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FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

ASSESSMENT OF WATER QUALITY AND SPATIAL DISTRIBUTION OF THE MAJOR POLLUTANTS IN NGERENGERE RIVER CATCHMENT, TANZANIA

BY

ROSE MERO


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

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In collaboration with

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DECLARATION

I, **Rose Elisamon Mero**, declare that this research report is my own work. It is submitted for the degree of Master of Science in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for any other degree of examination in any other University.

Date: ____________________

Signature: _____________________

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DEDICATION

This is for my Dad and Mom,
Mr and Mrs. E.O. Mero.

ABSTRACT

Pollution from natural and anthropogenic processes threatens available fresh water resources. This is the case for Ngerengere River in Wami/Ruvu basin in Tanzania. The pollution is aggravated by agricultural and industrial wastewater from upstream sources. The deteriorating water quality poses risks to health and livelihoods, with most affected communities located downstream of the catchment. Few studies have been done on pollution in Ngerengere River catchment. Hence little information is available on the distribution and contribution of major sources of pollution and their impacts to downstream users. This study aimed at assessing the spatial distribution of potentially polluting agricultural and industrial activities, and their contribution to pollution in the catchment. Specifically, the physico-chemical assessment of pollution levels along the river was done, followed by the assessment of river health through biological assessment of macroinvertebrates' sensitivity and diversity. Furthermore, mapping of the spatial distribution of pollution sources and the estimation of their relation to pollution levels were undertaken. During the study period (February- March 2011), four sampling campaigns at nine points were assessed for physico-chemical parameters (including heavy metals), according to Standard Methods. Pollution levels were correlated to the distribution of pollution sources through overlaying landuse and pollution distribution maps and calculating the dominant landuse in a selected buffer area from the sampling points. The GIS work was done using the ArcGIS software. River health was assessed through the diversity of macro-invertebrates according to the SASS 5 Method. Results showed high concentrations of physico-chemical parameters, which give indications of intensive agricultural activities and industrial activities. Total Phosphate showed a maximum concentration of 5mg/l, while TKN reached 120mg/l at the industrial release point. Peak concentrations of Cadmium were observed to be 0.104 mg/l and similar trends existed for other heavy metals. These results were believed to be due to the textile effluent released upstream of the catchment and the increasing rate of agricultural development in the catchment. The results indicated high pollution and implied severe impacts to downstream users. Overall, results for bio-assessment indicated poor biological health of the river due to low diversity, abundance and richness. Statistical analysis confirmed significant differences in the physico-chemical concentrations and bioassessment results along the river at 95% confidence levels. From the mapping, the spatial distribution of pollution and landuse gave indication of the relationships between the pollution sources. The results obtained provided baseline information, which may be used in the development of appropriate Water Quality Management Systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ANZECC	Australian and New Zealand Environment Conservation Council
APHA	American Public Health Association
ASPT	Average Score Per Taxa
CCME	Canadian Council of Ministers of the Environment
EC	European Community
EPA	Environmental Protection Agency
FA	Factor Analysis
IUCN	The World Conservation Union
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
MNRT	Ministry of Natural Resources, Tanzania
MORUWASA	Morogoro Rural and Urban Water Supply Authority
NTU	Nephelometric Turbidity Units
PCA	Principal Component Analysis
SASS	South African Scoring System
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
TLAI	Tanzania Leather Association of Industries
TZDWS	Tanzania Drinking Water Standards
USGS	United States Geological Survey
WHO	World Health Organization
WRBO	Wami/ Ruvu Basin Office

CHAPTER ONE: INTRODUCTION

1.1. Introduction

Ngerengere River in Wami/ Ruvu basin in Tanzania is threatened by pollution due to natural and anthropogenic processes (MNRT, 2003; Yanda and Munishi, 2007). This situation has been aggravated by high levels of pollutants coming from agricultural activities, mainly at the foothills of Uluguru mountains located upstream of the Mindu Dam (MNRT, 2003; Franks *et al.,* 2005; IUCN, 2010). Also waste water from Morogoro town and industrial wastewater from Kihonda and Mzinga industrial areas, flow into the river system. Numerous studies (e.g. Franks *et al.,* 2005; Schosler and Riddington, 2006; Ramadhani, 2007 and Dietz, 2009) have confirmed a shift in land use practices within the catchment from natural forest to cultivated land. Large scale farming, such as sisal plantations, as well as small-scale farms growing vegetables and rice make use of fertilizers and pesticides to support their growth.

The impacts of pollution on fresh water resources differ, depending on the pollutant types, concentrations and the different water use, within the catchment area. In Ngerengere catchment, various development activities and land use practises have contributed to patterns of water pollution related impacts (Schosler and Riddington, 2006; IUCN, 2010). Among the most affected communities are Bwawani, Sangasanga villages and other settlements which depend entirely on the river for their domestic use and economic productivity e.g. livestock and fishing activities. Ngerengere town has constructed two boreholes for domestic water supply but other villages do not have this alternative. Hence, the villages continued dependence on the river poses a potential risk to their health and livelihoods.

According to Wami/Ruvu Basin plans, the catchment is divided into three zones, namely; upstream, mid reach and downstream (IUCN, 2010). Most of the pollution intensive activities, such as intensive agricultural activities involving the use of fertilisers and pesticides, are carried out in the upstream zone. About 171,382 ha of the catchment are used for agriculture (JICA, 2003).

Industries are located within the upstream and mid-reach zones and are among the polluters in the catchment. There are nine industries which release effluents either directly or indirectly into Ngerengere River. One industry located within a camp in the upstream zone, releases the effluent into wastewater ponds. The mixed wastewater is then discharged into the Mzinga stream and into Mindu Dam. Other industries which are located in Morogoro town and Kihonda industrial area release their effluent into Morogoro River which is a major tributary of

Ngerengere River. At Kihonda industrial area, a number of industries discharge effluents into the same wastewater ponds, but these ponds are currently not functional, and release raw effluents into Ngerengere River. The Downstream zone receives water with accumulated pollutants from the whole catchment and is expected to be highly impacted. To worsen the situation, the main water supply authority of Morogoro region (MORUWASA) does not supply water to villages located downstream of the catchment, thereby increasing the risk of a major disease outbreak.

Previous water quality studies in Ngerengere River Catchment have mainly focused on the Mindu Dam, located in the upstream zone (Ramadhani, 2007; MORUWASA, 2010). Also biodiversity loss due to landuse changes of Uluguru Mountains, (part of the Arc Mountains with a unique biodiversity) has received significant attention (Burgess, 2001; Franks *et. al.*, 2005; Yanda and Munishi, 2007). A detailed catchment water quality study including all three zones of the catchment is therefore required. There is need, to study the whole catchment in order to establish baseline data for developing guiding policies and plans so as to mitigate the potential impacts of water pollution. This study is a first step towards providing fundamental information for the development of a water quality management system to be incorporated into the Integrated Water Resource Management (IWRM) plans in the catchment.

1.2. Background

Ngerengere River catchment is the smallest catchment in the Wami/Ruvu basin and covers an area of 2780 km^2. Ngerengere River, which is the main river system in the catchment, originates from Uluguru Mountains, along with four other tributaries, namely Mzinga, Kulunge, Mgeta and Mlali streams. Ngerengere River drains the northern side of the Ruvu sub-basin while the other minor tributaries drain towards the southern part of the sub-basin. Water from these streams is collected in the Mindu Dam whose purpose is to supply drinking water to Morogoro urban area. From the Mindu dam, the river passes through Morogoro town towards the east, passing Mikese and Sangasanga villages towards Ngerengere township, located downstream of the catchment. It finally joins the lower Ruvu River which flows towards Dar es Salaam city. Ngerengere River receives additional discharge from other tributaries, the main ones being Morogoro and Bigwa streams. These two streams originate from the other part of Uluguru Mountains and flow through Morogoro town before joining Ngerengere River at Kihonda and Tungi, respectively.

Studies show a variation in landuse patterns among downstream and upstream communities which pose different threats to water quality (Burgess, 2001; IUCN, 2010). On one hand, the downstream zone is characterised by less intensive activities, such as fishing, limited agriculture and livestock farming. The upstream zone, on the other hand has fish farming in Mindu Dam, intensive agriculture coupled with frequent forest fires which have led to high rates of sedimentation and chemical pollution in the dam (IUCN, 2010). Furthermore, the major industries which release large volumes of pollution intensive effluent to the river are located within the upstream and mid-reach zones. As a result, agricultural and industrial wastes have been identified as main pollution sources of the river system.

The water quality situation is made worse by the fact that there are intensive river-bank agricultural activities which influence illegal abstraction of water upstream at the foothills of Uluguru Mountains. Illegal abstractions minimize water flows towards the dam, leading to a more critical situation downstream, particularly during the dry season (Yanda and Munishi, 2007; Ramadhani, 2007). Increasing challenges of water quality and quantity have been identified as among the major problems facing downstream water users in the catchment (IUCN, 2010). Recently, it was reported that the volume of untreated wastewater effluents released from the Tanzania Leather and Associated Industries (TLAI) ponds have increased because the treatment ponds are currently not functioning (IUCN, 2010; MORUWASA, 2010). Furthermore, most of these industries' pre-treatment plants have been reported to not be properly functioning, thus allowing untreated or partially treated wastewater to be discharged into the river. The poor water quality challenge in Ngerengere River has direct impacts on people's health and livestock. It also has indirect effects on the economic activities of people e.g. aquaculture, recreational and irrigation. The Morogoro socio-economic profile of 1997 highlighted cholera and dysentery as being among the top five epidemic diseases prevailing in Morogoro rural area, where most of small villages located in the downstream zone, including Ngerengere town, are found. Yanda and Munishi (2007) also indicated the same challenge by highlighting the percentage increase of water borne diseases related patients in Morogoro rural area. This can be attributed to the pronounced pollution increase of the river due to the mentioned development activities.

Apart from its effects on human health and their livelihoods, water pollution disrupts river health integrity by negatively disturbing and toxifying aquatic organisms. While some fish and macro-invertebrates species may be tolerant to a range of pollution levels, others are much more sensitive (Flotemersch *et al.,* 2006), making them useful indicators of pollution in water resources. The dependency of humans on both terrestrial and aquatic resources for their survival and development triggers more attention on health and integrity of both resources by increasing focus on monitoring of the aquatic ecosystem. With increase of pollution related development activities, the need for frequent monitoring of physical, chemical and biological parameters of water quality is inevitable. The assessment of water quality status using physical and chemical analysis alone is the mostly recognised analysis in Ngerengere catchment like many other catchments in Tanzania. The current water quality challenges call for recognition of the additional biological component and other cost effective monitoring methods.

1.3. Problem Statement and Justification

Previous studies of Ngerengere River Catchment mainly focused on the investigation and evaluation of water quantity and quality challenges particularly at Mindu Dam and Uluguru Mountains (MNRT, 2003; Yanda and Munishi, 2007). These studies have been motivated by the reduction of the dam depth resulting from continuous sediment deposition and biological productivity. Being the main source of potable water in Morogoro city, the dam has attracted the attention of many researchers. A high deforestation rate and its impact on biodiversity and water resources in Uluguru Mountains is another area which has obtained researcher's attention. However, there is known to be limited information on the relationship and contribution of major pollution sources in the catchment to the increasing pollution along the river system and their potential impacts to downstream users of the river.

The current water quality challenges are contributed by the absence of an effective and integrated water quality management system which includes monitoring of physical, chemical and biological parameters/ indicators in the monitoring strategies of the catchment. This can be established by first assessment of the river quality status and determining the contribution of different sources to pollution levels. Project results will contribute to the establishment of prioritised planning and implementation of a water quality management system which relies on the identified and monitored pollutants.

The study therefore contributes to reducing the knowledge gap by quantifying the water quality status. It focuses on agriculture and industries with respect to selected physical, chemical and biological indicators. This will further enable monitoring of both river ecosystem health and quality for other uses. Finally, the study gives recommendations on the appropriate water quality monitoring system and prioritization of preventive and mitigatory measures of the water pollution in the catchment area, which is the prerequisite information in the development of IWRM plans for the basin.

1.4. Research Questions

1. To what extent do agricultural and industrial activities contribute to pollution of Ngerengere River?
2. What is the impact of water quality on the abundance, richness and community composition of macro-invertebrates of Ngerengere River?
3. How does the spatial location of selected pollution sources contribute to water quality along Ngerengere River?

1.5. Objectives

1.5.1 Main Objective

To assess water quality levels, trends and their relationship to the spatial distribution of selected pollution sources in the Ngerengere River Catchment, in Tanzania.

1.5.2 Specific Objectives

1. To assess water quality status in the catchment from February to March 2011 with a focus on selected sources (agriculture and industries).
2. To assess the current river ecosystem health and integrity through macro-invertebrates diversity, composition and abundance.
3. To determine the spatial location of pollutants and their relation to the levels and distribution of pollution in the Ngerengere River during the month of February and March 2011.

1.6. Methods

The study used the physical chemical assessment method to assess water quality status in the catchment. Furthermore, Factor Analysis Method was used to estimate the possible sources of pollution along the river using the physico-chemical assessment information. To achieve objective two, the study used the Bioassessment Method to assess the river ecosystem health and integrity. SASS 5 Protocol was used to assessment macro-invertebrates diversity, composition and abundance. Data analysis for the third objective involved the utilization of

ArcGIS software to map and visualize some aspects of the research and examine the distribution of pollutants sources and identify the areas with health risks.

1.7. Scope and Limitations of the Study

The study focused only on agricultural and industrial sources as the major sources of pollution in the catchment, and hence selected parameters which are closely related to these activities. The sampling site design also depended on the concentration and presence of pollution sources.

The study did not address in details the issues related to impacts of the selected parameters to public health. This was due to limited resources and lack of available information about the direct related health impacts from the poor water quality of the river.

Limited resources and time led to constrained sampling design which covered four and two sampling campaigns for physico-chemical and bioassessment data collection respectively. However, secondary data from the Wami/Ruvu basin offices were also used for analysis.

In terms of water quality standards the WHO Drinking Water Standards (2008); Tanzania Drinking Water Standards (2009) and DWAF Water Quality Guideline (Aquatic Ecosystem) (1996) and Australian Water Quality Guidelines (Aquatic Ecosystem) (2000) were used to compare with the measured values at different locations according to specific water uses.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

Water resources are fundamental to human health, aquatic ecosystems and also human economic development. Particularly, fresh water resources are more crucial for these purposes as compared to groundwater in most of the Southern Africa. Some of the activities which highly rely on surface water resources include domestic consumption, power production, irrigation, fishery and water for livestock. However, the same development activities in turn stress surface water resources through water scarcity and pollution (Jonnalagadda *et al*., 1991; Mathuthu *et al.,* 1993; Magadza, 2003).

2.2. Water Quality

Water quality describes the physical, chemical, and biological characteristics and conditions of water and aquatic ecosystems, which influence the ability of water to support the uses designated for it (CCME, 2006). Water quality involves the physical, chemical, microbiological, radiological and biological properties of water. It can mainly be altered by human activities which may affect/ change any of these properties to the extent of affecting aquatic and terrestrial organisms depending on it (DWAF, 1996).

Water pollution contributes to the occurrence of major epidemics which constantly affect the Southern African region and the World in general. A number of water-borne diseases such as diarrhoea, dysentery and Cholera have been reported to cause fatalities around the globe (Oguntoke *et al.,* 2009). Studies by Ongley (1999) and Levy (2007) have further confirmed a positive relationship between water pollution levels and an increased rate of water borne diseases in different regions of Africa. In Tanzania, Mohammed (2007) evaluated a number of water quality studies done in the coastal zone and identified critical findings which include high prevalence of water-borne diseases due to the consumption of untreated water directly from rivers and lakes which contain toxins, chemicals and nutrients; destruction of the aesthetic value of water resources due to disposal of oil and other fluids in water and the degradation of aquatic ecosystems.

Death, migration or extinction of aquatic organisms may occur as a result of severe pollution released in a river system (Davies *et al.,* 2000; Obire, 2008). However, some aquatic species can survive by adapting to adverse conditions and becoming pollutant tolerant species (Chutter, 1998; Dallas, 2000; Dicken and Graham, 2002). Consequently, a number of research studies have been conducted to assess the impacts of poor water quality to aquatic organisms (Chutter, 1998; Dicken and Graham, 2002). Some of these studies have resulted in the development of biological indices such as biodiversity index and Protocols e.g. SASS 5 protocol, which use macroinvertebrates as quality status indicators. Pollution source types are among the major factors influencing the type and severity of impacts to both people and other organisms.

2.3. Sources and Impacts of River Water Pollution

There are natural and anthropogenic sources of water pollution; nevertheless, anthropogenic activities are known to contribute more to the deterioration of water quality (Levy, 2007; Baig *et al.*, 2010). Pollution distribution varies based on whether it is a point or non-point source e.g. the distribution and impacts of pollutants from domestic wastewater and agriculture runoff are different. Some of the point sources include wastewater discharge from sewer systems and industries and for non-point sources includes return flows from agricultural lands, livestock feedlots and storm water runoff (Yu *et. al*., 2003)

2.3.1 Non Point Sources of Pollution (Agriculture)

Agriculture is one of land use activities of global concern due to its contribution to rivers and lakes pollution (Anderson *et al.,* 2003; Yu *et. al*., 2003). Organic compounds and agrochemicals such as fertilisers and pesticides carried by runoff during rainfall events and as return flows in irrigation schemes, are known to cause water pollution (Salama *et al*., 1999). Loading of nutrients in rivers has a number of adverse impacts including eutrophication which consequently results to the death of aquatic organisms (Carpenter *et al.*, 1998; WHO, 2002). Some of the agrochemicals, particularly pesticides, have high toxicity levels hence may cause extinction of some aquatic organisms (Sherratt, *et al.*, 1999; Lee, 2003). For example, Lee (2003) did a research study in Germany and concluded that pesticides affected a zooplankton *Daphnia magna* species. In Tanzania, Shilungushela (1993) and Ramadhani (2007) showed the direct impacts of agricultural activities on water quality which include pollution and sedimentation.

2.3.2 Point Sources of Pollution (Industries)

Globally industrial activities are among the major point sources of pollution globally reported to affect the environmental condition of water, air and soil (Yusuff and Sonibare, 2005**)**. In water resources, pollutants are mainly released from wastewater or leakage of chemical tanks which find their way into water bodies. Effluent flowing into the rivers is treated, pre-treated or untreated depending on the availability of appropriate infrastructures which consequently indicate varied impacts.

The major polluters of Ngerengere River include textile, tannery and sisal industries. These industries release large volumes of effluent containing chemicals and heavy metals directed to rivers and streams (Akan *et al.*, 2009; Deepali and Gangwar, 2010). Wastewater from textile industry, for instance, is a complex mixture of a number of chemicals ranging from organochlorides to heavy metals containing dyes (Yusuff and Sonibare, 2004). Textile effluent contains dyes and odour which have detrimental effects on aquatic life. The loss of macro-invertebrates diversity can be contributed by chemicals contained in textile and tannery effluent (Dube *et al.*, 2010). These studies highlighted the direct impacts of industrial activities on the aquatic life which also indirectly impact humans through the food chain relationship.

A study done by Akan (2007) in Nigeria showed the presence of heavy metals, including Chromium and Lead, which exceeded both local and international maximum permissible limits. The effluent directed to the river then consequently resulted in bioaccumulation of heavy metals in fishes and other aquatic organisms. In Tanzania, a number of studies in Dar es Salaam and Tanga confirmed continuous water quality deterioration in relation to industrial activities and suggested initiatives to reduce the severity of associated impacts (UNIDO/UNEP, 1982; Kondoro, 1997). In spite of the fact that a majority of studies have concluded that industries and agriculture are the major sources of pollution, there are also other sources of pollution with insignificant pollution levels which are associated with potential impacts.

2.3.3 Other Sources of Pollution

Other sources of water pollution of concern include solid waste disposal through leachates, vehicle service stations and recreational activities (Baig *et al.,* 2010). However, their impacts are less, compared to that of agricultural and industrial activities. The impacts of water quality deterioration to human and aquatic organisms do not only depend on the sources of pollution but also other factors such as pollution distribution along the river and different river water uses. A large number of pollution sources and multiple utilization of river water hinder easier prediction of pollution impacts when focusing only on fewer factors. Therefore a thorough investigation of all the factors and indicators explaining the river water quality is implemented in a number of basins and catchments. This status requires continuous assessment and monitoring of different parameters and environmental conditions causing changes in the quality of water.

2.4. Water Quality Assessment and Monitoring

The scales of human activities which interfere with natural processes of water resources have reached the point of affecting the subject basin and neighbouring basins (IUCN, 2010). This has complicated the water resources management systems where the need for comprehensive and accurate monitoring of water quality is inevitable. Water quality assessment enables the basins authorities to address the present and future impacts and risks of pollution respectively which implies continuous water quality monitoring.

For interpretation purposes, thresholds for the physical, chemical and biological indicators of water quality exist and are used as standard measures in different geographical areas. There are a number of international and regional water quality guidelines and standards e.g. WHO drinking water quality standards and South Africa aquatic ecosystem guidelines. Standards vary with the water use, source of pollution and sometimes geographical characteristics of the area e.g. water temperature standards for tropical regions are different from that in temperate regions. Most of the developing countries, including Tanzania, have water quality standards for different water uses which are in line with international guidelines. Water quality standards are commonly used in continuous monitoring of water quality in catchments, which is an important process in the water quality management programme.

In an effort to minimize water quality challenges, a number of countries have developed water quality management programmes (Chapman, 1996; Silberbauer, 1997) which encompass assessment, monitoring, mitigation and prevention of water pollution in order to ensure safe and healthy water resources. Depending on the selected indicators of water quality, there are a number of methods used in the assessment and monitoring of water quality. Those methods with a focus on the direct physical, chemical and biological parameters are commonly implemented in different parts of the world (Silberbauer, 1997; Day, 2000; Dicken and Graham, 2002). With improved technology, there are a number of indirect and cost effective measures of water quality measures which involve geographical information system, and modelling (Dias *et al*., 2006).

Anthropogenic activities in the catchment such as agricultural and industrial activities are important for economic development; however inappropriate practices resulting into water pollution consequentially threaten the health of both human and aquatic ecosystem in the catchment (Anderson *et al*., 2003; Yusuff and Sonibare, 2005). Water quality assessment and identification of major sources of pollution in a catchment is the crucial initial task in the development of an integrated water quality management system. The study involved assessment of the biotic and abiotic characteristics of water in terms of quality.

There are abiotic and biotic characteristics of water. Biotic characteristics are characteristics that are involving or are derived from living organisms, while abiotic characteristics are the ones involving or derived from non living organisms and their ecological relations. The physico-chemical indicators of water quality represented the abiotic characteristics while the bioassessment indicators such as macro-invertebrates represented the biotic characteristics of the water.

2.4.1 Physico-chemical Assessment

The physico-chemical assessment method employs assessment of physical and chemical characteristics of the river at a specific location and time. Among the major factors considered in choosing the parameters to be measured for the physico-chemical assessment are the sources of pollution. Other factors include the use of water and suspected distribution of pollutants. For instance, in assessing the drinking water quality, measurement of E.Coli is inevitable because it is among the indicators of faecal contamination in drinking water and portrays a high risk of water borne diseases to the users (Marsalek, 1978;). With consideration of the scope of the study on sources of pollution in Ngerengere river study, six physical parameters (colour, turbidity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), pH and Temperature); seven chemical parameters (Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Nitrate (NO_3), Total Kjeldah Nitrogen (TKN), Total Phosphate (TP), Ortho-Phosphate (OP), Sulphate (SO_4) and four heavy metals (Cadmium (Cd), Lead (Pb), Chromium (Cr) and Iron (Fe) were selected. Characteristics of these parameters give either a direct or indirect indication of the type and sometimes occurrence of pollution in water which in turn highlights possible sources of pollution.

Temperature

Temperature influences a number of other physical, chemical and biological processes and the ecosystems balance in rivers (Machena, 1997). It is the primary factor which influences water density whereby as the water becomes hot, its density lowers and vice versa. It also affects the solubility of chemical compounds hence influences some of the pollutants to dissolve in water (IUCN, 1994). For instance, by speeding up the denitrification rate in water, temperature can be indirectly used to measure nitrogen concentration in water by assessing the rate of denitrification in water (Smith, 1997). Increased temperature also contributes to increasing metabolic rates and reduces oxygen solubility in water, which consequently threatens the survival of aquatic life.

pH

pH is a measure of the hydrogen ion concentration. The pH scale ranges from 0 to 14 with a pH of 7 as neutral, less than 7 representing acidic solution and more than 7 representing alkaline/basic solution (WHO, 2008). pH influences some chemical and biological processes in water resources such as salinity, conductivity, permeability and toxicity (Mazlum *et al.*, 1999). Low pH increases solubility of metals and nutrients such as phosphates and nitrates making them available for uptake by plants and animals (WHO, 2002). Decomposition of dead algae blooms and dead plants by bacteria leads to a reduction of dissolved oxygen and consequently stress other aquatic organisms such as macroinvertebrates and fish (Manjare et al., 2010). In the presence of sediments, low pH and low DO facilitate the release of toxicant nutrients to the water column which has impact on aquatic life. Most organisms prefer a pH range of 6.5-8.0 because the lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5 (WHO, 2008).

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Electrical conductivity (EC) estimates the total ionic concentration in water and is an alternative measure of Total Dissolved Solids (TDS). TDS is a measure of the amount of dissolved material in the water column. The unit for EC is microsiemens per centimetre (µS/cm) and that of TDS is (mg/l). TDS for natural fresh water ranges from 0-1000 mg/l and EC range from 50-1500 µS/cm (WHO, 2008). High TDS reduces suitability of water for drinking as it may physically change clarity, colour and taste and sometimes even become unsuitable for irrigation depending on the concentrations. Kirk (1984) estimated the negative correlation between TDS levels and dissolved Oxygen (DO) levels, which showed impacts of dissolved solids aquatic organisms' health.

Turbidity

Turbidity is an optical property of water based on the amount of light reflected by suspended particles (Sadar, 2002). It is also known as the measure of water clarity. Turbidity is measured in Nephelometric Turbidity Units (NTU). The Secchi disk, which is mainly used to measure the depth of water bodies such as lakes and ponds, can indirectly express the turbidity of water.

High turbidity provides for bacterial colonies growth by providing enough surface area of suspended solids (Sadar, 2002). It also reduces light penetration and amount of dissolved oxygen which are fundamental ingredients for photosynthesis in water (Levy, 2007). Reduced food production by aquatic species and impairing of the food chain and interactions between aquatic and terrestrial species are among the known impacts of reduced photosynthesis due to high turbidity. Other impacts of high turbidity include clogging of fish gills, smothering of fish eggs and impairment of benthic macroinvertebrates habitat. A positive correlation between nutrients levels and turbidity levels in water suggests the possibility of attachment of chemicals and nutrients onto the suspended solids.

