University of Zimbabwe

Impacts of agricultural activities on the diversity of aquatic macroinvertebrates as an indicator of ecosystem health along the Lower Komati River, Swaziland

By

Vuyisile Dlamini

A thesis submitted in partial fulfillment of the requirements for the Master of Science Degree in Integrated Water Resources Management (IWRM)

Department of Civil Engineering

Faculty of Engineering

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Supervisors

Dr A. Murwira (UZ-DGES)

Eng Z. Hoko (UZ-DCE)

Dr C. Magagula (UNISWA- DBS)

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DECLARATION

I, Vuyisile Dlamini declare that this thesis is my own work. To the best of my knowledge it has not been submitted before for any degree at any university.

Signed: ………………………………… Date: …………………………………

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To God, you have been faithful. Thank you for granting me the grace to succeed.

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DEDICATION

To my parents, for all the sacrifices they have made for us to have the best. My younger brother, Menzi, and beautiful nieces and nephews may you be inspired to reach greater heights.

ABSTRACT

At present, sugar cane production requires more land than any anthropogenic activity in the lower Komati catchment. Despite its threat to water quality, not much is known about the impact of the increased agricultural land for sugar cane production on ecosystem health within the sub-catchment. The main objective of this research was to assess macro-invertebrates diversity as an indicator of aquatic ecosystem health in the lower Komati River as well as determine whether this diversity is a significant function of physico-chemical water quality parameters. Richness, Shannon -Weiner and Simpson's diversity indices were used to analyse and determine aquatic macro-invertebrates diversity. Water samples were also collected and analysed for pH, dissolved oxygen, electrical conductivity, turbidity, nitrates, ammonia and ortho-phosphates according to standard methods. Results show that diversity along agricultural fields decreased in diversity but increased at certain lengths after sugar-cane fields. However, the difference was not significant ($p>0.05$) between sites. It was found that some water quality parameters such as turbidity, dissolved oxygen, and ortho-phosphates showed a significant difference ($p<0.05$) between sites upstream and adjacent to the sugar cane fields. However, no significant relationship ($p>0.05$) was found between diversity and water quality parameters except turbidity. Based on PCA analysis and relating the PCs to diversity of aquatic macro-invertebrates results showed that a combination of increased turbidity and dissolved oxygen coupled with a decrease in temperature significantly explained the diversity along the Lower Komati River. It can be concluded that agriculture for sugar-cane production seem to have an limited influence on aquatic macro-invertebrates diversity due to increased turbidity which was shown to be the primary water quality parameter influencing diversity in the Lower Komati River. The study therefore recommends that further studies be undertaken during the winter season when flow has reduced to determine concentration of nutrients and the response of the macro-invertebrates during the winter season when the flows have been reduced.

Key words; agricultural land use, ecosystem health, macro-invertebrates diversity, water quality

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LIST OF ABBREVIATIONS AND ACRONYMS

CV-Coefficient of Variation

DO -Dissolved Oxygen

EC - Electrical Conductivity

IWRM –Integrated Water Resources Management

KDDP -Komati Downstream Development Project

KOBWA -Komati Basin Water Authority

N-Nitrogen

P-Phosphorus

PCA-Principal Component Analysis

SD-WQO -Swaziland Water Quality Objectives

SWADE-Swaziland Water and Agricultural Development Enterprise

TDS -Total Dissolved Solids

CHAPTER 1: INTRODUCTION

1.1 Background

The consequences of anthropogenic water-use activities and land-use management are becoming increasingly detectable in the environment. Rivers always borrow a great part of their character from the terrestrial ecosystems of their catchments. According to Kleyhans (1996) rivers mirror the landscape, providing insights on their catchments. Thus, ecological water management is important to enhance, the ecological integrity of aquatic systems and their immediate surroundings. Such management requires a profound understanding of ecosystem functioning and how communities are associated to their environment (Mackay and Masundire, 2002). Ecological integrity is defined by Roux (1999) as the maintenance of all internal and external processes and attributes interacting with the environment in such a way that the biotic community corresponds to the natural state of the type-specific aquatic habitat.

Aquatic ecosystems have been continuously modified by agriculture, disposal of urban, mining, and industrial wastes, and engineering modifications to the environment and inappropriate resource management along catchments (Allan, 2004). However, there has been major difficulty in distinguishing the influence of natural characteristics, including naturally occurring disturbances from changes caused by man. Despite these uncertainties, aquatic communities have been used to assess the quality of rivers and many practical methods have been developed. According to Day (2000) meaningful ecological indicators must be found in order to develop a scientifically sound prediction tool of environmental conditions through a data-analytical approach using environmental variables to predict biological communities. Human activities on all spatial scales affect both water quantity and quality, and may have disproportionate effect on the entire catchment. Inappropriate use of the water resources has an immediate impact on the livelihoods of some of the world's most vulnerable human communities, as they rely on the water resources for basic needs. As a result, this has called for measures to monitor the response of the river ecosystem to come up with good management practices.

Water resources in Swaziland are continually threatened by agricultural and industrial activities (Dlamini and Hoko, 2005; Mthimkhulu et al., 2005; Mhlanga et al., 2006). Agricultural production in Swaziland has increased due to demand to produce more food for subsistence and also high yields for commercial agriculture because of declining prices in the case of sugar prices (Terry, 2007). Past studies by Mthimkhulu et al. (2005) and Mhlanga et al. (2006) on aquatic ecosystem health and water quality respectively along the Mbuluzi River in Swaziland have indicated that the quality of water and aquatic ecosystem is strongly related to the land use activities along the catchment which are mainly agriculture and sugar milling. The same trend was observed by Engelbrecht and Roux (2006) and Gustafsson and Johansson (2006) on water quality along the Komati River which is mainly used for irrigation, and domestic supply. The water quality was said to have declined mainly because of sediment deposition, vegetation removal and agricultural return flows which threaten biodiversity as well as pose hazards to human health downstream of the river. SWADE (2008) indicated that Electrical Conductivity

(EC) levels in the Lower Komati River have significantly increased with time and exceeded the guideline limit of 1800 µS/cm from 2005 to 2008 February.

Lately, the lower Komati sub-catchment has been transformed to an agricultural catchment to make use of the water downstream of the Maguga dam, a joint venture, between the Swaziland and South African Governments. The Komati catchment is part of a transboundary river basin shared by Mozambique, South Africa and Swaziland. A lot of development has taken place along this river especially agricultural development on the Swaziland side. The Government of Swaziland's primary objective for development is the alleviation of poverty, thus it established the Komati Downstream Development Project (KDDP), an agricultural initiative to significantly improve the living standards of the rural farming communities along the lower Komati River Basin through improved agricultural production (SWADE, undated). The project impacts on about 20,000 people (directly and indirectly) in an area encompassing 27,000 hectares. It was conceived with four development pillars; firstly, setting up of smallholder farmer associations in the form and composition decided by the members to best further the aims of the project. Secondly, to design and implement measures to mitigate the environmental and social impacts of the scheme. Thirdly, to develop irrigated smallholder farms on approximately 7400 hectares of land, 5500 hectares sugar cane and 1900 hectares fruit and vegetables along the Komati River with the majority of the smallholder farmers growing sugarcane. Lastly, to monitor the measures designed to mitigate the environmental and social impacts of the scheme.

In terms of the South African National Water Law of 1998, the Komati River can be regarded as an aquatic resource, for its diverse and ecological biota, with social, ecological and economical benefits to the local population and the environment. Rural communities living adjacent to the river are dependent on the river for irrigation, drinking and various resources (Engelbrecht and Roux, 2006). However, the Komati River System is under pressure due to increasing agriculture, excess water abstraction upstream for irrigation, and thus modifying the water quality (Dlamini et al., 2007). Engelbrecht and Roux (2006) further state that the Lower Komati River is in a very poor condition, this is mainly attributed to flow changes and reductions, degraded riparian zone, poor water quality, excessive impoundments by weirs causing deficiency in available riffle areas. The demands and modifications in the lower reaches of the Komati River have increased to an extent that the lower part of the river ceases to flow during seasons of low flow. Nepid Consultants CC (2007) observed that there has been poor compliance from January to March 2004/2005 and 2005/2006 hydrological years as environmental flows were less than required. The flows were between 5.19 m^3/s and 7.71 m^3/s compared to the recommended flow which is between 8.18 and 9.73 m^3/s.

The overall condition of the riparian zones along the Komati River within KDDP Development Area is relatively poor as it is being cleared for cultivation, used as access routes by livestock, humans and for harvesting (Eco-consult Services, 2006). As a result it has been indicated that alien plants have invaded the riparian zone and are a threat especially the more aggressive weeds *Chromolaena odorata, Melia azerdarach, Senna bicapsularis, Lantana camara* and *Solanum mauritianum as* they tend to use more water than indigenous plants. The complex interaction between physical, chemical and biological entities as well as the riparian zone is likely to change species diversity in the river. This observation is supported by Allan (2004) who argues that the chemistry of the water flowing through a watershed is also directly affected by key elements determined by the terrestrial and riparian activities, and contributes in shaping the distribution of aquatic species. Thus this has allowed the detection of the significance of various important environmental variables structuring aquatic communities which have been shown to reveal predictable changes due to natural variability as well as anthropogenic alterations.

1.2 Problem statement

Studies have demonstrated that the transformation of land use through agriculture can profoundly impact on the catchment hydrology, degrade water quality, by increasing sediment load and erosion (Allan, 2004; Kashaigili, 2008). Studies in southern Africa have illustrated the susceptibility of water quality to agricultural land-use along cultivated catchments (Bagalwa, 2004; Mhlanga et al., 2006). However, few studies have been done on the specific responses of aquatic invertebrate diversity to environmental factors in the Komati catchment (Engelbrecht and Roux, 2006). Whilst, according to Mthimkhulu et al. (2005) it is necessary to quantify and monitor ecological change to generate information for long-term trend monitoring of catchment condition. Therefore, this study will use macro-invertebrates diversity to provide indications of the temporal and spatial biological condition of the lower Komati River in response to the environmental factors driving the conditions of the in-stream channel.

1.3 Justification

According to Strayer et al. (2003), land use in catchments and other human-induced disturbances have shown significant impacts on river's biodiversity and water quality. This is mainly because of mass transport of principal plant nutrients and sediment loads to the rivers from the agricultural land which increases turbidity levels. Therefore, it is important to conduct the study because ecosystem health is of primary concern in the Komati River as it is regarded as an aquatic resource, for its diverse and ecological biota, to the local population and the environment (Republic of South Africa Government, 1998). Furthermore, water quality issues on the lower Komati River have an implication on the development treaty which calls for protection of existing water quality for downstream domestic and agricultural users. Understanding the connection between landscape changes, aquatic ecosystem health is also essential to bringing an ecological and sustainable influence to Integrated Water Resources Management (IWRM) policy making and land use decisions that affect local communities as well as identify the appropriate spatial scale of rehabilitation required, improving the health of degraded parts of the river.

1.4 Objectives

1.4.1 Main objective

The main objective of this research was to assess macro-invertebrates diversity as an indicator of aquatic ecosystem health in the lower Komati River as well as determine whether this diversity is a significant function of physico-chemical water quality parameters.

1.4.2 Specific objectives

a) To determine the diversity of aquatic invertebrates along a selected section of the lower Komati river from February to April 2009.

b) To investigate whether the diversity of aquatic invertebrates is a significant function of specific water physico-chemical parameters, along the selected section of the lower Komati River

c) To identify priority parameters influencing water quality and diversity and their implication to water resources management in the catchment.

CHAPTER 2: LITERATURE REVIEW: Environmental factors and aquatic ecosystem health

2.1 Introduction

Research has increasingly recognized that human actions at the landscape scale are a principal threat to the ecological integrity of river ecosystems, impacting habitat, water quality, and the biota via numerous and complex pathways (Allan, 2004). Thus, rivers are now studied from a landscape perspective because they are strongly influenced by their surroundings. Besides the use of water, the manner in which land is used and pollution from a variety of sources can have a major impact on water resources. According to Strayer et al. (2003), land-use disrupts the geomorphic processes that maintain the riverscape and its associated biota and frequently results in a habitat that is both degraded and less heterogeneous. In addition to its direct influences, land use interacts with other anthropogenic drivers that affect the health of the aquatic ecosystems.

Ecosystem health is defined by Roux (1999) as the capability of an ecosystem to support and maintain a balanced, integrated and adaptive community of organisms having a diversity of species, composition and functional organisation comparable to that of the natural habitats of the region. Ecosystem health which can also be called ecosystem integrity can be said to be the measure of the ability of a system in its natural state to support and carry out all its functions. Ecosystem health is a growing concern in Southern Africa, mainly because of agricultural development along catchments which has lead to high pollution levels. Thus, according to the Republic of South African' Water Act of 1998, the aquatic ecosystem integrity has an equal status as the requirements of basic human needs. This recognizes the benefits provided by these ecosystems as being essential to humans.

UNEP (2006) recognised that the major human-induced threats to aquatic ecosystems and biodiversity are unsustainable exploitation, habitat change, pollution, invasions by exotic species, and global climate change. Since species thrive optimally with particular combination of physical and chemical attributes, disruption in water quality will lead to greater changes in river's ability to offer goods and services. In Southern Africa studies on pollution levels in river systems have been traditionally studied through physical and chemical water analyses. Chemical analyses can give very accurate measures of the amounts of individual substances in a river, but they only consider the water passing at the moment of collection (Mackay and Masundire, 2002). However, there has been a developing interest in finding out about the relation of land use along catchments and the health of rivers of those systems (Mthimkhulu et al., 2005). This has shown a deviation from the past, where the management of river systems had been based primarily on chemical water quality monitoring.

2.2 Agricultural land-use

According to the African Water Development Report (2006), in the past 30 years a huge proportion of Africa's land is being converted to agricultural use and by year 1999, about 202 million hectares (ha), nearly a third of is arable, was already cultivated. Marginal land and important natural habitats are being cleared to expand agriculture and support the growing populations, thereafter, leaving the land increasingly prone to erosion. In Malawi 24% of total forested area has been converted to arable land, in the lowlands of Lesotho 60% of natural grasslands have been converted to cropland, but still there is shortage of arable land resulting in extension of cultivated lands to marginal lands (IWMI, 2006). However, Mazvimavi (2002) argue that more than two thirds of the people in southern Africa cultivate without adequate soil conservation measures hence, the soils are susceptible to erosion and it may be serious on steep slopes as well as near stream banks. Excessive erosion, from the cultivated land may impair the quality of the water and reduce the capacity of streams to store and convey water.

Moyo and Mtetwa (2002) recognised that in southern Africa the transformation of natural vegetation to arable land which results to bare land, leads to erosion with increased sediment loads entering watercourses. As soil structure breaks down, surface run-off will increase, and may contain pollutants. The eroded material tends to settle where water moves slowly; in dams and streams, thereby degrading ecosystems, and changing the quality as well as the flow dynamics of a river. Moreover, with increased sediments deposition in the water body, in-stream and riparian alien vegetation is likely to grow as a result and tend to utilize greater volumes of water than indigenous vegetation, potentially resulting in reduced yields (Mackay and Masundire, 2002).

Additionally, Moyo and Mtetwa (2002) found out that most countries in Southern Africa, agricultural land use in particular contributes to degradation of the hydrology of watersheds through sediment transportation, deposition to the system. Davies and Day (1998) confirm these findings by concluding that most rivers in South Africa are naturally silt-laden and recently quite a number of agricultural malpractices have increased the rivers' sedimentation. Deposition is increased mainly because agricultural land generates large quantities of return flow which could be silt laden due to the destruction in soil structure. In the lowveld of Swaziland, communal grazing land, small-scale subsistence agriculture, has been converted to large-scale commercial agriculture (Mhlanga et al., 2008). The increased area under agriculture is likely to weaken the soil structure; as the soil is continually weakened through cultivation making water resources vulnerable to sedimentation. Thus, there would be increased sediment load from run-off and soil erosion to water resources as the soil's structure is weakened during land preparation. According to Engelbrecht and Roux (2006) water quality in the lower Komati catchment has deteriorated and this can be associated with the irrigation development in the lower reaches of the catchment.

2.3 Agriculture as a pollutant to the aquatic ecosystem

Water returning after irrigation is usually poor in quality since it is usually loaded with compounds of, nitrogen (N) and pesticides and phosphorus (P) if water is laden with sediments from the eroded soil (Mhlanga et al., 2006). These nutrients are sometimes applied in excess concentration leaving a surplus, thus the surplus will be washed away with runoff and sediments. High concentrations of P may occur in runoff from agricultural fields with high soil surface P content. According to Fuhrman et al. (2005), through years of fertilizer and manure mismanagement practices, P may build up in the surface soil to levels far exceeding the requirements for plant production. Rainstorms and subsequent runoff events transport the nutrient to nearby waterways. Furthermore, Strayer et al. (2003) observed that ploughing decreases soil percolation capacity as well as water storage capacity, altering the soil potential for water retention as well as the speed and amount of water rendered to the river. Therefore, nutrients are easily eroded to water ways.

Mhlanga et al. (2006) in a study undertaken in Swaziland concur that agriculture is the most common source of non-point pollution from run-off including return flows from irrigated agriculture. They concluded that this is because the inputs are often derived from extensive areas of land and transported overland, or seepage underground to the receiving waters. Furthermore, Carpenter et al. (1998) in a study done in the USA discovered that agricultural pollutants and urban activities are responsible for 90% of (Nitrogen) N inputs to over half of 86 rivers studied and 90% (Phosphorus) P in a third of the rivers studied. It was noted that these inputs are continuous, intermittent and linked to a seasonal agricultural activity or rainfall.

Strayer et al. (2003) support the findings that agriculture contributes to nutrient fluxes, in a study carried out in the eastern United States on a catchment with different land uses, the research found a relationship between contaminants in the stream and specific land uses on the catchment. A strong relationship was between agricultural areas with nitrogen-fertilised land use in the catchment and the mean nitrate concentration during high flow conditions, implicating fertiliser residues as the source of nitrate above plant requirements in sugar cane and bananas. Elevated concentrations of dissolved inorganic phosphorus were also related to fertilizer application in intensive cropping and to locally specific soil characteristics.

Carpenter et al. (1998) observed that the flux rates of nutrients to water from fertilizer and manure are influenced by rate, season, chemical form, method of nutrient application, amount and timing of rainfall after application and vegetative cover. Thus, N and P fluxes increase in surface water with application of on-farm fertilizers. Carpenter et al. (1998) further indicated that fertiliser losses are <5 % of that applied and are likely to be higher if it rains after application and sometimes they can be up to 20% and these exclude infiltration and leaching of N to groundwater. These influxes are a major concern in most ecological systems. Gustafsson and Johansson (2006) argue that N which is exported to aquatic ecosystems as a percentage of fertilizer inputs ranges from 10-40% for loam to clay to 25-80% sandy soils. The influx of these inputs to the ecosystem may interfere with the ecosystem's functioning.

According to Chapman (1996) the most obvious detrimental effect of nutrients to the ecosystem are the increased growth of algae and aquatic weed due to nutrients loading. Mackay and Masundire (2002) noted that most rivers in Southern Africa have been loaded with high phosphorus (P) and nitrogen (N) levels which have resulted in eutrophication. Eutrophication results to oxygen shortage due to the high production levels of nutrients, increased phytoplankton and epiphyte growth (Holeck et al., 2008). Thus, light penetration to the benthic zone will be reduced limiting photosynthesis; in that case O_2 levels will be reduced resulting in biodiversity loss as well. In freshwater like rivers, streams, and lakes, blooms of cyanobacteria are a prominent sign of eutrophication, which results in oxygen reduction. Over the last few years total phosphorus levels in the Hartbees dam, South Africa in the Crocodile River increased from 0.2 to 2.0 mg/l of which 60 % is immediately accessible to aquatic plants (Davies and Day, 1998). The increase was said to be from the surrounding agricultural land and it resulted in severe eutrophication levels with development of algal blooms dominating the dam, becoming toxic and destroying species downstream of the dam due to less oxygen levels.

Stewart et al. (2001) established a clear relationship between intensive agricultural activities and pollutants from land use, and it was found to have implications on the community structure of freshwater ecosystems which were said to be potentially severe. The study suggested that the concentrations of nutrients in fresh waters in many catchments is most commonly proportional to the area of land under agriculture as elevated nutrient inputs from agricultural sources contribute to water quality change. The lines of evidence to support this included primary factors affecting in-stream ecosystem health such as riparian vegetation condition, aquatic and riparian weed prevalence, vegetation removal and habitat loss. These factors were shown to be more important in reducing in-stream ecosystem health than water quality.

