29.5	53.3	22.9	0.0	0.0	90.0	0.1	13.6	1.0
	Max	7.8	11.5	51.0	1622.0	28.6	6.8	9.0	1200.0	1.7	25.5	2.6
S4	Mean	7.5	7.2	43.9	318.2	26.5	3.0	1.2	427.3	1.0	22.2	2.0
	SD	0.3	0.9	6.2	383.7	2.3	2.6	0.9	401.3	0.4	3.3	0.9
	Min	7.0	6.1	32.7	64.7	23.8	0.0	0.0	0.0	0.3	15.1	0.8
	Max	7.8	8.4	51.4	1234.0	31.1	6.9	2.6	950.0	1.4	25.7	3.7
S5	Mean	7.2	7.4	50.2	244.0	26.7	2.7	1.4	270.0	0.6	22.0	2.7
	SD	0.4	0.9	6.3	161.9	3.0	2.5	1.0	272.5	0.7	9.5	0.8
	Min	6.8	6.1	37.9	107.0	23.8	0.0	0.0	0.0	0.0	0.0	1.7
	Max	7.8	8.3	56.6	506.0	32.2	6.9	2.8	820.0	1.7	28.3	4.0
S6	Mean	7.1	8.8	44.6	297.1	24.1	2.7	1.0	572.3	0.9	22.0	2.1
	SD	0.4	3.0	8.5	270.3	0.7	2.4	0.8	645.3	0.7	4.6	0.9
	Min	6.7	7.0	35.4	77.0	22.8	0.0	0.0	0.0	0.2	16.4	0.7
	Max	7.6	16.0	57.5	732.0	24.8	6.8	2.1	2000.0	1.9	28.7	3.4

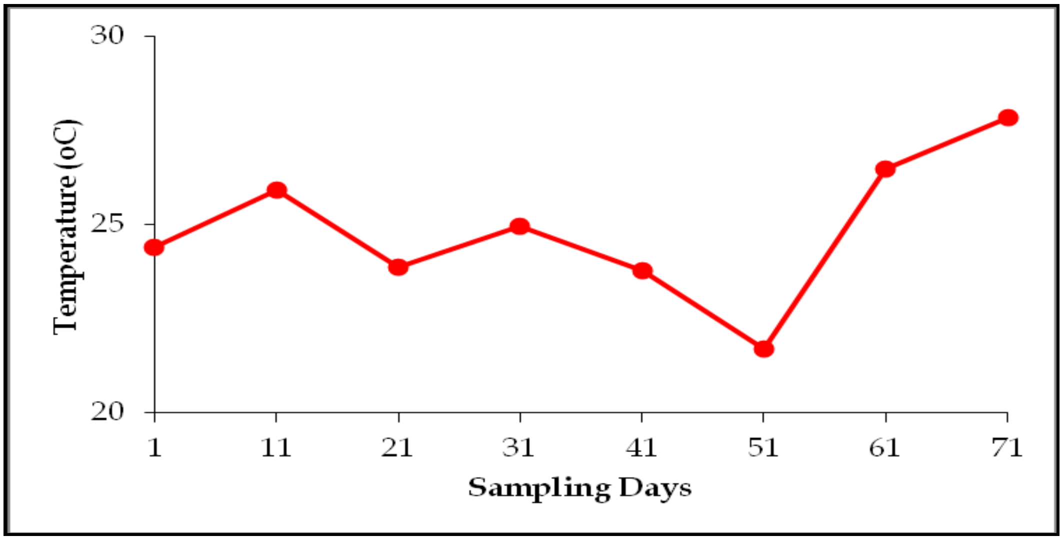

Figure 5.3: Temporal variation of temperature at Mungonya River

5.3.2 Spatial Variation of Temperature

The temperature mean values ranged from 24.1±0.7 ^{o}C to 26.7±3.0 ^{o}C. In comparison to Tanzania water quality standards, the temperature ranges were within allowable standards. The highest temperature value was noticed at S5 as shown in Figure 5.4 which was probably due to sampling times as well as sampling location point. Sampling point 5 (S5) was one among the point that was highly utilized in terms of anthropogenic activities along the river banks and there is less vegetation cover at this site thereby exposing the water surface to sun.

There was no significant differences (p=0.101) in temperature among the 6 sampling points. The temperature of the river was within the allowable TWQS of 25-35 ^{o}C. Figure 5.4 depicts spatial variation of temperature at Mungonya River.

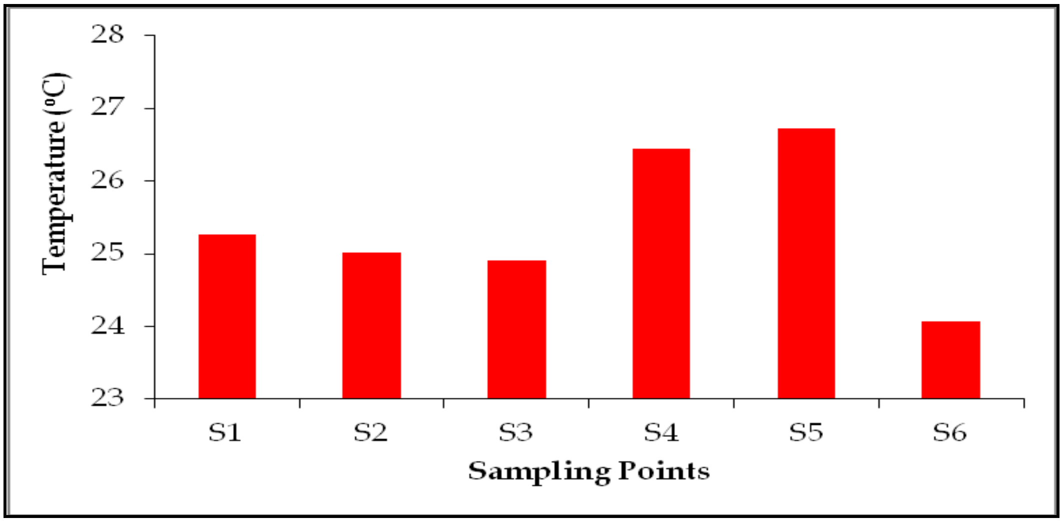

Figure 5.4: Spatial variation of temperature at Mungonya River

5.3.3 Temporal Variation of Turbidity

Figure 5.5 shows the temporal variation of turbidity at Mungonya River. The high turbidity of 759.67 mg/l recorded on Day 1 can be attributed to the high rainfall that fell on the day. The study area experiences the rainfall season from October to May each year. The rainfall could have also caused high turbidity during Day 31. Stream bank cultivation along the river banks disturbs the banks which became weak and when it rains the soil is washed away into the river thereby increasing turbidity. A study carried out by Bwalya (2015) high turbidity values indicate the possible presence of micro-organisms, clay, silt and other suspended solids in water, which affects its aesthetic value by causing it to appear cloudy. The turbidity threshold is indicated by dotted line (Figure 5.5), values above the dotted line exceeds the allowable standard limits.

5.3.4 Spatial Variation of Turbidity

Figure 5.6 shows spatial variation of turbidity at Mungonya River. The mean turbidity values ranged from 202.5±256.7 NTU at S1 to 413.2±534.7 NTU at S3. The highest turbidity value was recorded at S3 (Figure 5.6). This can be attributed to rainfall as well as farming activities that were conducted just a few meters from the river banks. When it rains soils were washed into the river resulting an increase in turbidity.

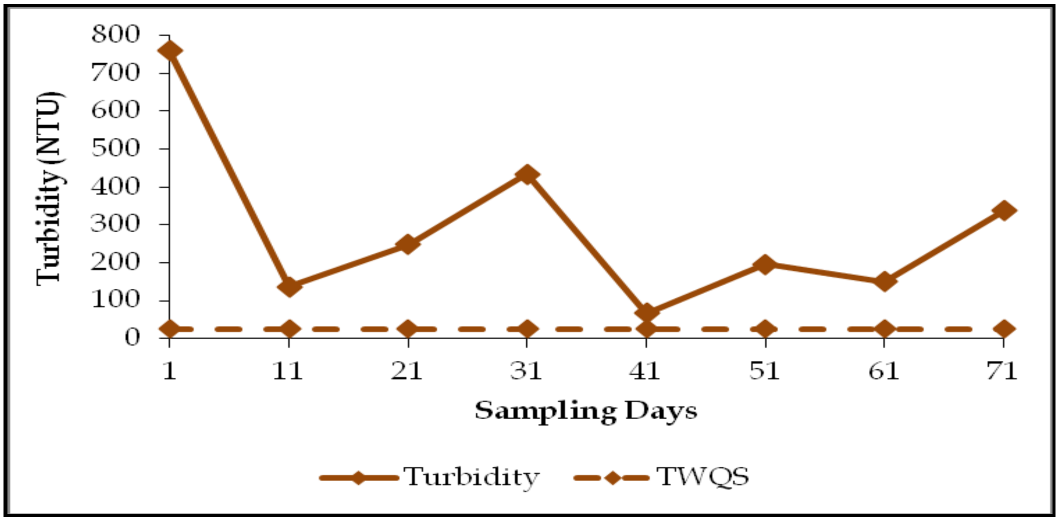

Figure 5.5: Temporal variation of turbidity in Mungonya River

There was no significant differences (p=0.861) in turbidity among 6 sampling points. According to Tanzania Water Quality Standards (2008) and WHO (2008), turbidity <25 NTU is required. The turbidity of the river was above the allowable Tanzania water quality standards.

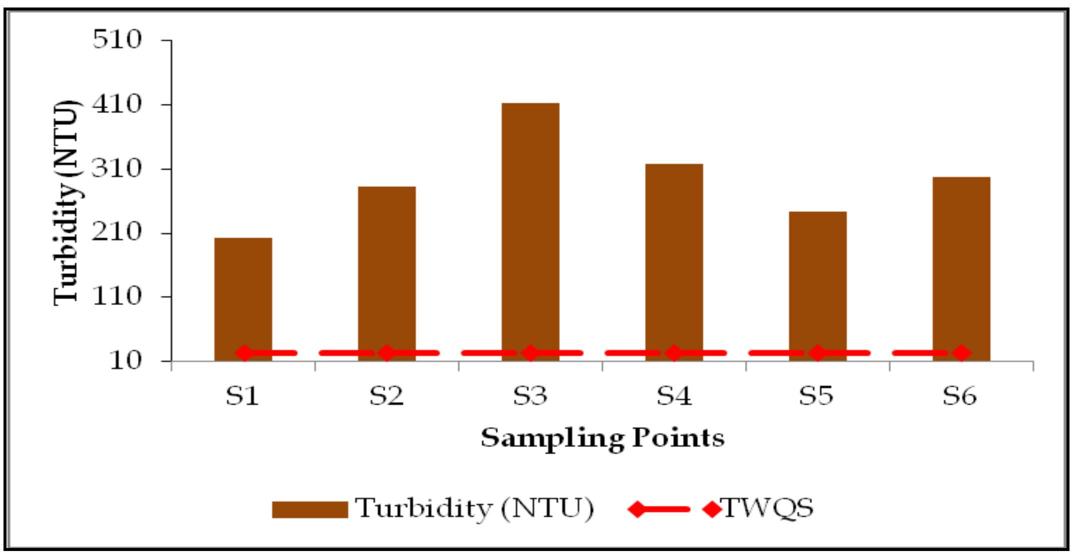

Figure 5.6: Spatial variation of turbidity at Mungonya River

5.3.5 Temporal Variation of Total Suspended Solids (TSS)

Figure 5.7 shows the average temporal variation of TSS at Mungonya River. Highest TSS was recorded on Day 11 and drops at Day 21 and Day 71 (Figure 5.7). The highest TSS was 1.54 mg/l at Day 11 and the lowest was 0.44 mg/l at Day 41. The high values of TSS were caused by rainfall which brought in eroded material into the river.