Nutrients

Nutrients are essential elements for the control of species composition, diversity, and dynamic functioning of many terrestrial and aquatic ecosystems (Chambers *et. al.*, 2006). In aquatic ecosystem, excessive nutrients may cause adverse problems such as toxic algal blooms, loss of dissolved oxygen, hence fish kills, loss of biodiversity and loss of aquatic plants and microorganisms (Days and Davies, 1998). This consequently impairs the quality of water for drinking, industry, agriculture and recreation**.** The key nutrients of concern are nitrogen and phosphorous.

Nitrogen

Nitrogen may occur as Dinitrogen oxide (N_2O), Ammonia (NH_3), Ammonium ion (NH^{4+}), Nitric acid (HNO_3), Nitrite (NO_2^-) and Nitrate (NO_3^-). However Ammonia, Nitrite and Nitrate are known to be the most significant in biochemical processes because they rapidly dissolve in water (Levy, 2007). Nitrogen is an essential requirement for photosynthetic processes in plants. In agriculture, the amount of nitrogen which is not taken by plants is washed away by runoffs to the river, whereby excess release can have adverse effects on aquatic life (Jordan *et al.*, 1997). However, the impacts vary with different nitrogen forms found in water such as nitrite, nitrate and ammonium compounds which are the major causes of eutrophication. Jordan *et al.*, (1997) reported that nitrate concentration exceeding 1mg/l have high toxic level to frogs, amphibians and aquatic insects. Nitrogen may also have impacts to terrestrial organisms. For example consumption of water with nitrate concentration exceeding 10mg/l may cause the blue-baby syndrome to children (Corell, 1998).

Phosphorus

Phosphorus is mainly found in a form of phosphates (PO_4^{-3}), either organically-bound phosphates or inorganic (orthophosphates & polyphosphates) and exists in either particulate phase or dissolved phase (Correll, 1998). As a growth limiting nutrient, phosphorous is an essential element for plants, but in excess, it results in the excessive growth of algal and aquatic plants which has both direct and indirect impacts to water quality (Levy, 2007). The decomposition of dead algae and plants utilizes dissolved oxygen in water which consequently suffocates and kills fishes and other aquatic organisms. In a river channel with a high flow rate, pollution sources and the seasons attribute to variations in levels and distribution of phosphorus load along the river. A study by Deegan and Peterson (1992) highlighted that the point sources contribute more in phosphorus load in river during the dry season while non point sources dominate more during the rainy season.

Sulphate (SO_4^{-2})

Sulphate occurs in solid minerals, anthropogenic compounds and as aqueous component in a solution and natural water (Alexander, 1985). In water, sulphate naturally occurs as a result of weathering of rocks and other geological formations particularly gypsum, anhydrites and barite (Alexander, 1985). As an anthropogenic compound, it may occur as a result of municipal e.g. treated/ untreated sewage, agricultural or industrial discharges in water. Sulphate is used in the manufacture of fertilisers, hence its concentration is found in agricultural runoff to the rivers. Sulphate is positively correlated to crop production hence it is needed to support plant growth (Carpenter *et al.,* 1998). Being used as a fertilizer, sulphate levels in water have increased in a number of rivers over time increasing risk to aquatic ecosystem health

Sulphate is widely used as a raw material in the tannery, pulp mills, textile, soap and breweries industries, among others (Kanu *et al.,* 2011); it is also one of the important raw materials in mining, sewage treatment plants, textile, soap and leather processing industries (Yusuff and Sonibare, 2005). Sulphate is mostly found in industrial effluent even if it was used as a raw material. For example sulphuric acid is also widely used in a number of industries for pH regulation, are process regulations, as conductive agents, anti-condensation agents and other uses results into discharge of sulphate intensive effluent.

The major effect of higher sulphate levels in water to people is the laxative effect which may lead to dehydration. For plants, high sulphate concentration above 1000mg/l may render water suitable for irrigation. High sulphate may also cause scale build-up in pipes, production of dark slime that can clog plumbing (Tufekci *et al.*, 2007)

Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD)

Chemical Oxygen Demand (COD) represents the level of biodegradable and non-degradable organic pollution and Biological Oxygen Demand (BOD) indicates the extent of biodegradable organic pollution in the aquatic system. BOD and COD are known to be potential and reliable indicators of pollution from domestic, industrial and agricultural activities (Hur, *et al.* 2010). In most cases COD values are found to be higher than BOD values because COD consider both biodegradable and non-biodegradable organic materials while BOD is for biodegradable organic materials only (Barclay and Buckley, 2000). Moreover, BOD and COD are closely related to nutrient levels as they all deduce presence of organic materials in water. However, levels of the three parameters may vary in different pollution sources, which justify their variations at different sites along the river

Heavy metals

Heavy metals within the required amount are necessary in life support of both terrestrial and aquatic organisms (Fermer, 2001), but excessive concentrations may have detrimental effects. The major anthropogenic sources of heavy metals include industries and agriculture activities particularly the use of agrochemicals. Other sources include the geochemical structures, mining activities, urban storm and landfill leachates (Fermer, 2001).

Most industrial effluents contain both inorganic and organic complex compounds which are toxic to aquatic organisms (Dube *et al.*, 2010). Tannery and textile industries are known to release large quantities of heavy metals such as Chromium, Cadmium, Iron and Lead (Dube *et al.*,, 2010; Deepali and Gangwar, 2010). Raw materials used in tanning industries contain heavy metals e.g. Chromium sulphate salt which contaminates air, soil and water and are associated with heavy diseases burdens (Bosnic *et al.*, 2000; Tamburlini *et. al.*, 2002). Textile effluent contains formaldehyde (HCCHO), heavy metals (mostly lead, zinc and mercury) and others which can cause significant environmental degradation (Akan, *et. al.*, 2007). In agriculture the application of pesticides and herbicides is a major contributor of heavy metals in water resources.

Cadmium and Lead are highly toxic to humans as well as animals and plants. Both are highly soluble in water and long term exposure by consumption can result in kidney damage and bone toxicity (Newman and Mcintosh, 1991). Lead accumulates in the body through repeated exposure which consequently can have irreversible effects on the nervous system, particularly to young children (Fermer, 2001). Chromium and Iron elements are also threat heavy metals to humans and aquatic ecosystems (Akan *et. al.*, 2009). High Chromium levels cause allergic *dermatis* condition while excessive Iron poses serious health problems such as vomiting, cardiovascular collapse and diarrhoea and failure of blood to clot due to Iron deficiency (Tamburlini *et. al.*, 2002; Akan et. al., 2009). Long-term exposure to heavy metals has toxic effects to aquatic species (Fermer, 2001), whereby their excessive concentration has lethal impacts on aquatic life which can further reach humans through food chain relationship between terrestrial and aquatic organisms.

The physico-chemical assessment of heavy metals and other parameters is a recognised effective method for assessment of the spatial and temporal variations of pollution. However without further assessment of biological effects of pollutants, it is difficult to make a reliable conclusion about the water quality status of the catchment/ basin (Feminella, 1999). Therefore, biological assessment which reveals the ecosystem health and integrity is essential in complimenting the physico-chemical assessment of the river.

2.4.2 Biological Assessment

The biological assessment method involves use of aquatic organisms such as fish assemblages, macroinvertebrates, diatoms and periphyton assemblage to assess and monitor the quality and overall ecosystem health (Flotemersch *et al.,* 2006). A healthy aquatic ecosystem is defined by a good habitat with varied biotopes, high diversity, composition and abundance of species (Feminella, 1999; Flotemersch *et al.,* 2006). The capacity of aquatic organisms such as macroinvertebrates and fish to survive in harsh conditions makes them excellent indicators of water quality because aquatic organisms fall into the group of pollutant tolerant organisms (which survive in harsh conditions) and sensitive ones, which either became extinct or migrate to cleaner locations (Flotemersch *et al.,* 2006). It may take longer time for organisms to adapt and migrate to certain water quality conditions hence bioassessment recognizes long term water quality status and can highlight threats of pollution at early stages (Dallas, 2000). For that reason, bioassessment is an effective tool for early warning of environmental damage threatening aquatic organisms.

Macro-invertebrates are the commonly used biological indicators in bioassessment studies in rivers and streams (Barbour *et al.,* 1999; Flotemersch *et al.,* 2006). This is due to their abundance in most rivers, including headwater streams where other types of bioindicators such as fish do not stay. Macro-invertebrates diversity gives a wider representation of sensitivity to pollution. They are easy and simple to identify and their lifespan helps in the integration of short term disturbances in the water (Barbour *et al.,* 1999).

Macroinvertebrates Classification

Macro-invertebrates classification is based on factors such as the habitat, which focus on the number of biotopes (Harvey, 2006; Bredenhand, 2005), functional feed group (Bowd *et al.,*

2006) and type of invertebrates e.g. insect/non-insect (Gooderham and Tsyrlin, 2002). However, these different classifications may not necessarily distinguish the occurrence of tolerant and intolerant species.

Invertebrates' habitat refers to the physical surrounding of the instream biota determined by channel structure and hydrological regime (Bredenhand and Samways, 2009). A habitat contains a number of biotopes where different species can reside (Bredenhand, 2005). The five common types of biotopes in a river are mainly categorised according to the channel structure and hydrological regime of the river. These biotopes are; riffle, pool, run, backwaters and cascades and are described as shown in Table 1

Table 1: Types of physical biotopes and their associated surface flow types

Physical biotope	**Surface flow type**	**Description**
Riffle	unbroken standing waves	Upstream facing wavelets which are not broken
Pool	no perceptible flow	No net downstream flow, a floating object placed in water remains stationary
Run	rippled flow	No waves but general flow direction is downstream with a disturbed rippled surface
Cascade	chute flow	Low curving fall in contact with substrate
Backwaters	-	No through flow of water but water tend to enter and exit using the route

(Adapted from: Harvey, 2006)

Macro-invertebrates belong to different functional feeding groups depending on the food gathering techniques and the associated river continuum concept characteristics (Bredenhand, 2005). The key functional feeding groups found in rivers include shredders, grazers, collectors and predators. Table 2 shows the characteristics of macro-invertebrates according to the ideal river continuum concept.

The third classification is based on whether they are insect or non insect. Macro-invertebrates are grouped into class insecta and non-insecta. The class insecta group comprises seven orders, namely Plecoptera, Ephemeroptera, Tricoptera, Odonata, Diptera, Hemiptera and Coleoptera. The non-insecta group is represented by class Crustacea, phylum Mollusca, phylum Annelida, phylum Nematode and phylum Platyhelminthes (Gooderham and Tsyrlin, 2002). The functional feeding groups and physical habitats of either insect or non-insect group determine their dominance and variations along the river.

Table 2: Relationship between the River Continuum Concept and Invertebrates Characteristics

River reach	Functional feeding group	Macro-invertebrates characteristics	Ecosystem health
Upper reaches	High collector, shredders	Low abundance	Low biological production
	Low grazers	Low diversity	Poor habitats
Mid reaches	High grazers, collector, shredders	High abundance	High biological production
		High diversity	Diverse habitats
Lower reaches	High collectors	Low abundance	Low biological production
		Low diversity	Poor habitats

In a polluted river, only a few taxa number which are tolerant to pollution will be found in that habitat and pollution sensitive taxa will either get extinct or migrate (Dallas, 2000). Hence impaired ecosystems are dominated by tolerant species while the undisturbed ecosystems are composed of both tolerant and sensitive species, some examples of which are shown in Table 3.

Table 3: Examples of Pollution Sensitive and Tolerant Macro-invertebrates Groups

Pollution sensitive group	Pollution tolerant group
Ephemeroptera (Mayflies)	Oligochaeta (worms)
Plecoptera (Stoneflies)	Chironomids (midges)
Tricoptera (Caddisflies)	Branchuria

The South African Scoring System (SASS 5 Protocol)

There are a number of biological assessment methods which include protocols, indices and models, whose applications vary according to the study objectives, geographical settings and biological indicators used (Barbour *et al.*, 1999; Dicken and Graham, 2002; Bowd *et al.*, 2006, Flotemersch *et al.*, 2006; Ollis *et al.*, 2006). For example, in Southern Africa, the commonly used method is the SASS 5 protocol which was devised in South Africa in 1972 and was fully developed in 1998 (Chutter, 1998). The system is based on the variations of macro-invertebrates sensitivity to water quality impairment and the fauna assemblages which give an indication of the long-term water quality conditions. It also measures the species richness and evenness, which represent species diversity; however the system can only identify invertebrates up to the family level. The varied sensitivity to pollution makes macro-invertebrates good indicators of water quality.

With regards to sensitivity to pollution, the pre-defined taxa have been assigned weightings or scores, ranging from 1 (most tolerant to pollution) to 15 (most sensitive to pollution) as documented in a SASS 5 score sheet (Ollis *et al.*, 2006). Macroinvertebrates from each biotope in a site are identified and three indices namely, SASS 5 scores, number of taxa and Average Score Per Taxa (ASPT), are calculated (Ollis *et al.*, 2006). SASS scores, which is the sum of taxon scores sampled, are calculated from the SASS 5 score sheet. SASS scores divided by the total number of taxa present, gives the Average Score Per Taxon (ASPT). The number of taxa represents taxa richness while SASS score and ASPT give interpretation of water quality from the collected data (Dallas, 2000). Hence the SASS 5 Score and the ASPT provide an overall assessment of water quality status. However, ASPT is known to be a more reliable measure of water quality compared to SASS score because it gives pollution sensitivity per each taxon at a site (Ollis *et al.*, 2006). Using the three indices, Chutter (1998) developed a guide as shown in Table 4, for the interpretation of the results and providing meaningful information about the quality of a river.

Table 4: Guide for Interpreting SASS 5 Indices (SASS scores and ASPT)

Category	**Total Scores**	**ASPT**	**Water Quality**
A	> 100	> 6	Natural water quality, high biotope diversity
B	< 100	> 6	Natural water quality, reduced biotope diversity
C	> 100	< 6	Border between natural water quality and deterioration
D	50-100	< 6	Some deterioration Some deterioration in water quality
E	< 50	Variable	Major deterioration in water quality

(Source: Chutter, 1998)

For easier assessment and interpretation, Adamus and Brandit (1990) identified a list of some macroinvertebrates pollution indicators for certain kinds of pollution as shown in Table 5.

Table 5: Invertebrates Pollution Indicators

Pollution type	**Pollution indicator**
Nutrient enrichment	Increased ratio of worms, stoneflies and midgets to insects
Low dissolved oxygen	Increased ratio of worms and midgets to insects
Heavy metals	Increased ratio of worms and midgets to insects
Sedimentation	Abundance of hemipterans and coleopterans
Low pH	Decrease in mayflies and midgets
Industrial	Decrease in molluscs, midgets, mayflies and daphnids
Impoundments	Increased dipterans and decreased mayflies, caddis flies and stoneflies
Heated effluent	Reduced community richness

(*Source: Adamus and Brandit, 1990*)

Applicability and Limitations of SASS 5 Protocol

The SASS 5 Protocol has been widely used in Southern African monitoring health and integrity of rivers and has been found out to be an effective and reliable water quality assessment method (Moyo and Wroster 1997; Dallas *et al.,* 1999; Dallas, 2000; Dickens and Graham, 2002; Gratwicke, 1999; Madikizela and Dye, 2003). In South Africa, the River Health Programme incorporates SASS 5 as the rapid biological assessment technique (Dallas, 2000) after SASS 5 proved to be an extremely useful water quality assessment tool. However the method is well applicable only in perennial, lotic systems with low to moderate flow regimes and is not applicable in lakes, wetlands or estuaries (Dallas, 2000; Dickens and Graham, 2000; Bowd *et al.,* 2006). This is because high flows in rivers tend to destroy favourable habitats for a majority of macroinvertebrates and the sampling process may also be a challenge.

The use of physico-chemical and biological assessment methods together gives the status of the river ecosystem health and integrity. However, these methods are time-consuming, discontinuous in time and space, expensive and do not give information related to sources and spatial distribution of pollution (Zhou *et al.,* 2010). The integrated water quality management programme for catchments and basins require interactive monitoring methods which give detailed and accurate results. From the mentioned limitations of both physico-chemical and bioassessment method, the use of advanced methods which can complement these methods by minimizing their limitations is inevitable. Geographical Information System (GIS), Remote Sensing (RS) and modelling techniques are among the advanced methods which are less tedious which can give valuable information in terms of sources and the geographical distribution of pollution compared to the previously discussed methods. Since modelling require long and consistent historical water quality database, which is mostly absent in Tanzania and many African countries, GIS and RS techniques are more effective and affordable.

2.4.3 Water Quality Monitoring using GIS and RS tools

A number of studies have confirmed the reliability of Geographical Information System (GIS) and Remote Sensing (RS) tools in the assessment of both quality and quantity of water (e.g. USGS, 1998; Baja, 2003; Mouratidis *et al.,* 2010; Zhou *et al.,* 2010). Water quality assessments of lakes, reservoirs and ponds, mostly focusing on eutrophication and related aspects such as algal blooms and chlorophyll A levels, have been widely conducted (Silberbauer, 1997; Palethorpe *et al.*, 2004; Zhou *et al.*, 2010). A number of studies which consider the relationship between the catchment or watershed activities and rivers pollution levels have been done (Zampella and Procopius, 2009). Water quality monitoring can be done electronically with well developed GIS and RS systems without frequent visit to the project site which enables it alone to give reliable water quality information. However, in situations with inadequate technology, the use of physico-chemical and biological information, together with GIS and RS information is required to effectively assess and monitor water quality levels.

For non-point sources of pollution, the spatial distribution of pollution along the river due to landuse activities in the catchment can be determined using an existing physical, chemical or biological water quality database and the landuse maps developed from the existing satellite images of the project area (Rauch *et al.,* 1998; Zhang *et al.*, 2009). Knowing landuse and pollution distribution in the catchment can be used to estimate the pollution contribution from different landuse at specific locations. With ArcGIS software, this can be achieved through the use of buffer operation in demarcating possible influencing area close to the river point and calculating the percentage area for each landuse in the buffer area (Baja, 2003; Al-Tamimi, 2005). The landuse with a high percentage area is more likely to contribute more in pollution of the river reach than others. The rationale of this method is to determine the relationship between landuse and different pollutant types and assess the accuracy of statistical methods of pollution sources estimation such as factor analysis. However, due to the presence of point sources of pollution, which can be known or unknown, detailed information of the locations and amount of pollution from point sources of pollution is required. The detailed procedures of the described water quality assessment methods were applied to Ngerengere River catchment, which is threatened by pollution which is impacting on both terrestrial and aquatic life.

CHAPTER THREE: STUDY AREA

3.1 Location

Ngerengere River Catchment is part of the Wami/Ruvu basin, in Tanzania (Figures 1 and 2). It has an area of about 2,780 square kilometres and is located between latitude 6^o 27' 24.46" to 7^o 20' 0.06" South and between longitudes 37^o 57' 24.61" and 38^o 31' 30.61" East. The catchment extends from the western part of the Uluguru mountain ranges eastwards to the mid plains of the Ruvu catchment towards the Indian Ocean. Ngerengere River Catchment covers a large percentage of Morogoro region such as the Morogoro urban district and some parts of Morogoro rural district, namely Mlali, Mzinga, Mgeta, Sangasanga, Mikese townships and Ngerengere military area.

3.2 Geology and Topography of the Study Area

In terms of hydrological and topographical features, the upstream zone, where there are number of water sources, is comprised of Uluguru Mountains, which are approximately 700 - 2600 m above sea level as the highest points (IUCN, 2010). The mid reach follows, in terms of altitude, having slightly elevated hilly areas with moderate undulation, ending up with downstream reach with pre-dominantly low-lying areas. The altitude downstream ranges from 350 m to 500 m above sea level towards Lower Ruvu sub-catchment.

The geology of Uluguru Mountains and the Western side of Ngerengere catchment is composed of Precambrian rocks, which are mainly meta-sedimentary. This type of rock can be divided into three major lithological groups: acid gneisses, granulites and crystalline limestone (JICA, 1994). The south-eastern area of the Uluguru Mountains is occupied by the Karoo rocks which consist mainly of sandstone and shale, which was originally deposited in shallow fresh to brackish water. They consist of coarse sandstone, mudstone and olitic limestone.

Sediments of young (Tertiary and Quaternary) ages occur in the catchment area of the Ngerengere River near Morogoro Municipality and in the elevated rolling hills and floodplains along the Ruvu River. The Tertiary deposits consist of sandy clay, clayey sand with lenses of pure sand or clay, gravel and calcareous fragments. The Quaternary deposits were formed in the alluvial fan and are subject to swampy condition during the wet season; they consist of clay, silt, sand and rarely gravel (MoWLD, 2005).

3.3 Climate

The catchment receives bimodal rainfall, the first short rainfall season (Vuli) starts in November to early January followed by a short dry season. The second long rain season (Masika) starts at the end of February and goes to May followed by a long dray season. The annual rainfall varies between 800 mm to 1000 mm, except for the Uluguru Mountains with a mean rainfall reaching over 1500 mm (Yanda and Munishi, 2007). WRBO (2008) reported that on rainfall at the eastern side of Uluguru Mountains may exceed 2500 mm while the western side receives less. Average monthly minimum and maximum temperatures are almost the same throughout the basin; the coldest month is August (about 18°C) and the hottest month is February (about 32°C). The annual average temperature is about 26°C.

3.4 Landuse

The analysis of land cover/use has shown that in 1955, a large percentage of the area was covered by thickets and open woodlands. Some few areas, especially in the northern part of the Uluguru Mountains, were under mixed cropping (Yanda and Munishi, 2007). In 1995, more of natural woodland has been converted to farmland, particularly sisal estates and mixed crops. Between 1995 and 2000, there was an extensive expansion of agriculture at the expense of the natural vegetation cover (Yanda and Munishi, 2007; Dietz, 2010). The land cover is now characterized by mixed cropland that encroaches and extends into marginal lands such as hilly, steep slopes and river bank (riparian) ecosystems. Such a situation has increased the exposure of land surface to erosion agents and increased surface runoff. The main problem has been an unsustainable farming practice which is characterized by cultivation on the steep slope and shifting cultivation and slash. Other problems include the limited use of soil conservation measures and high encroachment into riparian and fragile ecosystems.

3.5 Socio-economic Activities

The Ngerengere catchment is estimated to have a population of over 1 million people (IUCN, 2010). There are a number of water uses in the catchment including domestic, irrigation, fish farming, industrial and environment, whereby domestic water supply takes a high percentage of water use from the river. Morogoro Urban Water and Sewerage Authority (MORUWASA) the biggest user in this category, abstract water from Mindu dam built across the Ngerengere River. The reservoir is located 7 km south of Morogoro along Iringa Road. It is located to the Southeast of Ngerengere river valley, at a gap between the Uluguru and the Mindu Mountains.

The major rivers that feed the reservoir include the Mlali, Mgera, Lukulunge, Ngerengere and Mzinga and only Ngerengere River flows out downstream of the reservoir (Kihila, 2005).

Upstream of Mindu Dam, the main water use is agriculture and livestock watering. A number of studies highlighted the impacts of agricultural practices on the steep slopes of Uluguru Mountains, including forest degradation, soil erosion and water quality deterioration (Burgess, 2001; MNRT 2003; Franks *et. al.,* 2005). In the mid-reach zone of the catchment, the major water uses are domestic, industrial, agriculture and aquaculture; whereas the downstream zone is dominated by agriculture which is less intensive compared to that of the upstream zone. Observation from the field visit and analysis of landuse maps indicated a high increased rate of agriculture activities and population growth at Ngerengere town, located downstream zone which might exacerbate the water pollution threats.

In terms of crops cultivated in the catchment, the upstream zone is dominated by maize, banana, tomatoes and vegetables. Crops like maize, rice and sugarcane are dominant at the foothills of Uluguru Mountains, resulting in a high sedimentation rate of Mindu Dam (Kihila, 2005). A combination of irrigation and seasonal cultivation, complemented by the application of fertilizers and pesticides throughout the year, makes this zone a potential source of pollution from agriculture activities. The mid-reach zone is dominated by sisal plantations, maize, vegetable farms, including tomatoes and pepper, while the downstream zone is mainly dominated by fields of maize, vegetables for subsistence use, and a newly developed a large-scale paddy plantation for the military camp. JICA (2003) reported that there are about 171,382 ha of agricultural land used for 82 irrigation schemes in the catchment. It appears that this has increased since then.

Ngerengere River is also a potential water source for livestock watering. In 2005 about 25% of the total livestock population of Morogoro were found within Ngerengere catchment (IUCN, 2010). The river supplies water to both on-movement and ranches pastoralists. The largest livestock population in Tanzania is cattle followed by goat, sheep, pig and chicken. Similar trends occur in Morogoro region (JICA, 2003). A high percent of livestock keeping practice were dominated at the upstream zone, followed by downstream zone and lastly the mid-reach zone. The reason is that a large part of the mid zone is covered by the urban area.

Fish farming is another activity of economic importance in the catchment, and this depends on Ngerengere River for water. Before the construction of Mindu Dam, fishing along the river was an important economic activity of the local people in the downstream zone. However, Mindu Dam and intensive agricultural activities near the source of the river contribute to the decreasing river flow, particularly during the dry season. Yanda and Munishi (2007) reported the average annual flow rate decrease by 5 m^3/s at Morogoro Bridge station and 17 m^3/s at Mgeta station, but gave a general conclusion that there was an increased flow rate in Ngerengere catchment. Currently fishing activities in Morogoro are supported by aquaculture centres which own a number of ponds in the region; about 60% of which are located downstream of the catchment.

Industrial activities which depend on and pollute the river are rapidly growing in the catchment. There are about nine industries in Morogoro which directly or indirectly discharge their effluent into Ngerengere River. Previous water quality reports done by WMBO indicate that industries are the major sources of pollution in Ngerengere River and a number of actions were proposed to mitigate the situation.