Thus, it can be said that streams draining agricultural lands are likely to exhibit characteristics of inputs from the fields and nutrient fluxes from agriculture as major sources of pollution in rivers thus affecting the aquatic ecosystem. These rivers in turn will support fewer species of sensitive insect and fish taxa than streams draining natural cover catchments as the nutrients from fertilizers and organic material have been shown to lead to oxygen depletion, enhanced weed growth and increased turbidity.

2.4 Ecological indicators used in ecosystem health

MacDonald and Niem (2004) stated that ecological indicators are mainly used to assess the condition of the ecosystem health, as early-warning signals of ecological problems, and as barometers for trends in ecological resources. It has been recognised that, if chemical analyses were paired with the ecological indicators they can show the state of the water over a long period of time. Different riverine organisms have been used as ecological indicators in studies on ecosystem health ranging from fish assemblages, macro-invertebrates, diatoms, protozoans, and zooplankton (Gratwicke et al., 2003; Smith et al., 2006; Holeck et al., 2008;). Day (2000) argues that riverine organisms are preferred mainly because they are usually confined to those parts of the river where physical and chemical conditions are suitable.

Fish received general attention due to the intolerance of certain species to particular environmental conditions (Kleynhans (1999). Zooplankton abundance and changes in community composition are also reflective of the overall conditions in the water as evidenced by nutrient levels (Holeck, 2008). However, riverine invertebrates are particularly the mostly preferred biotic indicators, than other indicators. According to Day (2000) riverine macro-invertebrates are usually present in large numbers in most streams, fairly biodiverse, have relatively short lifespans, and differ in their tolerances to pollutants and other aspects of water quality. Moreover, they are suited for river quality assessment since a relatively large amount of data exists, their identification is relatively simple.

Macro-invertebrates besides being river health indicators can also help in water purification, an ecological process of considerable economic value, burrowing invertebrates aerate sediments to release nutrients (Flautt, 2007). So, their composition and abundance provide a reliable indication of the overall ecological state of that water resource. On the other hand, Gyedu-Ababio and van Wyk (2004) argued that macro-invertebrates faunal assemblages at any site are not only dependent on the water quality at the time of sampling but also on habitat change and seasonal variability. Habitat disturbances alter species composition and abundance, they can predict if change is from habitat, water quality or seasonal variability. Thus, Kleynhans (1996) suggested that it is important to evaluate habitat integrity to monitor any changes which might affect the invertebrates' distribution. This is easily recognised on species with more specific habitat preferences and which are more susceptible to certain types of disturbance.

2.4.1 Aquatic macro-invertebrates diversity as an ecosystem health indicator

Several recent studies have demonstrated that a functional approach to ecosystem health indication is analysing biota traits indicating species ecological functions and diversity as they can provide information about the quality, amount of water available in the habitat and the integrity of the ecosystem as a whole (Day, 2000; Brainwood et al., 2004; Smith et al., 2006). It has been recognised that macro-invertebrates decrease in diversity as ecosystem health deteriorates. Vinson et al. (2008) in their study on the response of aquatic macro-invertebrates to oil spillages noted that diversity of aquatic macro-invertebrates was low in sites with severe oil deposits, but increased within a few metres of these sites. Taxonomic richness and diversity declined with increasing oil levels, suggesting that the oil pollutant limited the occurrence of aquatic macro-invertebrates assemblages.

According to Brainwood (2004) macro-invertebrates' diversity and richness have been noted to respond more directly to larger scale and localised watershed influences. However, not all organisms are equally sensitive to disturbance, it is equally important to identify species that are restricted to a narrow range of conditions as they may be good indicators of change. A variety of macro-invertebrates require specific habitats, conditions and they also respond differently to in-stream and land-scape perturbation. In a study on lake restoration Flautt (2007) noted that the main focus should be particularly on *Ephemeroptera* (E), *Tricoptera* (T), and *Plecoptera* (P) orders because of their sensitivity to stream conditions and viability to act as stream health indicators. Comparing pre- and post-restoration data sets, they revealed that these sensitive macro-invertebrates increased substantially in the months after the restoration project had been completed. It was concluded that the population ratio of the sensitive macro-invertebrate species to tolerant species indicated that the lake was recovering.

Moreover, MacDonald and Niemi (2004) noted that resident species' diversity can also be used as indicators of change in ecosystem health as they can reflect an early decline of a habitat. In Swaziland, a survey was carried out along the Lusutfu River on the response of macro-invertebrates on an agricultural catchment; *Perlidae* and *Heptagenidae* were identified as resident species (Eco-Consult Services, 2006). It was observed that, the water quality of the river deteriorated, with decrease in these sensitive resident species due to the sugarcane plantations. Therefore, species' diversity was used to set assessment points for the river's health status and water quality monitoring. Smith et al. (2006) concur that resident species' diversity can be used as ecosystem and river health indicators; in their study the adult *Odonata* which was a resident taxa and occupied a spectrum of aquatic habitats was used successfully to assess the river's health. The results revealed that their diversity scores decreased along environmental gradients showing a similar trend to other macro-invertebrates used earlier on. Thus, these vagile insects reflected the immediate structure of the habitat, as well as the general condition of the river.

On another study by Flautt (2007) it was concluded that early signs of degradation were shown by the loss of intolerant and long-lived taxa. Sensitivity scores of benthic macroinvertebrates were used as early indicators of whether or not rivers and their canopies were changing in quality. Degraded streams were shown by an overall decrease in taxa richness. Heavily affected streams were dominated by a few, highly-tolerant taxa. So, overall the use of macro-invertebrates' diversity serves as a sign for any decline in ecosystem health. The disappearance of resident species and sensitive species has been shown as one of the common indicators. However, the presence of tolerant species can not be overlooked since they also indicate some form of pollution in the system. When the ecosystem improves it is likely that the disappeared species will appear again and diversity improves.

2.5 Physico-chemical water quality parameters affecting ecosystem health

According to Chapman (1996), the ecological valence of species is restricted by specific physical and chemical water attributes requirements which vary throughout the species' life cycle. In any case, a significant relationship has been established between stream water quality and land use. These parameters may also indicate some contamination from the landscape, and a variation in natural conditions of the area such as; geology, climate and morphology. Davies and Day (1998) suggest that the following parameters are usually measured in biological assessments: temperature, turbidity, conductivity, pH, dissolved oxygen, and nutrients (nitrogen and phosphorus) as well as the velocity and discharge of the river. Nutrients can also be important in cases where there are possibilities of eutrophication in that river and the types of ecosystems within a hydrosystem can be localized and harbor a quite unique community reacting to the water quality changes.

2.5.1 Temperature

Temperature has an influence on a number of aquatic variables. Chapman (1996) stated that increased temperature may result in decrease of oxygen solubility, since water bodies undergo temperature variations with normal climate changes. Additionally, aquatic organisms from microbes to nekton are dependent on certain temperature ranges for their optimal health. Davies and Day (1998) observed that optimal temperatures for most macro-invertebrates depend on the species: some survive best in colder water, whereas others prefer warmer water. Ultimately, there are two kinds of limiting temperatures; the maximum temperature for short exposures and a weekly average temperature that varies according to the time of year and the life cycle stage of the species (DWAF,1996). So, organisms use these changes as cues for activities such as migration, emergence and spawning. This is mainly because macro-invertebrates are sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside this optimal range for a prolonged period of time, organisms may get stressed die.

Flautt (2007) in a study on the Creek lake concluded that high water temperatures can limit the diversity of aquatic species present as well as impact dissolved oxygen saturations as it was discovered that thermally stressed tributaries with increasing trend in summer temperatures become a primary water quality concern as some species disappeared. Water temperatures consistently above 20°C and as high as 26°C rendered some species extinct. In the lake, at one instance, the water temperatures were reported to be as high as 28°C, more species disappeared, and this was because the temperatures were approaching the upper threshold for many warm water species.

2.5.2 Turbidity

Chapman (1996) points out that turbidity in water sources is usually due to sediment particles from the landscape suspended in the water column. It is brought from soils in the watershed, and depends on rainfall which transports the sediment from the landscape to the waterbody. In fact, rainfall and turbidity are correlated, in a study by Walters et al. (2006), long-term water quality fluctuation showed a decrease in turbidity with reduction of runoff rate. This was accompanied by an increase and decrease of forest and agricultural fields, respectively. The forest cover decreased runoff through increased percolation. From the correlation, it was inferred that turbidity was derived from soils due to rainfall.

Turbidity in water bodies tends to determine the depth to which light is transmitted and hence primary production and predation (Davies and Day, 1998). It results from the scattering and absorption of light by particles. Turbidity varies with season, biological activities as well as surface runoff carrying soil particles. This in turn controls the amount of primary productivity by controlling rate of photosynthesis hence plays an important role in structuring the freshwater communities. As the suspended material settle out they may smother and abrade riverine plants and animals, smothering the firm substratum for them to cling, therefore blanket their food (Chapman, 1996). Thus aquatic ecosystems subject to excessive turbidity may be dominated by few species that are best able to cope with these alterations in the habitat.

2.5.3 Dissolved Oxygen

According to the EPA-AU (2006) dissolved oxygen (DO) is important to aquatic life especially for the organisms which help in the river's self purification process. DO vary seasonally/daily in relation to temperature, salinity, turbulence and photosynthetic activity. So, determining DO is important in biological assessment since it influences biological and chemical processes, and it is vital for aquatic life. Davies and Day (1998) argue that organic pollution can impact on DO, less DO can indicate the presence of organic matter pollution and most of the time sensitive species may die. Moreover, when oxygen levels decrease, sensitive fish and other aquatic organisms will move out of the area or die.

2.5.4 pH

The pH of water is a measure of the concentration of hydrogen ions (Kaiff, 2002). It can be determined or affected by the geology of an area and present biotic activities. The largest varieties of aquatic animals prefer a range of 6.5-8.0; pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction (Kaiff, 2002). Ultimately, many chemical and biological reactions are controlled by pH in water. A low level of pH which is acidic makes toxic elements and compounds to become mobile and ready for uptake by aquatic plants and animals. So, the level of pH in a stream can influence the pattern of species diversity.

Streams with low pH levels support less diversity of species (Vinson et al., 2008; Raj and Azeez, 2009). However, DWAF (1996) argues that high concentrations of dissolved oxygen may decrease the effects; this is common particularly if there are alkaline conditions as a result of intense photosynthetic activity of aquatic plants, which is normally accompanied by high levels of dissolved oxygen. Most rivers have a buffering capacity which affects the rate of change of pH in aquatic systems but in poorly buffered waters, pH can change rapidly, which in turn may have severe effects on the aquatic biota (DWAF, 1996).

2.5.5 Nutrients

Phosphorus (P) and nitrogen(N) are common nutrients and are associated with inorganic and mineral constituent of sediments in a water body which can be mobilized by bacteria, and released to the water column (Carpenter et al., 1998). They are rarely found in high concentration in surface waters because they are actively taken by plants. Generally high phosphorus concentrations are seen in areas that drain highly intensive agricultural lands situated on till or clay plains. Walters et al. (2006) in their study discovered that high nutrient and sediment levels were primarily the result of runoff and erosion. Most P and 50% N are lost in suspended particles and P is easily eroded and is the most reactive in freshwaters. Agriculture contributes to the increase of these nutrients, as most fertilizers contain these nutrient compounds. During rainfall events, phosphorus levels may be elevated by runoff from the agricultural land, and by re-suspension and flushing of deposited material from the river bed to the water column. Several chemical bonding processes regulate the amount of inorganic phosphorus which is bonded usually to organic polyphenols and adsorbed onto suspended particulate material (Pellaud, 2006). Adsorbed phosphorus may be released from the sediments under conditions of high flow and under anoxic conditions from both sediments and water.

Nonetheless, according to Raj and Azeez (2009), pH can determine the form of phosphorus in natural surface water and the equilibrium of different forms. Of these, orthophosphate species are the only forms of soluble inorganic phosphorus directly utilizable by aquatic biota. The presence of high levels in aquatic environments may indicate pollution which may result in eutrophication. However, occasional increases in the inorganic phosphorus concentration above target water quality range is less important than continuously high concentrations. Excess amounts of these nutrients, especially phosphate, can cause extensive algae growth resulting in eutrophication.

Ammonia is another common pollutant and is one of the nutrients contributing to eutrophication. Commercial fertilizers contain highly soluble ammonia and ammonium salts. Following the application of fertilizer, if the concentration of such compounds exceeds the immediate requirements of the plant, irrigation waters can transport these nitrogen compounds into aquatic systems and some may be adsorbed onto suspended, bed sediments and colloidal particles (DWAF, 1996). Since water temperature and pH are the most significant factors that affect the proportion and toxicity of un-ionized ammonia in aquatic ecosystems as an increase in either results in an increase in un-ionized ammonia in solution, and hence an increase in toxicity to aquatic organisms. This is supported by Davies and Day (1998) who indicated that excessive ammonium gas can alter the structure and functioning of biotic communities as oxygen levels will be reduced for organism's uptake. As water quality changes and becomes poor only pollution tolerant species will remain.

2.5.6 Velocity and Flow rate

According to Chapman (1996) knowledge of water velocity enables the prediction of the time of arrival downstream of a contaminant, flow rate of a water body on the other hand can affect its ability to assimilate and transport pollutants. Knowledge of water velocity enables the prediction of the time of arrival downstream, of a contaminant accidentally discharged upstream (Kaiff, 2002).Water velocity can vary within a day, as well as from day to day and season to season, depending on hydrometeorological influences and the nature of the catchment area. In addition, Smith et al. (2006) argue that flow regime is a major factor in the mobility, availability and spatial distribution of contaminants within a river. During periods of low flow, stream bed sediments act as a sink for phosphorus. If the particulate matter settles and there is biotic uptake of phosphorus, these can result in phosphorus removal from the water column to the sediments. In places where the flow is low and water is shallow, excess nutrients can encourage the growth of algae and aquatic vegetation. It is important that these are noted at sampling, because they have effects on the biota movements since they support organisms and determine the structure of the stream bed.

From the literature, it can be seen that changes in land use for agricultural production is an important driver of water and soil pollution as agriculture releases huge quantities of phosphorus, nitrogen, and sediments to streams affecting aquatic ecosystems. Thus, there is strengthened evidence of the causal relationship between water quality and ecosystem health as water quality parameters are likely to change affecting the presence of species as there is increased sedimentation, turbidity, and euthrophication which reduce dissolved oxygen and raise water temperatures affecting species' presence. The integrity of aquatic ecosystems has been shown to be dependent on the availability and the quality surface water resources, as well as all activities in the catchment. Thus areas adjacent to agricultural lands are likely to have high turbidity, nutrients, conductivity, low pH, with reduced flow rate because of sedimentation.

2.7 An IWRM approach to ecosystem health studies

Some governments and international development and conservation organizations use the Integrated River Basin Management (IRBM) approach for water management thus; biodiversity habitat and ecosystem functions must become an integral part of all sound water resource management programmes. (IWMI, 2006). This approach is urgently required for the sustainable use of aquatic ecosystems. The IRBM approach is similar to Integrated Water Resources Management (IWRM) and considers the river or lake, basin/aquifer as an ecologically defined management unit (UNEP, 2006). Yet, still such ecosystems typically remain poorly integrated within land and water resources management systems plans. Integrated River Basin Management (IRBM) therefore needs to be adequately applied at variety of scales depending upon the size of the river basin. This is because a healthy and resilient aquatic and terrestrial ecosystem provides a range of services to people, and secure food and livelihoods in most Africa countries. However, agriculture the most prevalent economic activity is seen as a major driver of degradation, reducing the capacity of the ecosystems to deliver services to people (IWIM, 2006). So, an IWRM approach is necessary as it shows an improved recognition of the economic value of ecosystem services and their contribution to land and water productivity, hence, food and livelihoods security.

CHAPTER 3: DESCRIPTION OF STUDY AREA

3.1 Location

The study area lies along the lower Komati River Basin. It is part of a 25,000 ha area extending on both sides of the Komati river from near Madlangempisi in the south-west to the border with South Africa near Mananga in the north-east of Swaziland. More specifically, it stretches from the eastern end of Nyonyane Sisa Ranch to Mananga Border Gate, where the Komati River enters South Africa. It covers Sihhoye, Mpofu, Nyakatfo, Sidwashini, and Nkambeni hinter land. Figure 1 shows the study area together with main rivers north of Swaziland.

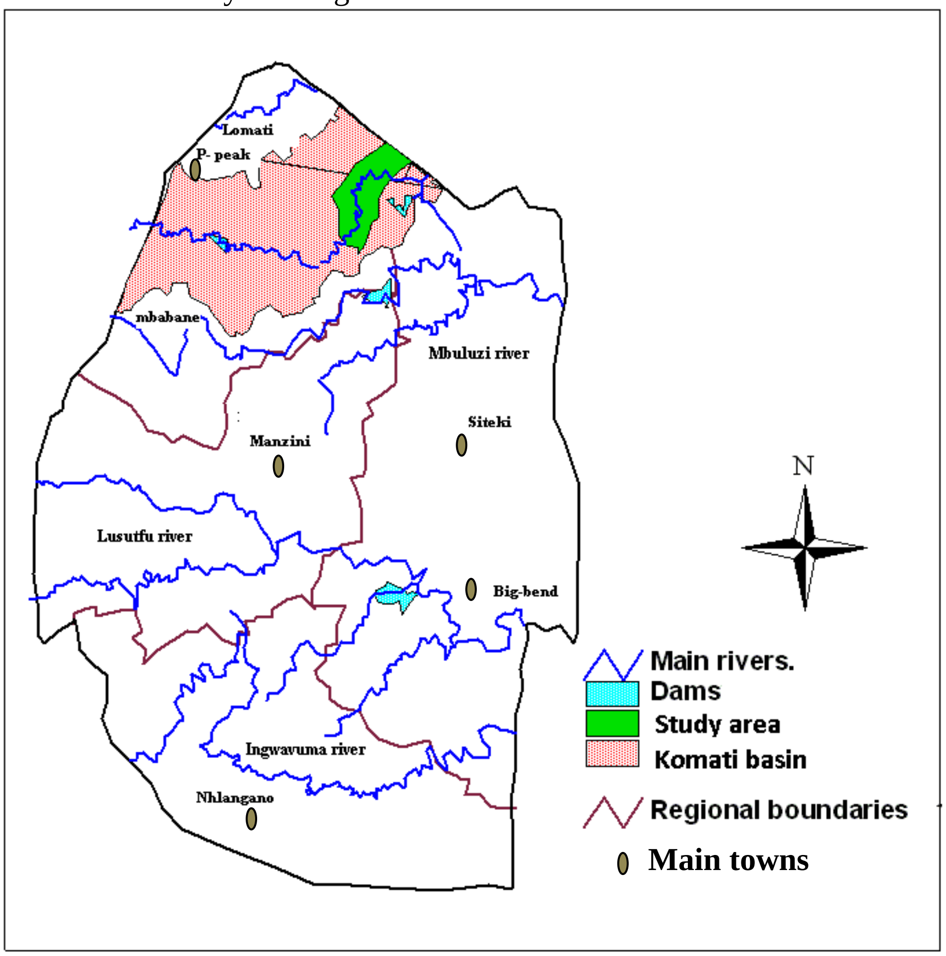


Figure 3.1 Map showing location of study area in Swaziland

3.2 Climate

The study area is under a sub-tropical and semi-arid climate. The mean annual rainfall is about 780mm with large inter-seasonal variations (300mm to 1200mm) (Appendix A ,Table 7.1). The summer rains are between October and March and the cool dry winter period ranges from May to August. Annual evaporation is about 2,100mm with monthly averages of 6-8mm per day in the summer months. Irrigation is thus necessary in all years with net applications of between 500mm and 1200mm needed for sugarcane. Summer maximum temperatures are around 34.8^{o}C and winter minimums are about 10^{o} C, with no frost.

3.3 Topography and Soils

The area consists of hills, foot slopes and undulating plains with altitude ranging from 300 to 600m. The geology is medium to coarse-grained granite with dolerite intrusions and alluvial deposits locally. The granite-derived soils of the project area vary from shallow sandy loams to deep sandy soils with rocky outcrops. The land changes from flat to undulating alluvial terraces to sloping hills as it moves away from the Komati River. The soils have been divided into four main groups by their geology and parent material namely – sandy and loam soils over sandy-clay loams; very well drained, deep medium-coarse sands; shallow, well drained sandy and clay loam soils and moderate-poorly drained soils and miscellaneous soils along the foot slopes and depressions amongst hills and outcrops. Soils of higher quality are used for growing sugarcane while soils of lesser quality will be used to grow other crops like banana and also for grazing.