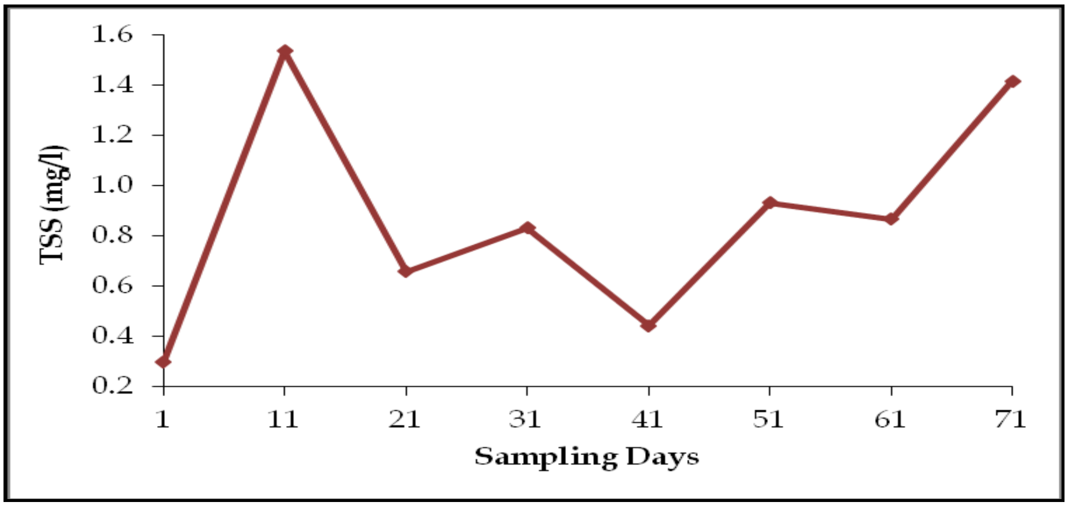

Figure 5.7: Temporal variation of TSS at Mungonya River

5.3.6 Spatial Variation of Total Suspended Solids (TSS)

Figure 5.8 depicts spatial variation of TSS at Mungonya River. The highest TSS value was recorded at S2 (Figure 5.8). The mean values for TSS was ranged from 0.6±0.7 mg/l to 1.1±0.7 mg/l. The TSS values were within TWQS (2008) and WHO (2008), range of TSS≤100 (mg/l). TSS was not significantly different ($p=0.701$) among the 6 sampling points.

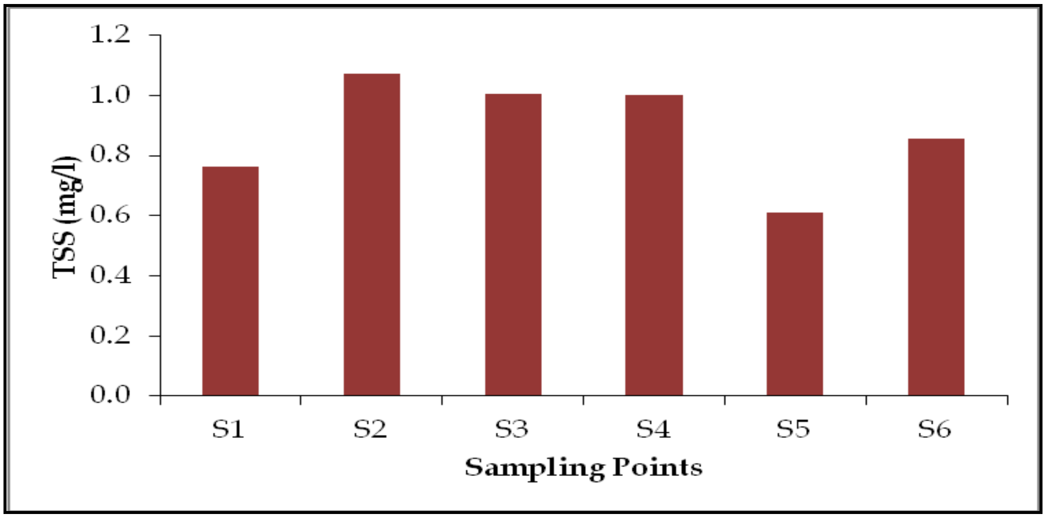

Figure 5.8: Spatial variation of TSS at Mungonya River

5.3.7 Temporal Variation of Total Dissolved Solids (TDS)

Figure 5.9 below shows the variations of TDS from sampling Day 1 to Day 71. The lowest value of 15.35 mg/l occurred at Day 1 while the highest value of 25.30 mg/l was observed at Day 41. High values were associated with high loading of sediments from rainfall. The TDS values were within standards of 1000 mg/l according to TWQS (2008) and WH0 (2008).

5.3.8 Spatial Variation of Total Dissolved Solids (TDS)

Figure 5.10 shows spatial variation of TDS at Mungonya River. The TDS values ranged from 20.1±4.1 mg/l at S1 to 22.2±3.3 mg/l at S4 (Figure 5.10). Rainfall could have contributed to high TDS. S4 was the confluence point that receives the water from S5 and S3 that's why it has high TDS. The TDS values were within TWQS (2008) and WHO (2008) standards of TDS≤1000 mg/l. TDS was not significantly different ($p=0.973$) among 6 sampling points.

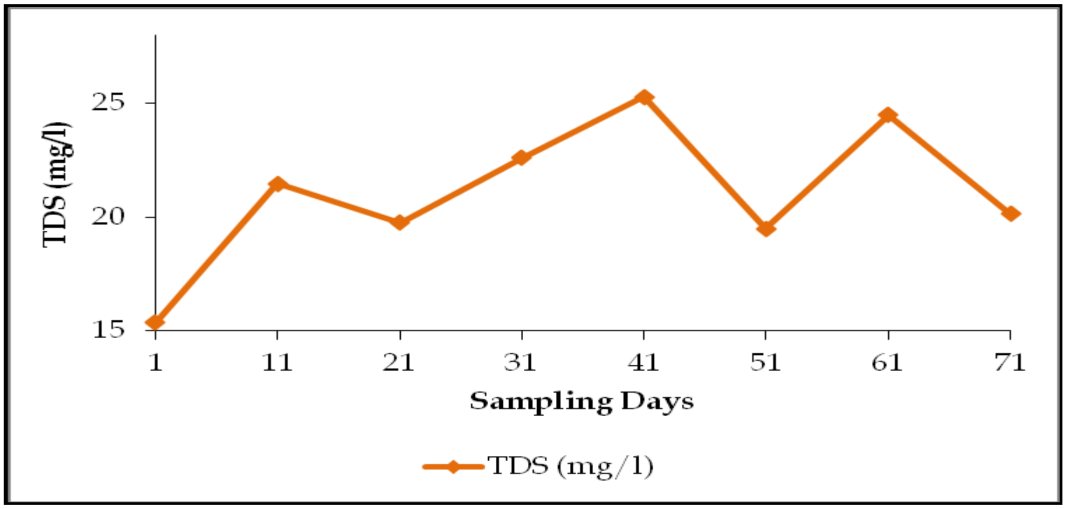

Figure 5.9: Temporal variation of TDS at Mungonya River

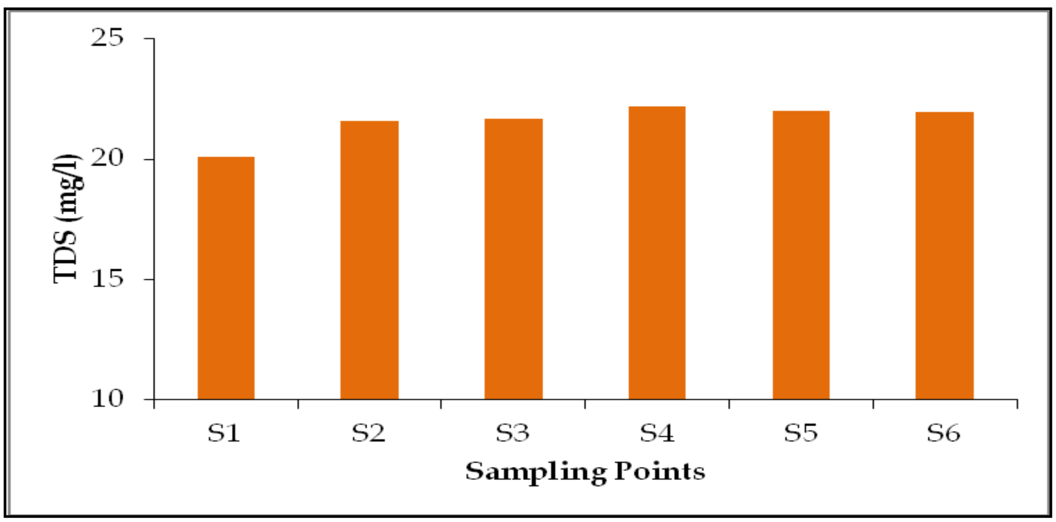

Figure 5.10: Spatial variation of TDS at Mungonya River

5.3.9 Temporal Variation of Electrical Conductivity (EC)

Figure 5.11 shows temporal variation of EC at Mungonya River. The EC fluctuated from Day 1 to Day 71 (Figure 5.11). The high EC was recorded at Day 41 and the lowest at Day 1. The high EC could be attributed rainfall. Different studies showed a negative relationship between discharge and conductivity levels such as the increase in discharge would result in the decreased levels of conductivity levels in a river (Bwalya, 2015).

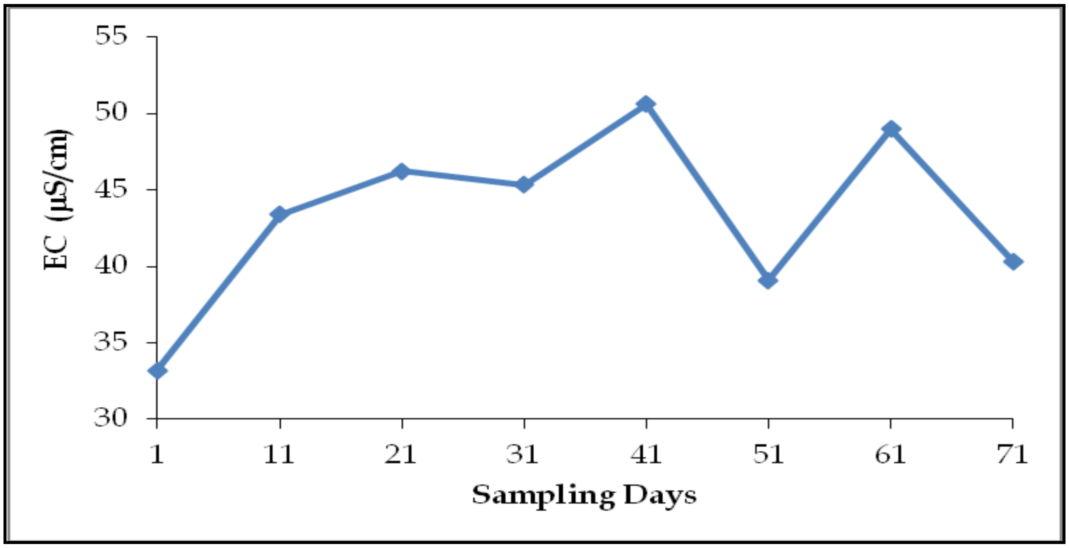

Figure 5.11: Temporal variation of EC at Mungonya River

5.3.10 Spatial Variation of Electrical Conductivity (EC)

Figure 5.12 show the spatial variation of EC at Mungonya River. The mean electrical conductivity (EC) values ranged from 40.5±7.8 µS/cm at S1 to 50.2±6.3 µS/cm at S5. High EC and total suspended solids (TDS) concentrations in a broad sense reflect the pollution burden to aquatic systems (Mero, 2011). Conductivity is a convenient, rapid method of estimating the amount of dissolved solids present in water. Conductivity depends upon the quantity of ions dissolved in water and on their mobility (Nkuli, 2008). There was no significant difference ($p=0.175$) in conductivity among the 6 sampling points. The river water was within Tanzania Water Quality Standards (2008) and WHO (2008) of EC <1500 (µS/cm) was required and at this river the water met the desirable water quality standards.