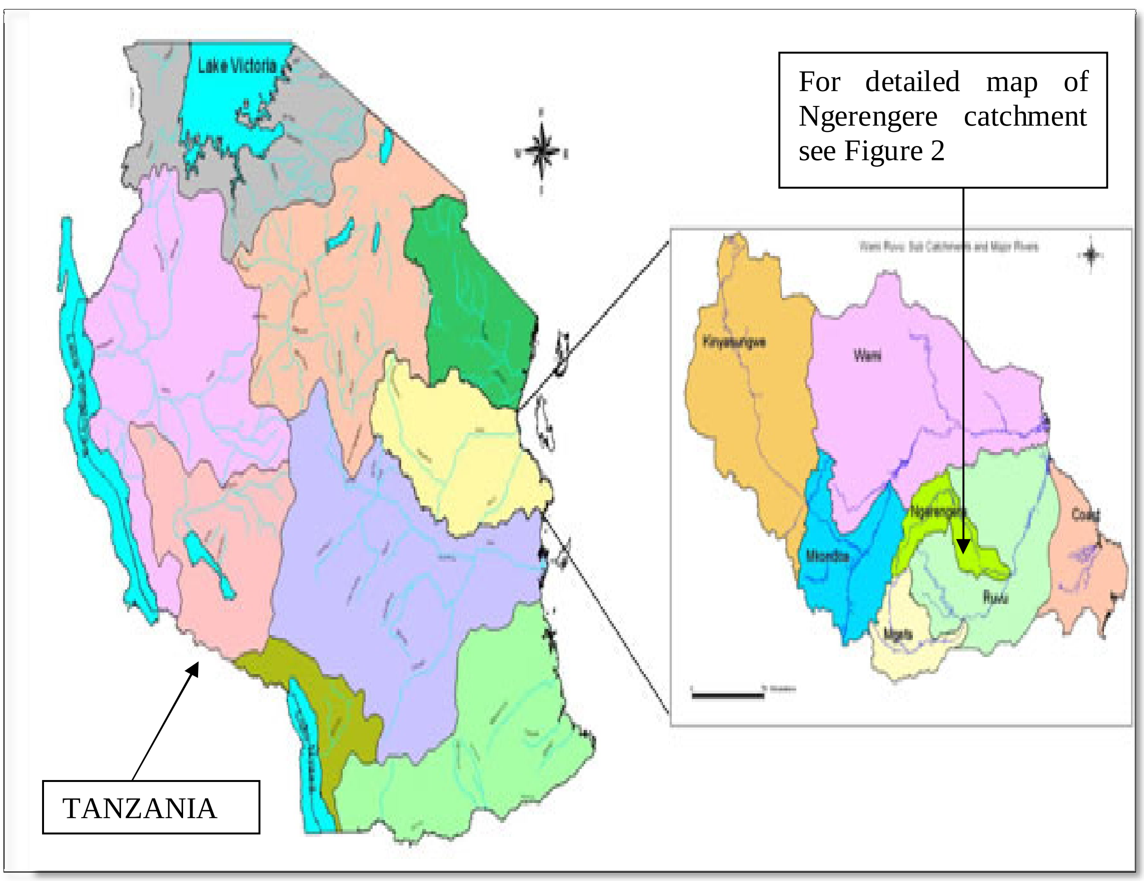

Figure 1: Location of Ngerengere Catchment, Wami/Ruvu Basin, Tanzania

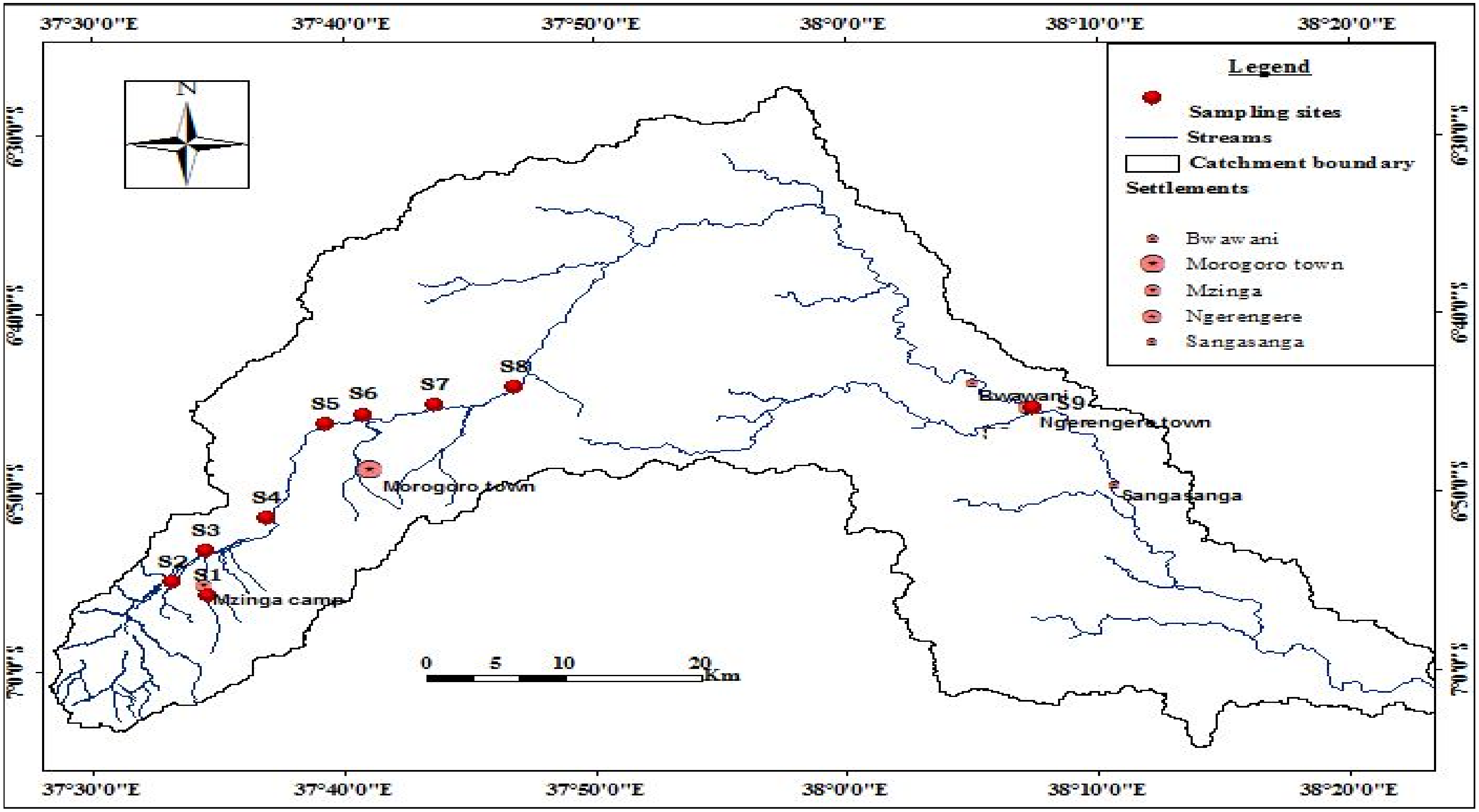

Figure 2: Ngerengere Catchment Map locating the Sampling Sites

CHAPTER FOUR: MATERIALS AND METHODS

A number of water quality assessment methods such as physico-chemical assessment, biological assessment, use of advanced technology such as Geographical Information System (GIS), Remote Sensing (RS) and models exist and are implemented in various parts of the world (Silberbauer, 1997; Chutter, 1998; Dallas 2000; Dicken and Graham 2002; Mouratidis, 2010). However in most parts of Africa, including Tanzania, the mostly used method is the physico-chemical assessment however which have been proved to give inadequate results by a number of studies. This study used different methods to identify pollution sources, quantify the water quality status and determine the relationship between the distribution of the sources and pollution levels along the river. Physical, chemical, and biological water quality indicators were used to assess the spatial and temporal variations of pollutants along the river. The information was then used to determine the spatial distribution of pollution and its relationship to pollution sources within the catchment.

4.1 Study Design

The study design considered the five sampling operations i.e. parameter selection, sampling sites locations, sampling frequency, data collection and analysis methods as documented by Schitz (1995).

4.1.1. Selection of Parameters

The parameter selection exercise was mainly based on the selected sources and their relationship to different parameters and the potential effects of the parameters to water users. The availability of equipment for measurements and the possibility of both onsite and laboratory measurements were considered. Parameters measured included; colour, turbidity, pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Total Phosphate (TP), Ortho-phosphate (OP), Total Kjeldah Nitrogen (TKN), Nitrate (NO_3), Sulphate (SO_4^{-2}) and heavy metals; Chromium, Cadmium, Iron and Lead. Activities contributing to the release of pollutants from agricultural fields such as the excessive application of fertilizers and the release of raw effluent from industries, particularly textile and tannery industries found in Ngerengere catchment were the major factors which influenced the selection of the mentioned parameters.

4.1.2. Sampling Sites

The sampling sites selection was based on the sources of pollution, accessibility and ease of onsite sampling and testing and the presence of representative biotopes. Others factors included the distance from the sampling sites to the nearest gauging station, and the location of identified point sources of pollution.

A total of nine sampling sites were selected, eight sites located along the river and one at the TLAI industrial outlet pipe. Apart from the above mentioned criteria, the selection of sampling sites recognised the existing three zones of the catchment. A number of sampling sites were grouped in each zone. Sites 1-4 represented the upstream zone which is basically the source of the river. Sites 5-7 represented the mid-reach zone which is around Morogoro urban area, dominated by urban and industrial activities, settlements and mono cropping agriculture. Sites 8 and 9 represented the downstream zone which has few sources of pollution, where people directly rely on the river for many activities such as domestic use and fishing. The locations are shown in Figure 2 and are described in Table 6

Table 6: Site Locations, coordinates and their Characteristics

Site No.	**Site name**	**Eastings (m)**	**Northings (m)**	**Characteristic**
Site 1	Mzinga juu	342758	9233453	Natural vegetation
Site 2	Ngerengere bridge	340121	9234871	Cultivation
Site 3	Mzinga bridge	342674	9238028	Cultivation +Residential
Site 4	Mindu dam	347075	9241467	Water body
Site 5	Kihonda bridge	351354	9251133	City centre
Site 6	TLAI Industrial outlet	354223	9252121	Cultivation +Residential
Site 7	Tungi bridge	359408	9253139	Cultivation
Site 8	Kimango farm	365302	9254960	Cultivation
Site 9	Ngerengere town	403155	9252850	Cultivation +Residential

Site 1 (Mzinga Juu) was located at the foothills of Uluguru Mountains, about 2 km upstream of the military camp in Mzinga stream. Mzinga stream (first tributary to Ngerengere River) passes through a less impaired land. The river reach is dominated by runs and riffles which are among the basic biotopes for a majority of macro-invertebrates. Therefore, Site 1 was suspected to accommodate more of macro-invertebrates, hence was considered to be the reference site

Site 2 (Ngerengere Bridge) was located along Ngerengere stream, which is the second tributary into to Ngerengere River, among the five tributaries from Uluguru mountains. The site is about 2.3 km downstream of the military camp, but the stream does not pass within the camp like Mzinga stream. The stream was dominated by stream bank cultivation. Some of the planted crops included rice, maize, tomatoes and green vegetables, which are cultivated throughout the year and are supported by fertilizers application. The site was expected to give detailed information on the impacts of agricultural activities on the river.

Site 3 (Mzinga Bridge) was located at the lower stretch of Mzinga stream, approximately 3km downstream of the military camp. This part of the stream, like Ngerengere stream, was characterised by stream bank cultivation and also receives wastewater from wastewater ponds containing domestic and industrial effluent from the camp. The industry located inside the camp is suspected to contribute to the release of toxic effluents into the river. Previous studies done at Mindu Dam (Ramadhani, 2007) found traces of heavy metals in the dam which were higher at Mzinga stream than at other tributaries entering Mindu dam. The site was selected to give information about both industrial and agricultural activities.

Site 4 (Mindu Dam) was located near the outlet point of the Mindu dam containing water from the five tributaries from Uluguru Mountains. The site was characterised by non moving water body (lake) with complex biological processes. The dam was reported to have eutrophicated effect due to intensive agricultural activities along the stream banks and around the lake which also contribute to high sedimentation rates (Ramadhani, 2007). The site was selected in order to give water quality information from all the river sources, the efficiency of the dam in natural pollution reduction process and changes in nutrient levels from the previous studies.

Site 5 (Kihonda Bridge) was located in Kihonda area along Dodoma Road, about 12 km from Mindu Dam. Urban farms, peri-urban settlements, Sokoine university campus, and MORUWASA water treatment plant, among other possible sources of pollution are located along the river reach before this site. The site was selected to give water quality information related to agricultural activities and the wastewater treatment plant.

Site 6 (Industrial outlet) was the industrial wastewater ponds outlet pipe which received effluent from a group of industries. The direct sampling of effluent from the pipe was done to assess pollution load contributed by these industries to the river. The effluent was from textile, leather and tannery, canvas and soap industries which are known to contain a large amount of chemicals in their wastewater.

Site 7 (Tungi Bridge) was situated a few meters before Tungi Bridge and about 2 km from Site 6 location. The area is dominated by sisal plantations. The river receives water from Site 6 and joins Morogoro River tributary which collects storm water and wastewater from domestic and business buildings in Morogoro town. Site 7 was selected to give water quality information from industrial and urban activities. The site was not a good habitat for macro-invertebrates because the river banks were highly accessible to people and animals.

Site 8 was located about 7 km from Site 7 characterised by few pools and runs biotopes which change with seasons. The landuse activities along the river before Site 8 (Kimango farm) included vegetable and sisal cultivation, located a few meters away from the river banks. It was confirmed that fertilizers and pesticides were not used in the vegetable farm. The area does not have any industrial or domestic activities. Being at the downstream zone, the site was selected to give information on levels of pollution reaching the downstream zone.

Site 9 (Ngerengere Town) was the last point located downstream of the catchment, a few meters downstream of Ngerengere Town. The river collects water from the main Ngerengere River and smaller tributaries along the way and flows towards the lower Ruvu River which is the main source of water for Dar es Salaam city.

4.1.3. Frequency of Sampling

Four sampling campaigns for physico-chemical parameters and two campaigns for the biological assessment indicators were conducted at the same sampling sites. Standard methods for sampling and analysis of physico-chemical and bioassessment parameters, according to APHA (2001) and Chutter (1998) respectively, were used. Physico-chemical parameters were collected on 9th and 23rd February 2011 and 9th and 23rd March 2011 representing the end of the short dry season and beginning of the long wet season (Masika) respectively. Bioassessment data was collected on 18th February 2011 and 25th March 2011.

4.2 Data Collection

4.2.1. River Flow Measurements

The discharge rate measurements for the river at the sampling sites were taken every sampling day concurrently with water quality measurements. The data was used for the evaluation of pollution loads. At Sites 1, 2, 3 and 8, the water levels were measured from the nearby stations and the Hydrata software was used to estimate the discharge rate in cubic metres per second (m^3/sec). A current meter was used to take measurements at Sites 5, 6 and 7. No flows were recorded for Site 4 which is a reservoir. The spot measurements, historical discharge data and literature were used to calculate the average discharge rates for the different points along the river.

4.2.2. Physico-Chemical Assessment Methods

Four sampling campaigns were conducted from February to March 2011. The sampling exercise for each campaign started at 0600 hours continued up to 1100 hours. Samples were taken to the laboratory for analysis. The grab sampling method was used. Two samples in 1.5l bottles were collected at each site. One sample was for heavy metal analysis and the other sample was fully topped up for analysis for BOD_5 and other parameters, according to the procedure described in APHA (2001). The samples were then stored in the cooler box with ice cubes, waiting to be transported to the laboratory for analysis. Physical parameters such as temperature, EC, TDS and pH were measured on site, using the (WAGTECH) EC meter for the first three parameters, and a (HACH) pH meter for pH analysis.

Samples collected for heavy metals analysis were preserved with dilute nitric acid (2 ml) in 1.5 l before transporting to the laboratory for analysis. The analysis was according to Method Number 3111B using the Frame Atomic Absorption Spectrometer (AAS 240) as described in Standard Methods (APHA, 2001). Prior to analysis, the samples were digested in order to dissolve all solid particles into liquid form, as required by the AAS machine. After digestion, 0.2 ml of each sample was diluted to 20 ml by adding distilled water and was injected to the machine. The spectrometer uses the direct proportional relationship between absorption and concentration, hence the wavelength for absorption of each parameter (element) was set according to the standard solution. The measured absorption values were converted to concentration based on the standards applied.

4.2.3. Biological Assessment Method

Data collection for biological assessment was conducted according to SASS 5 protocol procedures. A macro-invertebrate net was used to capture macro-invertebrates from each of the available biotopes per site whereby sample from each biotope was collected and stored in 1 litre polyethylene bottle. The sampling exercise was done according to the SASS 5 protocol procedures whereby a mesh net was held few centimetres downstream of the target biotope e.g. stones and cobbles. The target point was disturbed by kicking to dislodge the invertebrates to flow in the direction where the mesh was set. The distance from the sampling site and the kicking time differed from one biotope to the other according to the protocol. Collected samples were labelled accordingly and were topped up with a solution containing 70% v/v ethanol for preservation before being sent to the laboratory for further analysis.

Due to the challenges of limited expertise and availability of all the equipment on site, a full on-site biological assessment according to the protocol's instructions could not be undertaken. Sample collection was followed by an initial on-site assessment and other samples were transported to the laboratory for analysis.

Secondary data and Literature review

Informal consultations of key informants at different institutions such as Morogoro Rural and Urban Water Supply Authority, Wami/ Ruvu Basin Office, Sokoine University of Agriculture and iWASH were done and secondary data on water quality, quantity, land uses and economic activities were collected at these institutions and were used to support the analysis.

4.3 Analytical Methods

4.3.1 Objective 1: Physico-Chemical Methods

For both physical and chemical parameters, sampling preservation and analytical protocols were conducted according to standard methods (APHA, 2001) as shown in Table 6. The specific laboratory analysis methods selected were based on applicability, availability and affordability.

Statistical analysis

The physico-chemical parameters were statistically analysed using the following methods: Firstly the results were compared to recognised drinking standards and aquatic ecosystem guidelines, namely, the Tanzania Drinking Water Standards (TZDWS, 2004), WHO drinking water standards (2008), South Africa aquatic ecosystem guidelines referred to as DWAF (1996) and Australia and New Zealand Water Quality Guidelines -aquatic ecosystem (ANZECC, 2000). The aim of these analyses was to check if measured values are within both national and international required limits. TZDWS and WHO drinking water standards were used because in some parts of the catchment such as the downstream zone, a number of villages e.g. Sangasanga and Bwawani use river water for both domestic (drinking) and production purposes.

The South Africa aquatic ecosystem guideline (DWAF 1996) and Australia and New Zealand Water Quality guidelines (Aquatic Ecosystem2000) were selected for use in this study because currently there are no equivalent guidelines in Tanzania; the relevant authorities are still preparing them. Specifically, DWAF (1996) was selected because of similar environmental conditions and development activities practices in the majority of Southern African countries, which can have similar or closely related impacts in water resources characteristics. ANZECC

(2000) was selected because Australia and New Zealand are advanced, and have long term experience with aquatic ecosystem researches, hence the guidelines have more information. Australia and New Zealand also have the tropical conditions which are similar to that of Tanzania and these conditions contribute to defining the characteristics and the type of aquatic ecosystem in water resources. Aquatic ecosystem guidelines were used to compare against all sites in the catchment in order to assess the levels of ecosystem health at different locations.

Table 7: Water Quality Parameters and Analytical Methods Used in the Study

Parameter	**Abbreviation**	**Units**	**Equipment/ Analysis method**	**APHA method number**	**Equipment brand**
Colour		mgPt/l	Spectrophotometer	2120 C	HACH
Turbidity		NTU	Turbidity meter	2130 B	HACH
pH			pH meter	4500-H^+	HACH
Temperature	T	^oC	Conductivity meter	2550	WAGTECH
Electrical Conductivity	EC	µs/cm	Conductivity meter	2550	WAGTECH
Total Dissolved Solids	TDS	mg/l	Conductivity meter	2550	WAGTECH
Biological Oxygen Demand	BOD_5	mg/l	Manometric BOD device	5210 B	OXITOP
Chemical Oxygen Demand	COD	mg/l	Titration (closed reflux method)	5220 C	
Nitrate	NO_3	mg/l	Spectrophotometer	4500-NO^{3-}B	
Total Kjeldah nitrogen	TKN	mg/l	Macro-Kjeldah method	4500-Norg B	
Total phosphate	TP	mg/l	Ascorbic acid method	4500-P E	
Ortho-phosphorus	OP	mg/l	Turbidimetric method	4500-P E	
Sulphate	SO_4^{-2}	mg/l	Atomic Absorption Spectrometer	4500-SO_4^{-2} E	
Iron	Fe	mg/l	Atomic Absorption Spectrometer	3111 B	AA240
Lead	Pb	mg/l	Atomic Absorption Spectrometer	3111 B	AA240
Chromium	Cr	mg/l	Atomic Absorption Spectrometer	3111 B	AA240
Cadmium	Cd	mg/l	Atomic Absorption Spectrometer	3111 B	AA240

Microsoft Excel software was used in conducting the descriptive statistics, temporal and spatial variations analysis and graphical representation of results. These were done in order to give out the descriptive summary of the physico-chemical analysis and highlight the similarities and variations among and between parameters along the river and at different times.

Pollution load calculations

Pollution load estimation at different locations along the river was done using the source monitoring method as explained by EPA (2009). This method is based on monitoring discharge volume over the sampling period and the pollutant concentration. The pollution load is then given by the formula;

Pollutant load = pollutant concentration × volume ....Eqn 1

Factor Analysis

The Factor Analysis method using the SPSS software was used in the estimation of pollution sources contribution to the water quality levels along the river. The main purpose of the method is to facilitate better understanding of water quality and ecological status of water systems in situations with a large number of parameters or sampling sites. Previous studies have demonstrated the usefulness of the method in evaluating sources of pollution using the physico-chemical water quality results measured at their project sites (Mazlum *et al.,* 1999; Voutsa, 2001; Singh *et al.,* 2004). The Factor Analysis method involves three main analysis stages namely, the hierarchical cluster analysis, factor analysis and linear regression analysis in the identification of the most influencing parameters to the observed/ measured water quality status. The most influencing parameters are used to estimate the potential sources of pollution at a specific location.

In this study, sampling sites were grouped in clusters according to correlations of the measured values using the hierarchical cluster analysis. Hierarchical clustering is the most common approach in which clusters are formed sequentially, by starting with the most similar pair of objects and forming higher clusters step by step. Prior to the analysis; the data were standardized to produce a normal distribution of all variables. In the standardization, the raw data were converted to unit less form of zero mean and a variance of one, by subtracting from each variable the mean of the data set and dividing by the standard deviation. This type of ordination reduces the dimensionality of the data set and minimizes the loss of information caused by reduction.

The Ward method of cluster analysis by means of squared Euclidean distances measure of similarity was used. The Euclidean distance usually gives the similarity between two samples and a ‘distance’ can be represented by the difference between analytical values from both the samples (Otto, 1998). The results are typically illustrated by a dendrogram (tree diagram) which provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity, with a dramatic reduction in the dimensionality of the original data.

Each cluster formed was then used in the factor analysis where the Principle Component Analysis (PCA) method using the correlation matrix was used to develop new and fewer variables (components) from a combination of a number of parameters with correlated values. PCA provides information on the most meaningful parameters while describing the whole data set with minimum loss of original information (Mazlum *et al.*, 1999). It can be expressed mathematically as shown in Equation 2.

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + ... + a_{im}x_{mj} \text{ ....Eqn 2}$$

Where:

z = the component score

a = the component loading

X = the measured value of variable

i = the component number

j = sample number

and **m** = total number of variables.

The PCA technique extracts the Eigenvalues from the correlation matrix of the original parameters. Eigenvalues give a measure of the significance of the variables, thus the number of variables/ components formed is based on the Eigenvalues. Eigenvalues of 1.0 or greater are considered significant (Singh *et al.*, 2004).

The estimation of the most influencing parameters in the formation of each of the new variables (components) was done in the third stage using linear regression analysis. The results were then used to estimate possible sources of pollution for each cluster along the river. The part and partial correlation method was used.

4.3.2 Objective 2: Biological Assessment Method

Laboratory analysis involved identification, sorting and analysis of the macroinvertebrates using a stereomicroscope and data interpretations according to the SASS 5 protocol (Chutter, 1998). Each collected sample was placed in a plastic tray and left to stand for 5 minutes for sediments to settle and to allow invertebrates to emerge. The visible species were first identified and then others (smaller sized macro-invertebrates) were identified using a stereomicroscope. The sampled macro-invertebrates were identified up to the family level according to the SASS 5 score sheet for easier interpretation and discussion.

Statistical analysis

The bioassessment data was further statistically analysed using the following methods: Interpretation of results using the SASS 5 score sheet and comparison of the results with the classification guide by Chutter (1998). The guide for interpretation of bioassessment water quality data (Table 4) was used to interpret the data from each sampling site in terms of SASS 5 scores and ASPT.

Descriptive statistics, spatial variations of biological data and graphical representation of the results using Microsoft Excel software, were done in order to give the descriptive summary of the biological assessment analysis and to highlight the similarities and variations among and between parameters along the river.

Hierarchical cluster analysis, Ward's method, was used to cluster sampling sites according to correlations of the biological data. In this study only SASS score values were used to form sampling sites clusters whereby SASS scores describe areas with pollution tolerant invertebrates and areas with pollution sensitive invertebrates along the river (Graham and Dicken, 2002).

4.3.3 Objective 3: Relationship between Sources of Pollution and their Distribution in the Catchment.

The ArcGIS v.9.2 software was used in the analysis as follows. Development of the Ngerengere River Catchment landuse map using Landsat image 4-5TM using the supervised classification method was done using the ArcGIS software. Two scenes of the Landsat images for December 2010 and January 2011 were first pre-processed, enhanced and later classified using the supervised classification using the maximum likelihood algorithm classifier. The presence of the Ground Control Points (GCP's) from the study area recorded by the Global Positioning System (GPS), and the catchment landuse map of 2008 developed by IRA, Tanzania, simplified the use of supervised classification. Maximum likelihood algorithm in the supervised classification was used. The landuse map was then overlayed with the pollution distribution map indicating pollution concentrations at each sampling site.

Estimation of the influence of non-point sources (land use) of pollution along the river was done by calculating the percentage area of different landuse from four buffer areas i.e. 1000 m, 1500 m, 2000 m and 2500 m radius. For each sampling site and buffer, landuse with a high percentage is used to estimate the dominating landuse in that area which can probably be considered as the most influencing area to the pollution levels at that site.

4.4 Quality Assurance

Samples for physico-chemical parameters were analysed in triplets, each of 500 ml. Results were averaged in order to reduce both sampling and measurement errors. Samples for heavy metals were collected in different bottles from the others and they were preserved by 2ml of nitric acid. The sample bottles to be used for BOD_5 analysis were fully topped in order to avoid contamination of the sample by air. All the sampling equipment and tools were sterilised before sampling and carefully washed with distilled water after each sampling process and were all labelled. In-field measuring equipment such as pH meter probes were carefully rinsed using distilled water and were wiped with clean tissue after every sampling process. The samples were taken early in the morning each time in order to avoid variations in measurements, arising from weather changes, particularly caused by temperature variations. Samples were stored in cooler boxes filled with ice cubes in order to keep them in refrigerant condition before analysis.

For bioassessment, sampling and analysis, triplicate samples from each site and biotopes were collected and combined after analysis for calculations of average abundance and number of species per site. All the samples taken for laboratory analysis were preserved by a 5ml containing 70% ethanol v/v solution before taking to the laboratory.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Water Quality Status Based on Physico-chemical analysis

A total of 17 parameters were measured during the study period, and these are; six physical parameters, seven chemical parameters and four heavy metals. The physical parameters measured were pH, temperature, colour, turbidity, electrical conductivity and TDS. Chemical parameters measured were COD, BOD_5, nitrate, TKN, total phosphate, ortho-phosphate and sulphate while the heavy metals involved Cadmium, Chromium, Lead and Iron. General findings showed poor water quality in the catchment. The summary and descriptive statistics of the results are shown in Tables, 8, 9 and 10. Of note was that, samples taken at Site 6 (the industrial outlet pipe) were aimed to evaluate the pollution contribution from a group of industries which release effluent into the river. Samples collected from this site all showed high concentrations of all parameters.

pH

pH values ranged from 6.7 - 8.9 during the sampling period at all the sites along the river. The average monthly values were 7.6 and 7.5 in February and March respectively as shown in Table 8. In comparison to drinking water standards, all the pH values measured were within the permissible limits for both Tanzania Drinking Water Standards (TDWS) (2004) and WHO drinking water guidelines (2008). Likewise, pH values were below the aquatic ecosystem limits according to DWAF (1996) and ANZECC (2001) guidelines.

pH values below the maximum permissible limits for drinking and for aquatic ecosystem health and the average minimum changes in pH over time showed that the water was not highly polluted. A pH between 7 and 8.5 is ideal for biological productivity and pH < 4 is detrimental to aquatic life (Deekae *et al.*, 2010). pH changes with temperature and impacts on dissolved oxygen levels in water, which in turn affects biochemical and chemical reactions such as photosynthesis in water (Manjare *et al.*, 2010). However, results of other parameters indicated high pollution in contrast to pH results.