3.4 Land and water use

In the Komati catchment about 20 000 ha of the upper catchment has been cleared of natural vegetation to make place for alien plant species of timber (AfriDev, Knight Piésold Joint Venture and JTK Associates, 1999). More to that, the middle parts of the catchment is dominated by rural community activities such as subsistence and small scale farming of livestock and fruit , the lower parts have mainly intensive agricultural production introduced by the Government of Swaziland. Komati Downstream Development Project (KDDP) is a project partly funded by the Government of Swaziland (GoS) and participating farmers who, by joining farmers' associations, converted their subsistence farms into communally-operated commercial farms (SWADE, 2002). The farmers grow mainly sugar cane, with 2984 hectares developed so far along the lower Komati. Sugar cane is preferred because of its advantage given that it favours temperatures in the region and also that it is easier to secure finance for on-farm developments from the private banking sector as market value for sugar is good (Terry, 2007). The main operations in the sugar-cane farms are soil preparations, planting, fertilizer application, irrigation, fertilizer and ripeners application, weed control chemicals.

3.4.1 Soil preparations and planting

After the first cane crop is harvested the soil is tilled in preparation for the next crop. Conventional soil tillage system is dominant in this area. The main tillage operations are to a depth of 15-20cm, using a mouldboard plough. This plough lifts the stumps on the edge if set very shallow, but will invert the sod if set too deep. Occasionally, sub-soiling is required to break up hardpans that form at the bottom of the plough layer. Preparatory tillage in this area is most frequent since ratooning is twice, thus the soil is mostly susceptible to erosion since ploughing breaks the soil to smaller particles. Planting material is hand cut from cane plants less than one year old grown specifically for seed. The cane is planted manually by hand. Planting is usually in January during the rainy season. The cycle of sugar cane ploughing takes about 12months to grow then the field is left for ratoon. The ratoon crop is harvested in the following 12 months. After that the field is generally left fallow throughout the rainy season until the next planting the following October to November. Some ploughing is also done during the rainy season as a part of field preparation for end-of-season planting.

3.4. 2 Fertiliser application

The fertilisers are then applied at the time of planting. Fertiliser is applied to furrows during the ridging operations. On average about 60kg Nitrogen (N) which is half of the total requirement and all the phosphorus applied during planting. On average 30-50kg of phosphorus per hectare are applied between April and July. A further 60kg/hectare of N is applied from August to December as a top dressing three months after germination. So, all the fertilizer is applied in the first 4 months of the 12months growing period.

3.4.3 Irrigation

On average about 1200 m^3/ha of irrigation water is required for sugar cane. About 3.14 Mm^3 on average is abstracted from the Lower Komati River between January and March for irrigation on the KDDP farms. The common on-farm irrigation system is the sprinkler together, with dragline sprinkler and centre pivot irrigation system. These irrigation systems are not changed throughout the different stages of growth of the crop. Fertiliser is applied to furrows during the ridging operations. After fertilizer application irrigation is necessary to dissolve the fertilizer into the soil system which on average supplies 50 mm gross in stand times of 6 to 12hours. With the soil susceptible to soil erosion, sprinkler irrigation after fertilizer application may result in surface runoff which may fertilizers. This may compromise the river’s water quality. The water quality in the lower Komati River is said to have declined mainly because of sediment deposition, vegetation removal and agricultural return flows which threaten biodiversity as well as pose hazards to human health downstream of the river (Engelbrecht and Roux, 2006). SWADE has recently embarked on a water use efficiency campaign through water accounting, where there is a daily recording of the amount of water applied and soil water depth, to reduce the amount of water used during irrigation.

3.5 Land and Water resources use management

The KDDP farmers’ associations are responsible for the management of sugar cane farms along the Lower Komati River to minimize negative environmental impacts from the development project. Farmers are encouraged to mitigate negative impacts at the planning, development (land preparation, etc.) and operational phases. SWADE (Swaziland Water and Agricultural Development Enterprise) an implementing body assist the farmers by carrying out bio-physical studies to assess the status and establish presence of threatened flora and fauna, mortality levels of vertebrates during farming, and impacts of livestock activities (SWADE, undated). An on-going monitoring of the water quality at various sites along the Komati River is conducted every two months (SWADE, 2002). The studies and monitoring surveys are done in individual Farmers' Associations (FAs) to impart skills for environmental mitigation. This involves farmers engaging in different activities such as rehabilitating degraded land, nature conservation and good land management practices.

3.6 Human development

The process of commercializing subsistence, extending irrigation onto customary tenured land in the semi-arid Lowveld and converting land to sugar cane production farms by the Government of Swaziland is to overcome widespread rural poverty, raise incomes and improve food security (Terry, 2007). This development was designed to raise productivity and viewed as a means of poverty reduction, either directly through raising farm incomes, or indirectly through the multiplier effects that will result from increased economic activity in the Lowveld region.

3.7 Legislative, Policies and Institutional framework governing water use

Since the Komati River is a transboundary water course there are specific Bi-National agreements covering the basin; the Joint Water Commission (JWC) treaty covering all watercourses shared by South African and Swaziland, the Treaty on the Development and Utilization of the Water Resources of the Komati River Basin and the "Komati Basin Development Treaty"(TIA, 2002). The development treaty states that land and water resources in the basin should be managed as to not result in the degrading of the existing environment and also that the parties take all reasonable measures to ensure the protection of the existing quality of the environment.

Moreover, the Lower Komati basin is also governed by the Swaziland Water Act of 2003 which advocates for environmental sustainability of water resources. The Act states that water resources development for irrigation shall be preceded by a feasibility study to ensure that the intended projects are economically, environmentally, socially viable and sustainable. A number of factors have to be considered in determining the irrigatibility of areas; soil type, depth, type of irrigation, salinity, slope and erosion hazard. However, projects aimed at poverty alleviation may be exempted from the requirement for economic viability.

Main institutions that a responsible for land and water resources management are the (NWA) National Water Authority and Swaziland Environmental Authority (SEA). NWA is a premier institution created in 1967, responsible for development, distribution, control, and conservation of water resources (Swaziland Water Act of 2003). Nonetheless, SEA is responsible for pollution control and ensures that compliance certificates after proponents of projects have done EIA (Environmental Impact Assessment) and Comprehensive Mitigation Plan (CMP). This is a requirement from the SEA Act of 1992 that there is need to protect water and other natural resources from pollution. With regard to irrigation projects, the Swaziland Government Water Act of 2003 requires a feasibility study where the proponents of the project are expected to state how they will protect and control land degradation due to water use and reclaim soils where irrigation would cause avoidable degradation. In all the Government of Swaziland is responsible to regulate, co-ordinate all water use agencies in the country, regulating and monitoring the quality and quantity of water resources.

CHAPTER 4 : MATERIALS AND METHODS

4.1 Study design

4.1.1 Location of sampling site

The study was aimed at assessing the impact of agricultural activities for sugar cane production on the diversity of macro-invertebrates along the lower Komati River. Seven sampling sites were chosen, macro-invertebrates and water quality samples were taken from these sites based on their location in relation to sugar cane fields along the Lower Komati River (Figure 4. 1). The sampling sites were categorised into 3 main groups. Firstly, were sites upstream before the sugar-cane fields, secondly, were sites draining the sugar-cane fields, and lastly sites downstream after the sugar-cane fields along the Lower Komati River. The first two sites upstream were the control sites and the rest were experimental sites. The sampling sites were denoted WQ for identification. The different sites were chosen to determine the diversity of aquatic macro-invertebrates and quality of the water upstream before the sugarcane fields, as well as after the sugar cane fields. The sampling sites are described in Table 4.1

Data from the sampling sites was collected between February and April 2009 and it included geographical coordinates for sampling points, water quality variables, macro-invertebrates data and flow rate at the time of sampling. Figure 4.1 shows positioning of sampling points.

Table 4.1 Description and location of sampling sites

Sites		Co-ordinates	
Site number	Description	Latitudes	Longitudes
WQ 1	About 3km Upstream before the KDDP[1] sugar cane fields	25^{o}.93.41`	31^{o}.75.916
WQ 2	About 100m upstream of KDDP' Madlangempisi FA[2] sugar cane fields	25^{o}.94.347`	31^{o}.74.781`
WQ 3	Along KDDP'Ngcayizivele after Mzimnene and Komati confluence.	25^{o}.95.69`	31^{o}.72.264`
WQ 4	Along KDDP' Vuka Sidwashini FA sugar cane fields	25^{o}.94.647`	31^{o}.56.259`
WQ 5	100m upstream of KDDP' Mpofu FA sugar cane fields	26^{o}.26.10	31^{o}.32.832`
WQ 6	Downstream of KDDP's Intamakuphila FA sugar cane fields	26^{o}.28.29`	31^{o}.34.280`
WQ 7	Downstream 1 km after KDDP's sugar cane fields.	26^{o}. 60.04`	31^{o}.30.927`

*[1] **KDDP- Komati Downstream Development Project*** *[2] FA-**Farmer's Association***

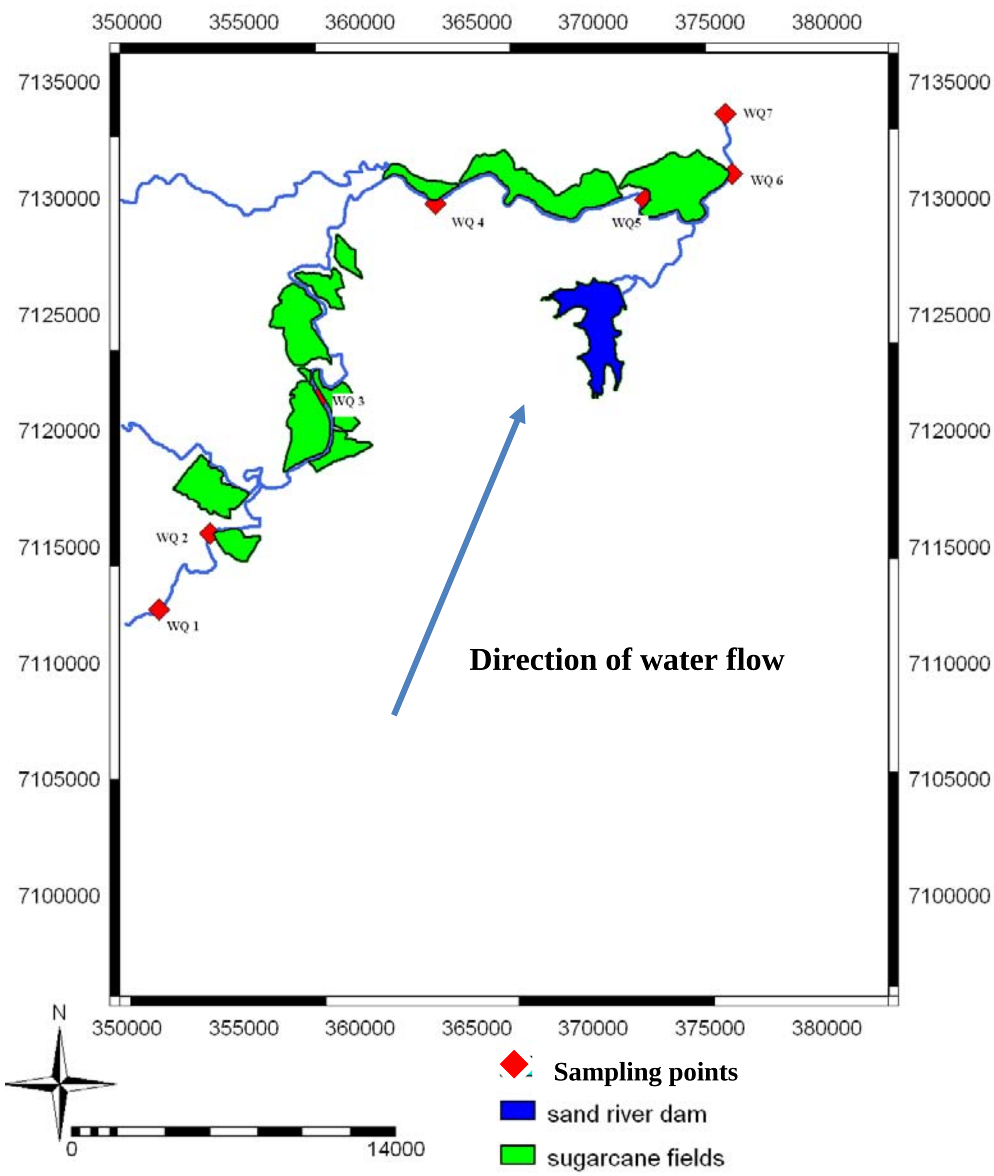


Figure 4.1 Map showing sampling sites in relation to agricultural land use

4.1.2 Selection of parameters

After sampling sites were established aquatic macro-invertebrates samples were collected to ascertain macro-invertebrates diversity and richness. Additionally, water samples were collected for water quality analysis for pH, turbidity, conductivity, dissolved oxygen (DO) and nutrients (nitrates, nitrites ammonia and ortho-phosphates). Both nitrates and nitrites were measured since nitrogen is present in many different forms and is continually changing molecular form and geographical location (Atasoy et al., 2006). The streamflow of the river was also determined during each sampling campaign. The physico-chemical assessment, as well as the streamflow was taken since according to Chapman (1996) these properties can influence the habitat of aquatic systems and the biota of the catchment. Nutrient levels were measured, since sugar-cane agricultural practices include intensive inputs of nitrogen and phosphorus fertilizers.

4.1.3 Sampling methods and frequency

Grab sampling technique was used to collect water samples, it was chosen because the river is free flowing and according to EPA-AU (2006) grab samples may be used to represent "some well-mixed surface waters", where water is free flowing, and there isn't much variation in volume and velocity per day which can affect the parameters, which was the case with this river. Sampling was twice a month during the summer rains and towards the beginning of winter season from February to mid-April 2009. Sampling in between seasons will help to determine the ecosystem health when the flow is high and reduces, during and towards the end of the rainy season. This is done to detect if there are any species which might be affected by the flow levels as suggested by Chapman (1996).

4.2 Methods of data collection and analysis

4. 2.1 Establish aquatic macro-invertebrates diversity

Aquatic macro-invertebrates were sampled using a modified approach to the South African Scoring System (SASS 5) as the aquatic macro-invertebrates were identified in the lab rather than in the field. The SASS5 method is based on two principles; firstly, that some invertebrate taxa are much sensitive to water quality impairment than others, hence some occur in less impacted waters and others in more impacted waters. Secondly, invertebrate faunal assemblage at a site is dependent not only on water quality at the time of sampling but on the conditions that might have prevailed; they react to pollution that might have occurred in that site (Day, 2000).

SASS5 was chosen because it tends to cover all biotopes where different species may live (vegetation, riffle, and pool). Secondly, this sampling method was chosen because according to Mthimkhulu et al. (2005), Swaziland and South Africa's rivers; Komati, Sabie and the Crocodile have ecological similarities in invertebrates' abundance hence, the index is easily applicable in Swaziland. Aquatic macro-invertebrates were then analysed to determine their diversity and richness as ecosystem health indicators. As suggested by Roux (1999) diversity can show that a system is able to support and maintain a balanced community of organisms. The basic assumption being that a high richness and diversity represents a high ecological integrity as it is considered sensitive to organic pollution, it is assumed that when there is organic pollution effects richness and diversity will decrease.

4.2.2 Assessment of habitat integrity

The sampling sites' habitat integrity was also determined. In this sense the assessment of the habitat integrity of a river can be seen as a precursor of the assessment of biotic integrity. It follows that in this context habitat integrity and biotic integrity together constitutes ecological integrity. According to Karaus (2004) habitat quality plays an important role in determining the distribution of macro-invertebrates since local assemblages are mainly controlled by local conditions. Sites with a more diverse and mostly natural habitat are expected to have a greater diversity of invertebrates, but this may not indicate the water quality in which they live.

Therefore, the Habitat Integrity Assessment classification was adopted as suggested by Kleyhans (1996) to establish if habitat quality had any significant impact to major macro-invertebrates diversity along sites. Primarily, it assessed the number and severity of anthropogenic perturbations along river and damage potentially inflicted on the habitat integrity of the system. These disturbances include abiotic factors, such as water abstraction, weirs, dams, pollution and dumping of solid waste, and biotic factors, such as the presence of alien plants and aquatic animals which modify habitat. (Appendix D, Table 7.9). These components are said to be important because they may affect in-stream conditions thus affecting distribution of the macro-invertebrates. During the study emphasis on the present assessment was based on field-based site assessment, supplemented by reports from catchment studies. Thereafter, considering the instream and riparian habitat in each site it was assigned a class as presented in Table 4.2.

Table 4.2 Description of habitat integrity classes

Impact class	**Description**	**Score**
None- A	No discernible impact or the modification is located, has no impact on habitat quality, diversity, size and variability.	**90 - 100**
Small-B	The modification is limited to very few localities and impact on habitat quality, diversity, size and variability is limited.	**80-89**
Moderate-C	The modifications are present at a small number of localities; impact on habitat quality, diversity; size and variability are fairly limited.	**60-79**
Large-D	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not affected.	**40-59**
Serious-E	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	**20-39**
Critical-F	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	**0-19**

Source; Kleyhans,(1996)

4.2.3 Physico-chemical parameters analysis

Onsite grab samples were collected for, temperature, turbidity, pH, Dissolved Oxygen (DO) Electrical Conductivity (EC) and nutrients (nitrates, nitrites, ammonia and ortho-phosphates). Dallas (2000) suggests that measuring a range of water quality parameters will enable to determine prevailing condition of the water. A factor of 0.65, which is a conversion factor for aquatic water quality, was used to derive TDS from EC as suggested by DWAF (1996).

Dissolved oxygen and temperature were measured on site since they are unstable they tend to change quickly. For the other parameters samples were collected in 500ml glass bottles, labeled according to site number, kept in a cooler box with ice, to be analysed within 24hours to maintain sample integrity. For nitrates, nitrites, ortho-phosphates and ammonium ion; (NH_4^+), tablets were prepared and mixed with samples, then measured with a photometer. For nitrates and nitrites, and orthophosphates containers were rinsed thoroughly with the sample before use and 2-4ml of chloroform/ litre was added to the sample to retard bacterial decomposition as suggested by DWAF (1996) this is because phosphorus is readily adsorbed onto the surface of sample containers. Water quality analysis parameters and methods used in this study are presented in Table 4.3.

4.3 Data analysis

Diversity of the macro-invertebrates was determined using macro-invertebrates' richness, Shannon –Weiner diversity index and Simpson's diversity index. Biotic indices were developed largely to measure responses of species to pollution levels. The diversity indices are used to measure stress in the environment, considering that an unpolluted environment is characterised by a large number of species (Mason, 1996). Maximum diversity is obtained when a majority of species are present in a community. When an environment becomes stressed, species occur in relatively low numbers in a community.

Richness according to Clarke and Warwick (1994) is the measure related to the total number of taxa, it considers a sample with more species as diverse. On the other hand, Shannon Weiner's diversity index is a measure of species present which describes the average degree of uncertainty of predicting the species of an individual picked at random from the community. According to Clarke and Warwick (1994) with Shannon's Weiner's diversity index the uncertainty of occurrence increases both as the number of species increases and as the individuals are distributed more and more evenly among the species already present.

The diversity value of Shannon-Weiner is H' and ranges between 0 (indicating low community complexity) and 4 (indicating high community complexity). Lastly, Simpson's diversity index takes into both richness and equitability as it is the probability that a taxon is selected from different species. The greater the value of the index, the higher the diversity. Diversity range for Simpson's index is between 0 and 1 since it is about probability.

Table 4.3 Description of instruments used in the water quality analysis

Parameters	**Instrument**	**Units**	**Range**
Temperature, DO	Dissolved oxygen meter-WTW Oxi 330i set	°C, mg/l	
nitrates, nitrites, ortho-phosphates, ammonia	PC: multi-direct: Lovibond photometer	mg/l	1-30mg/l(nitrates), 0.01-0.5mg/l of $N0_2$(nitrites), 0.02mg/l-1mg/l of N(ammonia), 0.05-4mg/l of PO_4(orthophosphates)
pH	PC, multi-direct: Lovibond photometer	pH units	
Turbidity	Turbidity meter-Hach mode 2100A	NTU	
Conductivity	WTW conductivity probe Level 1	µS/cm	

(i) Richness was determined by counting the number of taxa sampled in a site.

(ii) Shannon-Weiner index formula;

$$H - \sum_{i=1}^{n} P_i \log P_i$$ ....***Equation 1***

Where: H'-Shannon –Weiner diversity index

P_i-proportion of the total count arising from the *i*th taxa(n_i).