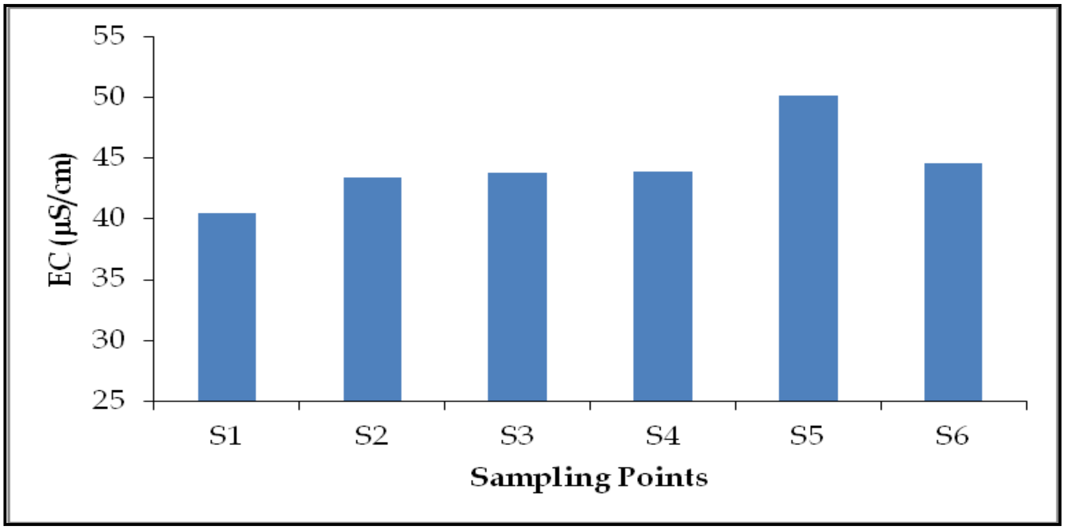

Figure 5.12: Spatial variation of EC at Mungonya River

5.3.11 Temporal Variation of Dissolved Oxygen (DO)

Figure 5.13 shows temporal variation of DO at Mungonya River. The minimum DO value was observed on Day 11 and maximum on Day 71. The DO is the temperature dependant so the higher temperature the lower the DO and vice versa. High DO might be attributed by temperature or sampling point location.

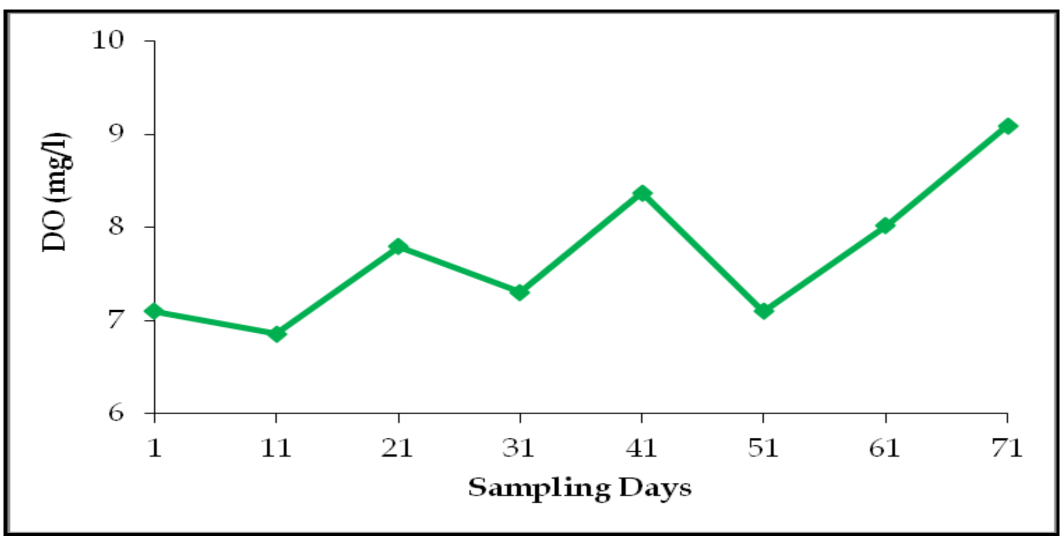

Figure 5.13: Temporal variation of DO at Mungonya River

5.3.12 Spatial Variation of Dissolved Oxygen (DO)

Figure 5.14 shows the spatial variation of the DO in Mungonya River. The DO values ranged from 7.2±0.9 mg/l to 8.8±3.0 mg/l. Oxygen availability is recognized as a key factor in aquatic ecology, it influences the composition of freshwater communities because its depletion in water bodies affects the distribution of many species, community structure and local richness (Mwangi, 2014). There were slight variations of dissolved oxygen among the sampling points however DO levels were within allowable TWQS (2008) and WHO (2008), stipulations of not less than 5 mg/l. The DO above the dotted line (Figure 5.14) fell within the threshold to be found in the river. Below the dotted line some macroinvertebrate will not survival. The DO variations was not significantly different (p=0.298) among the 6 points.

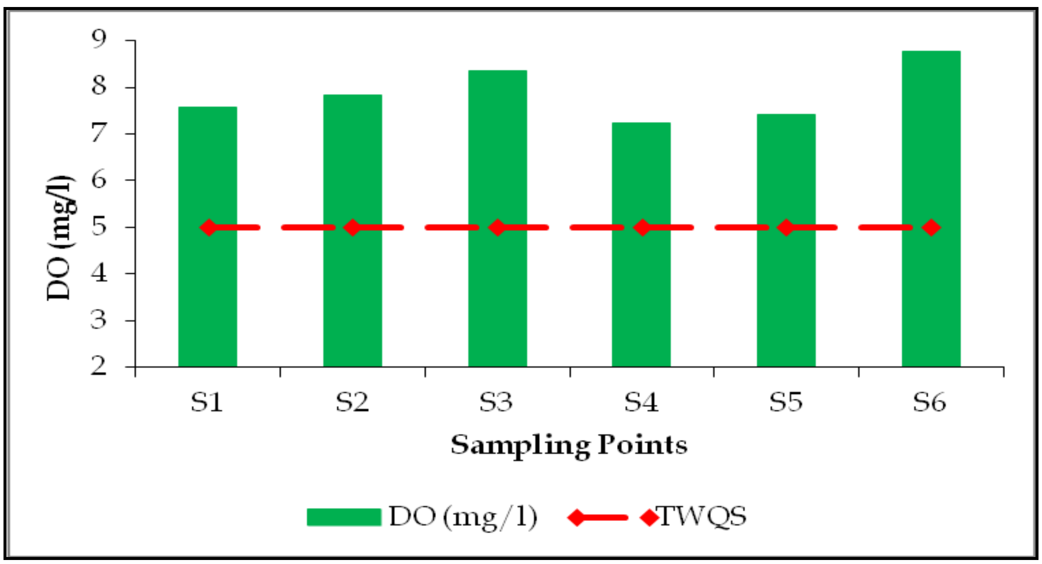

Figure 5.14: Spatial variation of DO in Mungonya River

5.3.13 Temporal Variation of pH

Figure 5.15 shows temporal variation of pH in Mungonya River. High pH value was recorded at Day 41 and lower at Day 51. At sampling Day 51 it has been noticed to have lower pH value and sampling Day 41 higher pH. The pH variations was probably due to high rainfall intensity which increases or reduces dilution of water that.

5.3.14 Spatial Variation of pH

Figure 5.16 depicts spatial variation of pH in Mungonya River. The pH ranged from 7.1±0.4 units to 7.2±0.3 units. The minimum pH was observed at S4 and the maximum were recorded at S5 and S3. The pH at all the six sampling points was within the allowable TWQS (2008) of 6.5-9.2 units. The pH variations was not significantly different (p=0.275) among all 6 sampling points.

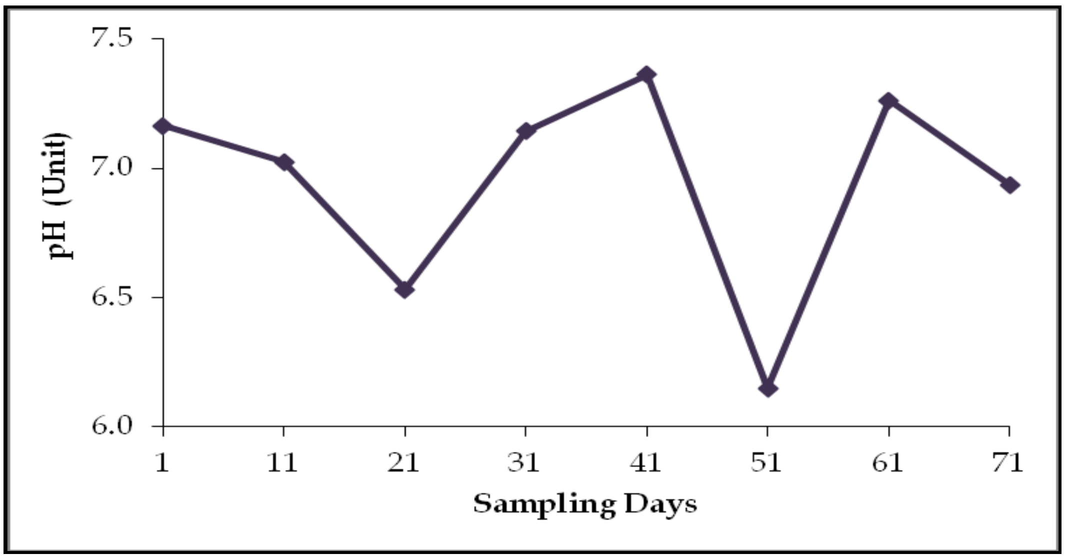

Figure 5.15: Temporal variation of pH in Mungonya River

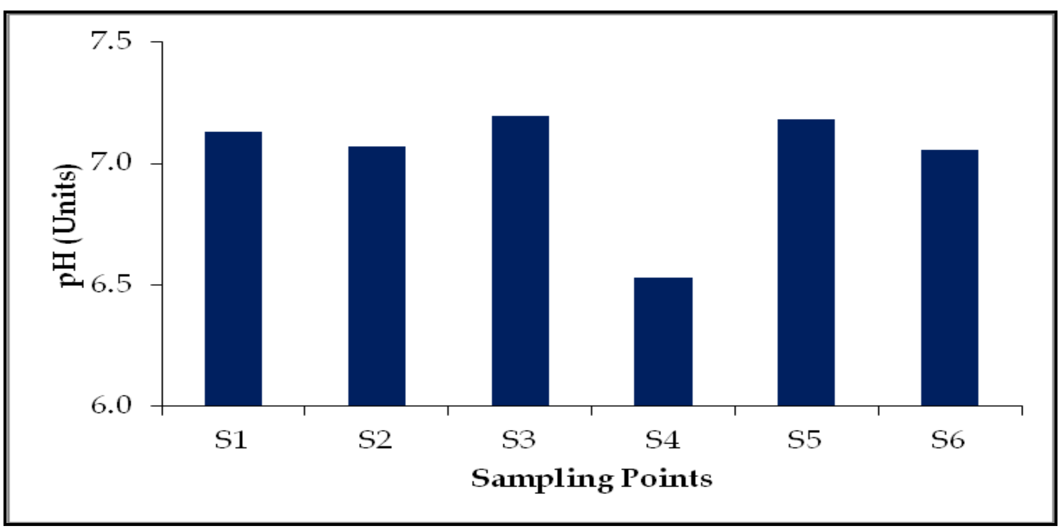

Figure 5.16: Spatial variation of pH in Mungonya River

5.3.15 Temporal Variation of Biochemical Oxygen Demand (BOD)

Figure 5.17 below shows temporal variation of BOD at Mungonya River. Highest BOD was recorded at Day 71 and lowest at Day 11. BOD values was not above the TWQS (2008) as well as WHO (2008) guidelines. The high BOD above standards depletes oxygen in aquatic ecosystems because microorganisms use up the dissolved oxygen. The depletion of dissolved oxygen is usually linked to accumulation and decomposition of dead organic matter which consumes oxygen and generates harmful gases such as methane (Mero, 2011). Therefore, the existence of nutrients in this river such as nitrates and phosphates in a body of water can contribute to high BOD levels. Nitrates and phosphates are plant nutrients and can cause plant life and algae to grow quickly. When plants grow quickly, they also die quickly.