Table 8: Descriptive Statistics of the Measured Physical Parameters

Zones	Stations along the river		Discharge (m^3/s)		Colour (mgPt/l)		pH		Temperature (^{o} C)		Turbidity (NTU)		EC (µS/cm)		TDS (mg/l)	
			Feb	March	Feb	March	Feb	March	Feb	March	Feb*	March*	Feb	March	Feb	March
Upstream	Site 1	Mean	0.94	1.59	35	515	7.2	7.1	24.8	23.5	3.5	76.5	47	33.85	24.4	17.4
		SD	0.41	0.47	21	91.9	0.1	0.035	0.35	0.14	0.7	12.0	2	1.9	1.0	0.7
	Site 2	Mean	0.40	1.66	53	999	7.1	7.2	26.0	23.4	6.5	199.5	74	36.65	34.45	19.15
		SD	0.21	0.29	46	489.3	0.1	0.141	0.35	0.78	4.9	101.1	28	0.4	10.5	1.9
	Site 3	Mean	0.74	1.93	39	1292.5	6.8	7.1	24.9	24.5	5	243	400	46.65	200.2	24.15
		SD	0.19	0.12	21	837.9	0.1	0.007	0.21	1.48	1.4	58.0	483	2.2	241.6	0.2
	Site 4	Mean	0	0	248	475	8.3	7.2	26	26.2	48.5	67.5	154	170.1	75.45	85.71
		SD	0	0	317	346.5	0.9	0.099	0.28	1.63	30.4	24.7	9	11.2	4.3	6.8
Mid-reach	Site 5	Mean	0.23	1.24	148	546.5	7.3	7.5	26.3	24.8	23.5	102.5	3570	3020	1880	1597.5
		SD	0.02	0.58	92	415.1	0.2	0.148	0.42	0.14	9.2	0.7	1287	268.7	763.7	258.1
	Site 7	Mean	0.48	1.71	1930	2445	8.0	7.9	26.2	25.5	246.5	465.5	4200	2922.5	2150	1452
		SD	0.17	0.21	1372	1633.4	0.3	0.134	0.28	0.42	122.3	331.6	1796	3079.5	975.8	1552.8
Downstream	Site 8	Mean	0.37	1.87	297	725	7.6	7.8	25.9	26.0	33.5	349	2649	1284.7	1344	699.36
		SD	0.04	0.13	301	233.3	0.2	0.078	0.00	0.35	31.8	343.7	1670	1039.9	864.1	564.8
	Site 9	Mean	0.95	2.15	2882	3338	7.5	7.6	25.3	26.5	910.5	560	392	2437	194.4	1220.5
		SD	0.42	0.13	3958	1255.1	0.1	0.092	0.28	0.07	1243.8	183.8	416	3228.6	210.2	1611.5
	Industrial pipe-S6	Mean	0.59	0.73	2530	2485	8.3	8.1	26.8	26.6	377	570	5233	5610	2695	2741
		SD	0.09	0.04	28	714	0.1	0.05	0.1	0.1	32.5	118.8	293	452.5	261.6	133.0

Note: *- all for year 2011

Table 9: Descriptive Statistics of the Measured Chemical Parameters

Zone	Stations along river		Discharge (m^3/s)		COD (mg/l)		BOD_5 (mg/l)		TKN (mg/l)		NO_3 (mg/l)		TP (mg/l)		OP (mg/l)		SO_4 (mg/l)	
			Feb*	Mar*	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Marc
Upstream	Site 1	Mean	0.94	1.59	36	12.9	7	5.7	10.1	8.6	0.3	0.15	0.06	0.07	0.04	0.06	10.7	8.7
		SD	0.41	0.47	15	5.2	1.4	0.5	3.0	1.4	0.3	0.1	0.02	0.01	0.007	0.04	3.5	1.9
	Site 2	Mean	0.40	1.66	70	18.8	13.5	7.1	19.6	19.9	1.7	2.34	0.11	1.22	0.07	0.12	10.9	13.0
		SD	0.21	0.29	34	8.8	0.7	1.6	11.9	17.1	0.4	0.3	0.04	0.28	0.042	0.01	4.3	3.2
	Site 3	Mean	0.74	1.93	47	30.3	7	10.9	14.3	23.3	1.5	1.50	0.09	0.84	0.05	0.15	11.5	12.8
		SD	0.19	0.12	2	7.5	9.9	8.0	3.6	2.8	0.7	1.2	0.007	0.12	0.017	0.07	4.3	0.2
	Site 4	Mean	0	0	48	38.4	24	18.7	14	14.5	1	1.47	0.10	0.14	0.12	0.66	12.7	7.4
		SD	0	0	22	19.2	5.7	2.4	4.0	6.3	0	0.0	0.05	0.04	0.025	0.80	4.5	0.3
Mid-reach	Site 5	Mean	0.23	1.24	145	110	26.5	19.9	9.25	10.8	1	0.46	0.14	0.90	0.08	0.65	9.8	13.7
		SD	0.02	0.58	61	62.5	12.0	7.2	1.2	5.7	0	0.1	0.007	0.48	0.028	0.38	5.1	9.7
	Site 7	Mean	0.48	1.71	1593	1108	525	515	47	27.2	3.6	3.01	1.92	2.07	2.69	1.77	15.4	12.9
		SD	0.17	0.21	470	65.1	248	35.4	0.0	13.1	0.5	3.1	1.03	2.19	3.220	2.07	1.5	1.6
Downstream	Site 8	Mean	0.37	1.87	380	278	50	26	15.1	16.9	2.3	4.01	1.83	2.42	2.12	2.01	9.7	8.8
		SD	0.04	0.13	198	82	28.3	22.6	5.5	10.5	1.3	2.2	1.923	2.25	2.542	2.67	4.2	1.3
	Site 9	Mean	0.95	2.15	83	60	30	17.3	28.58	27.9	2.3	2.04	0.94	2.35	0.80	0.70	16.6	18.7
		SD	0.42	0.13	16	18	14.1	3.2	19.8	22.0	0.4	0.1	0.544	0.49	0.694	0.42	13.1	0.2
	Industrial pipe-S6	Mean	0.59	0.73	2089	1870	1125	1075	113	83	3.1	2.8	1.5	1.9	2.4	1.5	24.1	20.1
		SD	0.09	0.04	1094	778	389	176	7.1	55.4	2.4	3.5	0.6	0.1	2.1	1.4	0.01	0.78

Note: *- all for year 2011

Table 10: Descriptive Statistics of the Measured Heavy Metals

Zones	Stations along river		Discharge (m^3/s)		Cd (mg/l)		Cr (mg/l)		Pb (mg/l)		Fe (mg/l)	
			Feb*	Mar*	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Mar
Upstream	Site 1	Mean	0.94	1.59	0	0	0.003	0	0	0	0.3	0.42
		SD	0.41	0.47	0	0	0.004	0	0	0	0.44	0.59
	Site 2	Mean	0.40	1.66	0.01	0.003	0.02	0.14	0.17	0	0.4	4.89
		SD	0.21	0.29	0.02	0.004	0.028	0.20	0.24	0	0.51	6.53
	Site 3	Mean	0.74	1.93	0.04	0.049	0.26	0.24	0.33	0.36	0.9	3.45
		SD	0.19	0.12	0.02	0.054	0.368	0.02	0.46	0.51	0.06	3.84
	Site 4	Mean	0	0	0.06	0.047	1.26	0.62	0.27	0.12	2.0	0.13
		SD	0	0	0.02	0.021	1.752	0.87	0.38	0.17	0.29	0.18
Mid-reach	Site 5	Mean	0.23	1.24	0.08	0.037	0.13	0	0.04	0.01	2.0	10.51
		SD	0.02	0.58	0.09	0.035	0.177	0	0.06	0.008	2.18	5.64
	Site 7	Mean	0.48	1.71	0.03	0.049	2.23	0.65	0.05	0.11	2.8	2.48
		SD	0.17	0.21	0.04	0.066	1.032	0.52	0.08	0.148	0.47	2.74
Downstream	Site 8	Mean	0.37	1.87	0.02	0.007	0.52	0.02	0.05	0.01	3.1	4.85
		SD	0.04	0.13	0.03	0.010	0.613	0.03	0.07	0.01	0.12	3.86
	Site 9	Mean	0.95	2.15	0.07	0.015	0.4	0.30	0	0.17	4.0	6.08
		SD	0.42	0.13	0.06	0.004	0.566	0.38	0	0.233	2.06	2.83
	Industrial pipe-S6	Mean	0.59	0.73	0.077	0.098	2.25	2.98	0.33	0.03	2.085	1.77
		SD	0.09	0.04	0.038	0.003	0.88	0.37	0.46	0.05	0.827	0.13

Note: *- all for year 2011

Temperature

Temperature readings ranged from 22.8 - 27.3^{o}C, with average values of 25.8^{o}C and 25.2^{o}C for February and March 2011, respectively. In comparison with the drinking standards and aquatic ecosystem guidelines, temperature values were below the maximum permissible limits. However, the wide temperature range suggested significant variations along the river that could be attributed to the slight variations in sampling times and the different sampling days for a particular site.

The maximum temperature was measured at Site 4, a point on Mindu Dam. The findings can be attributed to the slow water movement in the reservoir which facilitates heating up of the water as compared to the fast moving water in the river. Slightly lower temperatures were observed in March as compared to February. Results could have been due to the beginning of the wet season which, in Tanzania, is associated with lower temperatures than the dry season. A study by Kumar *et al.*, (2011) on temporal variations of physico-chemical parameters revealed a similar temperature pattern.

Colour

The minimum and maximum values for colour were 20 and 5680 mgPt/l, measured at Site 1 and 9 respectively. The average concentrations for February and March and their respective standard deviations are shown in Table 8. Throughout the sampling period, measured concentrations were above both drinking standards and aquatic ecosystem guidelines. The findings could be due to industrial and agricultural activities which are practised at different locations along the river.

Findings from Sites 6 to 9 may be influenced more by industrial activities located close to Site 6. Effluent from textile, leather and tannery industries are known to contain dyes and colours as a result of chemical processes (Gholami *et al*., 2001; McMullan, 2001). The results were also supported by Yusuff and Sonibare (2005), whose study identified colour as among the major contaminants from textile industries. In terms of time, March showed higher values of colour than February, owing to the river characteristics during the beginning of the rainy season. Rivers tend to collect solid and liquid wastes in the catchment lands during this period (Abowei, 2010: Deekae *et al*., 2010)

Turbidity

Turbidity ranged from 3 - 1790 NTU, with the highest value measured at Site 9. Turbidity results showed similar pattern to that of colour. Comparing the results with TZDWS and WHO drinking standards, findings showed that in February, only Sites 1 to 4 were below the maximum permissible limits, while Sites 5 to 9 exceeded the limits. In March, results for all sites exceeded the drinking water standards. Potential risk for aquatic ecosystem health was observed from Site 5 to Site 9 whereby water clarity was reduced by more than 10%, which is above DWAF and ANZECC guidelines.

A simple explanation for the high turbidity readings from Site 6 in February is the contribution of industrial effluent from Site 6 which flows towards Site 9. In studying major components of textile industrial effluent, Yusuff and Sonibare (2005) identified dyes as some of the major pollutants of river water that could increase turbidity. In March, high turbidity values may be contributed by rain wash off the urban streets, business areas and agricultural lands, which collect all wastes to the river. High variations of colour and turbidity with season make them good indicators of temporal variations of water quality.

Conductivity and TDS

Conductivity and TDS concentrations ranged from 32 - 5930 µs/cm and 17 - 2880 mg/l respectively, with maximum values measured at Site 6 and 7. In comparison to WHO drinking water standards, Sites 5, 6 and 7 exceeded the maximum permissible limits. Since communities residing in areas around these sites do not depend on the river directly for drinking water then there is lower potential risk to the health of people. However, any pollution increase at these sites may cause potential health risks to the downstream water users in future (Site 8 and 9).

High conductivity and TDS concentrations in a broad sense reflect the pollution burden to aquatic systems. The maximum values measured at Sites 6 and 7 could explain the effect of the disposal of raw/ partially treated effluent into the river. High concentrations of total dissolved solids and suspended solids are correlated with high BOD and COD values in water, which indicate the depletion of DO levels required by aquatic ecosystem (Jonnalagadda and Mhere, 2000)

COD and BOD

BOD and COD results ranged from 5 - 700 mg/l and 9 - 1925 mg/l, respectively, along the river. The average concentrations were 1100 and 1980 mg/l, respectively, at the industrial outlet pipe (Site 6). Maximum values for BOD and COD along the river were measured at Site 7, which could have been influenced by the industrial effluent at Site 6. The values for both parameters were above drinking standards and aquatic ecosystem guidelines at all the sites except Site 1. BOD and COD concentrations decreased with rainfall from February to March as shown in Table 9.

Results showed high concentrations of COD and BOD from Sites 6 to 9 which indicated high oxygen demand for decomposition of both degradable and non-degradable organic materials. High BOD and COD levels are associated with industrial activities and leachates from solid waste dumps (Kuyeli *et al*., 2009). Textile and tannery industries contain organic materials by-products which are released with the wastewater resulting into increased oxygen demand (Akan *et al*., 2009). The extreme high BOD concentrations obtained in the study are similar to those obtained in a number of studies done in assessing the pollution contribution of industries and landfill leachates to water resources. For example, a study by Barclay and Buckley (2000**)** found out that BOD concentration in textile industrial effluent is high and differs for different stages and materials. For polyethylene materials, BOD levels at scour stage range between 500 – 800 mg/l while the in the dyeing stage it ranged from 480 – 27000 mg/l. Another study by Tufekci *et al.,* (2007) confirmed that BOD levels of the textile wastewater before treatment was between 280 – 1140 mg/l. These results are also similar to studies done to assess pollution levels in tannery effluents, where the BOD concentrations of untreated effluent reached 1470 mg/l (Durai and Rajasimman, 2011). Apart from the industrial effluents, high BOD concentrations could have been contributed by the surface runoff and underground water movement containing leachates from the solid waste landfill found near Kihonda industrial area in Morogoro. Landfill leachates may contain high BOD up to 30,000 mg/l (Caireross and Feacham, 1983) and for young landfills it may reach 60,000 mg/l (El-Fadel *et al*, 2003).

Nitrate and TKN

Nitrate and TKN were measured to assess the organic and inorganic nitrogen concentrations in the river. Nitrate ranged from 0 - 5.6 mg/l and TKN ranged from 7.6 - 47 mg/l along the river during the project period. At the industrial outlet point TKN and nitrate ranged from 44 - 122 mg/l and 0.4 - 5.3 mg/l, respectively. Results for both parameters were below TZDWS and WHO drinking standards, while Sites 6, 7 and 8 were above the DWAF aquatic ecosystem guidelines. ANZECC standards are stricter. Only Site 1 was below the standard limit and the rest were above it.

Nitrogen results suggested contribution of both agricultural and industrial activities in the pollution of the river, because areas with such activities generally have high nitrogen levels. These findings are supported by a number of studies which highlighted that nitrogen and phosphorous are the major nutrients from agriculture fields, threatening river water quality (e.g. Lander and Moffitt, 1996; Carpenter *et al*., 1998; Donner, 2003). High nitrate levels in water are contributed by organic materials collected from agriculture fields during the rainy season (Sankar *et al*., 2009).

In terms of point sources of nitrogen, leather and textile industrial effluent are known to contain both organic and inorganic forms of nitrogen and other nutrients (Akan *et al*., 2007; Akan *et al*., 2009). Ammoniacal Nitrogen is usually higher than nitrate-nitrogen because daily fresh effluent is released from the liming and un-hairing processes in the tannery industries then flows direct to the river without staying in the wastewater ponds for pre-treatment, hence high TKN values (Bosnic *et al*., 2000).

TP and OP

TP and OP were measured to assess the total phosphorus concentrations in the river. TP ranged from 0.04 - 4 mg/l while OP ranged from 0.03 - 4.97 mg/l, with maximum concentrations at Sites 7 and 8. The DWAF guidelines showed that all values were within the required limits while, ANZECC aquatic ecosystem guideline showed that only Site 1 was within the maximum permissible limits.

High phosphate concentrations at Sites 7 and 8 could have resulted from industrial effluent releases at Site 6, which averaged 1.7 mg/l for TP and 1.95 mg/l for OP during the sampling period. Yusuff and Sonibare (2005) mentioned that phosphate is among the chemicals which are used in bleaching processes in textile industries and are then released into industrial wastewater. High phosphate values could also be contributed by agriculture runoffs during the beginning of the rainy season (Jonnalagadda and Mhere, 2000; Kuyeli *et al*., 2009).

Sulphate

Sulphate concentrations ranged from 7 to 26 mg/l along the river. The average concentration at Site 6 was 22 mg/l. The results did not suggest any particular trend but the noted high values were observed at Site 5 and Site 9. In comparison to the standards, sulphate values were below both drinking standards and aquatic ecosystem guidelines. Sulphate may be contributed by natural and anthropogenic sources at different points along the river. However, the use of artificial fertilisers by farmers at Ngerengere river catchment can justify these findings (IUCN, 2010).

Heavy metals (Cd, Cr, Pb and Fe)

For the four heavy metals measured, Cadmium (Cd) ranged from 0 - 0.14 mg/l, Chromium (Cr) ranged from 0 - 2.96 mg/l, Lead (Pb) ranged from 0 - 0.72 mg/l and Iron (Fe) ranged from 0 - 14.5 mg/l along the river. Maximum concentrations were measured at Site 5 for Cd, Site 7 for Cr, Site 3 for Pb and Site 5 for Fe. From the industrial outlet pipe (Site 6), the average concentration of each metal over the sampling period was 0.088 mg/l for Cd, 2.6 mg/l for Cr, 0.18 mg/l for Pb and 1.95 mg/l, for Fe. These readings give explanation on the influence of this point to concentrations of Cr at Site 7.

For drinking purposes, results showed that in February the river water at Sites 4, 5, 6 and 9 was not fit for drinking because Cd levels were above the recommended maximum permissible limits by the TZDWS and WHO drinking water standards while in March only water at Sites 6 and 7 exceeded the required Cd limits. Cr measured for Sites 1 and 2 were within the limits set by these guidelines (in February), and in March results for Sites 1, 5 and 8 were within the limits. For Pb, measurements within the standards were at Sites 1, 5, 7, 8 and 9 in February and Sites 1, 2, 5 and 8 in March, while for Iron Sites 1, 2, and 3 (in February) were within the drinking water standards. According to the aquatic ecosystem guidelines, measurements of samples from all the sites with exception of Site 1, exceeded the maximum permissible limits for Cd, Cr and Fe. This indicates that Site 1 is less impaired than other sites.

Heavy metals results suggested the release of heavy metals from industries located between Site 2 and 3 and the other at Site 6. The study done by Deepali *et al*., (2009) found out that about 0.018 ± 4.472 mg/l of Cd, 2.383 ± 0.0045 mg/l of Cr and 0.18-0.59 mg/l of Pb were released from textile industries which had similar characteristics to the results obtained from this study. A number of studies (e.g. Pathe *et al*., 2001; Akan *et al*., 2009; Deepali *et al*., 2009) have concluded that textile effluents contain Cr metal in excess compared to other metals and have the lowest Pb concentrations. Chromium is mainly found in wastewater from the dyeing process in textile industries and Chromium salt used in the tanning process in the tannery industries **(**AEPA, 1998; Akan *et al*., 2009)**.** Iron could also be justified by its presence in some diffuse sources of pollution such as pesticides used in farms, whose components can find their way to the river.

5.1.1 Spatial Variations of Water Quality along Ngerengere River

Sampling sites were located at different locations within the three catchment zones. The mean concentrations of each parameter during the sampling period were calculated and used in analysing the various spatial patterns. Each pattern/ trend gave characteristics of that river stretch in terms of water quality and also gave indication about the sources of pollution in different locations. Note that, Site 6 was not included in the analysis of variations along the river since it was not located along the river; rather, it was used to assess the influence of industrial activities to the water quality variations along the river.

The first spatial trend illustrated that pollution concentrations increased from the upstream zone, peaking at Site 7 in the mid–reach zone and decreasing towards the downstream zone. This was observed for COD, BOD_5, Cr, TDS and EC measurements as shown in Figure 3, which illustrates the impacts of industrial wastewater at Site 7. Increasing pollution concentrations along the river from the upstream zone suggested the possibility of contribution by industries and urban activities in this area and in the mid-reach zone. As for decreasing rates towards the downstream zone, the results suggested a decrease in sources of these pollutants in the downstream zone which can be explained by the absence of industrial activities and limited agricultural activities in the downstream zone. River self-purification effects may also be partially responsible for these results.

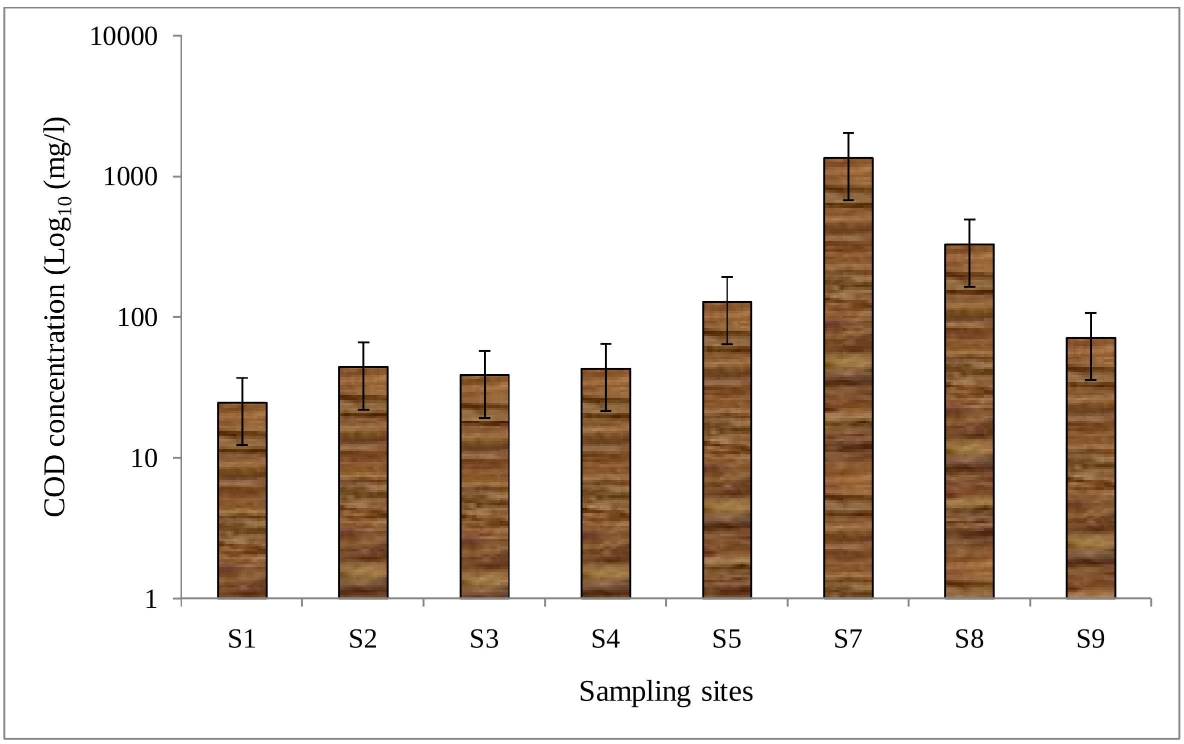

Figure 3: Variations of COD along Ngerengere River from February to March 2011

That the measured concentrations of BOD and COD increased towards Site 7, indicate that, the river stretch at mid-reach contained extremely high organic contents, leading to high oxygen demand for decomposition. The study by Akan *et al* (2009) found BOD concentrations in the range of 584 to 594.67 mg/l, and COD concentrations of 2399 to 3784 mg/l in the wastewater from textile and tannery. High concentrations of BOD and COD give insight on the low dissolved oxygen levels, high turbidity and sometimes high temperature which together give an indication of poor water quality (Sharma and Capoor, 2010).

TDS and EC trends give explanation about changes in water composition in terms of mineral concentrations. High values of these parameters at Site 7 could be contributed by the presence of dissolved and suspended solids which comprise of fine leather particles, residues from chemical discharges and reagents from different liquors originating from all stages of leather making (Bosnic *et al.*, 2000; Akan *et al.*, 2007). As expected, the electrical conductivity correlated positively with the total dissolved solids (TDS). Figure 4 shows the relationship between TDS and EC and from the graph the calculated average correlation factor k from all the readings along the river was 0.51. A number of similar studies have estimated the correlation factor to range from 0.35 to 1, but the majority of studies had an average of 0.5 and 0.7 indicating different levels of salinity in water (Neil and Cox, 1998; Atekwana *et al.*, 2004). The findings therefore indicate high salinity levels in water.