(iii) Simpson's Index formula;

1-D-Simpsons's diversity index................................ ***Equation 2***

$$D = \sum (Pi_2)$$

Where: D -Simpson's Diversity Index

P*i* - size of a taxa as a proportion of the total population in the site

The 3 indices were all used because according to Clarke and Warwick (1994) different diversity indices may emphasize species richness or equitability components of diversity to varying degrees i.e. Simpson's diversity index takes into account richness and equitability but less sensitive to rare groups which can be accommodated by Shannon's Wiener diversity index. Thus the three indices are used in this study for comparison purposes.

To test for significant differences in diversity and water quality between sites, data was tested for normality first using one-sample Kolmogorov – Smirnov Test in SPSS 13.0 and it showed that data followed a normal distribution thus parametric statistics were used.

ii) Relationship between water quality variables and diversity

To establish a relationship between water quality variables and diversity, parametric regression analysis was done on each water quality variable with each diversity index. This is as suggested by Galbrand et al (2007) that physiochemical water quality parameters, have complex impacts on species community structure and are all said to be somehow altered either by land-use or water-use management thus there is a relationship between physico-chemical parameters and diversity.

To identify priority parameters in the catchment Principal Component Analysis (PCA) and a screeplot was used to identify the number of Principal Components (PC's) to be used to explain the occurrence of some parameters. Regression analysis was then carried out to find out about the relationship between macro-invertebrates diversity and the chosen PC's. Basically, the order of analysis was PCA, scree plot and regression analysis. PCA was used in the study to identify water quality parameters that correlate to one another in the system as suggested by Raj and Azeez (2009). PCA identifies the compositional patterns and determines the major determinants of association among the water quality variables. PCA also allows the use of variables which are not measured in the same units (e.g. concentration of nutrients, temperature, pH, etc.). The underlying relationship between the water quality parameters is shown by parameters clustering in one Principal Component (PC). Water quality parameters are related to each other and the occurrence of certain parameters tends to describe the occurrence of other (Chapman, 1996).

A scree plot was then used to identify the number of Principal Components (PC's) to be retained in order to comprehend the underlying data structure as suggested by MacGarigal et al. (2000). On the basis of the scree plot test criterion, two Principal Components were retained for interpretation; these were shown by a major slope change (Appendix I, Table 7.13). SPPS 13.0 was used to obtain the PC loadings. The loadings of each PC were classified as suggested by Singh et al (2004) that component factor loading can be classified as strong, moderate, and weak corresponding to absolute loading values of (>0.75),(0.75-0.50) and (0.50-0.30) respectively. Negative values mean that the parameter is inversely related to the other parameters with positive values in the PC.

The regression analyses between the chosen Principal Components (PC's) and diversity will identify the most important predictor water quality parameters that explain diversity patterns in the catchment. In carrying out the regression analyses no assumptions were made about the distribution of variables.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Results

5.1.1 Diversity along a segment of the Komati River in 2009

5.1.1.1 Richness

Figure 5.1 illustrates presents taxa richness for all sites sampled from February to April 2009. Observations made between the sampling campaigns were that site WQ3 and WQ7 on 19 February and 23 March respectively recorded 7 taxa which was the highest number of taxa sampled during a sampling campaign. The lowest in a campaign was from WQ2, WQ 4 and WQ5 which had 1 taxa recorded on 05 Mach (Figure 5.1). The February sampling campaigns recorded 27 taxa which was the highest and the lowest was on the 05 March campaign which had 13 taxa sampled. Overall, a total of 33 taxa were sampled during the whole sampling period, site WQ1 (control site) recorded 21 taxa which was the highest sampled in the sampling period. The lowest was from site WQ3 which had 14 taxa sampled in all during the sampling period.

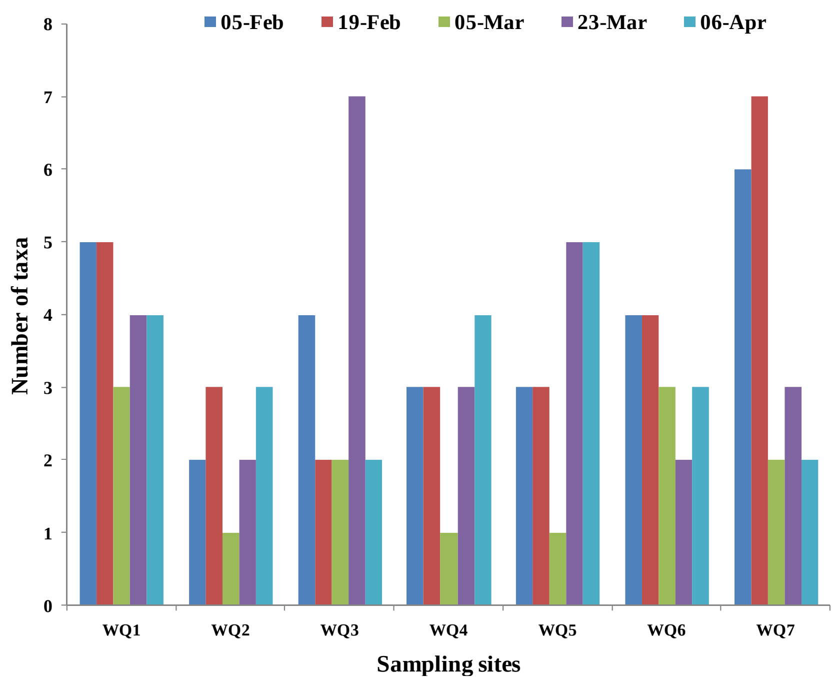


Figure 5.1 Taxonomic richness between sites during the sampling period along the lower Komati River

From the sites sampled along the lower Komati River, data show that there is no significant difference ($p>0.05$) between sites in taxonomic richness between sites.

Figure 5.2 shows taxon group richness recorded during the field campaign from February to April 2009. Four main groups were found during the sampling period; Odonata, Hemiptera, Crustacea and Diptera and other minor groups. The Diptera group was only found at site WQ1 and WQ5, with the Hemiptera, Odonata appearing at all sites. The Diptera group was only found in site WQ1 and WQ 5, with the Hemiptera, Odonata appearing in all sites. It can be observed that site WQ1 had all the taxon groups whilst site WQ3 had only 2 main groups the Hemiptera and the Odonata. In general, taxon group richness as shown in Figure 5 .2 was high in site WQ 1 as all the main groups sampled were observed in this site.

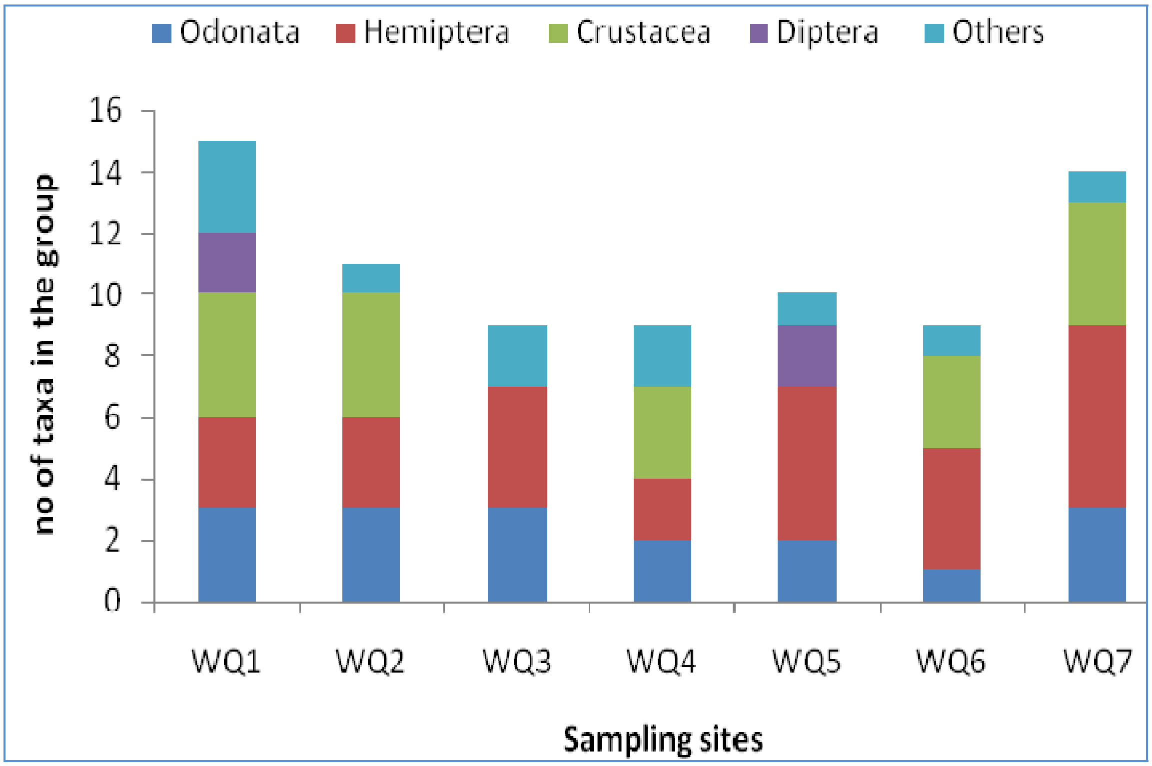


Figure 5.2 : Taxanomic groups at the sampling sites along the Lower Komati between February and April 2009

In contrast, site WQ 3 was the least varied site as it had the lowest taxon group richness. Taxa sampled from this site were only a presentation of 2 main groups of taxa; making it the least varied site during the sampling period.

5.1.1.2 Simpson's diversity index

Figure 5.3 illustrates species diversity using Simpson's diversity (1-D) along the lower Komati section in 2009. It can be observed that site WQ1 upstream had the highest score of 0.2; the lowest was from site WQ7 downstream with 0.11.

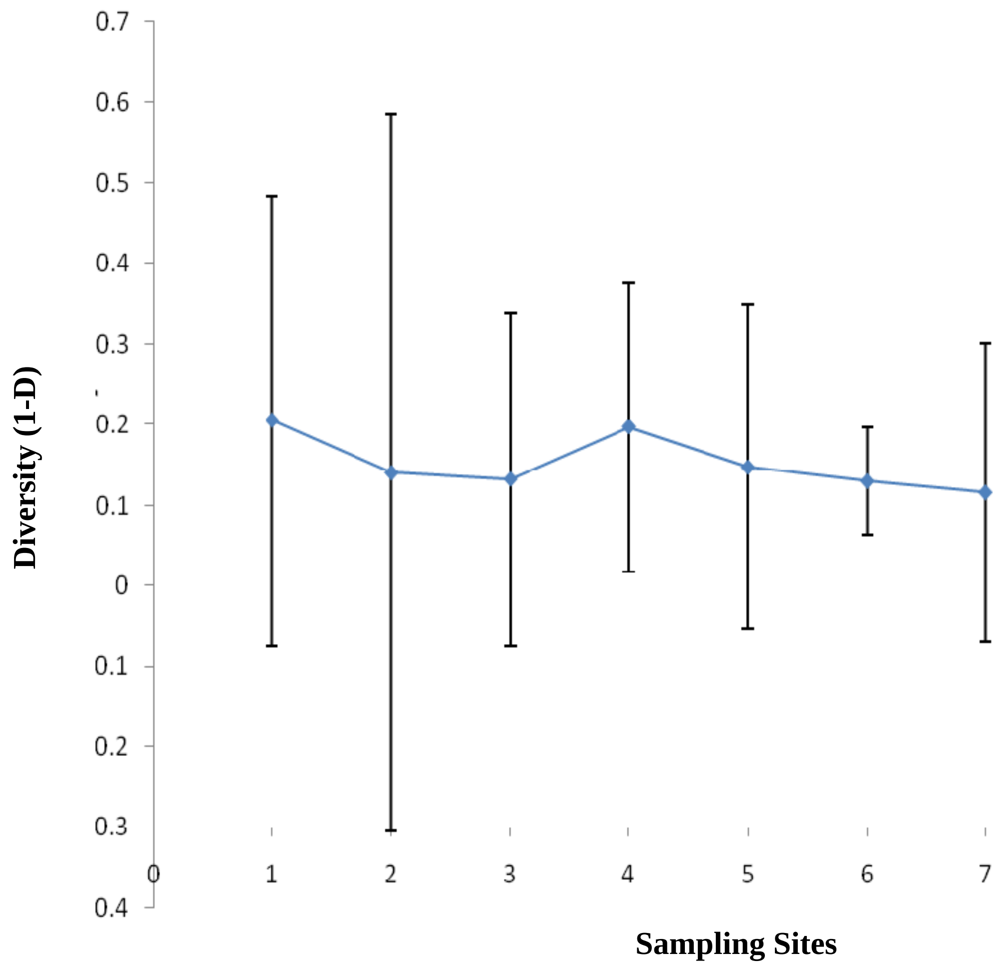


Figure 5.3 Variation of diversity (Simpson's index) along the sampling sites in 2009 using confidence intervals

Site WQ4 shows an increase in diversity after it dropped at site WQ3. The graph further shows a steady decrease again from site WQ5 to WQ7 downstream. Generally, diversity seems to be high upstream and declines as it gets downstream. Site WQ4 is the only site showing results comparable to site WQ1 upstream, However, there is no significant difference in diversity using Simpson's index ($p>0.05$) between sites upstream and those draining sugar-cane fields.

5.1.1.3 Shannon-Weiner diversity index (H')

Figure 5.4 shows diversity using Shannon Weiner's diversity index (H') along the lower Komati section in 2009. It can be seen that diversity ranged from H'=0.6 in site WQ3 to H'=1.02 at site WQ1 upstream. The results follow the same trend as using Simpson's diversity index. Diversity at site WQ1 is high and shows much decrease at site WQ3 which is adjacent to sugar-cane fields. However, diversity this time picks at site WQ5 compared to WQ4 using Simpson's index. Generally, diversity also shows a decrease in all the other experimental sites using Shannon-Weiner's index. However, there is no significant difference (p>0.05) in diversity between sites using Shannon-Weiner's index.

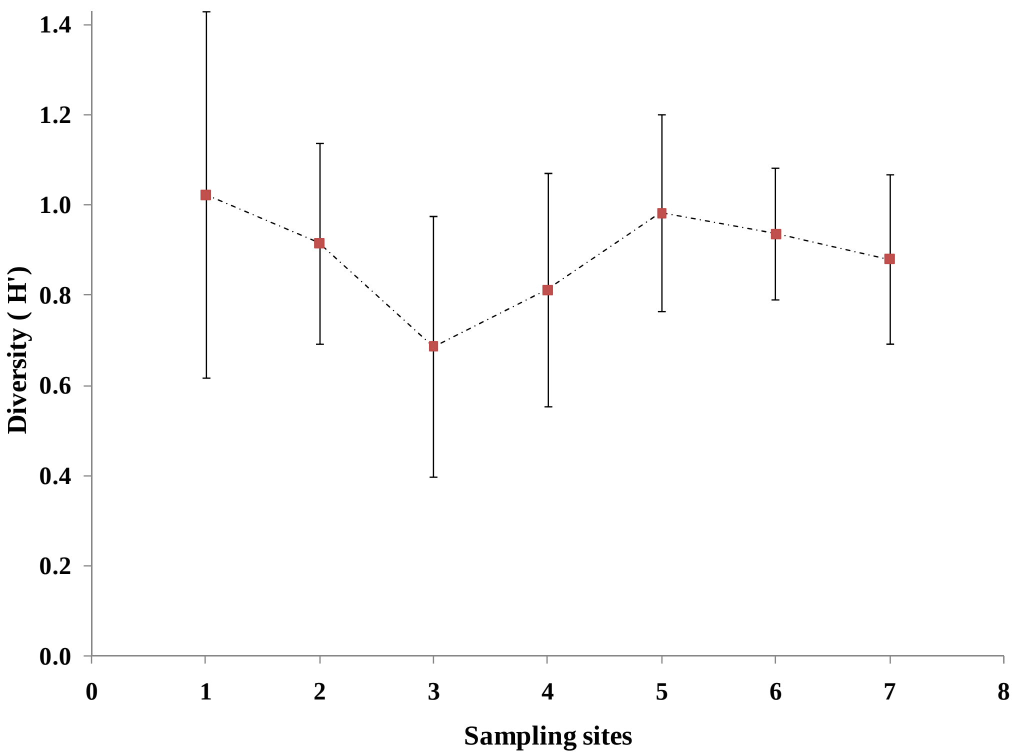


Figure 5.4: Variation of diversity (Shannon Weiner's index) along the sampling sites in 2009 using confidence intervals

The trend in species diversity using all the diversity indices show a major decrease along site WQ3 which is mainly along the sugar-cane fields. Basically, the diversity pattern is the same in all sites as it shows a V-shape. However, comparing sites there was no significant difference (p>0.05) in aquatic macro-invertebrates diversity using all the diversity indices.

5.1.2 Habitat characteristics

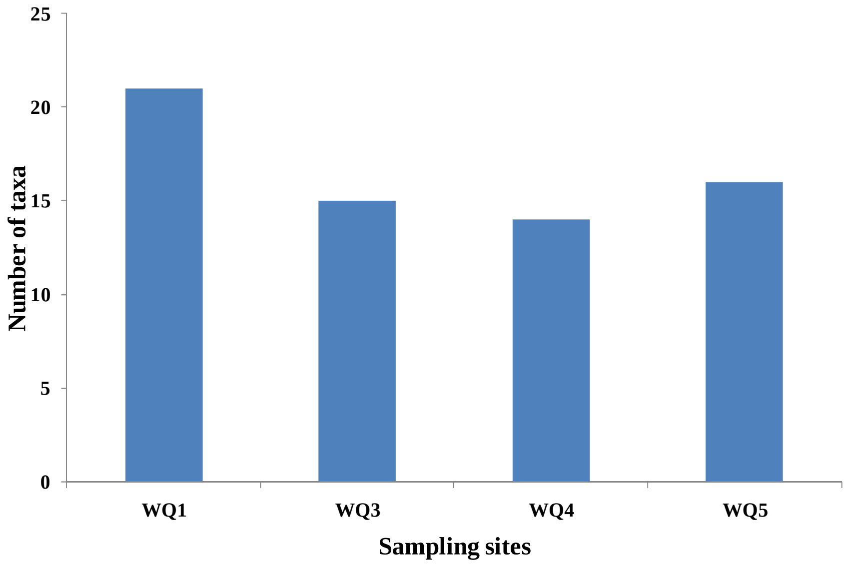
Table 5.1 illustrates the sampling sites classified according to the Habitat Integrity index. It can be observed that sites WQ1, WQ3 and WQ 4 were classified as B whilst WQ5 was classed as C after considering the state of the riparian and in-stream habitat. On the other hand, WQ2 and WQ7 were under class D whilst site WQ 6 fell under class E. For purposes of the study, sites with A to C classes (WQ1, WQ3, WQ4 and WQ5) were categorized as Group 1 and those with D to F (WQ2, WQ6 and WQ7) were categorized under Group 2. The first group shows sites which had minimal habitat disturbance and group B shows sites with disturbance which might greatly influence aquatic macro-invertebrates distribution.

Table 5. 1 Classification of sites using the Index of Habitat Integrity.

Sampling site	Instream veg	Riparian veg	Substrate	Total score	class
WQ1	Class C-79%	Class B-82%	muddy	81%	B-limited
WQ2	Class D-42%	Class D-46%	Sandy-gravel	44%	D-extensive
WQ3	Class C-60%	Class C -61%	Sandy-gravel	61%	B-limited
WQ4	Class D-58%	Class C-62%	Silty-muddy	60%	B-limited
WQ5	Class C-61%	Class D-59%	Sandy-gravel	60%	C-moderate
WQ6	Class E-32%	Class E-22%	Sandy-gravel	27%	E-critical
WQ7	Class D-54%	Class D-47%	gravel	51%	D-extensive

Overall, the habitat integrity of the selected section of the Lower Komati River for the purposes of this study can be classified as moderate to poor for both instream and riparian conditions.

Figure 5.5 illustrate taxa richness along Habitat Group 1 which is made of sites from Class A to C which are sites with habitats ranging from natural to modified.