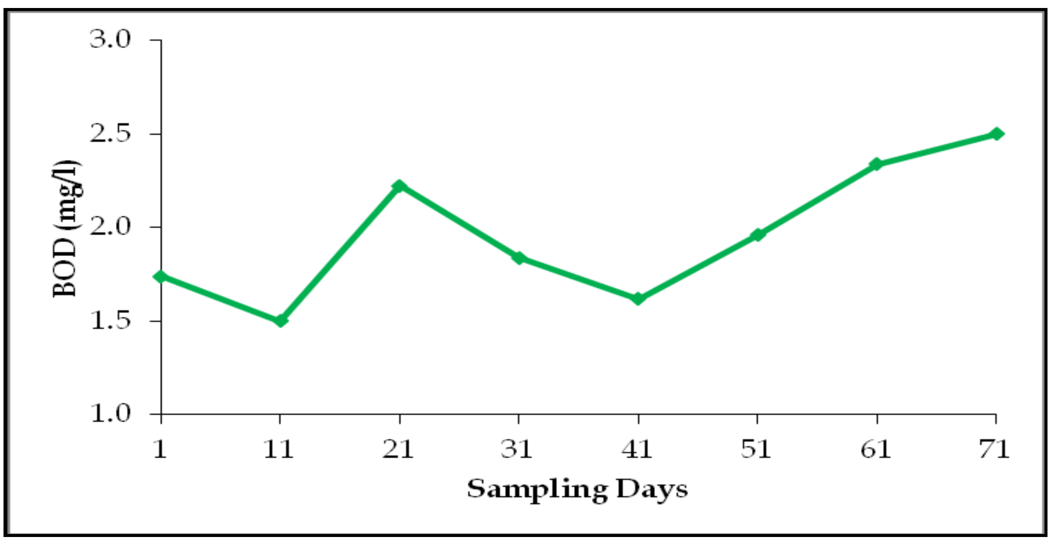

Figure 5.17: Temporal variation of BOD at Mungonya River

5.3.16 Spatial Variation of Biochemical Oxygen Demand (BOD)

Figure 5.18 shows spatial variation of BOD at Mungonya River. The mean BOD values ranged from 1.6±0.4 mg/l to 2.7±0.8 mg/l. The highest BOD value was recorded at S5 and lowest at S1 (Figure 5.18). The high BOD could be linked to irrigation activities that use fertilizers thereby contributing to the increase nutrients in the river. BOD values were within the TWQS (2008) and WHO (2008) standards of 6 mg/l. The BOD variations was significant different (p=0.041) among all 6 sampling points.

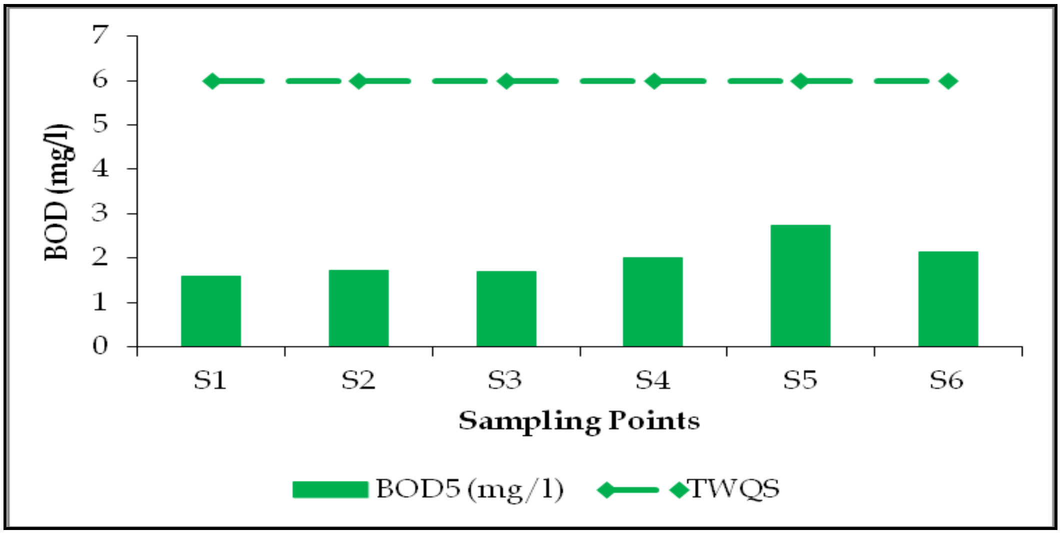

Figure 5.18: Spatial variation of BOD at Mungonya River

5.3.17 Temporal Variation of Nitrate (NO_3^-)

Figure 5.19 shows temporal variation of nitrate at Mungonya River. The highest nitrate concentration of 6.83 mg/l was recorded at Day 1. Day 31 and Day 51 had lowest nitrate concentration of 0.02 mg/l and 0.12 mg/l respectively.

5.3.18 Spatial Variation of Nitrate (NO_3^-)

Figure 5.20 depicts spatial variations of nitrate at Mungonya River. Mean nitrate values ranged from 2.6±2.4 mg/l to 3.0±2.6 mg/l. The concentration was highest at S2 and S4 (Figure 5.20). The concentration was lowest at S3. Nitrate values were within the TWQS (2008) and WHO (2008) standards of 75 mg/l. The nitrate variations concentration was not significant different (p=0.999) among all 6 sampling points.

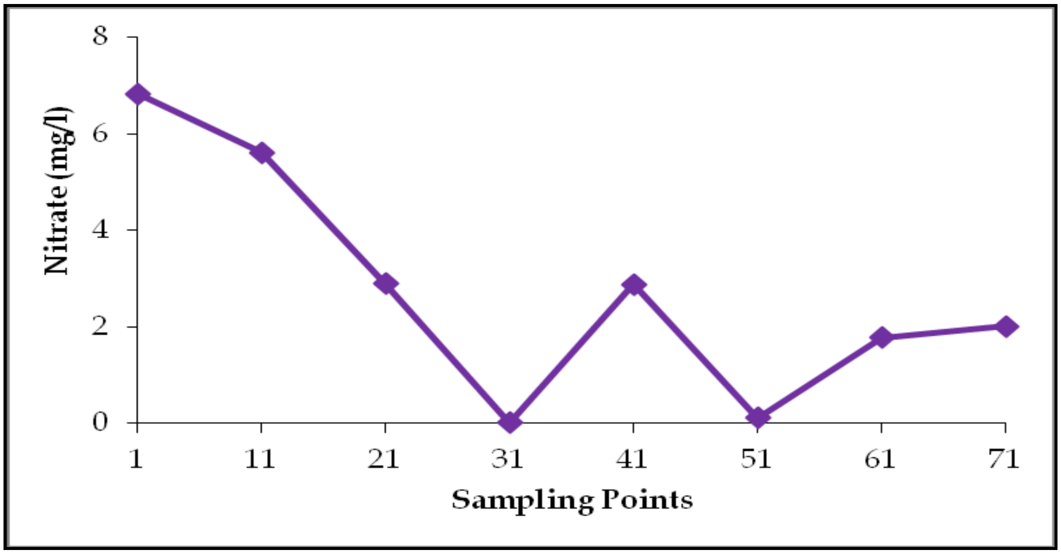

Figure 5.19: Temporal variation of nitrate at Mungonya River

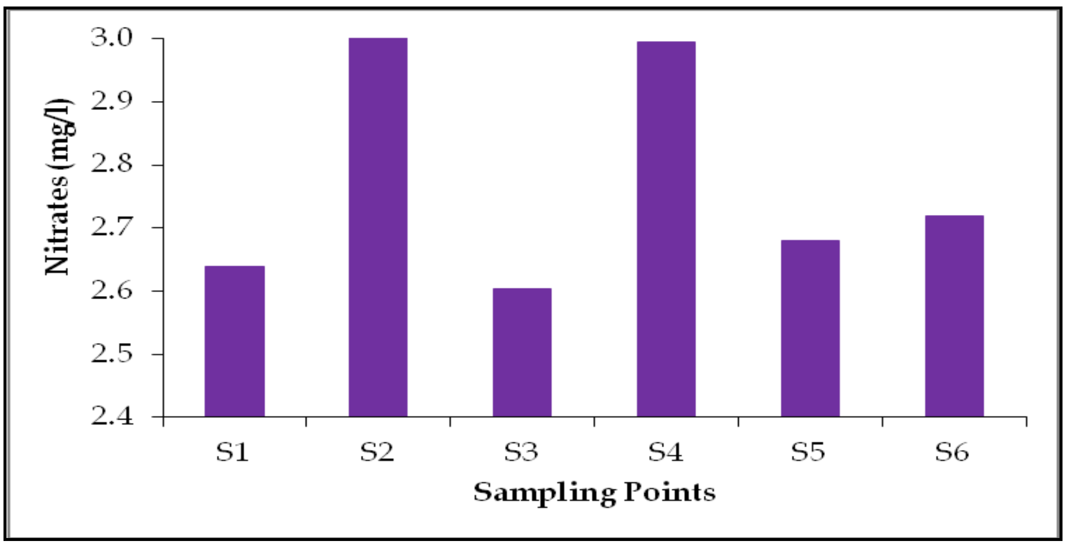

Figure 5.20: Spatial variation of nitrate at Mungonya River

5.3.19 Temporal Variation of Phosphate (PO_4^{-3})

Figure 5.21 shows temporal variations of phosphate at Mungonya River. Highest phosphate was recorded on Day 31 and lowest on Day 51. The variations linked to irrigation activities that were carried out along the river banks.

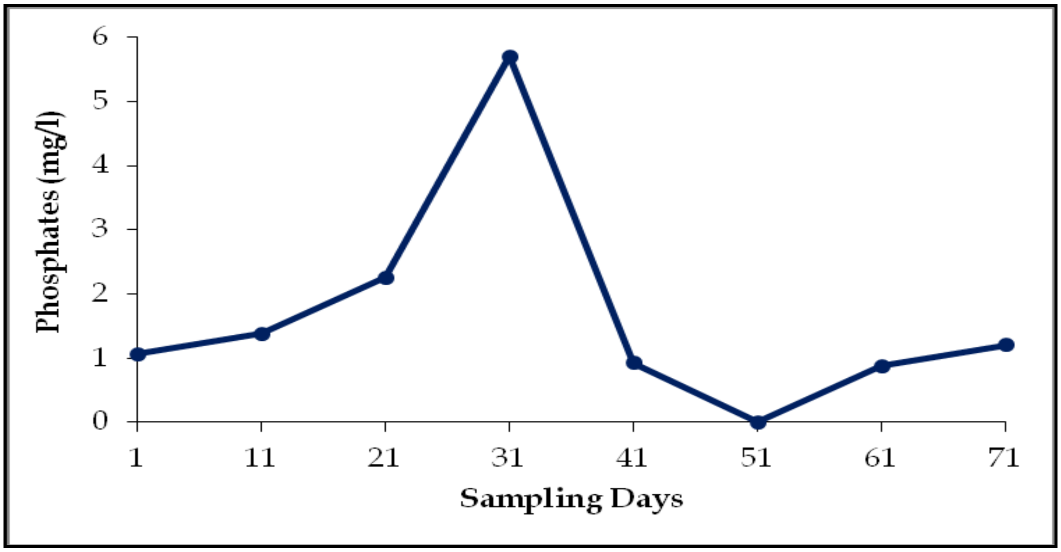

Figure 5.21: Temporal variations of phosphate at Mungonya River

5.3.20 Spatial Variation of Phosphate (PO_4^{-3})

Figure 5.22 shows spatial variation of phosphate at Mungonya River. The phosphate concentration ranged from 1.0±2.9 mg/l to 2.2±2.9 mg/l. Highest concentration were recorded at S1, S2 and S3 and lowest was at S4. Phosphate values were within the TWQS (2008) and WHO (2008) standards of 5 mg/l. Phosphate concentration was not significant different (p=0.825) among all 6 sampling points.