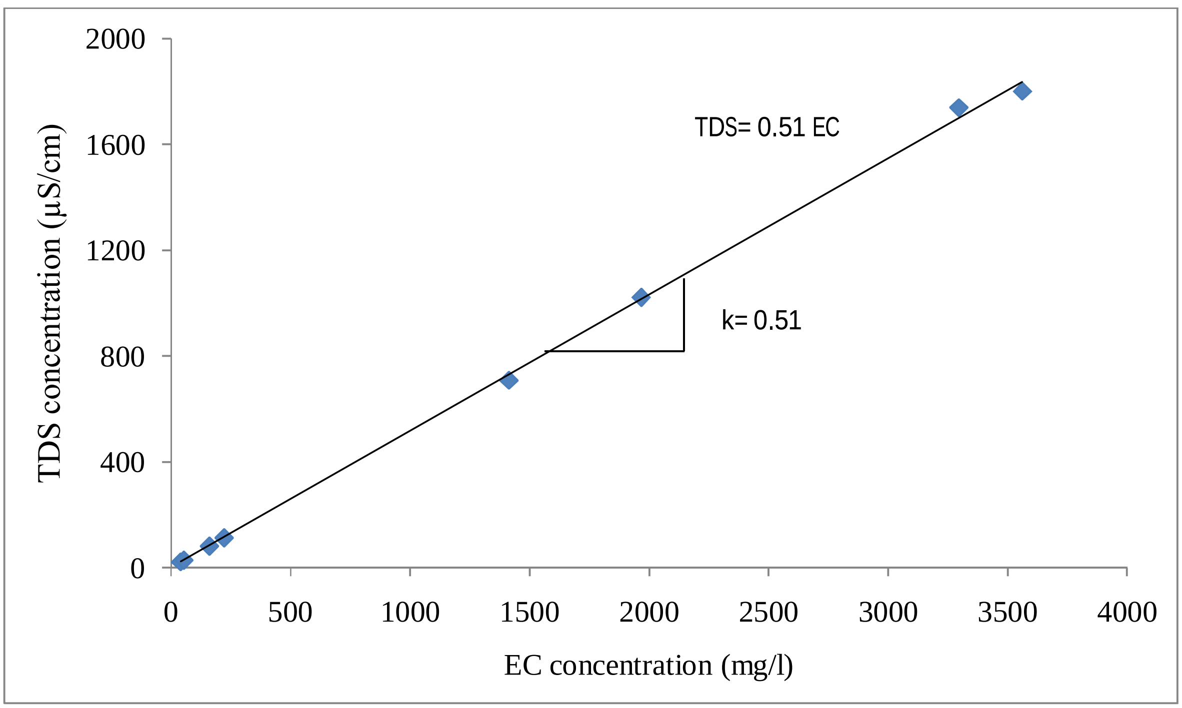

Figure 4: Relationship between Conductivity and TDS along Ngerengere River (Feb-Mar, 2011)

Cr concentration at Site 7 gives a clue about the by-products from textile, leather and tannery industrial processes. The use of Chromium as one of the chemicals in tannery and textile industries makes it a heavy metal of higher potential risks than other elements from these industries (Akan *et al*., 2009).

The other spatial variation trend shows higher pollution concentrations at Site 3 and Site 7 followed by a decrease towards the downstream zone. Lead and Cadmium results along the river showed this trend as shown in Figure 5. As explained in section 4.1, these two sites are located near industrial wastewater ponds. High Pb and Cd dilution in the river could be a reason for lower concentrations observed in sites before and after Sites 3 and 7.

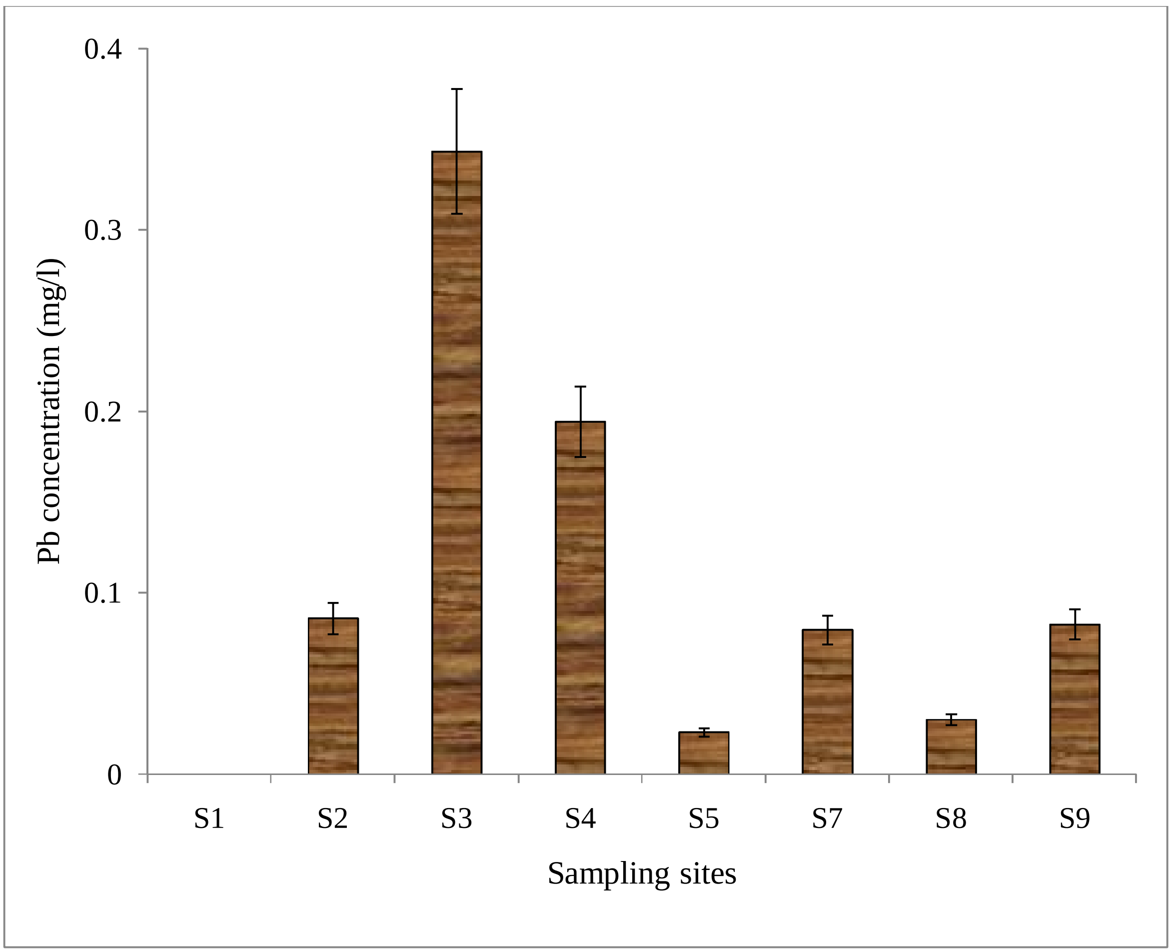

Figure 5: Variations of Lead along Ngerengere River (Feb-Mar, 2011)

This spatial trend gives an overview of the major sources of heavy metals in the catchment where Cr, Cd and Pb concentrations were higher at sites closer to industrial areas. With regards to health effects, high dilution effects of Cd, Cr and Pb in the river after Site 7 to levels below the maximum permissible limits, suggest low health risks to the people residing in the downstream zone. As explained by Newman and Mcintosh (1991) and Fermer (2001), consumption of water with excessive levels of Cd and Pb may cause kidney damage and negative effects to children's nervous systems, respectively. The long-term release of Iron into water increases the risk of getting cardiovascular collapse disease (Tamburlini, 2000; Fermer, 2001). These facts highlight the potential health risks to the people residing in the downstream zone of Ngerengere River, in case pollution levels increase or persist at the current levels.

The third spatial trend shows high pollution concentrations at Site 2 decreasing towards Site 5 and increasing again at Site 7 and finally decreasing towards the downstream zone. This trend was observed in Nitrate, TKN and TP measures as illustrated by Nitrate in Figure 6. From the reconnaissance survey, Sites 2 and 3 are surrounded by river bank cultivation and Site 7 is located close to industrial activities and monocrop cultivation.

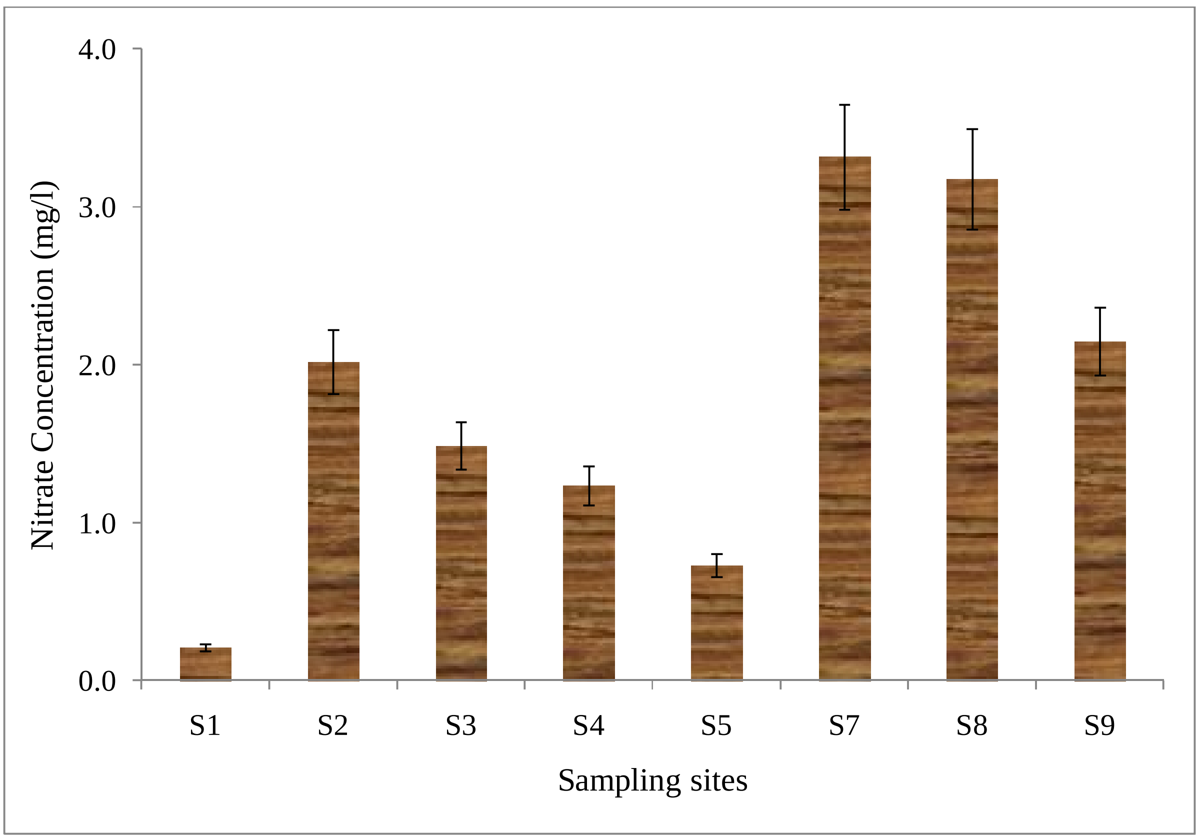

Figure 6: Variations of Nitrate along Ngerengere River (Feb-Mar, 2011)

A number of authors have documented the influence of agricultural activities on high nutrient concentrations and their respective impacts in water resources (e.g. Carpenter *et al.*, 1998;

Donner, 2003). This situation is mainly caused by excessive and improper use of fertilizers, pesticides and types of crops grown (Ndibalema, 1996**;** Obire, 2008). In the Ngerengere catchment, use of fertilisers and pesticides which is mostly done by farmers in the upstream zones can justify higher nutrient concentrations at Sites 2 and 3. On the other hand, the influence of textile and tannery industries on the high nutrients concentrations at Site 7 has been explained in Section 5.1.2.

In summary, agriculture and industries were identified as the major non-point and point sources of pollution. Water quality variation patterns along Ngerengere River were determined by the locations and spatial distribution of industrial and agricultural activities in the catchment.

5.1.2 Temporal Variations of Water Quality Status in Ngerengere River

The study was done during the end of the dry season (February) and continued up to the beginning of the long Masika rain season (March) in 2011. This period captured short-term variations in pollution concentrations due to seasonal change. Two temporal variation patterns were observed, the first showing pollution decrease with rainfall and the second one, showing pollution increase with rainfall.

The trend of decreasing pollution concentration with rainfall was illustrated by BOD_5, COD, EC, TDS, Cr and Cd concentrations as shown in Tables 8, 9 and 10. Monthly average concentrations of BOD_5 and COD decreased from February to March in most of the sampling sites and this was observed more frequently in sites located close to point sources of pollution e.g. industries. Figure 7 illustrates the COD concentration trends at Site 2 (upstream), Sites 5 (mid-reach) and Site 9 (downstream) showing that the trends are not influenced by locations but rather by season change.

These results highlight the rainfall dilution effect on contaminants and also signify facts demonstrated by Moniuzzaman *et al.* (2009) that pollutants concentration from point source are reduced by rainfall due to dilution effect. Increase in fresh water, increases dissolved oxygen levels and dilute organic contents in water hence, reduces both biological and chemical oxygen demands (Sankar, 2009; Sharma and Capoor, 2010). However, Kuyeli *et al* (2009) argued that in some cases, parameters such COD and BOD may remain in higher concentrations and may pose more health risk to the aquatic ecosystem because industrial ponds and manholes can overflow during the rainy season and release more effluent into the river.

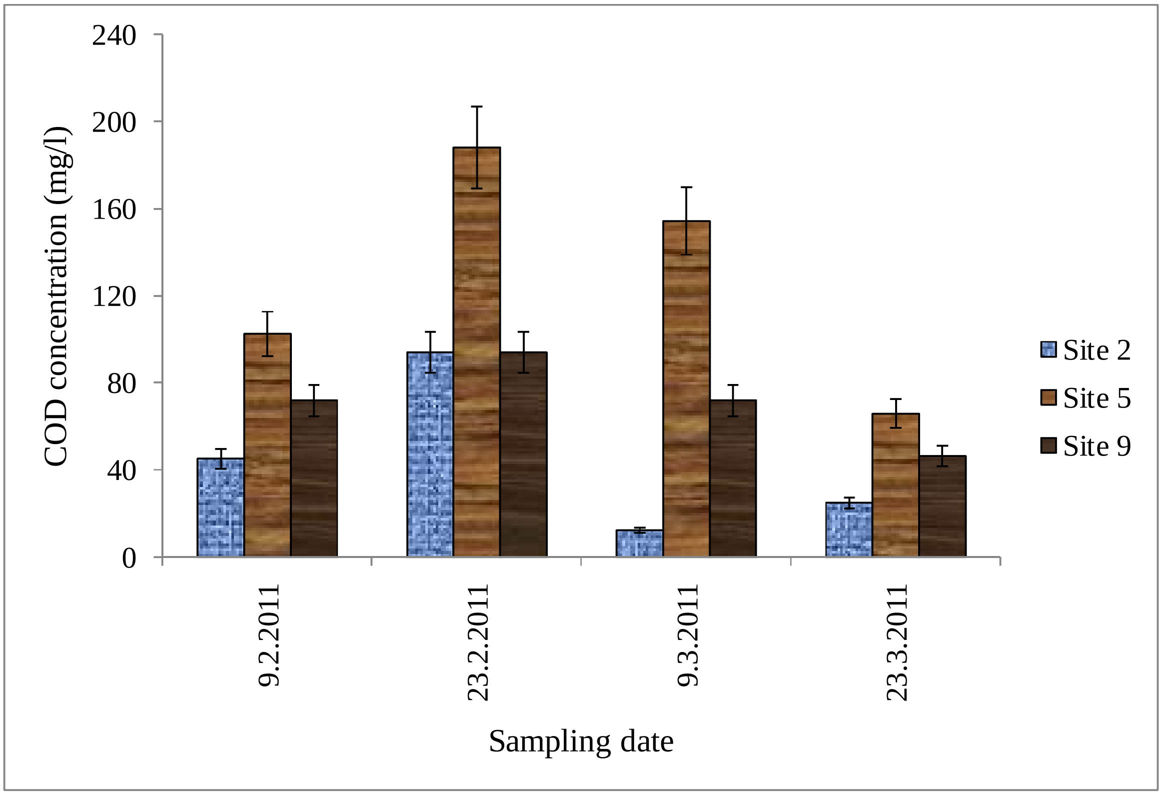

Figure 7: Temporal variations of COD at Ngerengere River (Feb-March, 2011)

TDS and EC average monthly concentrations decreased from 738 to 640 mg/l and 1436 to 1244 mg/l, respectively, and Chromium (Cr) readings went from 0.6 mg/l to 0.25 mg/l as shown in Tables 8 and 10, respectively. These results demonstrate that chemical concentrations in water decrease with increasing of fresh water e.g. rainfall. A number of studies have confirmed a negative relationship between discharge and conductivity which is mainly caused by the dilution effect of water to solutions (Kirk, 1984; Jonnalagadda and Mhere, 2000). Further explanation for this trend can be high evaporation rates during the dry season which tend to increase chemical concentrations in the river.

Increasing pollution with rainfall trend was clearly shown by colour, turbidity, total phosphate and Iron readings. Monthly average concentrations of these parameters increased from February to March in different locations in the three catchment zones indicating the impact of seasonal change on pollution in a river as illustrated by total phosphate in Figure 8. Colour and turbidity trends can be explained by the fact that during the beginning of the rain season, river water changes colour and becomes highly turbid because the rain washes off all solids and liquid wastes from the catchment and are collected by surface runoffs to the river.

During the rain season, use of river water directly for domestic use, e.g. drinking, is of potential health risk because high turbidity is associated with the presence of bacteria and pathogens as solid particles in water increase the surface area for attachment of bacteria and pathogens (Sadar, 2002). For aquatic flora and fauna, high colour and turbidity concentrations reduce light penetration in water which in turn reduces rates of biological processes such as photosynthesis and decomposition (Bootsman and Hecky, 1999).

The average phosphate concentration increased from 0.63 to 1.33 mg/l from February to March 2011 and this could be caused by a number of factors depending on the landscape and activities practised in different parts of the catchment. Rainfall could have facilitated erosion in the upstream zone where river bank cultivation is dominant in the foothills of Uluguru Mountains. Research studies have identified sources of phosphate in river water to include phosphate regeneration in a water column due to turbulence and high flow caused by rainfall (Deegan and Peterson 1992), surface runoff collecting nutrients from agricultural fields and urban areas (Kuyeli *et al.*, 2009; Bannada, 2011) and weathering of rocks due to abrasion and erosion (Franks *et al.*, 2007).

The relationship between Iron concentration and river flow/discharge was in contrast to research findings by Yahaya *et al.* (2009) who concluded that Iron concentration decreased with the discharge increase. The observed trend might be caused by the weathering of rocks and mixing up of sediments in water resulting in the release of Iron into the water column. Heavy metals concentrations reduce with increased river flow; however the steep slopes of the Uluguru Mountain, which accelerate weathering and erosion, might have contributed to these results.

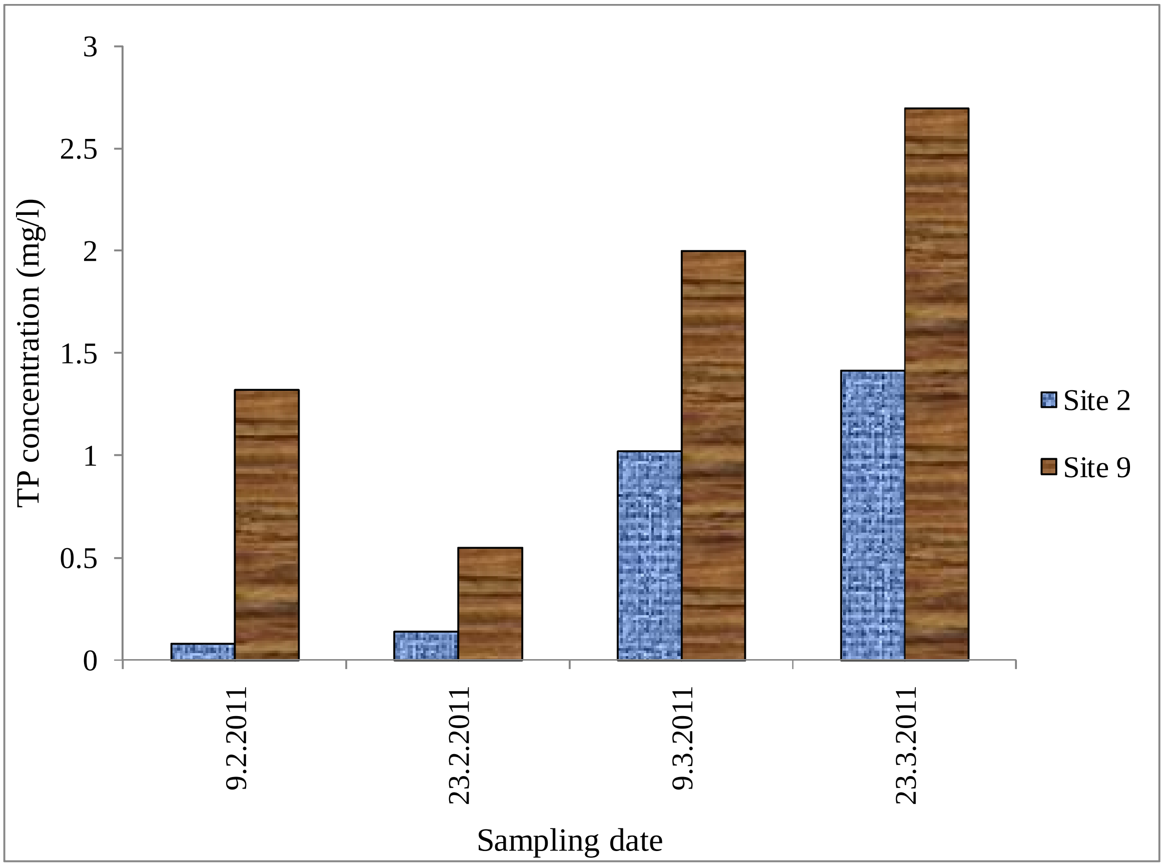

Figure 8: Temporal variations of TP at Ngerengere River (Feb-Mar, 2011)

5.1.3 Pollution Load

Assessment of pollution load in kilogram per day at different locations along the river was done using the Source Monitoring Method developed by EPA (2009). Spatial variation trends of pollution load in kg/d were similar to that of pollution concentrations in mg/l. Table 11 shows discharge measures at all the sites along the river and pollution load for selected parameters. The results show that Site 4 has zero pollution loads for each parameter because it is located at the Mindu reservoir where discharge is zero. Maximum average discharge at Site 9 (at Ngerengere town) was 1.55 m^3/s and might have been caused by the unexpected rain on 8th February 2011, the night before the first sampling date. In general, similarities in pollution concentrations and pollution loads highlight that the average river flow over the sampling period did not have significant variations along the river to cause major changes in the pollution load trends.

Table 11: Summary Statistics of the Mean Discharge and Pollution Load of Selected Parameters along Ngerengere River (February to March, 2011)

Sampling sites	**Distance (km)**	**Discharge (m3/s)**	**TDS (kg/d)**	**TP (kg/d)**	**NO_3 (kg/d)**	**SO_4 (kg/d)**	**Cr (kg/d)**	**Pb (kg/d)**
Site 1	0	1.27	2186	7.04	21.27	1029	0.14	0
Site 2	4.7	1.03	1961	88.97	196.17	1114	10.57	2.95
Site 3	10.4	1.33	8372	72.22	171.38	1429	28.39	40.34
Site 4	16.2	0	0	0	0	0	0	0
Site 5	27.25	0.74	104498	49.68	34.71	830	1.26	0.72
Site 7	35.8	1.09	151252	192.34	296.30	1269	94.05	8.85
Site 8	43.07	1.12	77863	224.63	361.14	863	9.83	1.60
Site 9	105.73	1.55	121073	255.95	281.32	2413	44.31	15.29

Spatial variations of nutrients' load in form of nitrate and phosphate is one example demonstrating similarities of pollution load and pollution concentrations, whereby high values were observed in Sites 2, 3, 7, 8 and 9. However, high pollution loads measured at Sites 8 and 9 were in contrast to the pollution results as measured in pollution concentrations (mg/l). Figures 9 and 10 show pollution variation trends of nitrate and total phosphate along the river. Further to justifications in Section 5.1, these results indicate high effluent content from industrial ponds which cannot easily be diluted due to the low discharge rate from Site 7 towards the downstream zone. Spatial variation trends of Cr and Pb load, as shown in Table 11, could be caused by industrial effluent released at points between Sites 2 and 3 and at Site 6 as explained in Section 5.1. The high pollution load at Site 9 could be due to high discharges contributed by rainfall and discharge from tributaries joining Ngerengere River.

Calculations of pollution load using different formulas and models are widely used to estimate impacts of pollution from identified point and non-point sources of pollution (Arnold *et al*, 1995; Deng, 2010; NBCBN, 2010). Long-term assessment of pollution load facilitates predictions of future pollution in a particular area and hence such assessment can be used to prevent potential health impacts to people, animals and aquatic organisms (Bailey, 2008). Due to limited project time, future predictions of pollution load from industries could not be done; rather, only short-term spatial variations were established.

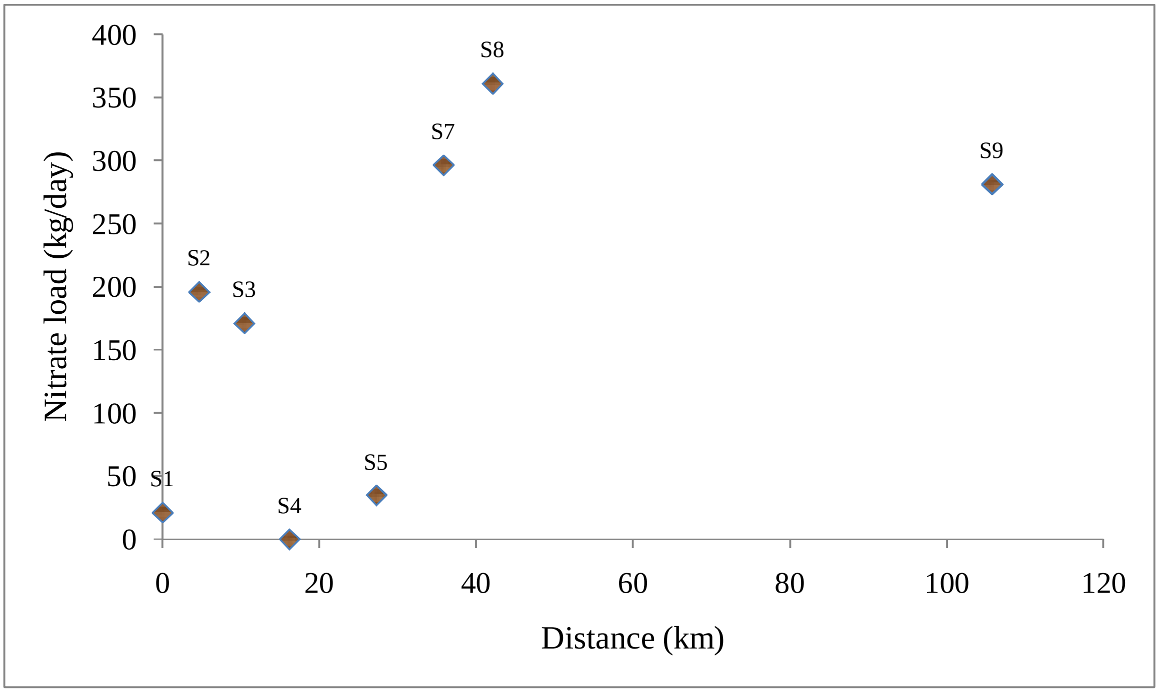

Figure 9: Spatial variations of Nitrate Load (kg/d) at Ngerengere River (Feb-Mar, 2011)

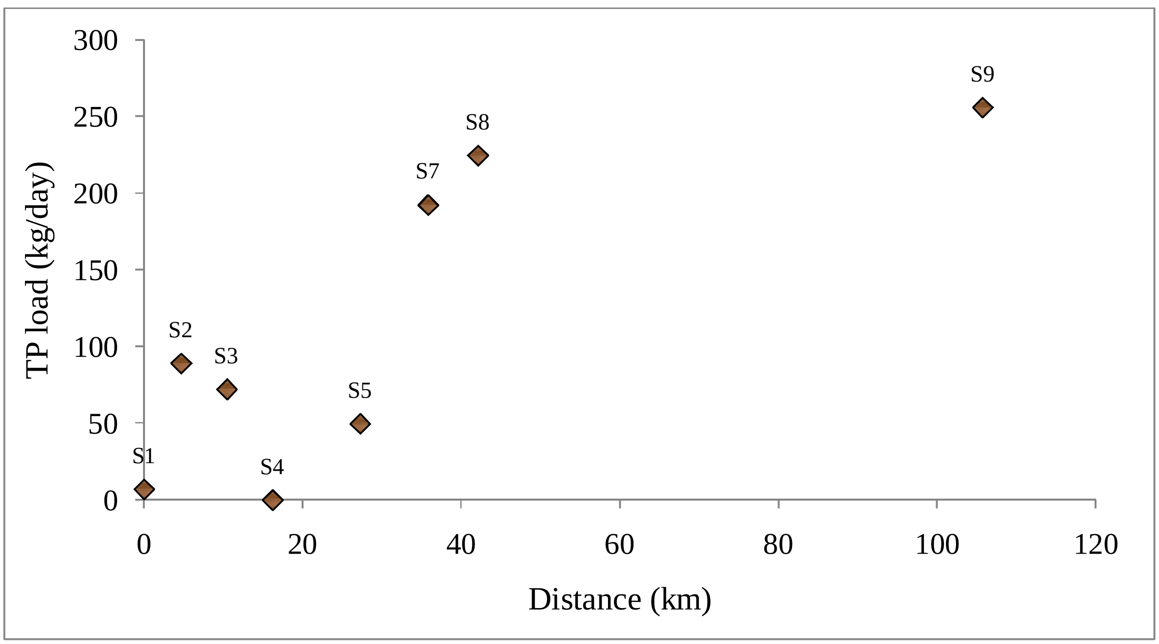

Figure 10: Spatial variations of TP Load (kg/d) at Ngerengere River (Feb-Mar, 2011)

5.1.4 Estimation of Pollution Sources using Factor Analysis

The physico-chemical data was subjected to the multi-variate statistical analysis (particularly Factor Analysis), in order to simplify evaluation and interpretation of water quality data and estimate the possible sources of pollution. As explained in Section 4.3.1, the method involves three analysis stages, namely: hierarchical cluster analysis, factor analysis and linear regression analysis. Only the sampling sites located along the river were used in this analysis and Site 6 only was used to evaluate any relationship between the analysis results and industrial activities in that area.