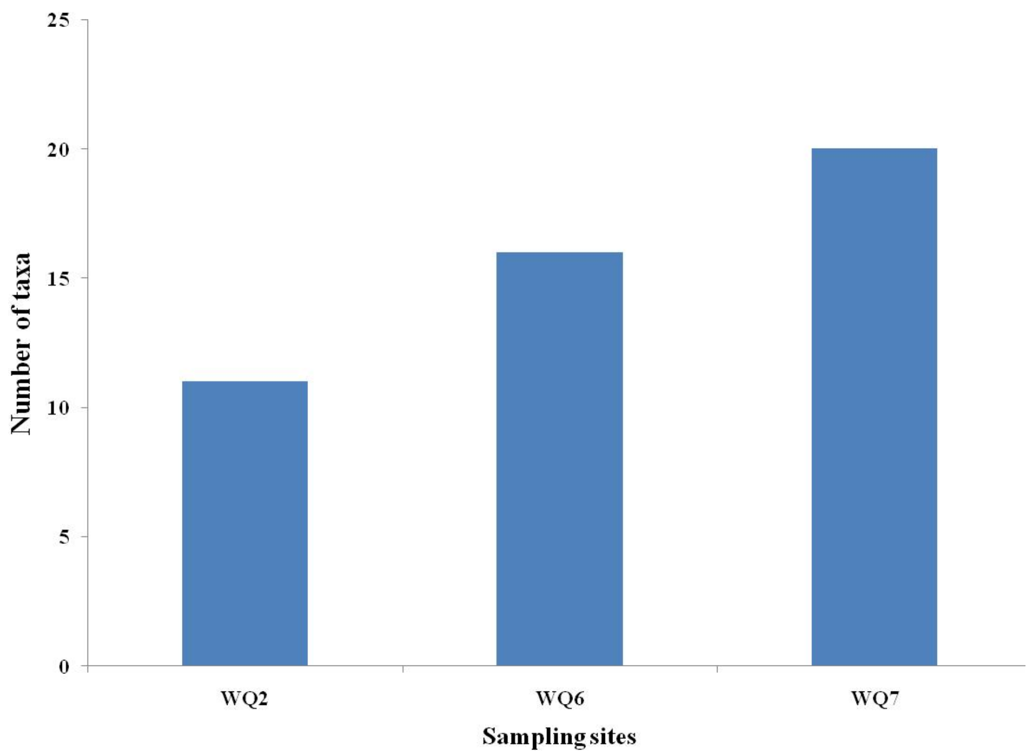


Classes A-C (wq1-B, wq3-B, wq4-B wq5-C)

Figure 5.5 Variation of taxa richness for habitat Group 1 along the sampling points between February and April 2009

It can be observed that site WQ1 had the highest number of taxa, the lowest number of taxa was found in site WQ4. Overall, sites adjacent to sugar-cane fields (WQ3 and WQ4) had low taxa richness compared to site WQ1 which is upstream. However, it can be observed that site WQ5 is adjacent to sugar-cane fields but has high taxa richness than site WQ3 and WQ4.

Figure 5.6 illustrate taxa richness along habitat group 2 which is made of sites from Class D to F which are sites with habitat integrity ranging from moderate to critically modified integrity. Site WQ2, WQ6, WQ7 fell under this category. The graph shows that site WQ7 had the highest taxa in this group despite that it had the same habitat integrity class as site WQ2 which recorded the minimum taxa.

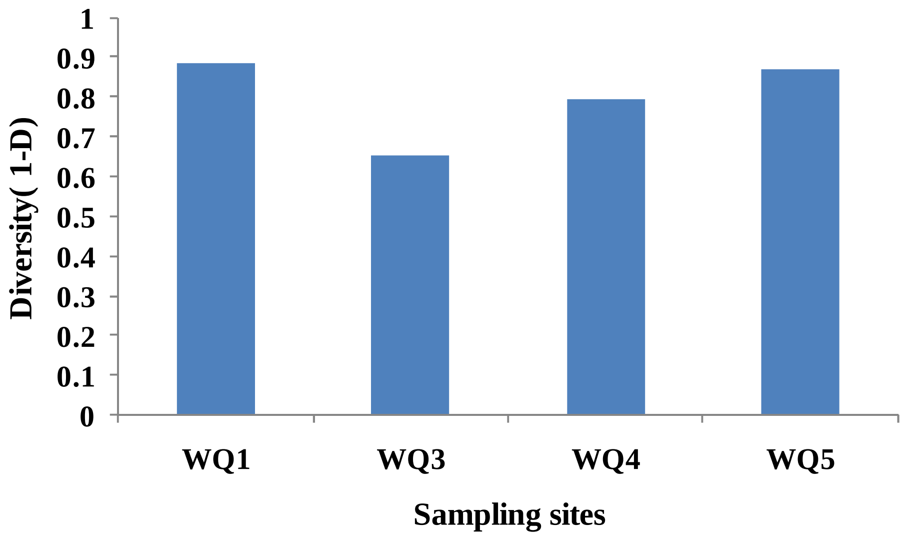


Classes D-F(wq2-D, wq6-E, wq7-D)

Figure 5.6 Variation of taxa richness for Habitat Group 2 along sampling points between February and April 2009

Overall, a significant difference ($p<0.05$) in taxa richness is observed between WQ2 and WQ7 which are sites upstream and downstream of the sugarcane fields

Figure 5.7 illustrate diversity using Simpson’s diversity index along Habitat Group 1 which is made of sites from Class A to C. It can be observed that site WQ1 had the highest diversity in the group, whilst site WQ3 had the lowest.

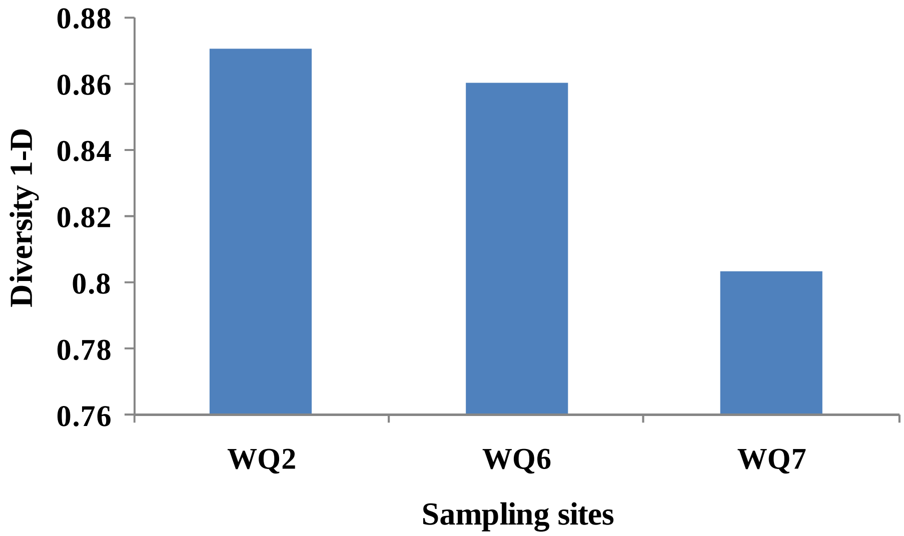


Classes A-C (wq1-B, wq3-B, wq4-B wq5-C)

Figure 5.7; Variation of diversity (Simpson's index) for Habitat Group 1 along sampling points between February and April 2009

Overall, diversity decreased from a maximum of 0.88 in site WQ1 to a minimum of 0.65 at site WQ3. Basically, site WQ1 and WQ3 showed a difference in species diversity having the same habitat integrity. Moreover, site WQ5 had the highest diversity than WQ3 despite that WQ5's habitat integrity is more deteriorated than WQ3 which had a moderately disturbed habitat. Furthermore, site WQ1's diversity is comparable to site WQ5 which had 1-D=0.88 and 1-D=0.86 respectively.

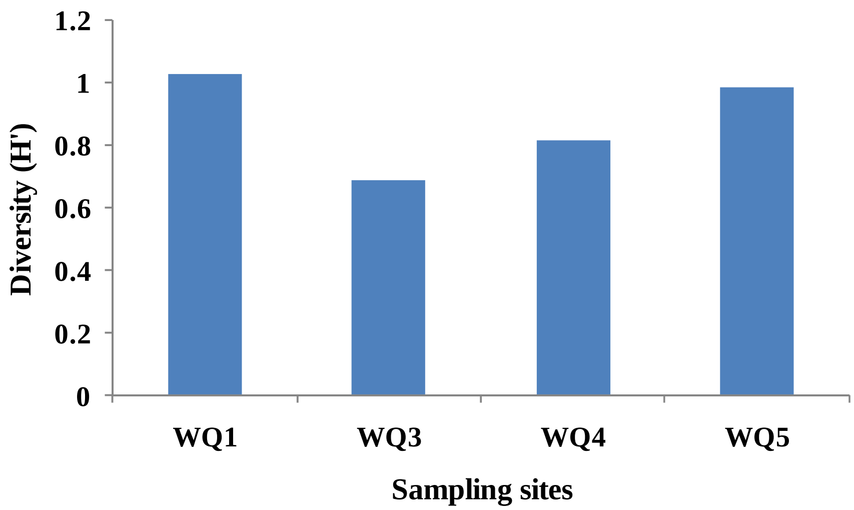
Figure 5.8 illustrate diversity using Simpson's index along Habitat Group 2. It can be seen that site WQ2 in this group had the highest diversity and WQ7 has the lowest which was the opposite of the observed trend with richness. Using richness, site WQ2 had the highest and WQ7 had the minimum. Moreover, diversity calculated using Simpson's diversity index, shows that site WQ 2 is comparable to site WQ 7 as they had 1-D= 0.87 and. 1-D=0.80 diversity respectively.



Classes D-F(wq2-D, wq6-E, wq7-D)

Figure 5.8 Variation of diversity (Simpson's index) for habitat group 2 along sampling points between February and April

Figure 5.9 illustrate diversity using Shannon Weiner's diversity index along sites from habitat group 1. It is observed that site WQ1 had the maximum and WQ 3 had the minimum diversity in the group (H=1.02 and 0.68). Furthermore, the graph shows that site WQ1 and WQ5 have comparable diversity. Overall, Shannon Weiner's index shows the same pattern as Simpson's diversity index in diversity distribution, as diversity as difference between sites despite them having the same habitat groups.



Classes A-C (wq1-B, wq3-B, wq4-B wq5-C)

Figure 5.9 Variation of diversity (Shannon-Weiner index) for Habit group 1 along sampling points between February and April 2009

Figure 5.10 illustrate diversity using Shannon Weiner's diversity index along sites from habitat group 2. The graph shows that site WQ6 had the highest diversity (H=0.93) with WQ7 (H=0.88) having the lowest diversity in the group.

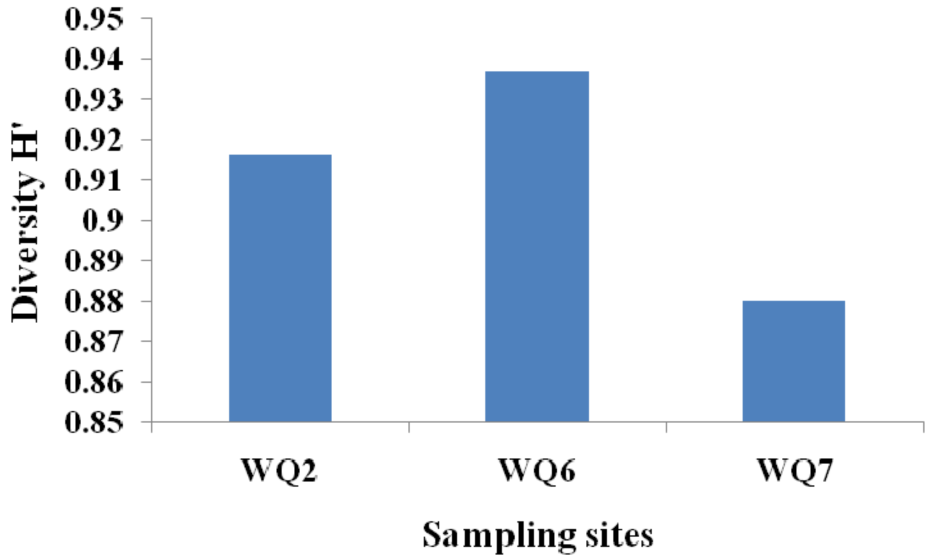


Figure 5.10 Variation of diversity (Shannon-Weiner's diversity index) for Habit Group 2 along sampling points between February and April 2009

5.1.3 Water physico-chemical parameters and diversity of aquatic invertebrates

5.1.3.1 Water physico-chemical parameters

Table 5.2 presents average values, standard deviation, and coefficient of variation (%) of water quality parameters sampled and analysed between February 2009 and April 2009 (temperature, turbidity, pH, conductivity, TDS, saturation and Dissolved Oxygen (DO)).

Temperature

Table 5.2 shows average temperature values, it can be observed that site WQ 1 upstream had the minimum reading of 22.58±2.95^{o}C and site WQ3,downstream had the maximum temperature reading of 26.56±2.33 ^{o}C . Disparity in temperature between sites can also be observed between sites WQ1 and WQ2 in all the sampling campaigns (Appendix G,Figure 7.3). There was also an observed difference in temperature between sites WQ7 and WQ1. Of all the temperature readings, 30% were within the guideline limit of the Swaziland Water Quality Objectives for aquatic,aesthetics and human health. Moreover, there was no significant relationship (p>0.05) between temperature and diversity of macro-invertebrtaes along the Lower Komati river during the sampling period

Table 5.2 Summary values for temperature, turbidity, dissolved oxygen, pH, and conductivity (mean, standard deviation and coefficient of variation) for the sampling sites between February and April 2009.

Site		Temp. (^{0}C)	Turb. (NTU)	pH	Cond. (µS/cm)	TDS (mg/l)	Sat. (%)	DO (mg/l)
WQ1	Mean	22.5	47.4	7.3	95.28	69.08	87.32	7.8
	SD	2.95	21.76	0.56	22.52	21.76	7.32	0.56
	CV(%)	13.11	45.91	7.67	23.64	31.50	8.38	7.18
WQ2	Mean	24.36	54.8	7.2	106.82	77.45	79.188	6.64
	SD	2.07	21.52	0.06	27.77	21.52	5.36	0.06
	CV (%)	8.50	39.27	0.83	26.00	27.79	6.77	0.90
WQ3	Mean	26.56	71.2	7.14	114.82	83.24	77.1	5.72
	SD	2.33	17.24	0.32	20.05	17.24	1.46	0.32
	CV (%)	8.77	24.21	4.48	17.46	20.71	1.89	5.59
WQ4	Mean	23.98	71.8	7.19	102.64	74.41	85.96	6.88
	SD	2.04	25.94	0.46	24.11	25.94	5.54	0.46
	CV (%)	8.51	36.13	6.40	23.49	34.86	6.44	6.69
WQ5	Mean	25.24	84	7.2	118.54	85.94	80.86	6.64
	SD	2.22	27.50	0.09	38	27.5	3.22	0.09
	CV (%)	8.80	32.74	1.25	32.06	32.00	3.98	1.36
WQ6	Mean	25.4	55.6	7.4	106.38	77.12	78.98	6.05
	SD	2.10	25.40	0.15	20.36	25.40	10.39	0.15
	CV (%)	8.27	45.68	2.03	19.14	32.94	13.16	2.48
WQ7	Mean	25.9	54	7.2	104.74	75.93	83.88	6.32
	SD	2.49	25.88	0.28	19.29	25.88	6.78	0.28
	CV (%)	9.61	47.93	3.89	18.42	34.08	8.08	4.43
% Samples exceeding limit	30%	100%	0%	0%		0%	0%	
SD-WQO	20-25	5	6.5-8.5	1800		80-120[a]	4	

Number of samples (n) = 5; SD-Standard deviation; SD-WQO-Swaziland Water Quality Objectives; a- South African aquatic water quality standards.

Significant differences at 95 % confidence level to assess the impact of sugar cane fields on water quality parameters are presented in Table 5.3.

Table 5.3 p-values for water selected major water quality parameters sampled in 2009

Parameter	WQ1/WQ2	WQ1/WQ3	WQ1/WQ4	WQ1/WQ5	WQ1/WQ6	WQ1/WQ7
Turbidity	0.523	**0.041**	**0.039**	**0.0017**	0.0539	0.674
DO	**0.024**	**0.001**	**0.043**	**0.026**	**0.015**	**0.009**
Ph	0.648	0.418	0.504	0.540	0.539	0.514
Ammonia	0.764	0.412	0.940	0.731	0.817	0.802
Phosphate	0.114	**0.014**	0.431	0.150	0.053	0.106
Nitrate	**0.046**	0.077	0.763	0.053	0.321	0.545
EC	**0.398**	0.106	0.484	0.180	0.271	0.403

p values in bold ($p<0.05$) suggests a significant difference between the two sites at 95 % confidence

Dissolved Oxygen and Oxygen saturation levels

Average oxygen levels assessed in all sites, were between 7.8 mg/l to 5.72 mg/l at site WQ1 and WQ3 respectively as shown in Table 5.2. Comparing between sites, the range was between 4.49mg/l from site WQ 5 to 8.75mg/l in site WQ7 (Appendix G, Figure 7.7). The observed oxygen levels in all sites were within the Swaziland Water Quality Objectives with a limit of 4mg/l. The maximum oxygen saturation concentration on average was 87.3±7.3% at site WQ1, the minimum was at site WQ3 with 77.1±1.4%. as shown in Table 5.2. The observed oxygen levels at all sites were within the Swaziland Water Quality Objectives with a limit of 4 mg/l. However, the oxygen saturation level at site WQ3 was below the South African Water Quality for Aquatic life with 80-120% as a limit.

The coefficient of variation of DO (Dissolved Oxygen) between sites during sampling periods was low as it ranged from 1% at site WQ1 and WQ5 to 7% at site WQ4 and WQ7. Although the temporal variation between sites during the sampling period was low there was a significant difference ($p<0.05$) between sites upstream (WQ1) and downstream (WQ3, 5, 7) in DO levels (Table 5.3).

Turbidity levels

The average turbidity levels from the sites were between 47.4±21.76 NTU and 84±27.50 NTU as shown in Table 5.2. The highest level was observed at site WQ 3 with 118 NTU on the 05 February sampling campaign and lowest at site WQ1 and WQ7 with 32NTU on the 19 February sampling campaign (Appendix G, Table 7.4). All the turbidity levels observed exceeded the maximum value of Swaziland's Water Quality Objective which has a limit of 5NTU (Table 5.1). Significant differences ($p<0.05$) were observed between site WQ1 (upstream) and sites WQ 3 and WQ 5, adjacent to sugarcane fields (Table 5.3).

Figure 5.11 illustrate a relationship between turbidity and diversity using Simpson's index. It can be observed that there is a significant relationship ($p<0.05$, $r=0.930$) between turbidity and diversity using Simpson's diversity index (1-D). The relationship shows that at low turbidity levels (47 NTU) diversity is 0.82 as turbidity increases to 50 NTU diversity increases as well. High diversity can be observed at a range of 50-55 NTU. However, at 70 NTU macro-invertebrates diversity tends to show a steady steep decrease until the last point with the highest turbidity level.

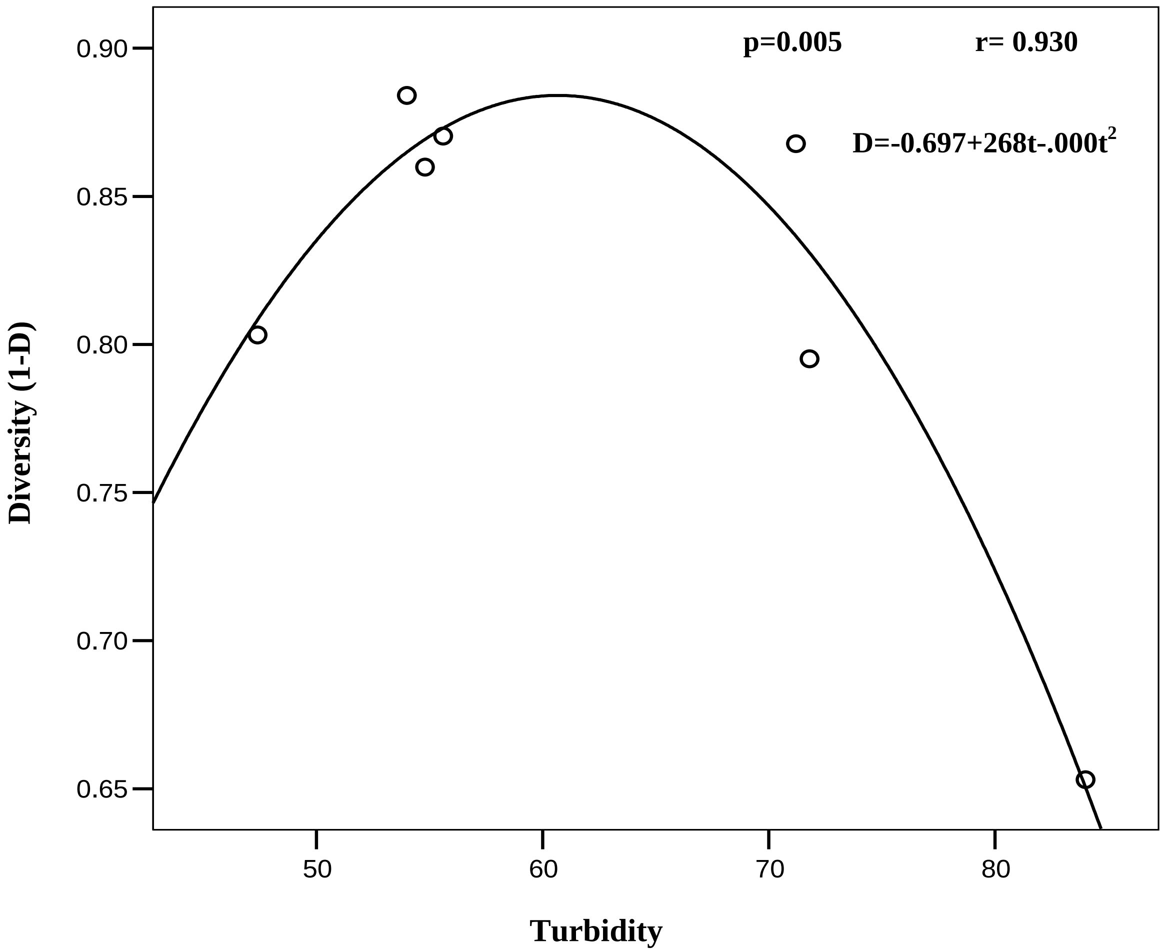


Figure 5.11 Relationship between turbidity levels and diversity (1-D) of aquatic invertebrates along the Lower Komati River.