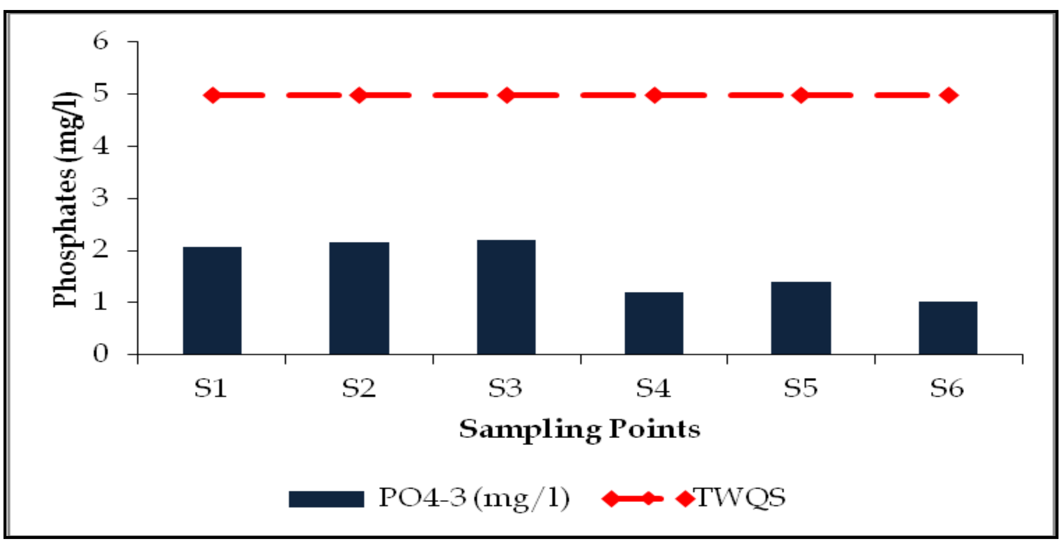

Figure 5.22: Spatial variation of phosphate at Mungonya River

5.3.21 Temporal Variation of Faecal Coliforms

Figure 5.23 shows the temporal variation of faecal coliforms at Mungonya River. Faecal coliforms were highest at Day 31 and lowest at Day 1. Faecal coliforms were above the standards during the whole sampling period it is supposed to be not more than 0 cfu/100ml. High faecal coliforms can be attributed to different factors. During the rain (wet) season the faecal coliforms counts are expected to be higher than during dry season because when it rains the runoff from different wastes are collected and discharged into the river (Bwalya, 2015). The faecal coliforms bacteria are considered as "indicator organisms" for pollution (Chaki, 2015) so where they are found they indicate that the water was not pleasant for drinking unless if treated.

5.3.22 Spatial Variation of Faecal Coliforms

Figure 5.24 depicts spatial variation of faecal coliforms at Mungonya River. Faecal coliforms mean values ranged from 270.0±272.5 cfu/100ml to 616.5±764.1 cfu/100ml. The highest faecal coliforms values were recorded at S1 and S6 (Figure 5.23). The lowest faecal coliforms were recorded at S5. Faecal coliforms values were above the TWQS (2008) and (WHO, 2008) standards of 0 cfu/100ml. Faecal coliforms was not significant different (p=0.840) among all 6 sampling points.

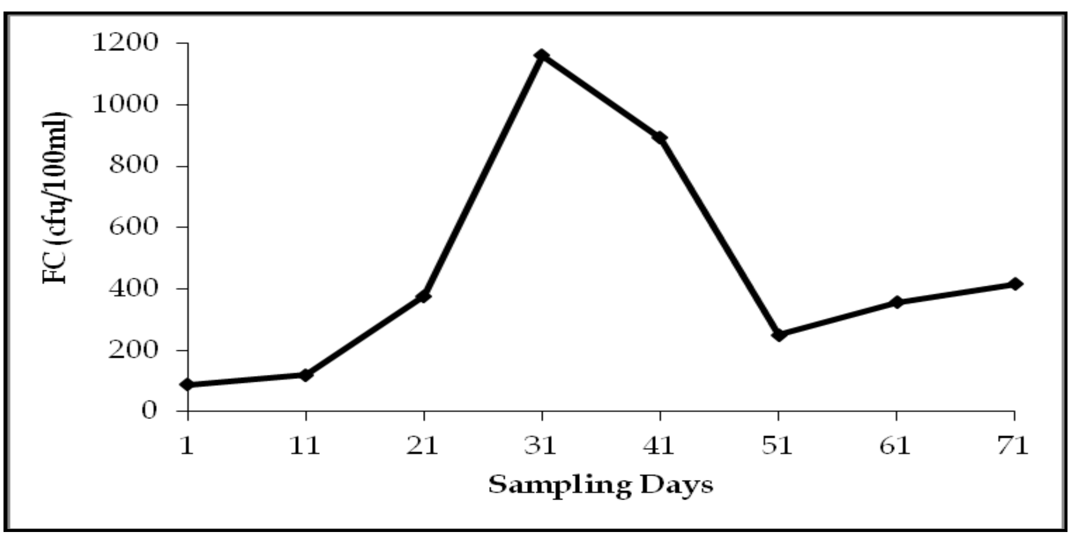

Figure 5.23: Temporal variation of faecal coliforms at Mungonya River

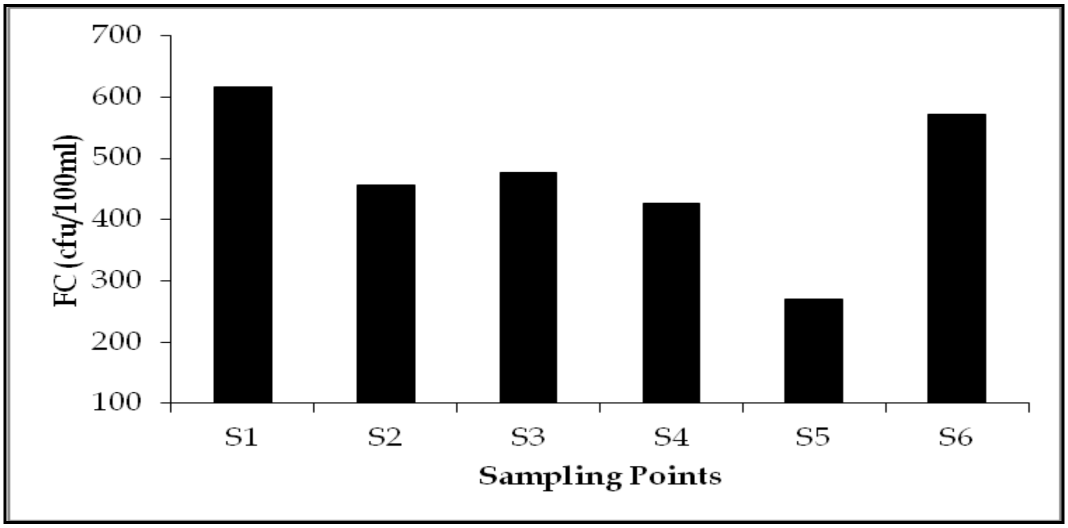

Figure 5.24: Spatial variation of faecal coliforms at Mungonya River

5.4 Water quality of Mungonya River based on NSFWQI

Table 5.2 shows the results of Mungonya River based on NSFWQI. The mean NSFWQI was 56.8 which indicate that the river status was medium or average. The highest value of NSFWQI 57.6 was recorded at S3 while the lowest value of 55.3 was recorded at S4 (Table 5.2). In a study by Mnisi (2010) the overall NSFWQI of the river was at category C (51-70) which indicated that the river was within the medium water quality status. The higher value of NSFWQI the better the water quality category. The overall water quality status of Mungonya River was found to be medium or average (51-70). The river was not polluted.

5.4.1 Spatial Variation of water quality in Mungonya River based on NSFWQI

Figure 5.25 below shows the spatial variation of water quality in Mungonya River based on NSFWQI. The results obtained in Table 5.2 above clarified that the medium or average water quality status. This linked to an increase of human activities that cause deterioration of water quality of the river. The anthropogenic activities that were carried out along the river can be the reason as to why the status of water quality of the river was not good. Figure 5.25 shows that among all six sampling points the NSFWQI were above fifty which indicates that the status of water quality at all the six sampling points were of medium or average quality. There was a weak correlation (r=-0.371) between NSFWQI and the sampling points.

Table 5.2: Water quality of Mungonya River based on NSFWQI

Sampling Points	NSFWQI Values	Category	WQ Rating Status
S1	56.8	C	Medium/Average
S2	56.8	C	Medium/Average
S3	57.6	C	Medium/Average
S4	55.3	C	Medium/Average
S5	56.9	C	Medium/Average
S6	57.4	C	Medium/Average
Overall NSFWQI	56.8	C	Medium/Average

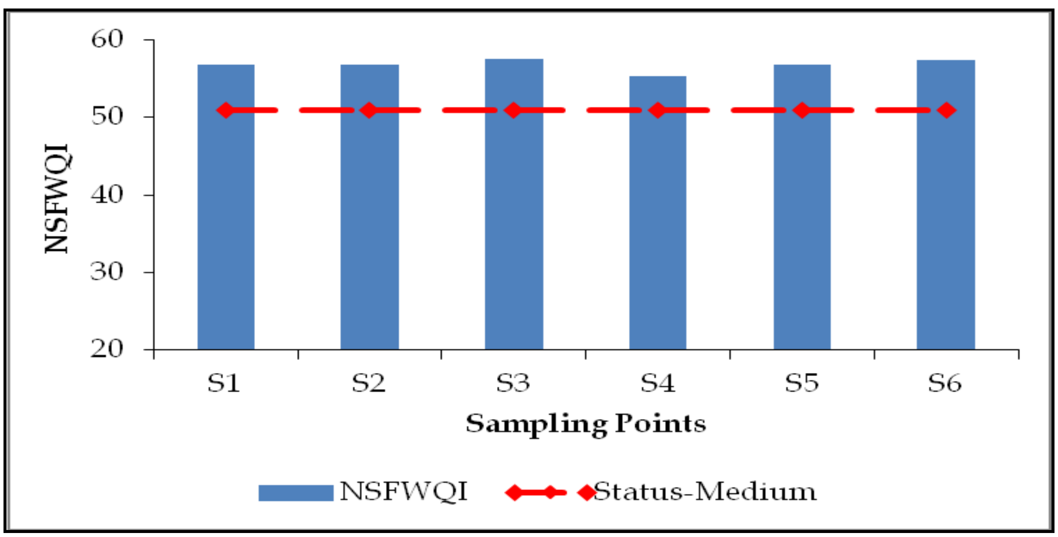

Figure 5.25: Spatial variation of water quality in Mungonya River-NSFWQI

5.5 Water quality of Mungonya River based on TARISS

5.5.1 Results of Mungonya River based on TARISS rapid bioassessment index

Table 5.3 depicts the water quality results for TARISS rapid bioassessment. The highest ASPT was recorded at S4 and lowest at S5. Results shows that S5 was highly utilized which linked to the human activities along the river banks. Also it has been observed that in TARISS 1 scoring sheet there was a typing error where instead of TARISS total score it was written SASS total score (Appendix 11).

Table 5.3: Results of Mungonya River based on TARISS rapid bioassessment index

Sampling Points	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
SASS Total Score	11	26	10	13	0	26
No of Taxa	5	5	3	3	0	6
FAIR	5	5	5	5	5	5
ASPT	**2.4**	**4.9**	**3.0**	**5.1**	**0.0**	**4.7**
Level of utilization or pollution	**2**	**5**	**3**	**6**	**1**	**4**
WQ Rating Status	POOR	POOR	POOR	FAIR	POOR	POOR

NB: Utilization; 1-highly utilized, 2-Medium utilized, 3-Low utilized, >3-Very low utilized

The zero ASPT values at S5 showed that the sampling point was highly utilized. This site had a high BOD of 2.7 mg/l which indicates pollution even though the BOD values were within acceptable standards. Also it was pointed out that S5 doesn't have high abundance, it has less sensitive organisms and lower diversity. The river between sampling points shows that there was some self purification as observed at S4 where water quality biotic integrity slightly improves.

5.5.2 Spatial variation of TARISS water quality assessment in Mungonya River

Figure 5.26 shows the spatial variation of TARISS water quality assessment in Mungonya River. Only S4 the water quality was fair while rest of the sampling points had poor water quality. Figure 5.26 all sampling points above the threshold line were fair and below that line were poor. There were significant differences between TARISS total score, ASPT and number of taxa among the 6 sampling points (Table 5.4).