Hierarchical cluster analysis of standardised results using the Ward's method resulted into two clusters. Cluster one comprised of Sites 1, 2, 3, 4 and 9 and Cluster two comprised of Sites 5, 7 and 8. Figure 11 shows the dendrogram highlighting cluster one which contains less polluted sites and cluster two with high polluted sites. Cluster one contains all sites in the upstream zone and Site 9 in the downstream zone. Cluster two contains all sites in the mid-reach zone and Site 8 in the downstream zone. These findings show that the downstream zone has two pollution conditions at different locations, high pollution at Site 8 and low pollution at Site 9. The distance of 63 km between the two sites suggests the possibility of the river's self-purification.

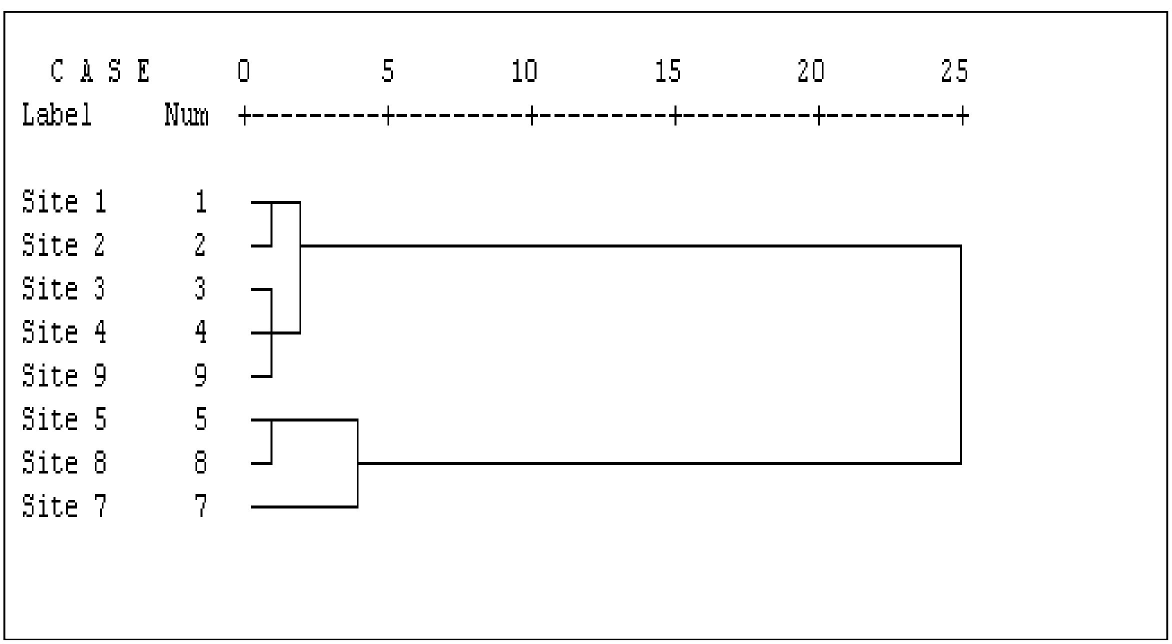

Figure 11: Dendrogram showing sampling sites clusters along Ngerengere River

Factor analysis using the Principle Component Analysis (PCA) method was used for analysis of characteristics of each cluster and extraction of a few variables representing the parameters influencing water quality status. The PCA method grouped the parameters in each cluster and formed new variables using the correlation matrix based on their influence to similar pollution characteristics.

Table 12: New Variables Developed from the Two Clusters and their Respective Parameters

Cluster 1				**Cluster 2**		
	Variable				**Variable**	
Parameter	**1**	**2**	**3**	Parameter	**1**	**2**
TP	0.979	-0.199	0.015	COD	0.99	0.141
Fe	0.979	-0.137	0.142	BOD_5	0.986	0.167
Turbidity	0.973	0.007	-0.175	Colour	0.975	0.22
Colour	0.972	0.008	-0.163	Cr	0.96	0.28
COD	0.97	0.212	0.061	Pb	0.956	0.293
TKN	0.952	-0.0071	0.285	TKN	0.938	0.347
TDS	0.951	0.101	-0.181	Turbidity	0.827	0.559
Nitrate	0.759	-0.016	0.526	EC	0.732	-0.681
Cr	0.043	0.982	0.182	TP	0.32	0.947
Cd	-0.277	0.949	0.046	Cd	-0.373	0.928
BOD_5	0.681	0.729	0.059	Nitrate	0.404	0.915
Pb	-0.082	0.212	0.898	TDS	0.672	-0.74
				Fe	-0.693	-0.721

Cluster one extracted three variables (clusters) which explain three different pollution variation patterns of influencing parameters along the river. Cluster two extracted two variables which explain two different spatial trends of the influencing parameters as shown in Table 12.

The part and partial correlation method of linear regression analysis was used and the summary results of all the analyses are shown in Table 13. The linear regression analysis results suggest that variables formed in cluster one were highly influenced by total phosphate, COD, TDS and nitrate concentrations for variable 1, Cadmium and Chromium for variable 2 and Lead for variable 3. On the other hand, variables formed in cluster two were influenced by Chromium and turbidity for variable 1 and total phosphate and Cadmium for variable 2.

Table 13: Summary Results of the Three Stages of Factor Analysis

Analysis	**Method**	**Results**				
Cluster analysis	Ward's method (Squared Euclidean distance)	2 Clusters				
		Cluster 1			Cluster 2	
		Site **1,2, 3, 4 & 9**			Site **5, 7 & 8**	
Factor analysis	Principle components analysis (Correlation Matrix)	Variables			Variables	
		1	2	3	1	2
	Eigenvalues	7.71	2.67	1.2	9.42	3.59
	% Variance	64.28	22.21	9.91	72.401	27.599
	Cumulative %	64.28	84.49	96.4	72.401	100
Linear Regression analysis	Part and Partial Correlation	Variable			Variable	
		1	2	3	1	2
		TP	Cadmium	Lead	Turbidity	TP
		COD	BOD_5		Chromium	Cadmium
		TDS	Chromium			
		Nitrate				

A simple justification for these findings is that for cluster one, Variable 1 explains that about 64 % of total variance has a strong positive loading of TP, COD, TDS and nitrate which can be interpreted as a mixture of agriculture activities and natural mineral composition of the river. A strong loading of COD may indicate low levels of dissolved oxygen in the particular sites which form Cluster one. Variable 2 explains that 22 % of the total variance has a strong positive loading of Chromium, Cadmium and BOD_5 which may be indicating industrial activities which could be between Sites 2 and 3 where there is an industry known to release heavy metals into the river. Finally, Variable 3 with 10% of the total variance has a strong positive loading of Lead and a negative loading of nitrate, indicating the possibility of the presence of high industrial pollution and less of agricultural pollution.

For Cluster two, Variable 1 explains that about 72% of the total variance indicates a strong positive loading of pollutants from both industrial i.e. Chromium and agricultural fields i.e. turbidity. Variable 2 with 28% of the total variance indicates strong positive loading of agricultural-related pollutants such as total phosphate and industrial pollutants such as Cadmium. Therefore pollution levels at Sites 1, 2, 3, 4 and 9 might be influenced more by both agriculture and industrial activities while pollution at Sites 5, 7 and 8 could be influenced more by industrial activities than agricultural activities.

5.2 Status of water quality based on biological assessment

From the biological assessment done to eight sampling points using the SASS 5 protocol a total of 21 families were identified at all sampling sites along the river.

Table 14: Macro-invertebrates identified in Ngerengere River from February to March, 2011

Sampling point	**Site 1**		**Site 2**		**Site 3**		**Site 4**		**Site 5**		**Site 7**		**Site 8**		**Site 9**	
Sampling day	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Family																
Oligochaeta								16				1	2			
Amphipoda		4														
Notonemouridae															2	6
Baetidae			220	58	1	2			2	2		4	8	12	12	4
Caenidae			2													
Heptageniidae	1	5														
Leptophlebiidae		3														
Teloganodidae	2															
Coenagrionidae			1	12												
Corduliidae													1			
Gomphidae	2		3	1									3	1	5	2
Pyralidae	4	2														
Belostomatidae	1		1			2							1	2		
Gerridae														2		
Elmidae	2	6	1	4									2	9		
Gyrinidae				2										14		
Ceratopogonidae							1									
Chironomidae			50	28		7	10	35	2	3	2	3	2	2	4	
Culicidae							1									
Tipulidae			1													
Thiaridae					1	4	43	63								

Table 14 shows the names and numbers of micro-invertebrates identified during the sampling period for 8 sampling sites. The results show that Site 1 was dominated by pollution sensitive families such as Heptageniidae, Leptophlebiidae, Teloganodidae and Pyralidae. Site 2 had both pollution sensitive families such as Elmidae and Gyrinidae and pollution tolerant families such as Chironomidae, Baetidae and Belostomatidae. Sites 3, 4, 5 and 7 had few taxa number mainly from pollution tolerant families such as Oligochaeta, Baetidae, Belostomatidae and Chironomidae. Sites 8 and 9 had a taxa number containing a combination of pollution tolerant and sensitive families.

Site observation results showed that Site 1 was less impaired than other sites and the area was not surrounded by human activities such as cultivation, settlements or industrial activities, thus the available biotopes were not destroyed or modified. However, the site had a lower taxa number which could be attributed to the few observed biotopes i.e. riffles, runs and riparian vegetations. Site observation results were positively correlated to the number and types of macro-invertebrates identified in Site 1.

For Sites 2, 8 and 9 the existence of both sensitive and tolerant families could be caused by human activities which vary with time or season. A typical example of such activities can be agriculture which involves seasonal disturbance of land and application of chemicals which consequently affect the nearby water resources. In spite of their tolerance to pollution, it was found that Thiaridae and Chironomidae are highly affected by the application of Fenvalerante pesticide in agricultural fields (Liess and Ohe, 2004).

Sites 3, 4, 5 and 7 results explain the effects of point source pollution to a river. Long-term pollution of a river stretch leads to migration or extinction of pollution sensitive taxa and the remaining tolerant taxa adapt to the stressful condition of water quality deterioration (Dallas, 2000; Ollis *et al.*, 2006). Oligochaeta, Chironomidae and Baetidae are among the pollution tolerant families found to exist in chemically polluted rivers in Southern Africa (Mason, 1996; Graham and Dicken, 2002; Dube *et al.*, 2010).

From the habitats conditions assessment, results showed that Site 1 was least impaired and had more biotopes as compared to other sites, hence it was selected as the reference site. Sites 5 and 7 were observed to have worse biotopes than others due to intensive human activities such as agriculture, washing and brick making practised along the river. Other sites had moderately degraded habitats associated with moderate human activities practised along the river.

Generally, apart from Site 1, other sites had poor habitats conditions which can be caused by a number of factors that include river bank agriculture, livestock watering, washing and bathing activities in the river, sedimentation levels and other contaminants in water. Bowd *et al* (2006) and Whisenant (2010) concluded that the absence of appropriate biotopes for macro-invertebrates can affect both the number of taxa and their diversity in a particular river stretch.

5.2.1 Water Quality Status based on SASS 5 Protocol

Biological data analysis using the SASS 5 score sheet for the data collected in 8 sampling sites had the following results; SASS scores ranged from 2 to 55, taxa number ranged from 1 to 7.and ASPT ranged from 2 to 11 as shown in Table 15. These findings suggest poor water quality and poor biotopes diversity because, according to SASS 5 indices interpretation guide by Chutter (1998), only Sites 1 and 2 scored B while the other sites scored E. Score B means the site has natural water quality with reduced biotope diversity and score E means major deterioration in water quality.

Table 15: Descriptive Statistics of Bioassessment Data for Ngerengere River (February-March, 2011)

Sampling Site	SASS score		Taxa number		ASPT	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Site 1	55	0.7	5.5	0.7	10	3.4
Site 2	42	6.4	7	1.4	6	4
Site 3	11	5	3	1	3.5	1.1
Site 4	8.5	3.5	3.5	0.7	2.4	2
Site 5	8	0	2	0	4	1.4
Site 7	8.5	9.2	2	1.4	3.5	0.4
Site 8	41	0.7	7	0	5.8	5
Site 9	33	1	4	1	9.6	2

SASS scores

SASS scores measure macro-invertebrates tolerance and sensitivity to pollution and stressful conditions in water. Results showed maximum average SASS score at Site 1 and minimum at Site 5, which are different from the maximum and minimum taxa number which is at Site 2 and Site 5, respectively, as shown in Table 15. These results showed that taxa sensitivity (SASS scores) and taxa diversity (taxa number) are influenced by different factors. One major factor contributing to high SASS scores is habitat quality which selects the type of macro-invertebrates existing in a certain site depending on the pollution status and environmental condition of that area (Dallas *et al*., 1999). Physico-chemical characteristics of water also contribute to variations in SASS scores, for example, high concentrations of parameters such as turbidity and BOD can affect respiration and photosynthesis processes in water which in turn reduces productivity and hence lowers the number and growth of macro-invertebrates (Bowd *et al.*, 2006).

Taxon Diversity (Taxa Richness and Abundance)

The results in Table 14 show that a total of 21 different families found from nine orders were identified and assigned predetermined SASS scores which is about half of the order numbers listed in the SASS score sheet. However, for each sampling site, the highest number of taxa was eight (at Site 2), which indicated low taxa richness at different sites. Poor taxa richness at different sites might be contributed by pollution or environmental stresses. Taxa richness is confirmed by the dominance of taxa adapted to polluted and stressed environment (Mason, 1996).

Results for Sites 3, 5 and 7 showed the lowest number of taxa which could be caused by the poor habitats quality observed at Sites 3 and 7. These two sites are highly being interfered with human activities. The number of individuals found in each taxon in a given site is known as taxa abundance. Bioassessment results showed high abundance of pollution tolerant taxa and low abundance of pollution sensitive taxa. A total of 78 Chironomidae (2 scores) were identified at Site 2 and > 100 of Thiaridae (3 scores) at Site 4 while the highest number of Heptageniidae (13 scores) was 6 at Site 1 and Notonemourida*e* (14 scores) was 8 at Site 9. High pollution levels in a majority of sites along the river can be attributes to a high abundance of pollutant tolerance families such as Chironomids and Oligochaeta (Mason, 1996). However, a high abundance of Baetidae can give an indication of both good and poor water quality, depending on their number i.e. Baetidae > 2 =12 scores while Baetidae 1=3 scores (Graham and Dicken, 2002). Hence taxa richness and abundance are important factors which determine the taxa diversity of the area, a fundamental index in biological water quality and integrity of aquatic ecosystem interpretation.

5.2.2 Variations of Pollution along the River Based on Bioassessment Data

Using the three SASS 5 protocol indices, there were spatial variations in macro-invertebrates, taxa number and ASPT in different catchment zones for each sampling period as well as for the combined data set. Results for all the three indices showed that there were high SASS scores, taxa number and consequently ASPT in the upstream and the downstream zones while the mid-reach zone had lower values as shown in Figures 12 and 13.

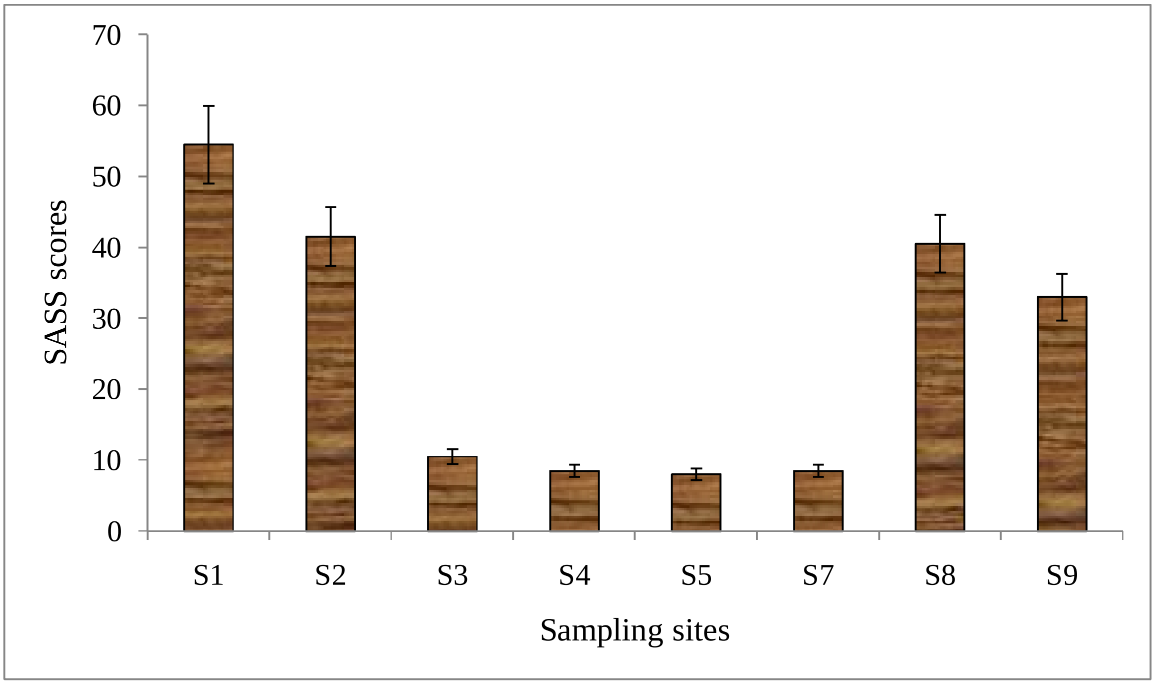

Figure 12: The graph of SASS scores along Ngerengere River (Feb-Mar, 2011)

These results trends are closely related to the physico-chemical analysis trends as shown in Tables 8, 9 and 10 where high concentrations for a majority of parameters were dominated at the mid-reach zone. Industrial activities being among the reasons for high pollution concentrations can also justify the biological assessment results. High BOD, COD, turbidity and conductivity are related to low dissolved oxygen, which indicates direct negative impact on the survival and production of living organisms (Solis, 1988; Kishore *et al*., 2005). Sites 3 to 7 had low SASS scores and they had low taxa number which explains high pollution and poor biotopes (habitat quality) (Chutter, 1998). However, results from the river water sample taken a few meters from Site 6 had moderately higher SASS scores than some of the sites along the river. This could be because at this point there were a high number of pollution tolerant families such as Oligochaeta and Baetidae.

Sites 1, 2, 8 and 9 were dominated by pollution sensitive taxa such as Crustacea, Plecoptera and Ephemeroptera, as shown in Table 14. These results could be contributed by good habitat quality and the presence of less toxic pollutants to aquatic organisms at Site 1 which was considered as the reference site. In spite of the river bank cultivation practices in the upstream zone along Sites 2 to 4, the riparian vegetation biotopes degradation at Site 2 did not affect the SASS scores and taxa number which is in contrast to the similar degradation effects on Sites 3 and 4. For Site 9, high indices values could be caused by the river's self-purification process which could be happening between Sites 7 to 9.

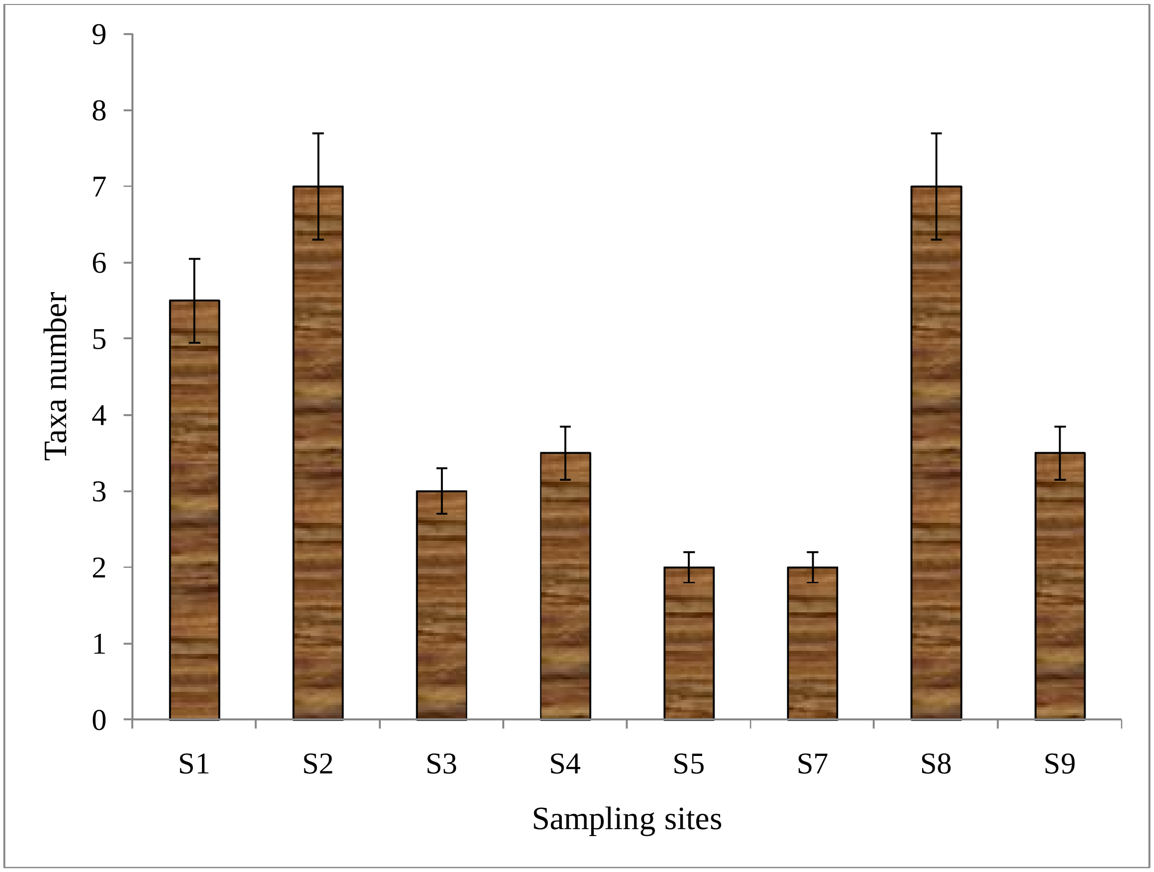

Figure 13: The graph showing number of families along Ngerengere River (Feb-Mar, 2011)

The grouping of sites according to poor and good water quality based on the macro-invertebrates existence and their variations along the river alone is inadequate. The proper grouping of the sampling sites according to the biological database, by using the hierarchical cluster analysis method, for effective planning of water quality management programme, was found to be appropriate.

5.2.3 Cluster Analysis of Macro-invertebrates data

The hierarchical cluster analysis using Ward's method was used to group sampling sites according to the bioassessment database. From the analysis results, a dendrogram which divides the sampling sites into two major clusters as shown in Figure 14 was developed. The two clusters are comprised of Sites 1, 2, 8 and 9 for Cluster 1 and Sites 3, 4, 5 and 7 for Cluster 2 which are similar to the previously discussed trends in the bioassessment spatial variation results (Section 5.2.1). The two clusters were formed with the interpretation that, Cluster one is dominated by pollution sensitive families while Cluster two is dominated by pollution tolerant families. In the previous discussion it was clear how closely these results are related to the physico-chemical results along the river.