The relationship between turbidity and diversity follows a uni-modal quadratic shape; it first shows a positive relationship. After maximum diversity is reached there a negative relationship between turbidity and diversity is shown. However, there was no significant relationship ($p<0.05$, $r=0.35$) between diversity and turbidity using Shannon-Weiner' diversity index and richness.

pH levels

The waters were neutral to slightly alkaline with pH values ranging between 7.14 at site WQ3 to 7.4 at site WQ6 (Table5.2). The pH at all sites during the sampling period fell within the target in the Swaziland's Water Quality Objectives ranges for aquatic health, irrigation, aesthetics and human health set at 6.5 and 8.5. Coefficient of variation was between 1% and 8% as shown in Table 5.2. However, there were no significant differences ($p>0.05$) in pH values between sites (Table 5.3).

Conductivity levels and Total Dissolved Solids

Average Electrical Conductivity (EC) levels were between 95.2±22.5 µS/cm and 118.5±38 µS/cm from site WQ5 and WQ1 (Table 5.2). The highest EC value was 55.4 µS/cm recorded at site WQ 7 upstream and lowest was 172.4 µS/cm at site WQ 3(Appendix G, Figure 7.6). TDS average range was between 85.9±27.60mg/l and 69.08±21.76mg/l. The TDS concentrations were directly proportional to the EC levels. Results show that when conductivity is high, TDS will also be high. Between all the sites there was no significant difference ($p<0.05$) in conductivity levels (Table 5.3).

The coefficients of variation (CVs) for all the measured water parameters in Table 5.2 were low since they were all less that 50%. The low CVs indicate a slight temporal change in water quality conditions of the streams during the sampling period. Turbidity was the only parameter that exceeded the limit set by the Swaziland Water Quality Objectives for aquatic health, irrigation, aesthetics and human health of 5NTU at all sites during the whole sampling period. The water quality parameters only exceeded the set limits at certain sampling periods. Thus in this study only turbidity was included in subsequent analyses to explain diversity in the Lower Komati River.

Table 5.4 presents average values, standard deviation, and standard deviation percentage of Ammonia, nitrates, nitrites, ortho-phosphates sampled and analysed between February 2009 and April 2009

Total Nitrogen

In this study total nitrogen will be the sum of ammonia and nitrates, this is mainly because, fertilizers used in the agricultural fields along the river are mainly inorganic. Nitrite levels measured were also in trace levels as shown in Table 5.2, thus will not be considered in further analyses. Average ammonia levels (ammonium ion; NH_4^+) were between 0.29±0.40 mg/l (WQ1) and 0.52±0.43 mg/l (WQ3) as shown in Table 5.2. The range for ammonia was between 0.13mg/l at site WQ7 to 0.25 mg/l at site WQ 3 (Appendix G, Figure 7.9) and this range was within Swaziland's Water Quality Objectives of 0.6mg/l.

On average, nitrate levels were between 0.02 mg/l and 1.22 mg/l (Table 5.3). The range on the other hand was between 0 mg/l from site WQ1, WQ 7 and 1.53 mg/l at site WQ3 and WQ5 as shown in Appendix G, Figure 7.10. In essence, total nitrogen in the river on average was between 0.315 mg/l and 1.62 mg/l. Total nitrogen's temporal variation was high between sites during the sampling period. Ammonia levels were between had a coefficient of variation ranging from 83% and 138% whilst nitrate was between 96% and 216%. However, there was no significant difference (p>0.05) between sites with respect to nitrate and ammonia levels during the sampling period (Table5.3).

Table 5.4 Summary values for ammonia, phosphates, nitrates and nitrites (mean, standard deviation (SD) and coefficient of variation (%)) for the sampling sites between February and April 2009

Site		Ammonia (mg/l)/N	Nitrates (mg/l)/N	Nitrites (mg/l)/N	Ortho-phosphates (mg/l)/P	Total inorganic nitrogen (mg/l P
WQ1	Mean	0.29	0.02	0.005	0.19	0.315
	SD	0.40	0.04	0.005	0.23	
	CV (%)	137	200	100	121	
WQ2	Mean	0.37	0.46	0.013	0.013	0.63
	SD	0.41	0.53	0.012	0.65	
	CV (%)	110	115	92	103	
WQ3	Mean	0.52	0.98	0.018	1.4	83.24
	SD	0.43	1.33	0.019	1.09	
	CV (%)	82	135	105	77	
WQ4	Mean	0.39	0.82	0.014	0.78	74.41
	SD	0.46	0.94	0.010	0.69	
	CV (%)	117	114	71	88	
WQ5	Mean	0.39	1.22	0.011	0.66	1.62
	SD	0.39	1.18	0.011	0.79	
	CV (%)	100	96	100	119	
WQ6	Mean	0.42	0.66	0.0078	0.91	1.087
	SD	0.56	0.72	0.007	1.16	
	CV (%)	133	109	89	127	
WQ7	Mean	0.34	0.06	0.004	0.67	0.404
	SD	0.44	0.13	0.004	0.69	
	CV (%)	129	216	100	102	
% Samples exceeding limit	-	0	0	-	-	-
SD-WQO	-	0.6	10	-	-	-

n = 5   SD-Standard deviation   a- SD-WQO-Swaziland Water Quality Objectives

Phosphates

From Table 5.4 it can be observed that the average phosphate levels were between 1.4±1.09mg/l and 0.19±0.23mg/l. The range was between 0.11mg/l in site WQ 1 and 0.78mg/l at site WQ3 (Appendix G, Figure 7.11) The phophates levels were significantly different ($p<0.05$) between site WQ1 and WQ3 along the lower Komati river.

5.1.4 Identifying primary parameters to water quality

Table 5.5 illustrates the Principal Component (PC) loading matrix in which loading contribution of each water quality parameter in a PC is shown. It can be observed that two PC's were produced. Component 1 and 2 were identified based on the scree plot's slope (Appendix H, Figure 7.13). After PC 2 a slope was observed thus subsequent PC's were discarded for analyses. It is assumed that these two PC's contain water parameters that explain the water quality status of the catchment satisfactorily.

Component 1 explains 59.75% of the total variance shown in (Appendix H, Table 7.10). Since the components show loadings of the measured water quality parameters. Component 1 shows a strong positive loadings (>0.75) of turbidity, conductivity, temperature, dissolved oxygen (DO), saturation, nitrates, phosphates with a strong negative loading (-0.754) of DO (Table 5.5). So, DO has an inverse relationship with the other parameters in the component.

Table 5.5 Component loading matrix showing loadings of physico-chemical parameters on significant principal components.

	Principal Components	
Variables	1	2
Turbidity	**0.825**	**0.500**
Conductivity	**0.920**	0.025
pH	-0.541	-0.355
Temperature	**0.757**	**-0.560**
Dissolved oxygen	**-0.754**	**0.652**
Saturation	**0.912**	0.318
Nitrates	**0.878**	0.309
Phosphates	**0.774**	0.193
Nitrites	**0.825**	-0.424
Ammonia	0.359	-0.175

*Bold values signify variable with significant loadings in that component.

The second component explains 15.48% of the total variance (Appendix H, Table 7.10). The second component has a moderate positive loading of turbidity and DO (0.500, 0.652, respectively) and a moderate negative loading of -0.560 on temperature (Table 5.5). In component two, temperature has an inverse relationship with turbidity and dissolved oxygen since it has a negative moderate loading with turbidity and dissolved oxygen having positive moderate loadings. Ammonia does not load significantly on any component captured.

Figure 5.13 illustrate that there is a significant relationship ($p<0.001$, $r=0.92$) between diversity (H') and Principal Component 2 which captures turbidity and dissolved oxygen. It can be observed that diversity tends to decline down with the slope. At high levels of Principal Component 2 (high turbidity, dissolved oxygen and low temperature) diversity will also be high and when it declines diversity follows the same trend. The optimal range for species diversity in Component 2 is between -1.0 and 0.0 which is when the relationship between the variables in the component does not exist. Diversity shows a decrease when Principal Component is at 0.5 and is at lowest when PC 2 is at 1.5. This shows that as the principal component increases diversity decreases.

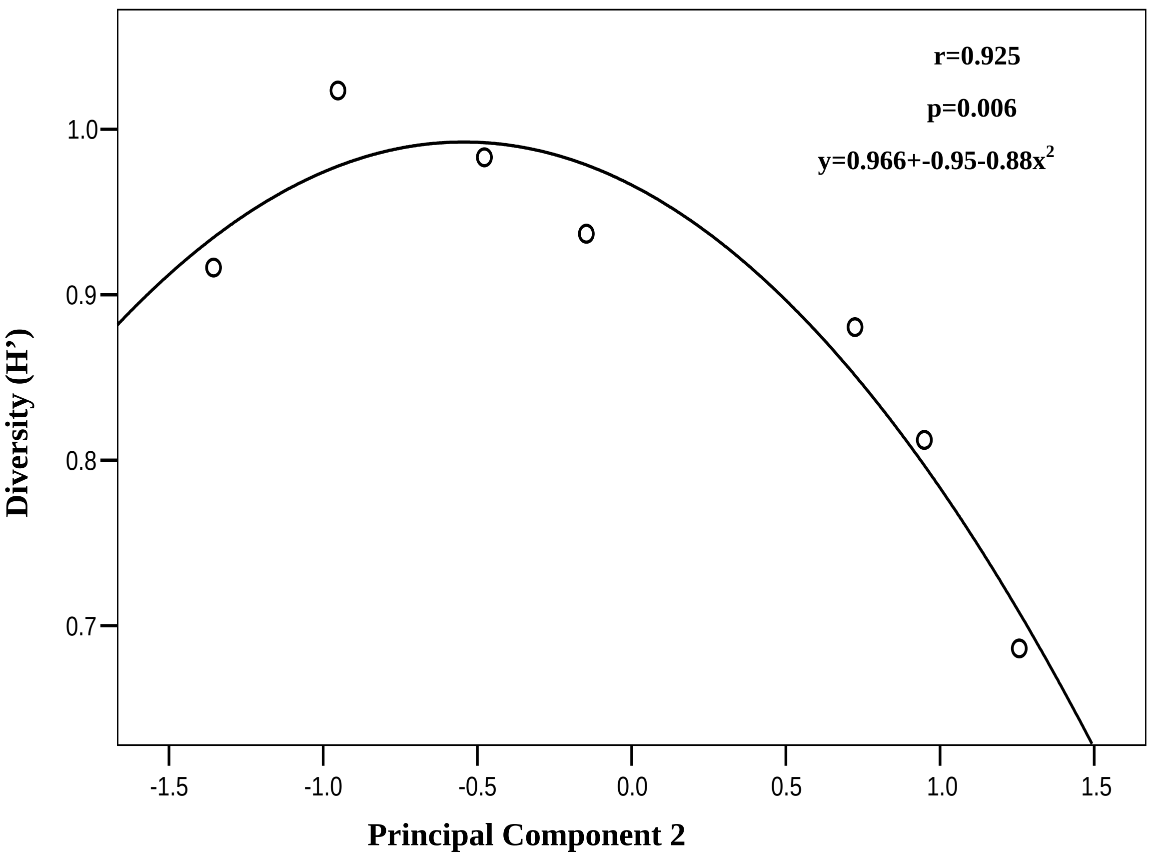


Figure 5.12 Relationship between diversity (Shannon- Weiner index) and Component 2 (Turbidity , Dissolved oxygen and Temperature)

Figure 5.14 illustrate a significant relationship ($p<0.001$, $r=0.886$) ,between diversity (1-D) and principal component 2 which captures turbidity and dissolved oxygen positively and temperature negatively. The relationship shows a similar trend with diversity calculated using Shannon-Weiner diversity in the previous paragraph. When the relationship between the water quality parameters (high turbidity, dissolved oxygen and low temperature), captured as component 2 increases diversity decreases as well.

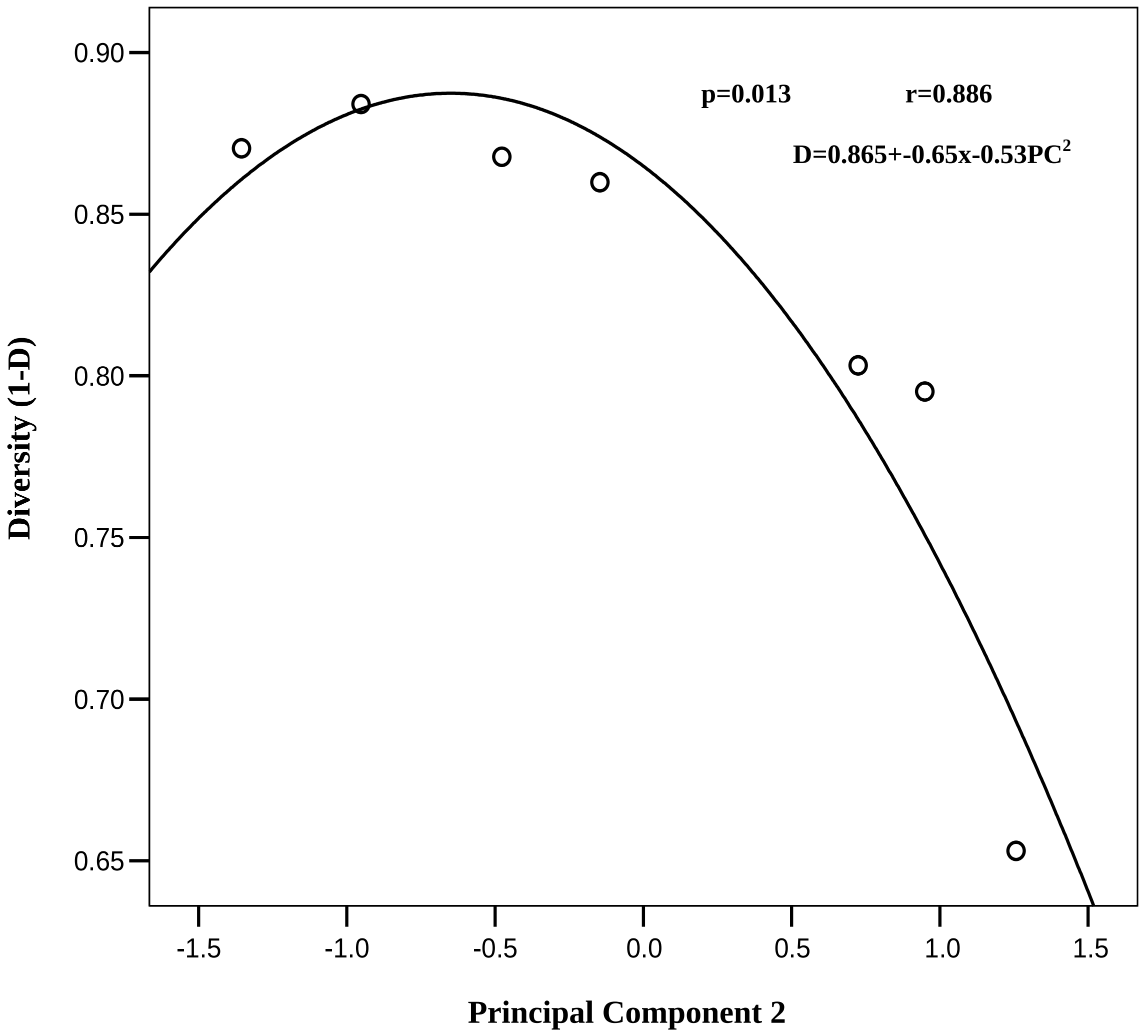


Figure 5.13 Relationship between diversity (Simpson's diversity index) and Principal Component 2 (turbidity and dissolved oxygen and temperature)

Overall, it can be observed that there is a positive significant relationship between Principal Component 2 and diversity using Simpson's and Shannon-Weiner diversity indices. When the relationship between the water quality variables in the Principal Component increases diversity decreases, if the relationship is non-existent diversity is at optimum. Basically, this shows that a high turbidity and oxygen levels coupled with decreasing temperature levels will result in low diversity.

5.2 Discussion

5.2.1 Spatial variability of diversity

The results indicate that richness along the Lower Komati River is affected by agricultural fields. A summary of taxa sampled in 2009 indicate that most of the taxa were highly tolerant to inorganic pollution, since 19 species which can be regarded as highly tolerant to inorganic polluted water and 12 moderately tolerant to inorganic pollution were sampled. Only two sensitive families Pyralida and Amphipoda which are highly intolerant to pollution were found during sampling and these came from site WQ1 upstream. (Appendix B, Table 7.3). According to Roux (1999) in ecological terms these taxa could act as indicators; in the event of pollutant entering the system since they are easily affected by pollution. They can therefore be seen as "early warning" or indicator species of an ecological shift within the system.

The results further indicate that WQ1 was the most diverse as it had all the main families than the other sites. So, site WQ1's structure was indicative of a healthy system. WQ3 on the other hand had the least heterogenic structure since it comprised of 2 main families(Odonata and Hemiptera) compared to the 4 found in the river at the time of sampling. This was observed by Galbrand et al. (2007) who found out that, rivers with diverse family structures are excellent indicators of a healthy system. This is mainly because diverse families require different conditions and functions of the system. So, it can be deduced that WQ3 was the most polluted as it indicate an unhealthy ecosystem, as it can not support diverse families.

Furthermore, the results show that, macro-invertebrates diversity along the Lower Komati River was high upstream before the sugar-cane fields. However, diversity deteriorates in sites draining the sugar cane fields and picks up again after the fields. This trend implies that even though diversity deteriorates in sites adjacent to the sugar cane fields, which may be due increased nutrient levels, it manages to recover again after the sugar cane fields. The same trend was observed by Mthimkhulu et.al (2005) along the Mbuluzi River in Swaziland, where pollution sensitive species disappeared along agricultural fields but re-appeared again after sugar-cane fields. Therefore it can be said that diversity may be affected by sugar cane fields through increase of organic pollution, but it can manage to recover at sites after the sugar-cane fields.

The inconsistency in diversity of site WQ4 and 5 to other sites draining sugar cane fields signifies a significant contribution of the Mpofu tributary joining the river at that site WQ4 and the contribution of spillage from the sand river dam at WQ5. The dam spillage and contribution of the tributary seem to be significant to dilute the organic pollution brought by the agricultural activities. This is mainly because the pollution levels at this sites decrease which may explain the increase of diversity in the site. However, increased richness along WQ3 during the campaign conducted 23 March can not be fully used as an explanation of an ecosystem health indicator. All of the taxa sampled along WQ3 on the 23 March were mainly highly tolerant to pollution i.e. Thiaridae, and Muscidae, Vellidae, Ashnidae, and no intolerant taxa was observed in this site at the time of sampling. Ravengai et al. (2004) on the yellow Jacket observed that when pollution levels increased, intolerant taxa disappear and tolerant taxa will dominant the site. Therefore, it can be said that siteWQ3 was the most polluted. In this study since tolerant species dominated the site it can be said that it was mostly polluted.

On the other hand, despite the diverse locations of site WQ1 and WQ7, diversity along these sites was almost comparable. Diversity increased at site WQ7 which was 1km downstream of the agricultural fields. It was generally expected that site WQ1 since it is upstream of the agricultural fields will have higher diversity than all the sites and that WQ7 will show a slight increase in diversity of species. This is mainly because literature has shown that diversity tends to recover after the removal of that environmental perturbation that affect the diversity (Mthimkhulu et al.,2005; Galbrand et al.,2007; Vinson et al.,2008). However, it was not anticipated that the diversity of the two sites will be comparable. Therefore it can be deduced that species diversity can be affected by agricultural activities, however, species can manage to recover after certain a certain a period. However, in this study the purification level of the river could not be fully determined since river purification from pollutants is dependent on a number of factors which include the flow rate and volume of water in the river in which the latter was not determined.