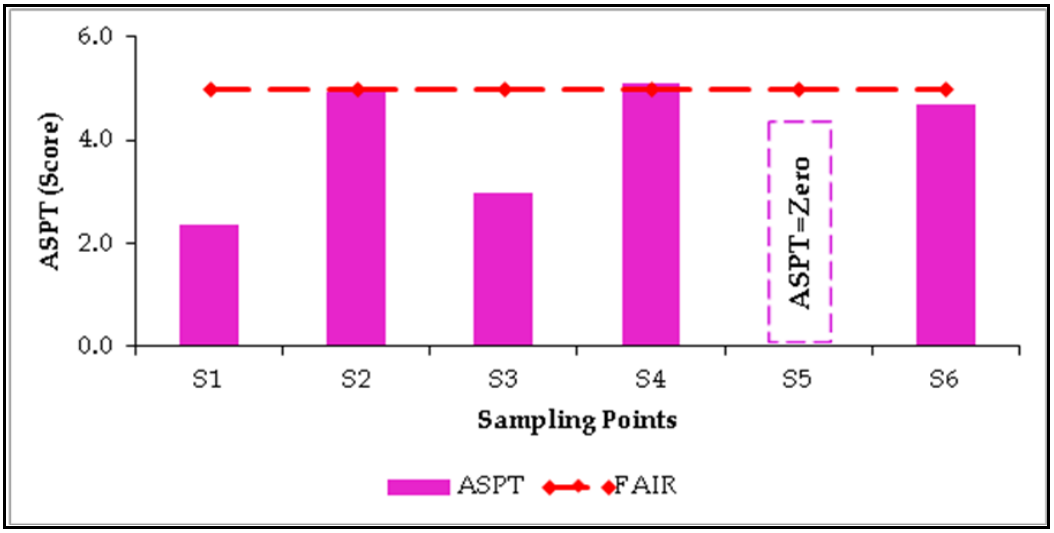

Figure 5.26: Spatial variation of TARISS water quality in Mungonya River

Table 5.4: Descriptive statistics for TARISS, Number of Taxa and ASPT

Index	Mean	Std. Dev	2-tailed Sig. level (p)	Number of points	Sig.(2-tailed)
TARISS Score	14.438	10.143	0.05	6	0.018
No of Taxa	28.670	16.717	0.05	6	0.008
ASPT	3.342	1.982	0.05	6	0.009

5.5.3 Temporal Variation of number of taxa at Mungonya River

Figure 5.27 shows the temporal variation of the number of taxa in Mungonya River. The number of taxa was lowest at Day 21. Bwalya (2015) attributed the decrease in the number of taxa to the increase in temperature because some of the macroinvertebrate do not survive within a certain range of temperature.

5.5.4 Spatial Variation of number of taxa at Mungonya River

Figure 5.28 shows spatial variation of number of taxa in Mungonya River. The lowest number of taxa was recorded at S5 and highest number of taxa was recorded at S6. The lower number of taxa probably was due to the highly river utilization at that particular sampling point.

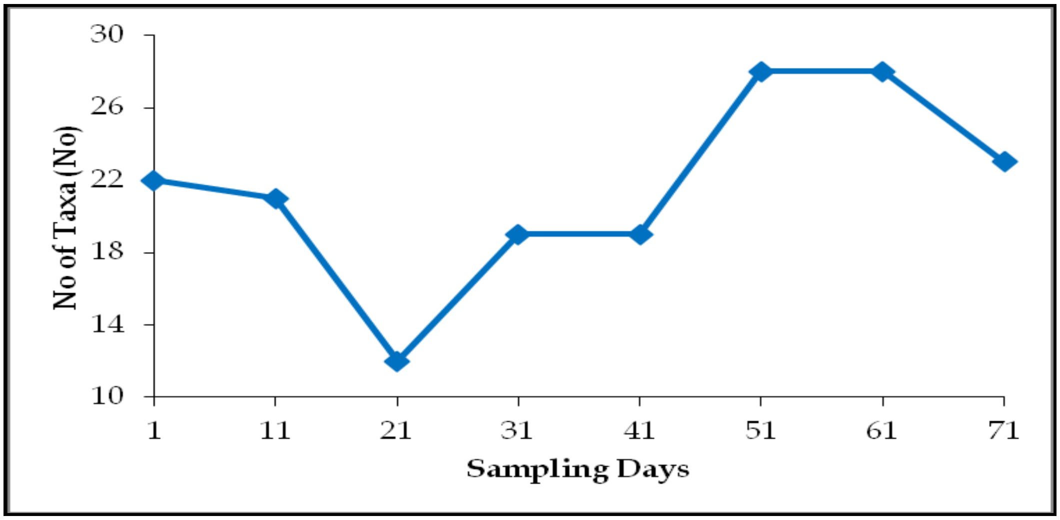

Figure 5.27: Temporal variation of number of taxa in Mungonya River

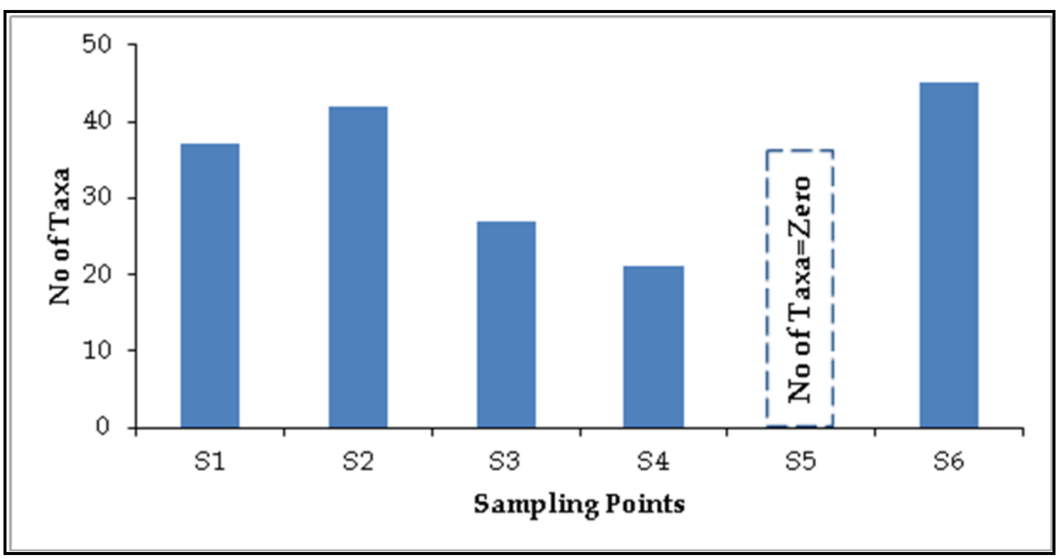

Figure 5.28: Spatial variation of number of taxa in Mungonya River

5.5.5 Temporal variation of TARISS total score at Mungonya River

Figure 5.29 shows the temporal variation of the TARISS total score at Mungonya River. The TARISS total score increased from Day 1 up to Day 51 then started to decrease from Day 61 to Day 71 (Figure 5.29). The highest score was recorded at Day 51 and lowest at Day 1. The increase and decrease of the score was linked to the presence of high or low rainfall and river utilization.

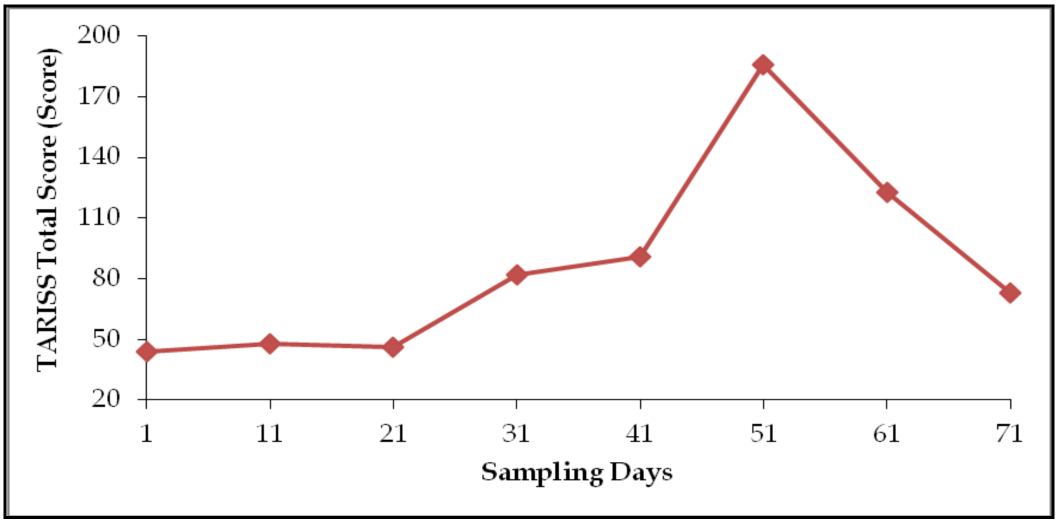

Figure 5.29: Temporal variation of the TARISS total score at Mungonya River

5.5.6 Spatial variation of TARISS total score at Mungonya River

Figure 5.30 shows spatial variation of TARISS total score at Mungonya River. The highest TARISS total score was recorded at S6 and lowest score was recorded at S5 (Figure 5.30).

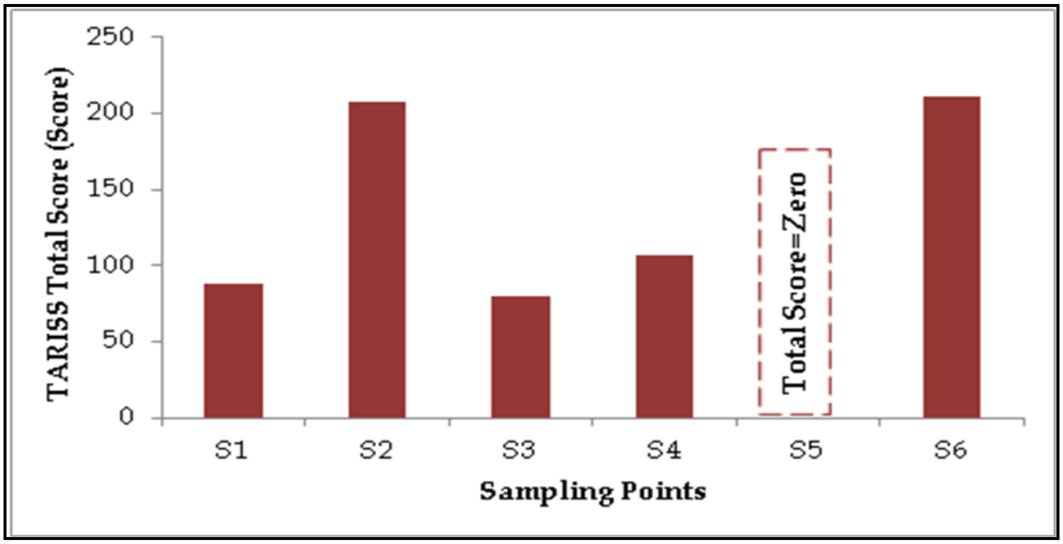

Figure 5.30: Spatial variation of TARISS total score at Mungonya River

5.6 Overall Results and Discussion

5.6.1 Correlations between LULC and water quality parameters

Table 5.5 shows the correlations of LULC and water quality parameters. The settlement and irrigation are the ones increasing rapidly which linked to water quality deteriorations. There was a positive correlation between settlement and nitrate, turbidity and faecal coliforms. The reason for the correlation between the settlement and, nitrate and faecal coliforms might be due to the human wastes that were collected as runoff and discharged to the river. There was a correlation between irrigation and nitrate, faecal coliforms and turbidity as well. The causes for this correlation was probably due to irrigation activities taking place along the river banks that use fertilizers which add nitrates as well but also human wastes from settlements, animal grazing would increase faecal coliforms. Generally there were *-Strong correlations, **-Medium correlations and ***-Weak correlations (Table 5.5) between land use and water quality parameters.

Table 5.5: Correlation between LULC and water quality parameters

Parameters	pH (Unit)	Turbidity (NTU)	EC (mS/cm)	Nitrate (mg/l)	FC (cfu/100ml)
Settlement	-0.385**	0.946*	0.077***	0.860*	0.941*
Irrigation	0.454**	-0.919*	-0.002***	-0.819*	-0.912*
Forest & Shrub	-0.697*	-0.670*	-0.947*	-0.808*	-0.683*
Grassland	0.980*	-0.514*	0.585*	-0.326**	-0.499*
Water & Marshy	-0.356**	-0.909*	-0.743*	-0.975*	-0.916*

* Strong correlations, ** Medium correlations, *** Weak correlations

5.6.2 Correlations between EC and TDS

Figure 5.31 shows the correlation between EC and TDS at Mungonya River. There was a strong relationship between EC and TDS (r=0.954). In Figure 5.31 it has been observed that in Mungonya river from December, 2015 to March, 2016 the EC (μS/cm)≈ 2.01∗TDS (mg/l).