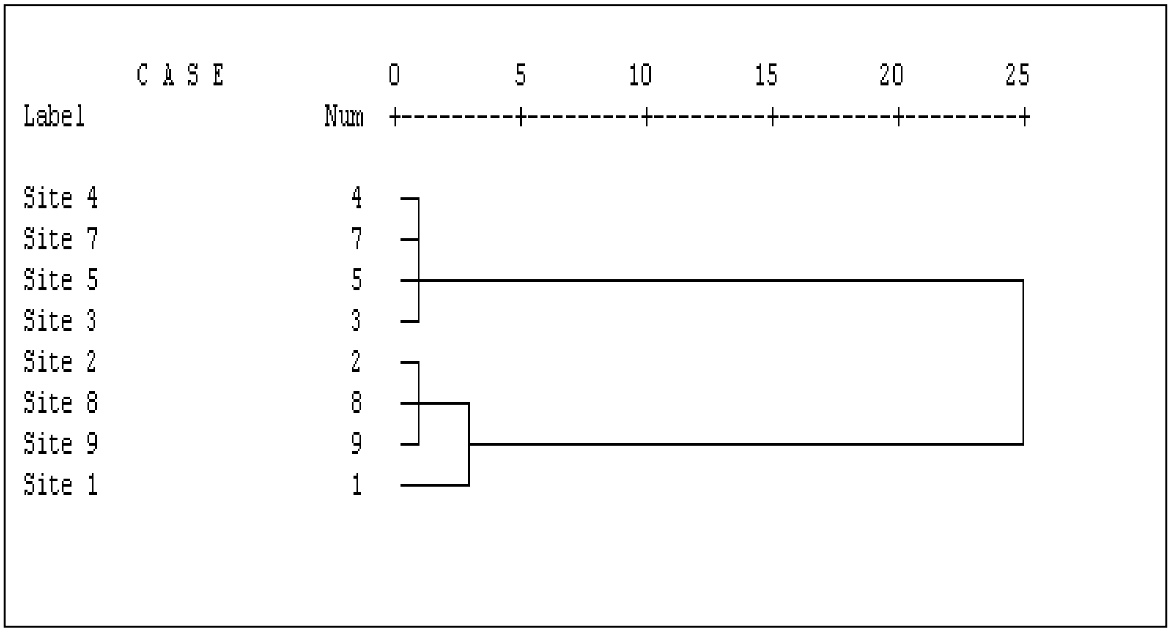

Figure 14: Dendrogram of sampling sites clusters along Ngerengere River based on bioassessment data

5.3 Mapping of Spatial Distribution of Pollution Sources in the Catchment

5.3.1 Development of Ngerengere Catchment Landuse Map

The development of the Ngerengere River Catchment landuse map using the supervised classification method was done with the ArcGIS software. The two image scenes of the Landsat image 4-5TM for December 2010 and January 2011 were first pre-processed, enhanced and later classified using the maximum likelihood algorithm classifier (using the supervised classification). A study by Al-Tamimi (2005), highlighted the increased accuracy in the output landuse maps when using the supervised classification as compared to the use of unsupervised classification. Maximum likelihood algorithm is the most commonly used algorithm in the supervised classification (Jensen, 1996; Schowengerdt, 1997).

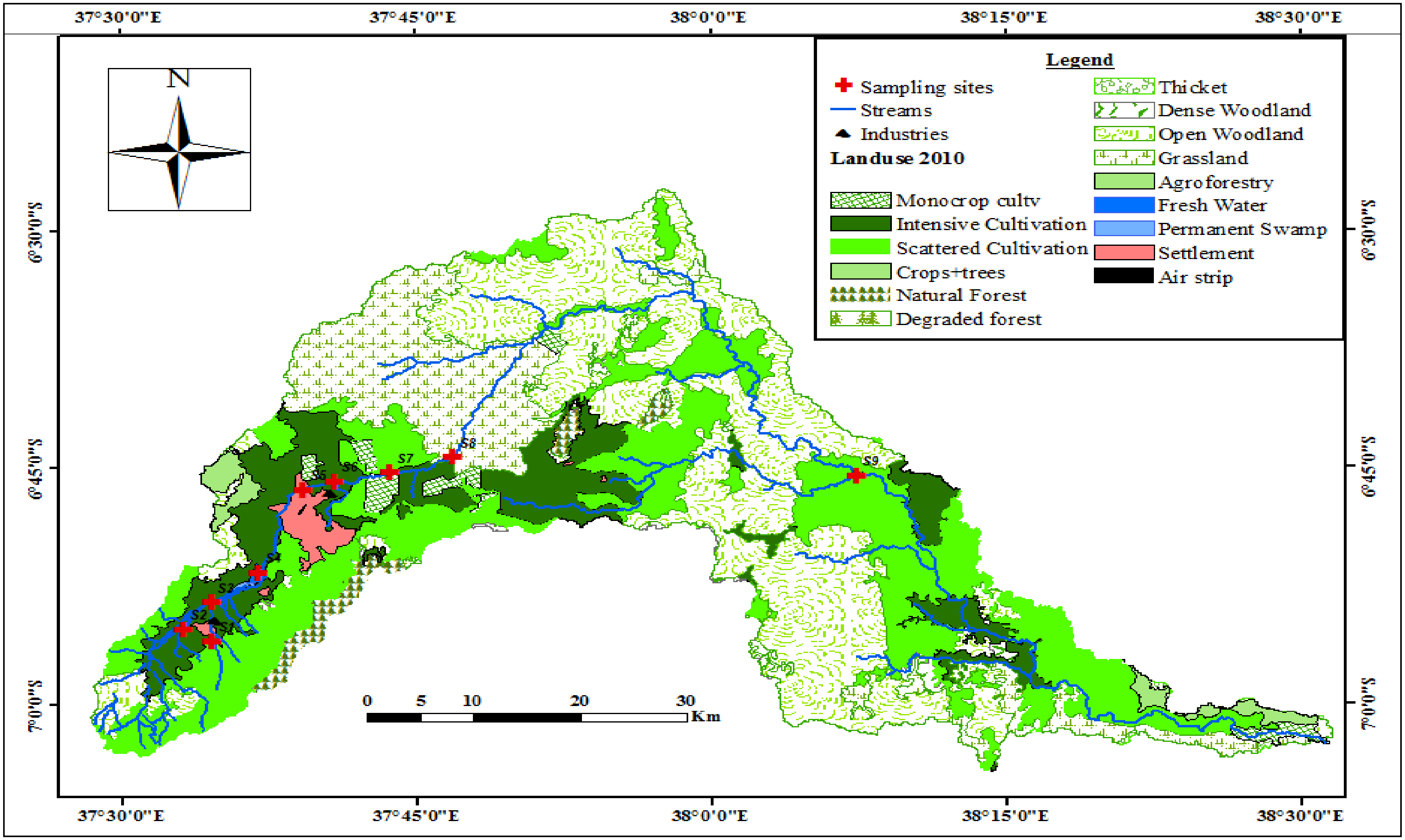

Figure 15: Ngerengere catchment landuse map showing sampling sites along the river

Accuracy assessment of the landuse maps from supervised classifications was done for the selected classes. The assessment was done by using the confusion-matrix method in which a set of random samples of classified data of the TM imagery and reference data collected from the field visits were compared. In spite of the fact that field visits were done from February 2011, which is different from the month that the images were taken, the confusion matrix method indicated 81% accuracy, making the images reliable resources to be used for this study.

The time that TM images were taken and physico-chemical data collected in the field was not significantly different to indicate major changes in the landuse pattern, particularly due to weather change. Use of images for December 2010 and January 2011 to develop the landuse map for the study between February and March 2011 gave reliable results because Morogoro and other coastal regions receive first short rains from November to December/ January and long rain season beginning in March, hence the images did not have any seasonal effect in the output landuse map. The developed landuse map with 15 classes is shown in Figure 15. The map has 5 classes of different cultivation types, namely intensive agriculture, scattered cultivation, cultivation with monocrop and cultivation with trees from a total of 15 classes.

The landuse map was then overlayed with the Ngerengere catchment shapefile showing sampling points along the river and the resultant map indicates the landuse activities surrounding each sampling site along the river as shown in Figure 15. The map shows a high concentration of intensive agricultural practices along the river. Intensive river bank agriculture is known for causing soil erosion and deterioration of river water quality (MNRT, 2003). In Ngerengere catchment, river bank agriculture has contributed to the changing of Mlali River from a perennial to a seasonal river. Worth noting are the two industrial areas located in the catchment which are the main point sources of pollution in this study. The presence of the two industrial areas brought both expected and unexpected variation trends of physico-chemical parameters.

5.3.2 Relationship between Landuse and Pollution Distribution in the Catchment

The landuse map was used to locate the specific pollution levels of selected parameters at each sampling site as shown in Figures 16, 17 and 18. Electrical conductivity was selected among the other physical parameters measured because its concentration at Sites 5, 6 and 7 exceeded drinking water standards. For all the sites, electrical conductivity readings exceeded aquatic ecosystem protection guidelines. High conductivity has detrimental effects to the aquatic ecosystem since it is positively correlated to BOD and COD which implies lower dissolved oxygen in water (Manjare *et al*., 2010). Hence conductivity was considered because it gives water quality information which can be explained by a number of parameters.

Nitrate was selected in the group of chemical parameters in spite of the fact that the nitrate concentrations were within both drinking and aquatic ecosystem protection guidelines. Nitrate is among the parameters that are from both point and non-point sources of pollution such as industry and agriculture; hence it gives more detailed information about water quality along the river. There is a high health risk to people and aquatic organisms associated with an excess of nitrogen concentrations in water e.g. blue-baby syndrome to children.

Among the measured heavy metals, Chromium concentrations were higher than concentrations of the others, particularly in areas close to industrial activities. High values were caused by the fact that Chromium is among the raw materials in textile and tannery industries which are found in the catchment (Akan *et al.,* 2009). There are high potential health impacts to people and aquatic organisms using water with high nitrate concentrations, hence it is also a parameter of concern.

The classification of pollution levels for different parameters was based on both drinking and aquatic ecosystem standards and guidelines as shown in Appendix 1. Pollution distribution maps for other parameters are found in Appendix 3. These figures broadly show the influence of landuse activities and other sources to pollution levels at each site. Landuse activities highly influence non-point sources of pollution in a catchment and in turn may affect other landuse activities located in the downstream zone of the catchment which depend on the same water sources (Zampella and Procopia, 2009).

Figure 16 shows conductivity variations along the river in relation to the landuse distribution as displayed in the map. Sites 6 and 7 highlight high conductivity concentrations which kept on decreasing along the river. The situation is more likely to be influenced by industrial effluent which is a point source and less by the agricultural activities as it can be observed on Sites 1, 2 and 3. The map also indicated the possibility of a river's self-purification as from Sites 7 to 9.

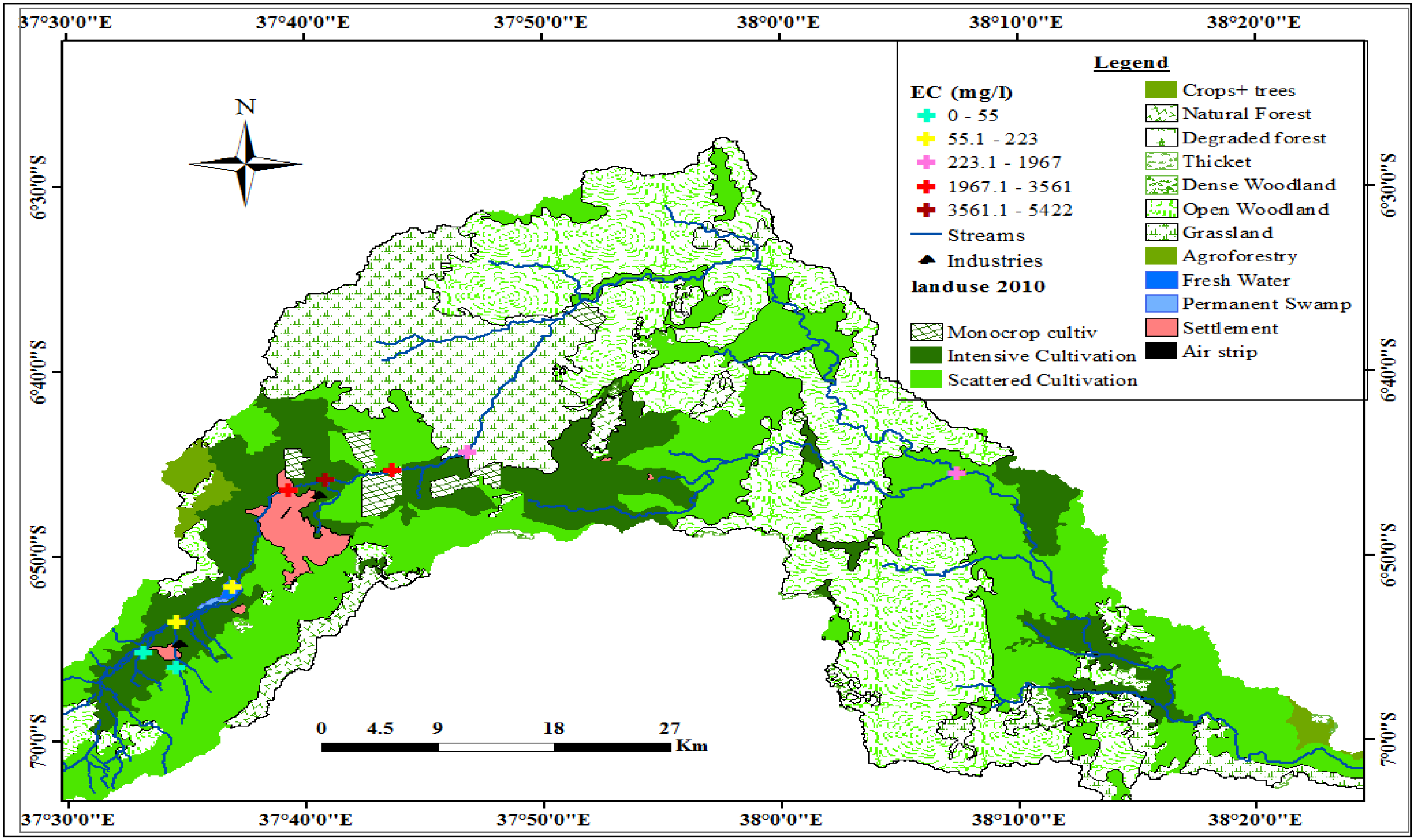

Figure 16: Ngerengere catchment landuse map showing conductivity variations along the river

Nitrate concentrations showed the influence of agricultural activities on the nutrients levels in the river as shown in Figure 17. Sites 2 and 3 indicated a collection of nutrient load from Mlali and Ngerengere Rivers which possibly settled down in Mindu Dam (Site 4). Sites 6 and 7 could be influenced by industrial effluent while Site 9 might also result from agricultural activities. With the high growth rate of agricultural activities, as shown in the right corner of the catchment, there is a high possibility of increase in nutrients in water before Ngerengere River joins the lower Ruvu River which flows to Dar es Salaam.

Chromium distribution, as shown by Figure 18, shows the possibility of point sources of pollution in the catchment and their distribution along the river. High concentrations at Site 6 and 7 suggest that the major source could be industrial effluent. Decreasing concentrations from Site 7 to Site 9 suggest river self-purification.

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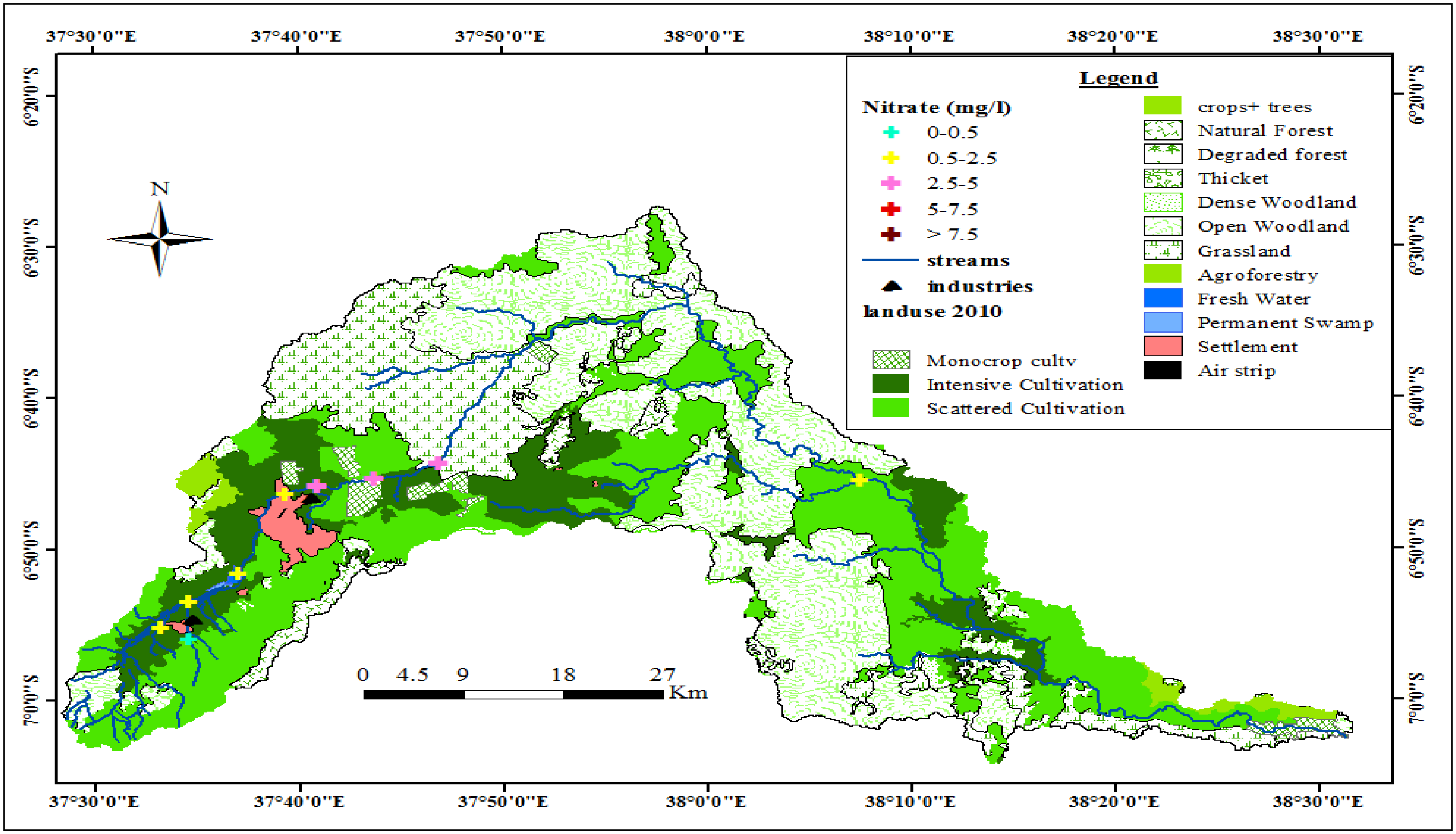

Figure 17: Ngerengere catchment landuse map showing Nitrate variations along the river

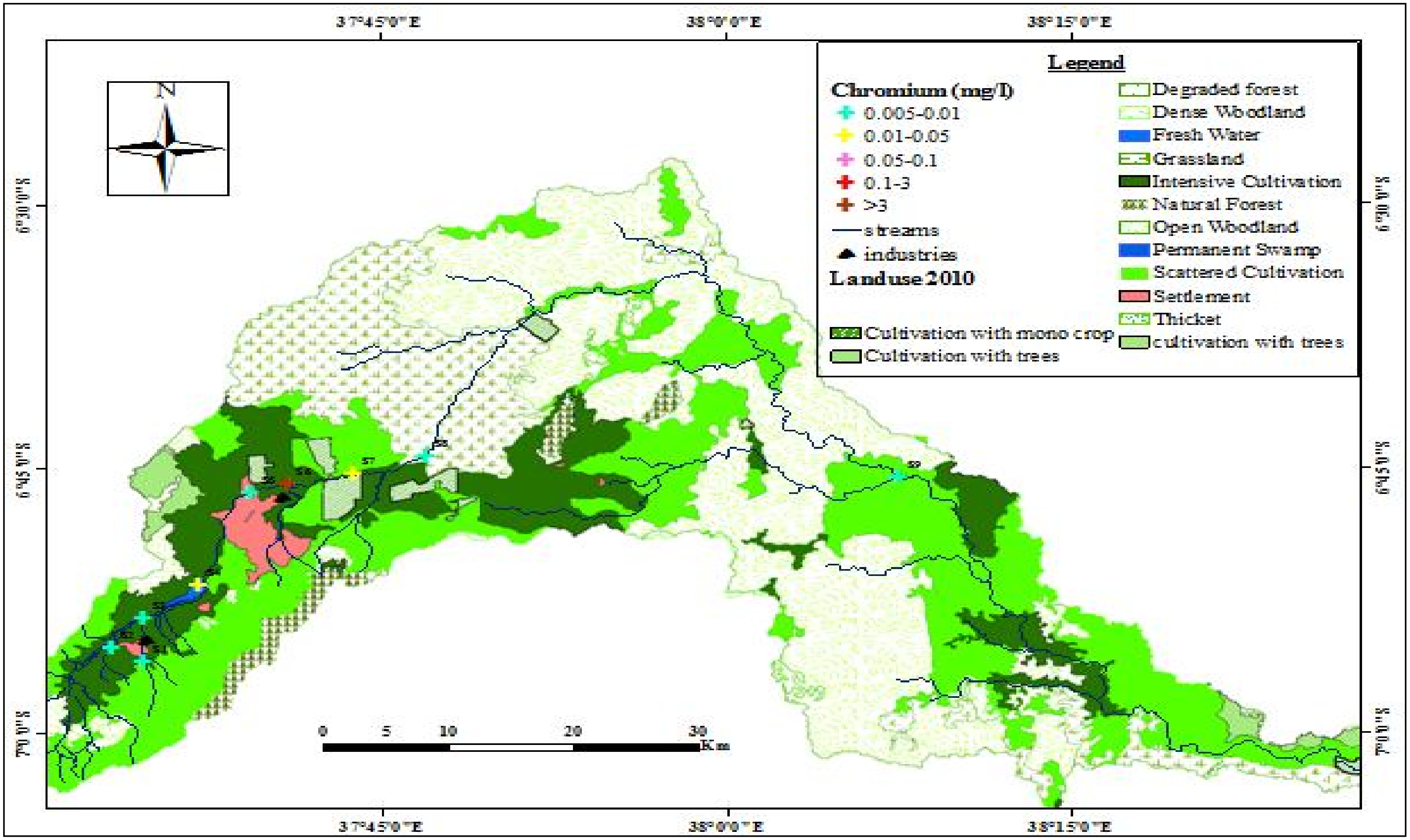

Figure 18: Ngerengere catchment landuse map showing Chromium variations along the river

5.3.3 Estimation of Pollution Sources along the River using Catchment Landuse Map.

Landuse activities very close to the water sources are known to highly contribute to water pollution as compared to the activities located far from it (Zampella and Procopia, 2009). This hypothesis was used to estimate the non-point sources of pollution contributing to pollution at each sampling site by using the buffer zone method. Baja *et al.* (2003) and Baja *et al.* (2002) highlighted the usefulness of using buffer zone in water quality projects to evaluate the potential risk of the non-point sources of pollution (landuse) to the quality of water bodies. This evaluation was done by creating buffer zones around each sampling site at 1000 m, 1500 m, 2000 m and 2500 m distance from the sampling point. The calculated percentage area of each landuse within the buffer zone represents their respective dominance. Figure 19 shows different buffer zones at different sites and the area covered by each landuse and Table. 16 shows a summary of the dominating landuse in percentage area at each sampling site along the river.

Apart from the fact that pollutants movement by surface runoff can be influenced by landuse, slope and soil type, it was estimated that erosion and surface runoff were highly influenced by landuse change, hence other factors were assumed to have negligible effects. Therefore, the same distance range from 1000 m to 2500 m was used to create buffer zones for all the sites in the catchment. The extreme buffer zone with a 2500 m radius was selected in order to include other landuse activities and evaluate their effects on river pollution as shown in Figure 20.

Results in Table 14 show that in the 1000 m buffer zone the dominant landuses are intensive agriculture at Sites 1, 2 and 3, followed by fresh water at Site 4. Since the four sites represent the upstream zone of the catchment, the overall results suggest dominance of intensive agricultural activities in the upstream zone. As confirmed by Burges (2001) that agricultural activities in the upstream zone are practised close to the river banks, the results suggest high erosion and pollution risks, particularly because this zone is located at the slopes of Uluguru Mountains which is another trigger for erosion.

At the 1500 m buffer, all the four sites in the upstream zone were dominated by both intensive and scattered cultivation. The mid-reach zone indicated domination of settlement and agriculture activities. Settlements at Sites 5 and 6 suggest point sources of pollution from domestic wastewater and urban runoff. The industrial area located at Site 6 contributes more to the pollution levels at that area compared to the agricultural activities as shown in the Tables 7, 8 and 9.