The results further indicate that the diversity indices used in the study follow the same trend as other ecosystem health indicators usually used with SASS5 method. Using SASS5 scores the range was between 4 and 55 which were from site WQ 3 to site WQ 6 respectively (Appendix B, Figure 7.1). ASPT scores ranged from 2 to 10.5 at site WQ3 and WQ1 respectively as shown in Appendix B figure 7.2. Both scores are low at site WQ3 which indicates deterioration in the ecosystem health. This is supported by Dallas (2000) who stated that sites which have lower SASS scores suggest a declining river health. This trend was equally observed in this study using richness, Shannon-Weiner and Simpson's diversity indices as site WQ3 had the lowest diversity using all the indices. Therefore, the SASS5, ASPT scores are comparable to the diversity indices as site WQ3 was identified as having the mostly deteriorated ecosystem health than all the sites. So, diversity indices can be safely used to predict ecosystem health as they are comparable to the SASS5 scores and ASPT (Average Score Per Taxa) which have been widely used successfully by Dallas, 2003; Mthimkhulu et al., 2005; Galbrand et al., 2007 to indicate ecosystem health of rivers.

The significant variation in species diversity can be attributed to several factors on the environment. According to Kleyhans (1996) abiotic factors influencing habitat integrity, pollution and sedimentation may influence the distribution of species. In this study important factors considered were abiotic factors since they can influence habitat integrity as well as pollution from agriculture. From the habitat integrity classes' data indicate that the habitat quality might have deteriorated in some sites. However, the quality of the habitat can not be used as a primary determinant of macro-invertebrates diversity. Sites from the same habitat class showed diversity variation relative to their location from the agricultural fields than habitat class. Although site WQ 1 and WQ 3 were from the same class of habitat integrity they still differed in diversity relative to their location from the agricultural fields. Although the sites were classed under one group of habitat integrity WQ1 had high diversity since it was upstream of the sugar cane fields and WQ 3 had low diversity since it was along sugar cane fields. Therefore, this shows that agricultural pollution had more influence that habitat integrity in determining species distribution. This is in contrast with Karaus (2004) who argues that invertebrate communities in lotic ecosystems tend to diverge compositionally with habitat integrity variability as local invertebrates assemblages are mainly controlled by local habitat conditions.Therefore; in this study the condition of the habitat was not a major determinant of the differences in aquatic macro-invertebrates diversity along sites.

The results further revealed that although, there seemed to be differences in taxon richness and diversity between sites, results indicate that the differences are not significant ($p>0.05$). This implies that there is no marked longitudinal zonation of invertebrate’s diversity along this section of the river in relation to sugar-cane production. Since there is no clear longitudinal pattern of changing diversity it appears unlikely that sugar-cane production played a significant part in determining the presence or absence of taxa in the river stretch during the sampling period. Similar results were found in a study by Fishar et al. (2006) along the Nile River where there was no significant relationship between macro invertebrates’ diversity despite an increase in a variety of dissolved salts and an overall increase in ionic concentration in a downstream direction due to agriculture, domestic and industrial activities.

The lack of significant difference between the sites could be explained by that the agricultural project along the Komati River is still in its mid term and any perturbations on the ecosystem health may have not yet accumulated to show any evidence. According to Birunga et al. (2007), some elements have to accumulate and be concentrated on the food chain before they can affect the distribution of aquatic species. Furthermore, it could be because of the time of sampling as it was during the summer season when the river had high flow rates (Appendix F, Table 7.11) and according to Chapman (1996), the distribution of organisms is strongly influenced by the movements of overlying waters and well mixing which can create spatial homogeneity. So, some species might have been moved by the high flows, migrated to areas of low flow thus creating homogeneity in the diversity between sites. For example according to Gerber and Gabriel (2002) the amphipoda is usually found in sites which have muddy sediments and leaf litter; however, in this study some of these taxa were sampled in sandy and pool habitats. This implies that they might have been moved by the high flow rates. Furthermore, the insignificant relationship between diversity between sites could also be due to the fact the sampling was limited to two months in summer. According to Dallas (2003) seasonal variability can show significant variation in species between sites as some species migrate with change in season conditions such as flow rate and temperature.

The study could not compare with historical data because of differences in the location of sites and different season of data collection.

5.2.2 Water quality parameters and diversity

The results indicate that temperature, Dissolved Oxygen(DO), conductivity, total nitrogen,ortho-phosphates, could not explain the diversity of macro-invertebrates along the Komati during the sampling period. Similar results were found by Trelo-ges et al. (2004) where water quality data in sugar catchments was found to be within guideline ranges and only increased in cases of pollution events like excess application of fertilisers followed by a heavy rainfall spate. Temperature ranges were within the SD-WQO (Swaziland Water Quality Objectives) which have a limit of 20-25 ^{o}C for aquatic life means of survival. Even the 26.56 ^{o}C which is slightly above limit of 25 ^{o}C reached at site WQ5 (Table 5.1), could not limit diversity . This can be confirmed by Davies and Day (1998) found out that because of the conflicting effects of high and low temperatures all organisms have an optimal range for growth and can often survive outside their optimal range espcially for shorter periods.

On the other hand, dissolved oxygen and oxygen saturation levels indicate that the water quality along the Lower Komati has been slightly depleted. This is supported by, DWAF (1996) which state that maximum saturation concentrations of less than 100 % saturation indicates that dissolved oxygen has been depleted from the theoretical equilibrium concentration. Although the oxygen levels have been slightly depleted, they are still above the limit set by the Water Quality Objectives of Swaziland at 4mg/l. This suggests that the oxygen levels therefore may not be a limiting factor to the diversity of macro-invertebrates along the Komati River at the time of sampling. This is supported by Chapman (1996) who observed that it is at concentrations below 5mg/l that the survival of biological communities will be affected, thus changing diversity structure. This is in contrary to findings by Fishar et al. (2006) who reported a positive significant relationship between DO and macro invertebrate fauna in the Nile River. The differences may be due to the levels of dissolved oxygen, in the Nile 90% of the time they were less that 3mg/l for a season. So, the lack of significant relationship in this study may be due to the oxygen levels as their significance to aquatic biota depends on the frequency, timing and duration of such depletion. During the sampling period all the levels were above 6mg/l with only one sampling campaign recording 5mg/l. Brainwood et al. (2004) discovered that it is only at continuous and rapid exposure that adverse effects on macro-invertebrates will be significant. Occasional short-lived depletion of oxygen levels is less important, thus can not be used as a primary influence of species diversity in this study.

On the other hand, most of the macro-invertebrates taxa sampled during the study can survive in dissolved oxygen tension areas i.e. Gyrinidae, Hydrophilidae, Gerridae and Corixidae as they usually float on quiet and surfaces of streams. According to Galbrand et al. (2007) Corixidaes are not dependent on DO from the water column, as they breath air from air bubbles under their wings obtained from the atmosphere. So, the oxygen requirement of these organisms is not high, thus this explains why dissolved oxygen may not be a limiting factor to the diversity of macro-invertebrates in this study.

The pH results indicate that the waters from the lower Komati River during the sampling period were almost natural. According to Davies and Day (1998) most natural waters' pH values range from 6 to 8. This implies that the Lower Komati River has the capacity to buffer it's self as indicated by Li et al. (2007) that most rivers have a buffering capacity which affects the rate of change of pH in aquatic ecosystems as they tend to resist rapid change of pH especially when the flow is high. It is expected that most aquatic species will tolerate and reproduce successfully within this pH range. Moreover, since the river is well aerated the dissolved oxygen may have decreased any effect of pH. DWAF (1996) argues that high concentrations of dissolved oxygen may decrease the effect of high pH values; this is common particularly if alkaline conditions are the result of intense photosynthetic activity of aquatic plants, which is normally accompanied by high levels of dissolved oxygen. This could be the case in the study area as site WQ7 had in-stream aquatic plants (Appendix E, Table 10) with pH levels slightly above pH 7 but it still had diversity comparable to site WQ1 which had almost neutral pH during the sampling period. Therefore, pH can not be used to explain the trend in species diversity along the Lower Komati River.

Since TDS was derived from conductivity results indicate that the water quality along the lower Komati have not been affected by conductivity and TDS (Total Dissolved Solids). This is in contrary to findings by Mhlanga et al. (2006) in the Mbuluzi River Swaziland; it was found that conductivity from sugar cane was significantly affecting water quality. The insignificant contribution of conductivity in the Lower Komati is mainly because of dilution of the ionic concentration due to high flow rates which was not the case in the Mbuluzi River. The conductivity values obtained in the study area conform to the Swaziland's Water Quality Objective guideline value so, it is unlikely that the water quality will be affected and aquatic life is likely to tolerate these levels. Little is known about the tolerance levels of aquatic organisms to changes in TDS concentrations but generally according to Davies and Day (1998) the rate of change and duration are more important than absolute TDS changes, especially in systems where organisms are not adapted to fluctuations in TDS. In this study not much is known about the adaptation of macro-invertebrates to the TDS results.

The water quality in the Lower Komati River during the sampling period had been slightly impacted by total nitrogen which is made of nitrates and ammonia. This was mainly because the total ammonia concentration measured was above 0.2mg/l of N which is a limit typical for surface water as suggested by DWAF (1996). With the surface water limits for ammonia levels exceeded it means that the water has been polluted, however, the pollution levels are still within the river's water quality objective set at 0.6mg/l of N. No impact on diversity can be expected from these levels of ammonia as it tends to be toxic to aquatic life at levels above 1 mg/l. Nitrate results also indicate that the water has been slightly affected by the agricultural pollution since Chapman (1996) states that natural water concentration should not exceed 0.1 mg/l and those affected by certain activities usually exceed 1mg/l of N. So, since the concentration in the Lower Komati River slightly exceeded the stipulated limits the water therefore was said to be slightly polluted with nitrates. However, there is no significant difference ($p<0.05$) between site WQ1 and WQ3 which are upstream and downstream respectively. Given the fact that, nitrite levels were available in trace elements they will not be considered but assumed that they were oxidized to nitrates.

Relating diversity with total nitrogen, results indicate that there is no significant relationship, which implies that the diversity pattern can not be explained by total nitrogen in the lower Komati. Anzecc (1992), states that, ammonia levels are usually less toxic to macro-organisms at temperature levels up to 25^{oc}, and pH range of 5.8 to 7.1, and this was the case in the lower Komati. This can be due to the fact that various physico-chemical parameters need to have a synergic effect with others for them to have an effect on the species. So, the low temperatures and pH levels within that range could not aid, ammonia to be toxic in the system.

Phosphorus results indicate that the water quality along the Lower Komati River has been impacted since it has levels exceeding the range of natural waters from 0.005mg/l to 0.020mg/l as suggested by Chapman (1996). No limits are stipulated on the water standards for phosphorus, this is because phosphorus in water is not considered to be directly toxic, any toxicity by phosporus in freshwater is in direct (Carpenter et al.,1998). The signficant difference in phosphorus levels between sites WQ3 and WQ1 can be due to the fact that these sites had minimum and maximum oxygen levels respectively. Low dissolved oxygen levels are known to favour phosphorus release to the water column. This is supported by Kannel et al.(2008) who argue that aerobic conditions do not favour the release of phosphorus in surface water, so there is more phosporus release in aerobic conditions. Thus, the impacts of phosphorus on water quality were mainly on site WQ3 because of the low oxygen levels. Carpenter et al.,1998 state that elevated phosphorus levels can increase a system's productivity and result in large amounts of organic matter falling to the bottom. Bacteria or other organisms decompose this matter using a lot of oxygen.

In this study, nitrogen levels were not significantly different between sites whilst there was a significant difference in phosphorus level. This is due to the fact that half of nitrogen is applied to the field in the first 4 months, and easily taken up by plants in the early stages. During the time of sampling the sugar cane fields were between 3-6 months thus nitrogen was easily taken by the plants and only half of the total requirement was applied which was 30kg/ha. Furthermore, nitrogen is soluble in water thus making it easier for plants uptake. Moreover, planted crop losses of N beyond the root are greater than losses from ratoon crop. Since some of the fields had planted crops the nitrogen might have been taken by plants and absorbed beyond the roots. On the other hand phosphorus is applied all at once whilst it can not easily dissolve in water. Most of the phosphorus might still have been available in the soil and carried though soil erosion to the stream. Trelo-ges et al. (2004) discovered that substantial amounts of phosphorus remain in the soil especially at moderate to high yields. This was mainly because P (phosphorus) is not easily soluble in water thus it is less likely that can it be lost through water-flow both laterally and vertically. Therefore the phosphate found in the water column is likely to have been transported through soil erosion as turbidity levels were also high indicating soil erosion effects.

Turbidity results indicate a significant difference ($p<0.05$) between the upstream and downstream sampling sites and this might be an indication that agricultural land-use for sugar-cane has an effect on water quality through increased turbidity levels along the lower Komati River. The effect may be due to increased soil erosion which might have been exacerbated by the summer rains, as observed in sampling campaign 1 and 4 which had the highest turbidity levels; this may be due to the fact that these sampling dates were on wet days (Appendix F, Table 7.11).

This can be supported by Davies and Day (1998) who realized that natural turbidity often increases with rainfall as spates wash particles from surface soils to rivers. Therefore, this implies that increased turbidity could be due to increased erosion from the fields which might have carried the phosphorus in the soil.

Furthermore, the results indicate a significant relationship between turbidity and diversity. This relationship indicates that turbidity in this study can be used to explain the trends in macro-invertebrates diversity along the lower Komati River. Turbidity levels less than 55NTU and at levels more than 60 NTU; diversity can not adequately support diversity. It is only at turbidity levels between 50 and 55NTU that diversity of macro-invertebrates along the Lower Komati River can be adequately supported, thus it increased. Basically, this implies that 50 to 55 NTU can be identified as the optimum range for macro-invertebrates survival in the lower Komati River. The maximum diversity at the optimum range could be due to the fact that turbidity is caused by colloidal matter which includes particles of silt and clay, dead and living organisms and particulate organic matter. This form of matter can be food to the aquatic macro-invertebrates. In essence, the colloidal matter at this range is adequate for the organisms to survive as they use it as “food”. Mason (1996) state that the Naucoridae rely on the substrata and colloidal material for food. Therefore, it can be deduced that when the turbidity levels are between 50 and 55 NTU, the colloidal matter is adequate for the organisms to survive in the Lower Komati River.

The diversity of aquatic macro-invertebrates in the Lower Komati River decreased as the amount of colloidal matter in the lower Komati River increases. Worth noting, is that the Naucoridae and Odonata were only found in sites with turbidity levels between 55 and 60 NTU and disappeared in sites with less turbidity levels (WQ1, WQ2). This implies that the range could be their optimum range of survival. This was mainly because most of the taxa rely through the skin for their source of oxygen so high turbidity will clog their skin pores. However, if the amount of colloidal matter increases diversity decreases.

Moreover, the colloidal matter when it decomposes uses up a lot of oxygen thus will reduce oxygen levels which are equally essential for their survival. Therefore, fewer organisms will survive when the turbidity levels are high. In addition, physically the increased turbidity levels may reduce light penetration, leading to a decrease in photosynthesis. The resultant decrease in primary production reduces food availability for aquatic organisms higher up the food chain. This is further supported by Davies and Day (1998) who indicated that highly turbid water impairs vision of organisms, clogs their gills and also interferes with the feeding mechanisms of filter-feeding macro-invertebrates i.e. Trichoptera larvae breathe through sensitive gills which are easily damaged and clogged by particulate matter. As a result, many species of this family were unable to withstand turbid conditions; as a result it was only recorded once in site WQ1 upstream.

The relationship between turbidity and diversity follows a uni-modal species response curve. That is, species diversity peak at some intermediate part of the turbidity levels. This pattern follows a model suggested by Caspersen et al. (1999) who stated that biota along an environmental gradient will tend to show a quadratic curve as it elucidates mechanisms underlying the distribution and abundance of species. This can be explained by the fact that species tend to cluster at optimum conditions and disappear at low and very high levels of environmental variability depending on the species tolerance levels and gradient type. This is mainly because environmental gradients are heterogeneous and that is shown through the response of species on the landscape. Therefore, in this study varying turbidity levels between sites explain the diversity pattern in the Lower Komati River.

The impact of agriculture on the lower Komati was limited since most water quality parameters which indicate agricultural pollution were below their thresholds and the control and experimental did not show any significant difference. Only turbidity and phosphates showed significant differences between the control and experimental sites. The significant differences indicate that the agricultural activities have an impact on the water quality through turbidity and phosphorus. However, no significant relationship was found between phosphates and diversity, meaning that phosphates could not explain diversity patterns in the Lower Komati River. This is in contrary to studies which indicated that streams on commercial agricultural farms are said to be polluted with fertilisers and chemicals, have high nutrients levels thus diversity could be explained by the nutrient levels (Magadza, 1997; Davies and Day, 1998). In this study little or no evidence can support these findings nor can the nutrient levels (Total Nitrogen and phosphates) explain the diversity along the river. This is consistent with a study by Gratwicke et al. (2003) where no relationship was found between water quality along commercial agricultural farms and fish diversity. In this study, turbidity was the only parameter which explained the diversity of macro-invertebrates. This suggests that turbidity was the primary influence of species richness and diversity along the Komati River. Although, the other water quality parameters did not show any significant relationship with diversity, it does not mean they do not have any impact on the diversity but they act as secondary factors with turbidity to influence diversity.

PCA analysis loading plot results which group related water quality parameters indicate the importance of the other water quality parameters in the river as secondary factors to turbidity. The results indicate that component 1 made of a correlation from turbidity, conductivity, temperature, dissolved oxygen, saturation, nitrates, and phosphates signifies that pollution is likely from agriculture. The component shows a high positive loading in parameters which are mainly associated with agricultural pollutants in rivers. The highest loading was from turbidity and phosphorus, and nitrates indicating sediment deposition containing nutrient from agricultural land. This is supported by Walters et al (2006) who observed that turbidity is usually brought from soils in the watershed, to the water body and can be an avenue through which nutrients may enter the water body. In the lower Komati phosphorus and nitrogen are the main nutrient used in fertlisers. Carpenter et al. (1998) support that phosphorus, nitrates and ammonia are the common nutrients and are associated with mineral constituent of sediments in agricultural catchments and are easily released to the water column through erosion

The erosion of phosphates and sediments to the water column is in the catchment could be due to the fact that ploughing is frequent in the catchment. Ploughing breaks the soil into small particles and most cultivator implements breaks the soil and the sugar cane fields. Since ratoon in the lower Komati is twice it means that preparatory tillage is most frequent and the soil is most susceptible to erosion which might increase the turbidity levels. Ratoon crops require minimum tillage and the canopy closure is earlier that a planted crop, so more ratoons greatly reduces soil erosion. This can be supported by Turner et al. (2004) who found out that soil erosion was lower during the ratoon crop year compared to fallow and planted-crop periods. This was mainly because of better ground cover which reduced the vulnerability of the soil erosion and minimal tillage.

In addition, sugar-cane grows slowly for the first few months and does not cover the soil until 4-5 months after planting. During the first 3-4 months, the cane makes little demand on the available space, water and nutrients thus the soil is susceptible to erosion and the applied nutrients can be easily washed away before they can be taken up. If released to the water column ion levels will increase resulting to conductivity increase as well. So, the absorptive properties of fine sediments coupled with the tendency of nutrients to bind to particles and be released to the water column makes turbidity and nutrient concentration and conductivity levels good indicators of the effects of the agricultural fields on water quality. Therefore, because of the rainfall events, during most of the sampling campaigns and exposed soils as the crops were within 3-6 months and mostly were planted, an easy pathway for nutrients and soil erosion to the river was created.

The clustering of the water quality parameters in Component 2 suggests an increase in solid material deposited to the river. The second component loading indicates a significant positive moderate loading of turbidity and temperature with a negative moderate significant loading o DO. This indicates the deposition of agricultural solids e.g. organic matter. So, the results suggest that with moderate turbid water, moderate oxygen will be available in the river leading to declining temperatures. This indicates that with increased oxygen and turbidity levels temperature levels will be equality reduced. This is mainly due to the fact that low temperature result in high oxygen levels in water. Furthermore, low temperatures will result is high turbid water as some solids in the water which fail to dissolve usually coagulate and be suspended in the water column.