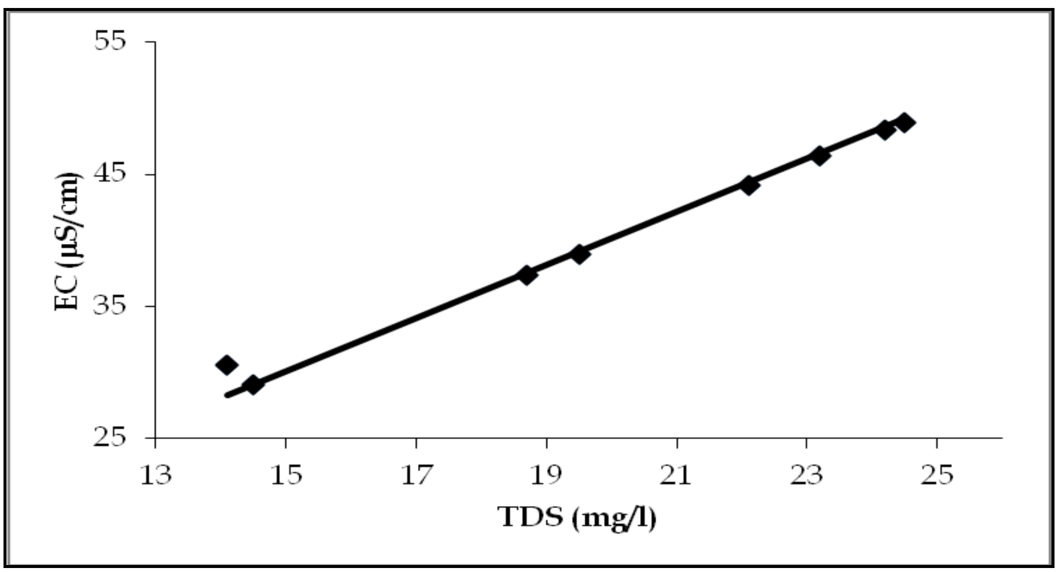

Figure 5.31: Correlation between EC and TDS at Mungonya River

5.6.3 Correlation between number of taxa and TARISS total score

Figure 5.32 shows the correlation between the number of taxa and TARISS total score at Mungonya River. The mean TARISS total score was 14.438±10.143 and mean number of taxa was 28.67±16.717. There was a strong linear positive correlation (R^2=0.78) between the number of taxa and TARISS total score.

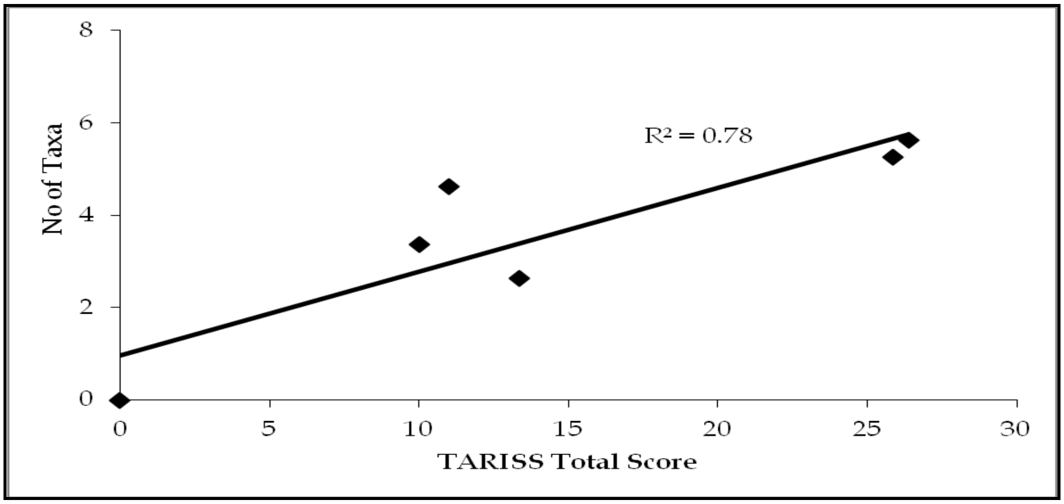

Figure 5.32: Correlation between the number of taxa and TARISS total score

5.6.4 Correlation between ASPT and number of taxa

Figure 5.33 shows correlation between ASPT and number of taxa. The mean ASPT was 3.342±1.982 and there was a weak correlation between the ASPT and number of taxa of r=0.314 among the sampling points.

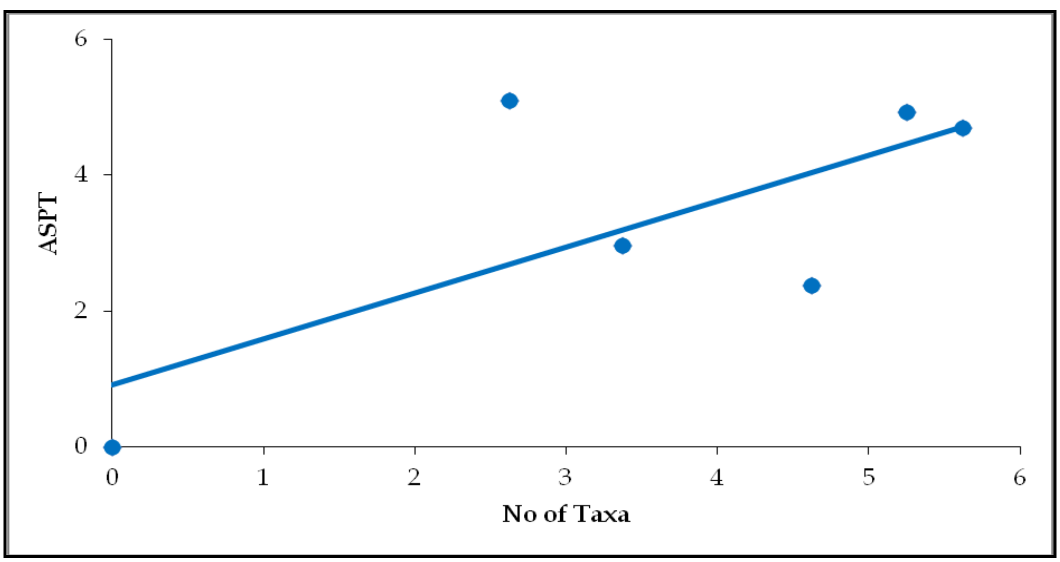

Figure 5.33: Correlation between ASPT and number of taxa

5.6.5 Correlation between TARISS total score and NSFWQI

Table 5.6 shows descriptive statistics for TARISS Score and NSFWQI. There was a weak correlation between NSFWQI and TARISS total score of r=-0.143.

Table 5.6: Descriptive statistics for TARISS total score and NSFWQI

Index	Correlation coefficients	Mean	Std. Deviation	Number of points	Correlation, r
TARISS total Score	Spearman's	14.438	10.143	6	-0.143
NSFWQI	Spearman's	56.795	0.806	6	-0.143

5.6.6 Correlation between ASPT and NSFWQI

Figure 5.34 depicts the correlation between ASPT and NSFWQI. There was a weak correlation (R^2=0.08) between ASPT and NSFWQI. Despites there was a weak correlation this indicates that both indices are useful assessment tools for assessing water quality.

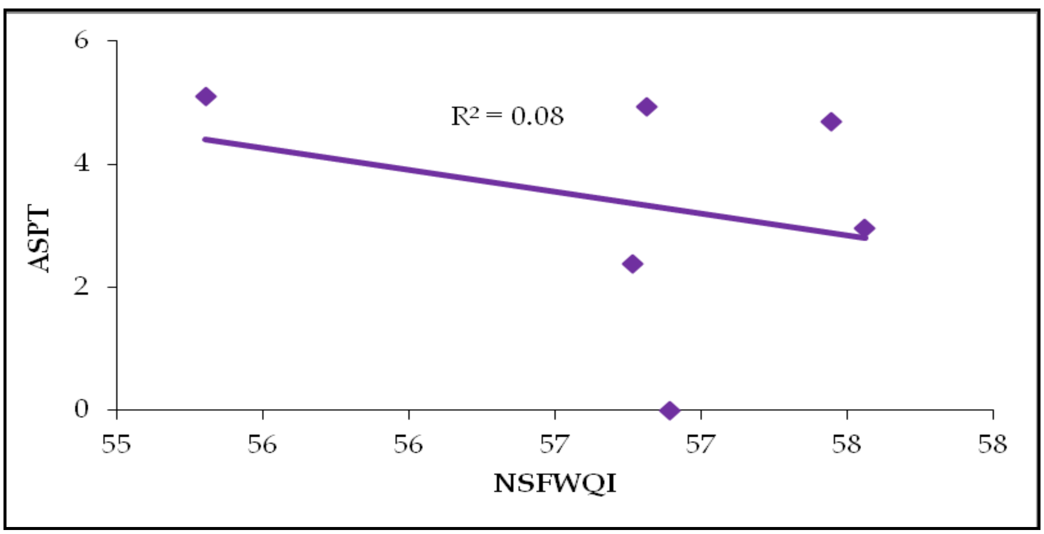

Figure 5.34: Correlation between ASPT and NSFWQI

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

i. From 2013 to 2016, there has been a significant increase in the irrigation practices and human settlements as shown by Land Use Land Cover images. Significant correlations between the water quality parameters (pH, turbidity, faecal coliforms, nitrate and electrical conductivity) and Land Use Land Cover were also recorded, which implies that the future increase of Land Use Land Cover might cause deterioration in water quality.

ii. The study showed that the water quality status of Mungonya River was within the Tanzania Water Quality Standards (2008) and WHO (2008) except for turbidity and faecal coliforms parameters which were below acceptable standards.

iii. The National Sanitation Foundation Water Quality Index indicated that the water quality status of Mungonya River was medium or average. The NSFWQI is an effective tool for understanding the dynamics between anthropogenic influences and water quality status of water bodies.

iv. The Tanzania River Scoring System (TARISS) rapid bioassessment method showed that the Mungonya River was highly utilized. The river health was fair. There was a weak correlation between NSFWQI and TARISS rapid bioassessment index, suggesting that both indices are useful assessment tools for water quality in this catchment, although the results seemed to point at TARISS as the more reliable index.

6.2 Recommendations

i. Control and mitigation measures should be put in place in order to avoid pollution of the Mungonya River. This may include periodic awareness campaigns where people are educated on the importance of water resources and their uses.

ii. Implementation of Integrated Water Resources Management and Development Plan (2015) for Lake Tanganyika Basin for managing Mungonya River should be in place.

iii. In assessing the river health it is recommended that one rapid bioassessment index should be used so as to come up with comprehensive conclusion regarding the health status of the river.

6.3 Recommendations for further studies

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

ii. It is also is recommended that the Lake Tanganyika Basin Water Board should develop a water quality database in order to facilitate improved water quality monitoring.

iii. A water quality monitoring program should be instituted at Lake Tanganyika Basin Water Board to collect physical, chemical and biological water quality data.