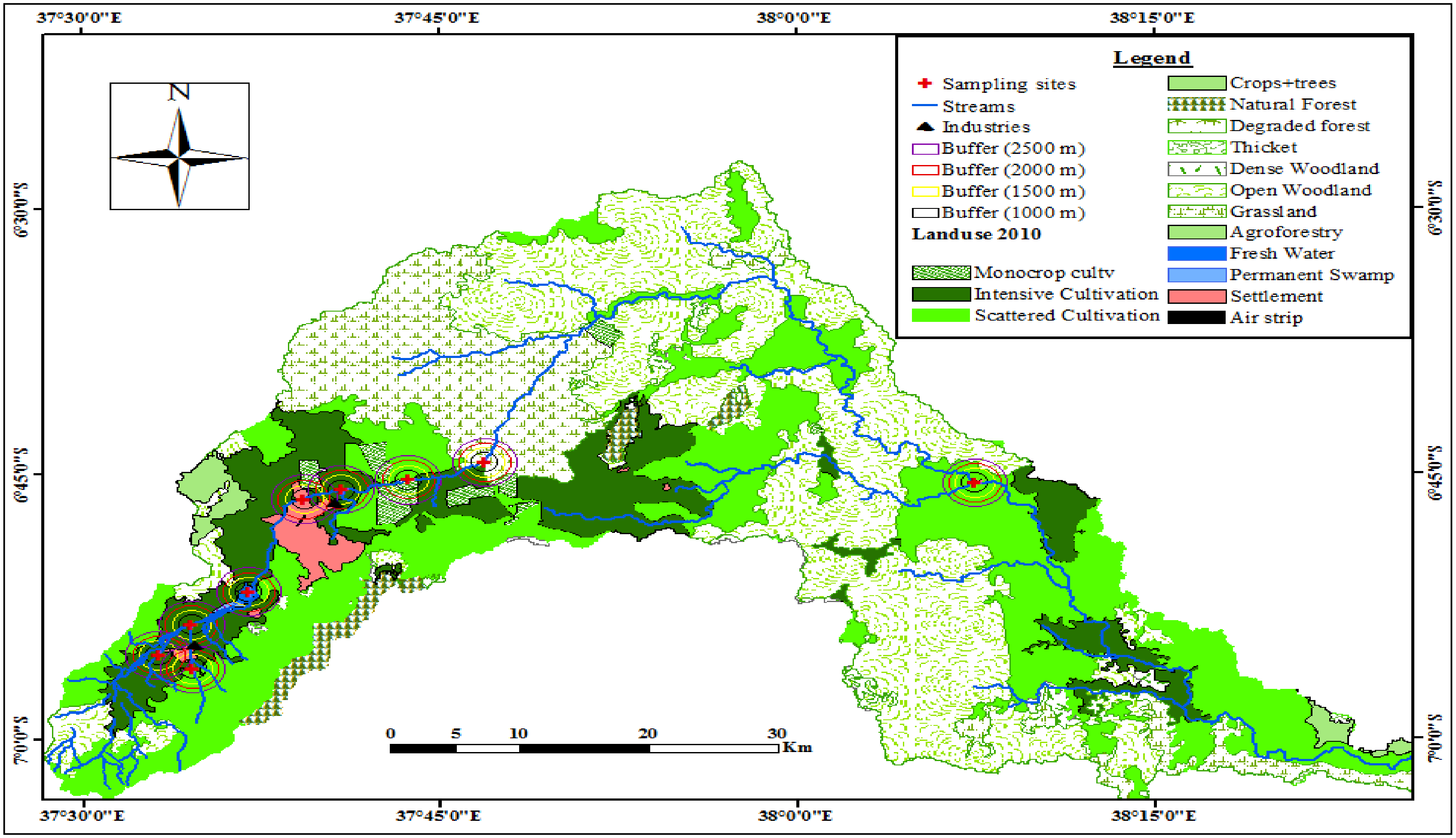

Figure 19: Ngerengere catchment landuse map showing four buffer zones (1000, 1500, 2000 and 2500 m)

Table 16: Summary of the Dominant Landuse in Percentage Area at each Zone along Ngerengere River

Site	**Buffer zone (m)**	**Dominant landuse practices**	**Landuse area (%)**	**Dominant Landuse/ zone**
Site 1	1000	Intensive Cultivation	54.5	**Intensive cultivation**
	1500	Scattered cultivation	45.6	
	2500	Scattered cultivation	47.4	
Site 2	1000	Intensive cultivation	96.4	
	1500	Intensive cultivation	92.4	
	2500	Intensive cultivation	76.2	
Site 3	1000	Intensive cultivation	100	
	1500	Intensive cultivation	100	
	2500	Intensive cultivation	97.6	
Site 4	1000	Fresh water	64.1	
	1500	Intensive cultivation	45.4	
	2500	Intensive cultivation	56.9	
Site 5	1000	Settlements	73.4	**Intensive and Monocrop cultivation**
	1500	Settlements	61.1	
	2500	Intensive cultivation	46.8	
Site 6	1000	Intensive cultivation	100	
	1500	Intensive cultivation	99.6	
	2500	Intensive cultivation	85.4	
Site 7	1000	Monocrop cultivation	52.5	
	1500	Monocrop cultivation	42.2	
	2500	Monocrop cultivation	40.8	
Site 8	1000	Grassland	89.4	**Scattered cultivation**
	1500	Grassland	86.2	
	2500	Grassland	73.1	
Site 9	1000	Scattered Cultivation	86.8	
	1500	Scattered Cultivation	94.1	
	2500	Scattered Cultivation	86.7	

The downstream zone (Sites 8 and 9) was highly dominated by scattered cultivation and settlements, respectively. This indicates less pollution contribution from the non-point sources e.g. agriculture, along the river. However, physico-chemical analysis indicated that Site 8 is highly polluted, which is most probably caused by the industrial effluent released at Site 6. Site 9 results indicated moderate water pollution because of the long distance between Sites 8 and 9 which suggests self-purification of the river

Considering the minimum distance between different sampling points, the 2500 m buffer resulted in overlapping in some areas e.g. Sites 1, 2 and 3 as shown in Figure 20. Treated separately, results for the 2500 m buffer zones showed a high percentage area of intensive cultivation for Sites 2, 3 and 4 and scattered cultivation for Site 1 indicating that the upstream zone can be described as the agricultural zone. According to MNRT (2003), Tanzania's Forestry law, a river non-utilization zone is 20 m to 50 m while the water law is more vigorous by indicating 200 m as non-utilization zone in order to establish sustainable water supply. Hence, the current situation does not only threaten the downstream users in terms of quality and quantity but also influences land degradation, which might be a potential threat in the future.

At a 2500 m radius, the dominating landuse at Sites 5 and 6 is intensive agriculture while monoculture cultivation dominates at Site 7 by 40.8%. Other activities such as settlements at Site 5 were no longer dominating activities but highly contributing to point source pollution to the river. Monocrop cultivation was observed to dominate at the mid-reach zone, which could also be a reason for high nutrient levels since monocrop cultivation is associated with the application of fertilizers and pesticides.

Site 8 and Site 9 did not show significant changes in terms of the type of landuse dominating in the area i.e. grassland and scattered cultivation, respectively; however the area covered by these landuses increased. A number of studies done by Zampella and Procopia (2009) and Baja (2003) highlighted that there is a relationship between landuse and water quality in a catchment and that changes in landuse influence either deterioration or improvement of water quality, depending on the type of landuse.

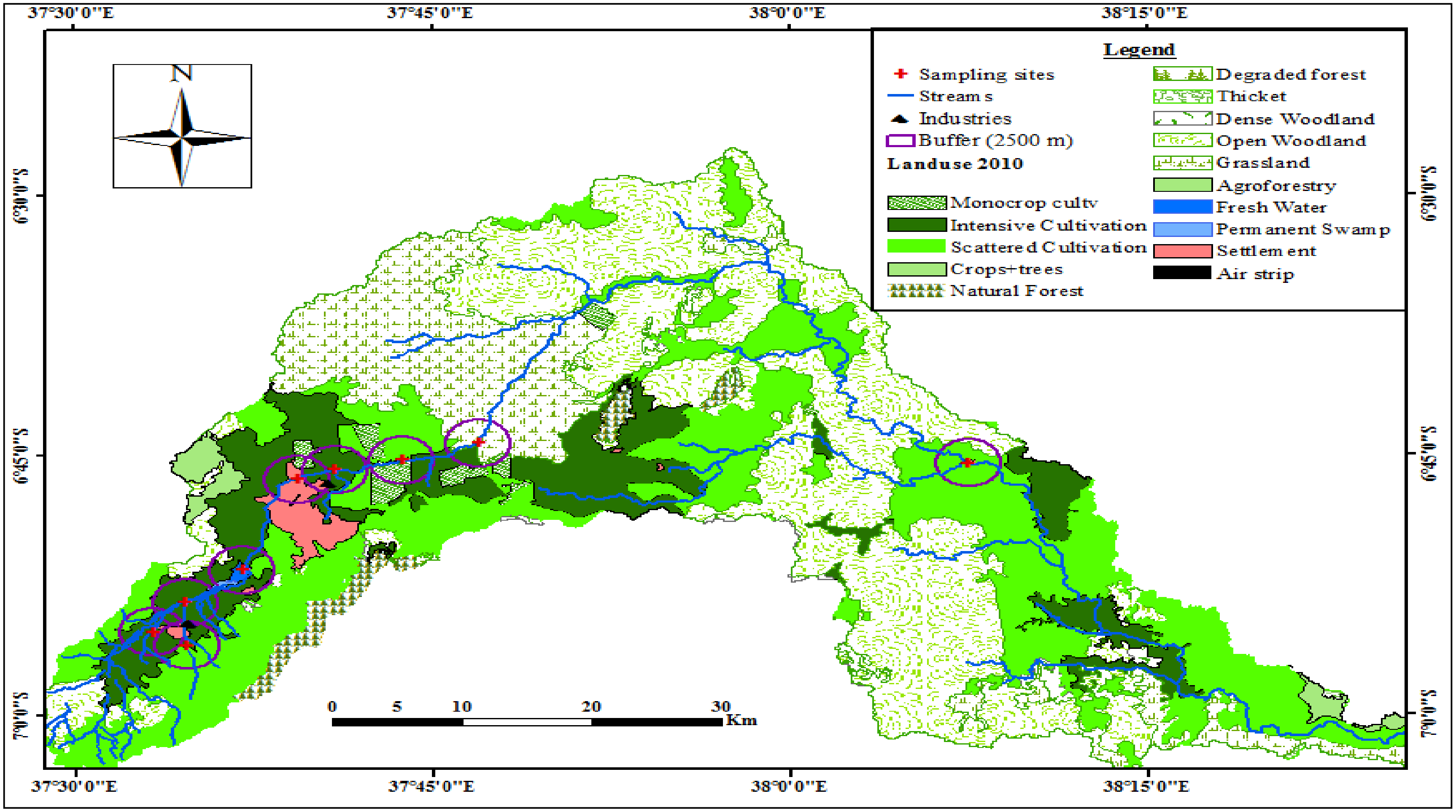

Figure 20: Ngerengere catchment landuse map showing the 2500 m buffer zone

CHAPTER SIX: SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

The study aimed at quantification of water quality status, determination of spatial distribution of pollution sources and their influence on river pollution. Specifically, the physico-chemical characteristics were quantified using physico-chemical assessment method and the type of landuse activities which influence water pollution were estimated using the Factor Analysis Method. The biological characteristics of the river were quantified using a bioassessment method. The physical and chemical characteristics database, together with a developed catchment landuse maps, were used to locate and estimate the most influencing landuses to the pollution at each site.

Physico-chemical analysis results indicated overall poor water quality and the measured parameters showed ranges of 20 - 5680 mgPt/l for colour, 22.8 - 27^{o}C for temperature, 3 - 1790 NTU for turbidity, 32 - 5930 mg/l for EC and 17- 2880 mg/l for TDS. Others were 5-700 mg/l for BOD, 9 - 1925 mg/l for COD, 0 - 5.6 mg/l for nitrate, 0.04 – 4 mg/l for total phosphate and 7 - 26 mg/l for sulphate. In terms of heavy metals, Cd had a range of 0 - 0.14 mg/l, Cr had 0 - 2.96 mg/l, Pb had 0 - 0.72 mg/l and Fe was 0 - 14.5 mg/l throughout the study period. Factor analysis results suggested that agriculture, urban and industrial activities influenced elevated pollution levels. Bioassessment results suggested poor water quality as shown by the low levels of SASS scores and taxa number with the ranges of 2 - 55 and 1 – 7, respectively, which resulted into low ASPT ranging from 2 - 11. High scores of pollution tolerant species in certain sites supported the fact that these sites have poor water quality. In estimating the sources of pollution in the catchment, the specific buffer zones of 1 km, 1.5 km, 2 km and 2.5 km around the sampling sites were overlayed on the landuse map. The results suggested dominance of river bank agriculture in the upstream zone, followed by the mid-reach and lastly the downstream zone. The dominant landuse activities at the extreme high buffer zone of 2.5 km were intensive agriculture for the upstream and mid-reach zones and settlements for the downstream zone.

6.2 Overall Discussion

The assessments done suggest poor water quality and poor river ecosystem health and also the study indicates that landuse types and activities carried out within the catchment influence the water quality status. The excessive concentrations of dissolved materials, turbidity and colour are related to both point and non-point sources of pollution in the catchment. For non-point sources, agriculture was found to be the major contributor of pollution while from the point sources of pollution industrial and domestic activities were identified to contribute to high concentrations. This was evidenced by high concentrations of most of the parameters measured from Sites 6 to 9 and the landuse activities around these areas.

In terms of chemical parameters, nitrogen concentrations in form of TKN and nitrate and phosphorous concentrations in form of ortho-phosphate and total phosphate showed that both agricultural runoff and industrial activities could be responsible for elevated concentrations of these chemicals in the Ngerengere River. This is supported by a number of studies which found out that fertilizers which are applied in agricultural fields are taken by surface runoff to rivers and thereby elevate nutrients levels in water. BOD and COD concentrations increased towards the mid-reach zone and read the maximum levels at Site 7 which indicates that the water contains high organic contents in this zone. The out of ordinary increase in concentrations of both BOD and COD at Site 7 showed the contribution of industrial activities to pollution levels in the river. It also highlights that the water has low dissolved oxygen and high turbidity concentrations which together give an indication of poor water quality. Elevated concentrations of Cr, Cd, Fe and Pb are related to urban and industrial activities, pointing to possible industrial waste water discharges enriched with these chemicals.

The low community composition, abundance and diversity of macro-invertebrates as shown through the values of SASS scores, taxa number and ASPT, support the physico-chemical results which indicate poor water quality. Areas that are dominated by urban and industrial activities had a high number of pollution tolerant families which confirms that these activities are among the major sources of pollution in the river. The identified dominant landuse activities suggest that agriculture is among the major non-point sources of river pollution at different locations along the river.

Consequently, such analyses have a great policy implication and might be useful to policy makers in regulating the sources of pollutants influencing water quality and protecting water courses from these contaminants within the Ngerengere River catchment and other catchments.

6.3 Conclusion

From the study, the following can be concluded;

1. The study results from physico-chemical analysis indicate high pollution levels in terms of concentration and weight, which can be contributed by the river bank cultivation and discharge of raw/ partially treated industrial effluent into Ngerengere River. Industrial

pollution concentrations decreased with change from dry to rainfall season while the agricultural pollution increased with the same change of season.

2. The biological assessment results show poor aquatic ecosystem health explained by the low diversity, richness and composition of the macro-invertebrates encompassed by domination of pollutant tolerant species at most of sampling sites along the river. The situation may be due to degraded habitats and release of raw toxic effluents to the river.
3. From the studied landuse map and pollution distribution in the catchment, agriculture was estimated to highly contribute to pollution in decreasing order from upstream, mid-reach to downstream zones. Meanwhile, the release of raw effluent from industries located at the mid-reach zone amplifies the effect in the downstream zone.

6.4 Recommendations

From the conclusions drawn, the following it can be recommends can be made;-

1. With the ongoing planning for development and implementation of IWRM plans at each basin in Tanzania, there is a need for the Wami/Ruvu Basin Office (WMBO) to invest in the development of an integrated water quality management system which encompasses physical, chemical and biological indicators of water quality and prioritises monitoring and mitigation according to the landuse distribution in the catchment.
2. Enforcement of the responsible national regulations which require all industries to pre-treat their wastewater to the required levels before release to water bodies by giving serious penalties and banning industrial operations to violators need to be implemented.
3. The river riparian zones should be buffered throughout the catchment and awareness meetings be conducted with the people living near the river on participatory environmental protection practices.

6.5 Recommendation for further studies

1. Modelling of the relationship between landuse activities and water quality in the catchment was not done due to limited information. Hence it is recommended that development of catchment water quality database and modelling of the landuse and water quality relationship to be conducted in order to facilitate monitoring.
2. Due to limited resources and time, assessment of other parameters such as mercury, pathogen, bacteria, oil products, phenols and Persistent Organic Pollutants, which are suspected to be present in the Ngerengere River, was not done, hence further studies looking at these parameters are recommended. Such studies will be important because, for

example, Mercury is among the major heavy metals released as by-product from textile, tannery and bullletbags industries and its excessive release in water is associated with toxic impacts to aquatic and terrestrial organisms.

3. For more reliable results on the temporal variations of both biotic and abiotic characteristics of water due to pollution, further studies which will take a longer time for collection of more data are recommended.
4. Assessment of the influence of altitude and slopes to the water pollution in Ngerengere River, particularly in the Mount Uluguru slopes, is recommended.
5. Assessment of the water quality status and biological integrity to the areas which were inaccessible during the study period is recommended in order to get more detailed information about the water quality status in the whole catchment.

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APPENDICES

Appendix 1: Table showing Measured Values against Relevant Water Quality Standards (mg/l)

	pH	**TDS**	**NO_3**	**PO_4**	**SO_4^{-2}**	**Cd**	**Cr**	**Pb**	**Fe**
Site 1	7.2	20.9	0.21	0.06	9.7	0	0	0	0.38
Site 2	7.1	26.8	2.02	0.66	11.9	0.007	0.08	0.09	2.62
Site 3	6.9	112.2	1.49	0.46	12.2	0.044	0.25	0.34	2.16
Site 4	7.7	80.58	1.24	0.12	10.1	0.054	0.94	0.19	1.04
Site 5	7.4	1738.8	0.73	0.52	11.7	0.058	0.06	0.023	6.28
Site 6	8.2	2718.0	3.0	1.7	22.1	0.1	2.6	0.2	1.9
Site 7	8.0	1801	3.32	2.00	14.2	0.038	1.44	0.08	2.62
Site 8	7.7	1021.7	3.18	2.13	9.3	0.013	0.27	0.03	3.97
Site 9	7.5	707.4	2.15	1.64	17.7	0.041	0.35	0.08	5.06
TZDWS (LL)	6.5	NAR	10	NAR	200	0.05	0.05	0.01	1
TZDWL (UL)	9.2	NAR	75	NAR	600	0.05	0.05	0.01	1
WHO (LL)	6.5	1000	50	NAR	250	0.03	0.05	0.01	1
WHO (UL)	9.5	1200	50	NAR	500	0.03	0.05	0.01	3
ANZECC (LL)	6.5	NAR	0.1	0.01	NAR	0.0002	0.01	0.001	1
ANZECC (UL)	9	NAR	0.75	0.1	NAR	0.002	0.01	0.005	1
DWAF (LL)	<0.5 rise	200	<0.5	<5	NAR	0.00015	0.007	0.0002	<10% rise
DWAF (UL)	<0.5 rise	1100	2.5	25	NAR	0.0004	0.007	0.0012	<10% rise

Note:

TZDWS- Tanzania Drinking Water Standards (2009)

WHO- WHO Drinking Water Standards (2008)

ANZECC- Australia and New Zealand Australian Guidelines for Fresh and Marine Water Quality-Aquatic Ecosystems (2000)

DWAF- South African Water Quality Guidelines -Aquatic Ecosystems (1996)

LL- Lower Limits

UL- Upper Limits

NA- Not Available

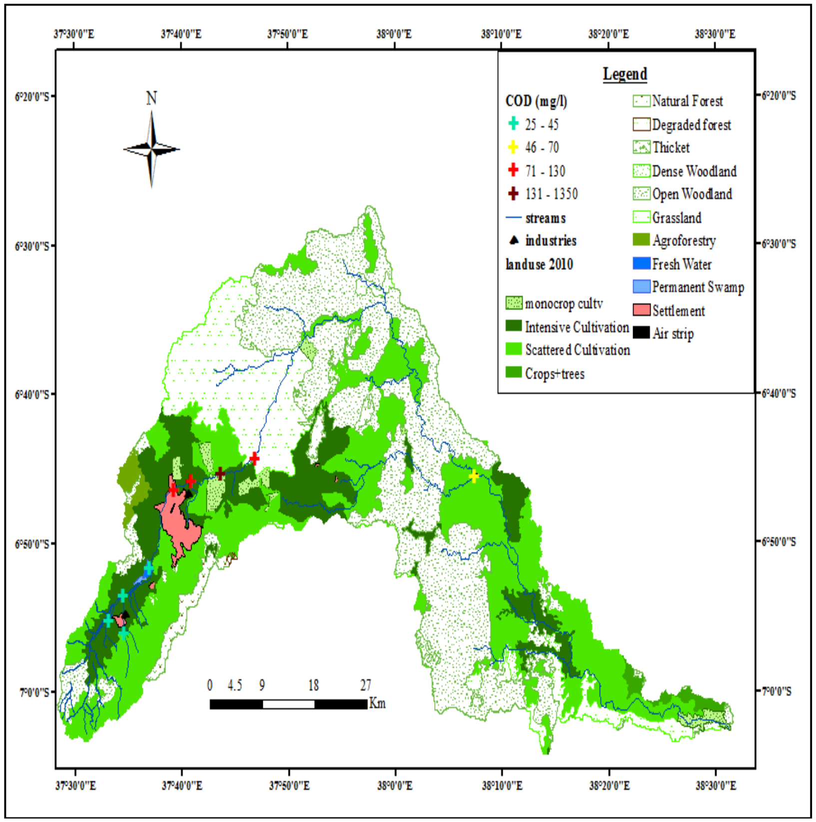
*- Amount change from the local and background values

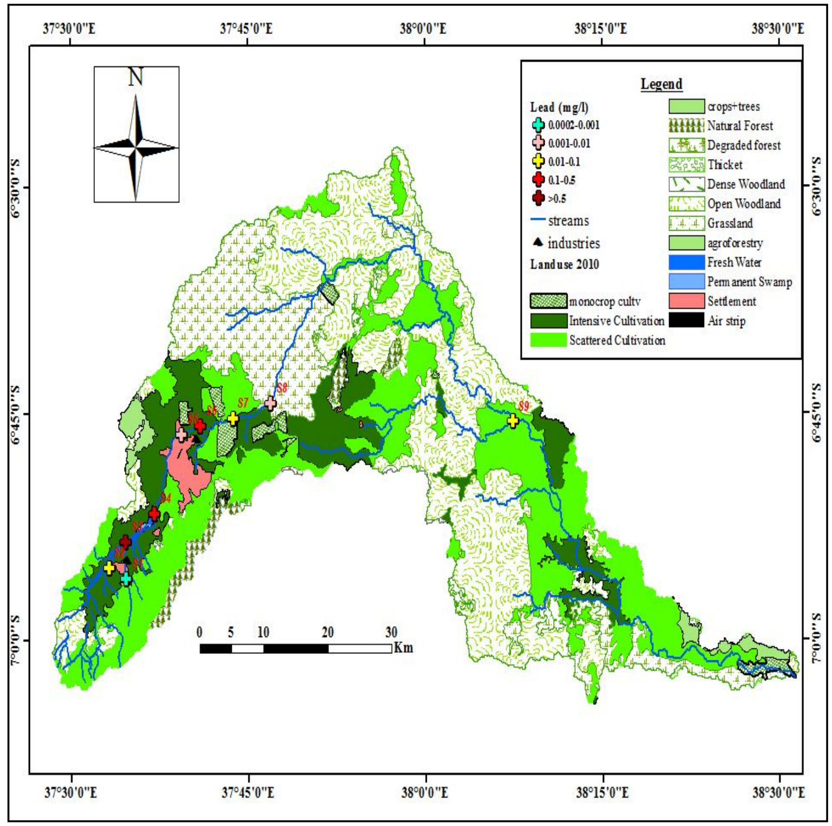
Appendix 2: SASS version 5 Score Sheet.

Date:	/ /				**Biotopes Sampled**	**Rating (1 -**	**Time**
RHP Site Code:	-	**Grid reference (dd mm ss.s) Lat:**	**S**		**Stones In Current (SIC)**		
Collector/Sampler:		**Long**	**E**		**Stones Out Of Current**		
River:		**Datum (WGS84/Cape):**			**Bedrock**		
Level 1 Ecoregion:		**Altitude (m):**		**m**	**Aquatic Veg**		
Quaternary Catchment:		**Zonation:**			**MargVeg In Current**		
	Temp		**Cond**		**MargVeg Out Of Current**		
Site Description:	**pH:**		**Clarity**		**Gravel**		
	DO		**Turbidity:**		**Sand**		
	Flow:		**Colour:**		**Mud**		
	Riparian				**Hand picking/Visual**		
	Instream						

Taxon		**S**	**Ve**	**GS**	**TO**	**Taxon**		**S**	**Veg**	**GSM**	**TOT**	**Taxon**		**S**	**Ve**	**GS**	**TOT**
PORIFERA (Sponges)	5					**HEMIPTERA (Bugs)**						**DIPTERA (Flies)**					
COELENTERATA (Cnidaria)	1					Belostomatidae* (Giant water bugs)	3					Athericidae	10				
TURBELLARIA (Flatworms)	3					Corixidae* (Water boatmen)	3					Blephariceridae (Mountain	15				
ANNELIDA						Gerridae* (Pond skaters/Water	5					Ceratopogonidae (Biting	5				
Oligochaeta (Earthworms)	1					Hydrometridae* (Water measurers)	6					Chironomidae (Midges)	2				
Hirudinea (Leeches)	3					Naucoridae* (Creeping water bugs)	7					Culicidae* (Mosquitoes)	1				
CRUSTACEA						Nepidae* (Water scorpions)	3					Dixidae* (Dixid midge)	10				
Amphipoda	13					Notonectidae* (Backswimmers)	3					Empididae (Dance flies)	6				
Potamonautidae* (Crabs)	3					Pleidae* (Pygmy backswimmers)	4					Ephydridae (Shore flies)	3				
Atyidae (Shrimps)	8					Veliidae/M...veliidae* (Ripple bugs)	5					Muscidae (House flies, Stable	1				
Palaemonidae (Prawns)	10					**MEGALOPTERA (Fishflies,**						Psychodidae (Moth flies)	1				
HYDRACARINA (Water mites)	8					Corydalidae (Fishflies & Dobsonflies)	8					Simuliidae (Blackflies)	5				
PLECOPTERA (Stoneflies)						Sialidae (Alderflies)	6					Syrphidae* (Rat tailed	1				
Notonemouridae	14					**TRICHOPTERA (Caddisflies)**						Tabanidae (Horse flies)	5				
Perlidae	12					Dipseudopsidae	10					Tipulidae (Crane flies)	5				
EPHEMEROPTERA (Mayflies)						Ecnomidae	8					**GASTROPODA (Snails)**					
Baetidae 1sp	4					Hydropsychidae 1 sp	4					Ancylidae (Limpets)	6				
Baetidae 2 sp	6					Hydropsychidae 2 sp	6					Bulininae*	3				
Baetidae > 2 sp	12					Hydropsychidae > 2 sp	12					Hydrobiidae*	3				
Caenidae (Squaregills/Cainfles)	6					Philopotamidae	10					Lymnaeidae* (Pond snails)	3				
Ephemeridae	15					Polycentropodidae	12					Physidae* (Pouch snails)	3				
Heptageniidae (Flatheaded mayflies)	13					Psychomyiidae/Xiphocentronidae	8					Planorbinae* (Orb snails)	3				
Leptophlebiidae (Prongills)	9					**Cassed caddis:**						Thiaridae* (=Melanidae)	3				
Oligoneuridae (Brushlegged mayflies)	15					Barbarochthonidae SWC	13					Viviparidae* ST	5				
Polymitarcyidae (Pale Burrowers)	10					Calamoceratidae ST	11					**PELECYPODA (Bivalves)**					
Prosopistomatidae (Water specs)	15					Glossosomatidae SWC	11					Corbiculidae	5				
Teloganodidae SWC	12					Hydroptilidae	6					Sphaeriidae (Pills clams)	3				
Tricorythidae (Stout Crawlers)	9					Hydrosalpingidae SWC	15					Unionidae (Perly mussels)	6				
ODONATA (Dragonflies &						Lepidostomatidae	10					**SASS Score**					
Calopterygidae ST,T	10					Leptoceridae	6					**No. of Taxa**					
Chlorocyphidae	10					Petrothrincidae SWC	11					**ASPT**					
Synlestidae (Chlorolestidae)(Sylphs)	8					Pisuliidae	10					**Other biota:**					
Coenagrionidae (Sprites and blues)	4					Sericostomatidae SWC	13										
Lestidae (Emerald Damselflies)	8					**COLEOPTERA (Beetles)**											
Platycnemidae (Brook Damselflies)	10					Dytiscidae/Noteridae* (Diving	5										
Protoneuridae	8					Elmidae/Dryopidae* (Riffle beetles)	8										
Aeshnidae (Hawkers & Emperors)	8					Gyrinidae* (Whirligig beetles)	5										
Corduliidae (Cruisers)	8					Haliplidae* (Crawling water beetles)	5										
Gomphidae (Clubtails)	6					Helodidae (Marsh beetles)	12										
Libellulidae (Darters)	4					Hydraenidae* (Minute moss beetles)	8					**Comments/Observations:**					
LEPIDOPTERA (Aquatic						Hydrophilidae* (Water scavenger	5										
Crambidae (=Pyralidae)	12					Limnichidae	10										
						Psephenidae (Water Pennies)	10										

Appendix 3: Ngerengere catchment landuse maps showing pollution distribution of COD and Lead





Appendix 4: Ngerengere catchment landuse maps showing pollution distribution of TKN and Turbidity