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APPENDICES

Appendix 1: Water quality parameters at all six Sampling points

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH	6.53	7.20	7.03	0.25	0.06
DO (mg/l)	7.23	8.78	7.87	0.59	0.35
EC (µS/cm)	40.50	50.15	44.41	3.16	9.96
Turbidity (NTU)	202.54	413.16	292.86	71.82	5158.46
Temperature (^oC)	24.08	26.73	25.41	1.00	1.00
Nitrate (mg/l)	2.60	3.01	2.77	0.18	0.03
Phosphate (mg/l)	1.03	2.19	1.68	0.52	0.28
FC (cfu/100ml)	270.00	616.50	469.94	121.62	14790.57
TSS (mg/l)	0.61	1.07	0.88	0.18	0.03
TDS (mg/l)	20.10	22.20	21.59	0.76	0.58
BOD_5 (mg/l)	1.60	2.74	1.98	0.42	0.18

Appendix 2: Water quality parameters-S1

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	6.54	7.78	7.13	0.44	0.19
DO (mg/l)	6.82	8.33	7.59	0.64	0.41
EC (µS/cm)	29.10	48.90	40.50	7.76	60.19
Turbidity (NTU)	27.00	787.00	202.54	256.72	65906.33
Temperature (^oC)	23.30	28.60	25.26	1.96	3.83
Nitrate (mg/l)	0.02	6.85	2.64	2.46	6.07
Phosphate (mg/l)	0.00	10.42	2.08	3.46	12.00
FC (cfu/100ml)	0.00	2400.00	616.50	764.06	583781.43
TSS (mg/l)	0.20	2.20	0.76	0.64	0.41
TDS (mg/l)	14.10	24.50	20.10	4.13	17.07
BOD_5 (mg/l)	1.14	2.16	1.60	0.38	0.15

Appendix 3: Water quality parameters-S2

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	6.62	7.72	7.07	0.40	0.16
DO (mg/l)	6.34	8.67	7.84	0.76	0.58
EC (µS/cm)	33.00	49.30	43.46	5.90	34.77
Turbidity (NTU)	39.30	621.00	282.20	239.75	57478.72
Temperature (^oC)	23.00	27.60	25.01	1.58	2.50
Nitrates (mg/l)	0.02	6.75	3.01	2.38	5.68
Phosphates (mg/l)	0.00	8.84	2.16	2.86	8.17
FC (cfu/100ml)	0.00	1800.00	457.13	599.66	359595.84
TSS (mg/l)	0.40	2.30	1.07	0.69	0.48
TDS (mg/l)	15.30	24.60	21.58	3.27	10.72
BOD_5 (mg/l)	0.72	2.76	1.72	0.62	0.38

Appendix 4: Water quality parameters-S3

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	6.75	7.84	7.20	0.33	0.11
DO (mg/l)	6.98	11.50	8.36	1.39	1.93
EC (µS/cm)	29.50	51.00	43.81	6.94	48.17
Turbidity (NTU)	53.30	1622.00	413.16	534.66	285863.55
Temperature (^oC)	22.90	28.60	24.91	1.82	3.33
Nitrates (mg/l)	0.01	6.80	2.60	2.44	5.95
Phosphates (mg/l)	0.00	8.97	2.19	2.82	7.96
FC (cfu/100ml)	90.00	1200.00	476.50	377.54	142538.00
TSS (mg/l)	0.14	1.70	1.01	0.68	0.47
TDS (mg/l)	13.60	25.50	21.70	3.77	14.20
BOD_5 (mg/l)	0.96	2.64	1.70	0.65	0.42

Appendix 5: Water quality parameters-S4

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	7.01	7.78	7.46	0.28	0.08
DO (mg/l)	6.07	8.35	7.23	0.94	0.88
EC (µS/cm)	32.70	51.40	43.89	6.20	38.44
Turbidity (NTU)	64.70	1234.00	318.21	383.72	147244.50
Temperature (^oC)	23.80	31.10	26.45	2.32	5.37
Nitrates (mg/l)	0.02	6.90	2.99	2.57	6.62
Phosphates (mg/l)	0.00	2.58	1.20	0.93	0.86
FC (cfu/100ml)	0.00	950.00	427.25	401.27	161014.79
TSS (mg/l)	0.30	1.40	1.00	0.38	0.14
TDS (mg/l)	15.10	25.70	22.20	3.31	10.99
BOD_5 (mg/l)	0.84	3.72	2.01	0.93	0.87

Appendix 6: Water quality parameters-S5

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	6.76	7.76	7.18	0.36	0.13
DO (mg/l)	6.10	8.25	7.43	0.89	0.80
EC (µS/cm)	37.90	56.60	50.15	6.34	40.25
Turbidity (NTU)	107.00	506.00	244.00	161.88	26204.86
Temperature (^oC)	23.80	32.20	26.73	2.96	8.73
Nitrate (mg/l)	0.02	6.88	2.68	2.48	6.17
Phosphate (mg/l)	0.00	2.84	1.41	1.05	1.10
FC (cfu/100ml)	0.00	820.00	270.00	272.51	74261.71
TSS (mg/l)	0.02	1.70	0.61	0.66	0.44
TDS (mg/l)	0.00	28.30	21.99	9.54	91.06
BOD_5 (mg/l)	1.68	3.96	2.74	0.82	0.67

Appendix 7: Water quality parameters-S6

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance
pH (Unit)	6.71	7.59	7.06	0.36	0.13
DO (mg/l)	7.00	15.98	8.78	2.96	8.78
EC (µS/cm)	35.40	57.50	44.63	8.54	72.90
Turbidity (NTU)	77.00	732.00	297.08	270.30	73064.39
Temperature (^oC)	22.80	24.80	24.08	0.73	0.54
Nitrates (mg/l)	0.02	6.82	2.72	2.35	5.54
Phosphates (mg/l)	0.00	2.14	1.03	0.77	0.60
FC (cfu/100ml)	0.00	2000.00	572.25	645.29	416400.50
TSS (mg/l)	0.16	1.90	0.86	0.73	0.53
TDS (mg/l)	16.40	28.70	21.96	4.58	20.94
BOD_5 (mg/l)	0.72	3.36	2.13	0.92	0.85

Appendix 8: Example of NSFWQI Calculation for Sampling Point 6

Parameter	Test result	Units	Q-value (I_i)	Weighting Factor (W_i)	Subtotal
pH	7.06	pH units	90	0.12	10.75
Change in temp	24.08	degrees C	14	0.11	1.56
DO	92.50	% saturation	96	0.18	17.24
BOD	2.13	mg/l	80	0.12	9.62
Turbidity	297.08	NTU	5	0.09	0.45
Phosphates	1.03	mg/l	18	0.11	1.99
Nitrates	2.72	mg/l	48	0.10	4.75
TSS	0.86	mg/l	97	0.17	16.49
Fecal Coliforms*	572.25	cfu/100 ml	26	0.17	4.34
**Only use one microorganism, not fecal coliforms AND E. coli*			**TOTALS=**	**1.17**	**67.21**
		Water Quality Index =			**57.44**
		Water Quality Rating =			**MEDIUM**

Appendix 9: Water quality results for Mungonya River based on NSFWQI

Parameter	Weights	Sampling Points					
		S1	**S2**	**S3**	**S4**	**S5**	**S6**
		Subtotal	**Subtotal**	**Subtotal**	**Subtotal**	Subtotal	**Subtotal**
pH	0.12	10.86	10.78	10.93	9.28	10.92	10.75
Temp	0.11	1.45	1.47	1.48	1.35	1.33	1.56
DO	0.18	16.96	17.22	17.68	16.48	16.76	17.24
BOD	0.12	10.16	10.04	10.06	9.75	9.01	9.62
Turbidity	0.09	0.45	0.45	0.45	0.45	0.45	0.45
Phosphates	0.11	0.97	0.93	0.91	1.71	1.46	1.99
Nitrates	0.10	4.80	4.58	4.82	4.59	4.78	4.75
TSS	0.17	16.49	16.49	16.49	16.49	16.49	16.49
FC	0.17	4.27	4.51	4.51	4.61	**5.37**	4.34
TOTALS	**1.17**	**66.41**	**66.47**	**67.34**	**64.70**	**66.56**	**67.21**
NSFWQI		**56.76**	**56.81**	**57.56**	**55.30**	**56.89**	**57.44**
NSFWQ Status		MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM

Appendix 10: TARISS Version 1 Scoring Sheet

TARSS Version 1 Scoring Sheet	Taxon		S	V	GSM	C	Taxon		S	V	GSM	C
@ 2013	**PORIFERA (Sponges)**						**TRICHOPTERA (Caddisflies)**					
Date:	**COELENTERATA (Cnidaria)**	5					Dipseudopsidae	10				
Site Code:	**TURBELLARIA (Flatworms)**	1					Ecnomidae	8				
River:	**ANNELIDA**						Hydropsychidae 1 sp	4				
Ecoregion:	Oligochaeta (Earthworms)	3					Hydropsychidae 2 sp	6				
Slope class:	Hirudinea (Leeches)	1					Hydropsychidae > 2 sp	12				
Landform:	**CRUSTACEA**						Philopotamidae	10				
Site Description:	Amphipoda	13					Polycentropodidae	12				
	Potamonautidae* (Crabs)	3					Psychomyiidae/Xiphocentronidae	8				
	Atyidae (Shrimps)	8					**Cased caddis:**					
Temp (°C):	Palaemonidae (Prawns)	10					Calamoceratidae ST	11				
pH:	**HYDRACARINA (Water mites)**	8					Hydroptilidae	6				
DO (mg/L):	**PLECOPTERA (Stoneflies)**						Lepidostomatidae	10				
Flow:	Notonemouridae	14					Leptoceridae	6				
Riparian Disturbance:	Perlidae	12					Pisuliidae	10				
Instream Disturbance:	**EPHEMEROPTERA (Mayflies)**						**COLEOPTERA (Beetles)**					
Latitude:	Baetidae 1sp	4					Dytiscidae/Noteridae* (Diving beetles	5				
Longitude:	Baetidae 2 sp	6					Elmidae/Dryopidae* (Riffle beetles)	8				
UTM	Baetidae > 2 sp	12					Gyrinidae* (Whirligig beetles)	5				
Altitude (masl):	Caenidae (Squaregills/Cainfles)	6					Haliplidae* (Crawling water beetles)	5				
Cond (mS/m)	Ephemeridae	13					Scritidae (Marsh beetles)	12				
Clarity (cm):	Heptageniidae (Flatheaded mayfli	13					Hydraenidae* (Minute moss beetles)	8				
Turbidity:	Leptophlebiidae (Prongills)	9					Hydrophilidae* (Water scavenger bee	5				
Colour:	Oligoneuridae (Brushlegged mayf	15					Limnichidae	10				
Time for each sampling each bioto	Polymitarcyidae (Pale Burrowers)	10					Psephenidae (Water Pennies)	10				
Stones In Current (SIC)	Prosopistomatidae (Water specs)	15					**DIPTERA (Flies)**					
Stones Out Of Current (SOOC)	Ephemerythydae	9					Athericidae	10				
Bedrock	Tricorythidae (Stout Crawlers)	9					Blephariceridae (Mountain midges)	15				
Aquatic Veg	Dicercomyzidae	10					Ceratopogonidae (Biting midges)	5				

MargVeg In Current	**ODONATA (Dragonflies & Damselflies)**						Chironomidae (Midges)	2			
MargVeg Out Of Current	Calopterygidae ST,T	10					Culicidae* (Mosquitoes)	1			
Gravel	Chlorocyphidae	10					Dixidae* (Dixid midge)	10			
Sand	Synlestidae (Chlorolestidae)(Sylpl	8					Empididae (Dance flies)	6			
Mud	Coenagrionidae (Sprites and blue	4					Ephydridae (Shore flies)	3			
	Lestidae (Emerald Damselflies)	8					Muscidae (House flies, Stable flies)	1			
	Platycnemidae (Brook Damselflie	10					Psychodidae (Moth flies)	1			
	Protoneuridae	8					Simuliidae (Blackflies)	5			
Hand picking/Visual observation	Aeshnidae (Hawkers & Emperors	8					Syrphidae* (Rat tailed maggots)	1			
	Corduliidae (Cruisers)	8					Tabanidae (Horse flies)	5			
	Gomphidae (Clubtails)	6					Tipulidae (Crane flies)	5			
	Libellulidae (Darters)	4					**GASTROPODA (Snails)**				
	LEPIDOPTERA (Aquatic Caterpillars/Moths)						Ancylidae (Limpets)	6			
	Crambidae (=Pyralidae)	12					Bulininae*	3			
Other taxa	**HEMIPTERA (Bugs)**						Hydrobiidae*	3			
	Belostomatidae* (Giant water bug	3					Lymnaeidae* (Pond snails)	3			
	Corixidae* (Water boatmen)	3					Physidae* (Pouch snails)	3			
	Gerridae* (Pond skaters/Water st	5					Planorbinae* (Orb snails)	3			
	Hydrometridae* (Water measurer	6					Thiaridae* (=Melanidae)	3			
	Naucoridae* (Creeping water bug	7					Viviparidae* ST	5			
Comments and Observations	Nepidae* (Water scorpions)	3					Neritidae	4			
	Notonectidae* (Backswimmers)	3					**PELECYPODA (Bivalves)**				
	Pleidae* (Pygmy backswimmers)	4					Corbiculidae	5			
	Veliidae/M...veliidae* (Ripple bugs	5					Sphaeriidae (Pills clams)	3			
	MEGALOPTERA (Fishflies, Dobsonflies & Alderflies						Unionidae (Perly mussels)	6			
	Corydalidae (Fishflies & Dobsonfl	8					**SASS Score**				
	Sialidae (Alderflies)	6					**No. of Taxa**				
Procedure:							**ASPT**				

Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gr
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) * = airbreathers

Appendix 11: Example of the Macroinvertebrate identification guide