Relating the principal component analysis results with diversity results indicate that component one made of high turbidity, conductivity, temperature, saturation, nitrates, phosphates and dissolved oxygen can not influence the diversity pattern in the Lower Komati River. Basically, macro-invertebrates diversity along the Lower Komati cannot be explained by the inverse relationship between turbidity, conductivity, temperature, saturation, nitrates, phosphates and dissolved oxygen. Lower levels of dissolved oxygen resulting from increased turbidity, conductivity, temperature, saturation, nitrates, nitrites and phosphates will not affect species diversity.

However, further analysis indicate that diversity can be explained by component two which is made of an inverse relationship between turbidity, dissolved oxygen and temperature. The relationship between component two and diversity was significant. So, this implies that the distribution of macro-invertebrates diversity in the Lower Komati River can be explained by increasing turbidity, dissolved oxygen levels which results in decreased temperature. The significant relationship between Component 2 and not Component 1 may be due to the fact that the latter is made of high dissolved oxygen which is the opposite of the former. According to Chapman (1996), DO is the principal factor in most aquatic ecosystems. So, the low DO in

Component 1 is the limiting factor, thus the component could not significantly explain diversity distribution in the Lower Komati River.

Overall, from the PCA analysis it can be concluded that turbidity is the main parameter affecting water quality. This is mainly due to the fact that turbidity retained a significant positive loading in all two Principal Components identified. This shows that turbidity was the primary parameter which influenced the water quality in the lower Komati River. This can be due to the fact that during the sampling period the stream-flow was high. According to Turner et al. (2004) increased stream-flow may result to river banks collapsed and thus create a pathway for nutrients and soil erosion which when deposited to the river increases turbidity levels. Furthermore, since the sugar cane crop was between 3-6 months the soil was susceptible to erosion which could have increased the turbidity levels making it a water quality parameter of concern in the catchment. Moreover, ploughing in the sugar cane fields is frequent since there are only two crop ratoons, thus the soil particles are easily washed to the water column. Turner et al. (2004) found out that soil erosion decreases as more ratooning is done. They further realised that soil erosion decreased during the ratoon crop year compared to fallow and planted-crop periods. This is mainly because of better ground cover which reduced the vulnerability of the soil erosion and minimal tillage as ratoon crops require minimum tillage and the canopy closure is earlier that a planted crop, so more ratoons may reduce soil erosion. Therefore, it can be deduced that turbidity levels are increased by soil coming from the sugar cane fields.

The high turbidity levels in the lower Komati River have implication on development treaty along the catchment. The development treaty states that land and water resources in the basin should be managed as to not result in the degrading of the existing environment and also that the all countries take all reasonable measures to ensure the protection of the existing quality of the environment. So, if the water quality is altered through turbidity the downstream users may be not able to use it. Therefore, the ratoon period should be increased to reduce the tillage rate in the catchment and mitigate any future changes in the water quality. Furthermore, site WQ3 should be a priority site in catchment management because of the high pollution and low diversity which indicates a deteriorated ecosystem due to inorganic pollution from the agricultural fields.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study concludes that land use for agriculture has minimal impact on ecosystem health based on the following findings;

1. There is no significant difference ($p>0.05$) in diversity between sites using Simpson's diversity index, Shannon Weiner index and richness indicating that although there might be variation in diversity it is not yet significant. The high stream-flow during sampling might have moved some organisms and created spatial homogeneity between sites.

2. There is a significant difference ($p<0.05$) in turbidity and phosphate levels between control and experimental sites along the Lower Komati River. This indicates that the water quality is impacted by sugar-cane growing activities with respect to turbidity and phosphates.

3. There is a significant relationship ($p<0.05$, $r=0.93$) between diversity and turbidity along the lower Komati River. This suggests that turbidity is the main parameter that determines the diversity pattern along the Lower Komati River and like all other environmental variables its heterogeneity in spatial occurrence results in a uni-modal species tolerance curve.

4. Principal Component Analysis (PCA) produced two Principal Components and all of them showed a significant loading in turbidity. This indicates that turbidity is the main parameter of concern in the catchment in altering water quality which should be a priority in catchment management.

6.2 Recommendations

1. Considering the fact that the study was carried out during the rainy season when the flow rates were high, and the 2008/09 rainy season had the highest average rainfall than the previous three years there is need for a similar study during the winter season when the flow rates have decreased. This would be to assess seasonal variation as well as pollution affects when the flow rates have decreased.
2. Secondly, further studies could be carried out to later when the agriculture production in the Lower Komati is on its long term as some elements are know to accumulate in the food chain.
3. Lastly, it is recommended that ratoon period be extended to avoid frequent tillage of the soil. Reduced tillage will mitigate soil erosion which increases turbidity in the catchment.

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APPENDICES

APPENDIX A: Rainfall data for 2003 -2009 along the Lower Komati

Table 7.1 Rainfall amounts for Madlangempisi station (Site 1)

Year	Rainfall amount (mm/month)											
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
2003	52	76.5	0	5	30.2	47.5	*	*	25	37	74.8	45
2004	166	108	150.5	30	3	8.5	26	0	20	44	68	107
2005	138	71.3	85.2	24	0	0	3	5.5	7.6	5.7	79	25.5
2006	125.5	155	111	28	0	0	22	14	16	44.8	106	*
2007	57.5	80	40	61	9	11	0	0	47.5	26	30	123
2008	111.4	55	36.1	*	*	15	0	0	12.5	14	121	24
2009	121.2	190	116.5									

Swaziland Government; Department of Meteorology (2009)

Table 7.2 Rainfall amounts for Mananga station (Site 7)

Year	Rainfall amount (mm/month)											
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
2003	42.6	104	4.7	3.5	13.9	22.9	0	0	29.9	22.4	28	64.6
2004	241.1	164	179.6	75	0	6.3	22.5	0.6	16.6	42.8	161.9	169.9
2005	163.3	106.5	30.7	21.9	7.4	0	5.5	5.5	7.6	5.7	135.7	28.1
2006	149.1	134.3	158.5	71.2	*	*	*	*	*	*	*	*
2007	16.5	90.5	70	108.5	6.5	23.5	10	46	35.5	*	69.3	159
2008	*	*	*	65.1	2.8	12.6	*	1.6	2.6	21.9	98.7	84.6
2009	147.8	186	124.3									

Swaziland Government: Department of Meteorology (2009)

APPENDIX B: Macro-invertebrates distribution and SASS scores indicating their sensitivities.

Table 7.3 Macro-invertebrates composition, distribution , abundance and their sensitivity scores sampled along the lower Komati River from February to April 2009 (site WQ1 –WQ4)

Order	Taxon	WQ4(Ngcayizivele)					WQ3(Mzimnene)					WQ2(Sidwashini)					WQ1(Madlangempisi)	
		05-Feb	19-Feb	05-Mar	23-Mar	06-Apr	05-Feb	19-Feb	05-Mar	23-Mar	06-Apr	05-Feb	19-Feb	05-Mar	23-Mar	06-Apr	05-Feb	19-Feb
Gastropoda	Thiaridae*																7	1
	Physidae							1	1									
Lepidoptera	pyralidae																1	
Diptera	Tabanidae																1	
	Ceratopogonidae																1	1
	Muscidae																	
	Simulidae		1															
	Culicida																	
Hemiptera	Gerridae*																	
	Corixidae*															7		
	Naucoridae		5	1	1	2		1	2		3	1					4	
	Hydrometridae*																	
	Notonectidae				1									3				
	Vellidae									1	1							
	Nepidae									1								
	Belostomatidae*						1										1	
Trichoptera	Ecnomidae																1	
	Hydroptilidae						1											
Crustacea	Potamonautidae*												1			2		
	Amphipoda				3								1			1		1
	Atyidae	1				3						3	3	2				2
	Palaemonidae	2											2					5
Turbellaria	Turbellaria	1						1										
	Noteridae											1						
Odonata	Protoneuridae														1			1
	Coenagrionidae		1			1					2							
	Cordullidae																	2
	Libellulidae									1				1	3			
	Aeshnidae									2	1							
	Calopteryggidae					1												
	Gomphidae													2				
Coleoptera	Gyrinidae									1								
	Elmidae										1							
	SASS SCORE	**21**	**16**	**7**	**23**	**25**	**12**	**10**	**7**	**25**	**32**	**20**	**34**	**13**	**13**	**19**	**31**	**55**
	NO OF TAXA	**3**	**3**	**1**	**3**	**4**	**3**	**3**	**1**	**5**	**5**	**4**	**4**	**3**	**2**	**3**	**6**	**7**
	ASPT	**7**	**5.3**	**7.0**	**7.7**	**6.3**	**4**	**3.3**	**7.0**	**5.0**	**6.4**	**6.6**	**8.5**	**4.3**	**6.5**	**6.3**	**5.1**	**7.9**

Table 7.4 Macro-invertebrates composition, distribution , abundance and their sensitivity scores sampled along the lower Komati River from February to April 2009 (site WQ5 –WQ7)

Order	Taxon	WQ7(Mananga 2)					WQ6(Mananga 1)					WQ5(Mpofu)				
Gastropoda		05-Feb	19-Feb	05-Mar	23-Mar	06-Apr	05-Feb	19-Feb	05-Mar	23-Mar	06-Apr	05-Feb	19-Feb	05-Mar	23-Mar	06-Apr
	Thiaridae*			3		1					2		30	1		
	Physidae															
Lepidoptera	pyralidae															
Diptera	Tabanidae															
	Ceratopogonidae															
	Muscidae											1				
	Simulidae															
	Culicida												1			
Hemiptera	Gerridae*				1							1				
	Corixidae*				1		1									2
	Naucoridae		2			1		2				1		1	8	
	Hydrometridae*	1														
	Notonectidae			1											2	
	Vellidae															
	Nepidae										3					
	Belostomatidae*	1						1							1	
Trichoptera	Ecnomidae															
	Hydroptilidae															
Crustacea	Potamonautidae*	1										1			1	
	Amphipoda	1	1		4					3					3	
	Atyidae			4	1				1	1					2	
	Palaemonidae	1	5				1									
Turbellaria	Turbellaria															
	Noteridae															
Odonata	Protoneuridae															
	Coenagrionidae		1			1		2			1				1	
	Cordullidae		1													1
	Libellulidae															
	Aeshnidae															
	Calopteryggidae															
	Gomphidae					2										
Coleoptera	Gyrinidae															
	Elmidae															
	SASS SCORE	**35**	**42**	**14**	**29**	**20**	**13**	**14**	**8**	**21**	**10**	**16**	**4**	**10**	**41**	**11**
	NO OF TAXA	**5**	**5**	**3**	**4**	**4**	**2**	**3**	**1**	**2**	**3**	**4**	**2**	**2**	**7**	**2**
	ASPT	**7**	**8.4**	**4.7**	**7.3**	**5.0**	**6.5**	**4.7**	**8.0**	**10.5**	**3.3**	**4**	**2**	**5**	**5.9**	**5.5**

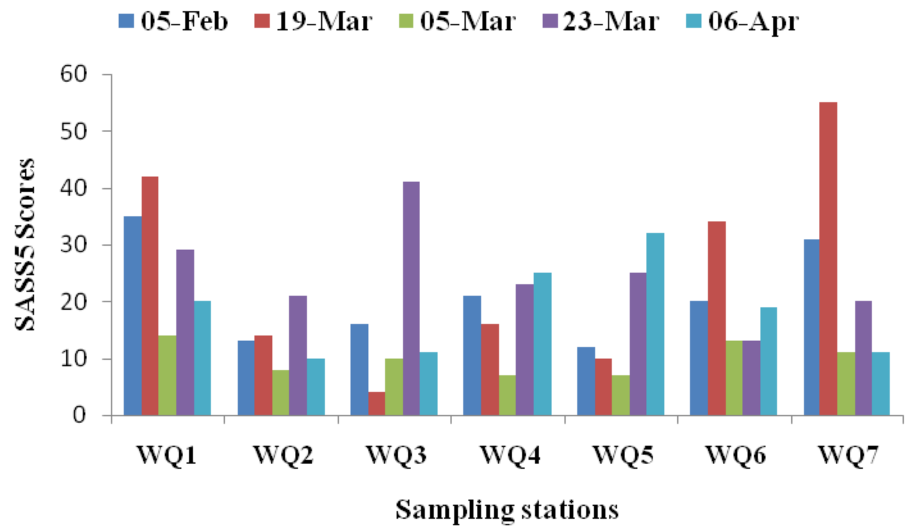


Figure 7.1 Variation of SASS scores for sites sampled along the Lower Komati River

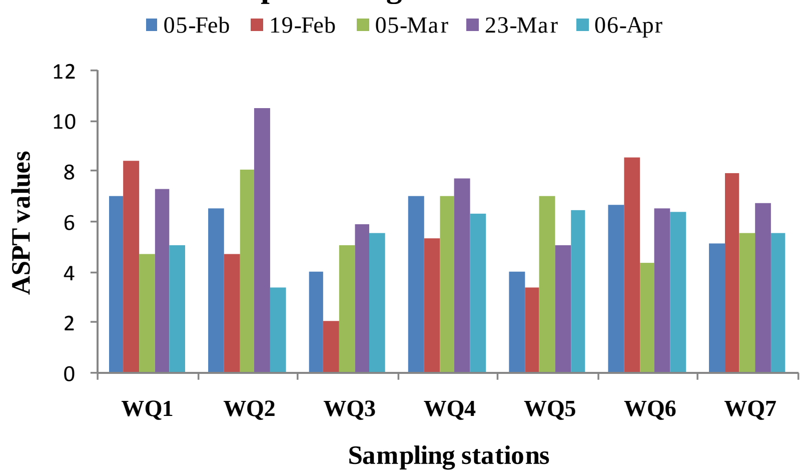


Figure 7.2 Variation of ASPT values for sites sampled along the Lower Komati River

APPENDIX C: Calculating diversity using Shannon-Weiner (H') and Simpson's(1-D) diversity indices

Table 7.5 Diversity calculation for site WQ1 to site WQ4)

[redacted]

Table 7.6 Diversity calculation for site (WQ4 to site WQ7)

[redacted]

APPENDIX D: Habitat integrity classification

Table 7.7 In-stream habitat weighting

CRITERION	**Sampling sites score**						
IN-STREAM	**WQ1**	**WQ2**	**WQ3**	**WQ4**	**WQ5**	**WQ6**	**WQ7**
Water abstraction (presence of pumps, irrigation etc.)	22	18	9	15	3	5	10
Extent of inundation	21	10	13	14	15	6	12
Water quality (clarity, odour, presence of macrophytes etc.)	20	17	9	15	19	12	17
Bed modification (bulldozing of bed)	21	3	19	16	17	4	10
Channel modification	17	12	17	13	19	13	15
Presence of exotic macrophytes	18	8	17	10	11	10	16
Presence of solid waste	19	5	21	19	22	16	15
Total score	138	73	105	102	106	56	95
% Score	79	42	60	58	61	32	54

Impacts rated on a scale of 0 to 25: (21-25 – none), (16-20 – limited), (11-15 – moderate), (6-10 – extensive), (1-5 – extreme), (0 – critical)

Table 7.8 Riparian zone habitat weighting

CRITERION	**Sampling sites score**						
RIPARIAN ZONE	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7
Water abstraction (presence of pumps, irrigation etc.)	24	15	9	16	6	2	16
Extent of inundation	19	13	17	16	19	11	10
Channel modification	20	15	17	18	15	8	5
Decrease of indigenous vegetation from the riparian zone	20	13	17	15	18	4	10
Exotic vegetation encroachment	21	6	17	16	20	3	16
Bank erosion	19	7	15	11	10	5	13
Total score	123	69	92	92	88	33	70
% score	82	46	61	62	59	22	47

Impacts rated on a scale of 0 to 25: (21-25 – none), (16-20 – limited), (11-15 – moderate), (6-10 – extensive), (1-5 – extreme), (0 – critical)

Table 7.9 Criteria used in the assessment of habitat integrity

CRITERION	
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment. Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids.
channel modification	May be the result of a change in flow which may alter channel characteristics causing a change in marginal in-stream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments
Bank erosion	Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both in-stream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.
Exotic vegetation Encroachment	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochtonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced

Source; Kleyhans,(1996)

APPENDIX E: Summary of biotopes per sampling period

Table 7.10: Biotopes found at sites during the sampling period, February to April 2009

Site Code	Sampling date	Marginal and Aquatic Vegetation	Stones, rocks(RIFFLE)	Gravel sand and mud(POOL)
WQ 1	05/02/09	present	present	present
	19/02/09	present	nil	present
	05/03/09	present	present	present
	23/03/09	present	nil	present
	06/04/09	present	present	present
WQ2	05/02/09	present	nil	present
	19/02/09	present	nil	present
	05/03/09	present	present	present
	23/03/09	present	nil	Present
	06/04/09	present	present	Present
WQ3	05/02/09	present	present	present
	19/02/09	present	present	Present
	05/03/09	present	present	Present
	23/03/09	present	nil	Present

Site Code	Sampling date	Marginal and Aquatic Vegetation	Stones, rocks(RIFFLE)	Gravel sand and mud(POOL)
	06/04/09	present	present	Present
WQ4	05/02/09	present	nil	Present
	19/02/09	present	nil	Present
	05/03/09	present	nil	Present
	23/03/09	present	nil	Present
	06/04/09	present	nil	Present
WQ5	05/02/09	present	present	Present
	19/02/09	present	present	Present
	05/03/09	present	nil	Present
	23/03/09	present	nil	Present
	06/04/09	present	present	Present
WQ6	05/02/09	present	nil	Present
	19/02/09	present	nil	Present
	05/03/09	present	nil	Present
	23/03/09	present	present	Present
	06/04/09	present	present	Present

Site Code	Sampling date	Marginal and Aquatic Vegetation	Stones, rocks(RIFFLE)	Gravel sand and mud(POOL)
WQ7	05/02/09	present	present	Present
	19/02/09	present	nil	Present
	05/03/09	present	nil	Present
	23/03/09	present	nil	Present
	06/04/09	present	present	Present

APPENDIX F: Flows recorded during the sampling period

Table 7.11 Flows recorded at Mananga (downstream at WQ7), Madlangempisi (upstream between site WQ1 and WQ2)

	Mananga	Madlangempisi
Date	Average flow rate (cumecs)	Average flow rate (cumecs)
05 Feb.	31.66	25.87
19 Feb.	27.65	28.64
05 march	49.41	40.85
23 march	35.37	33.07
07 April	13.99	10.85

APPENDIX G : Variation of water quality parameters along sampling sites from February to April 2009

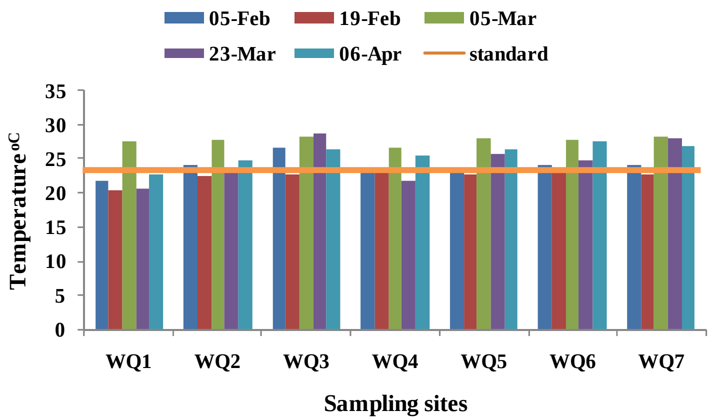


Figure 7.3 Variation of temperature along sampling sites in 2009

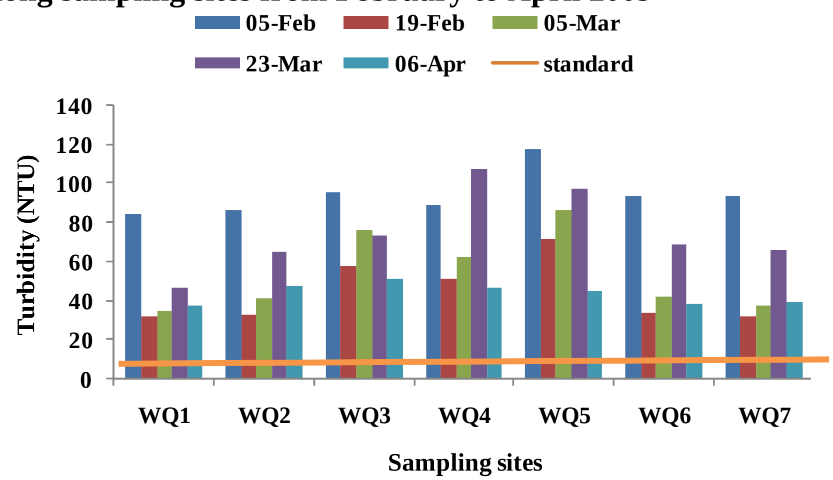
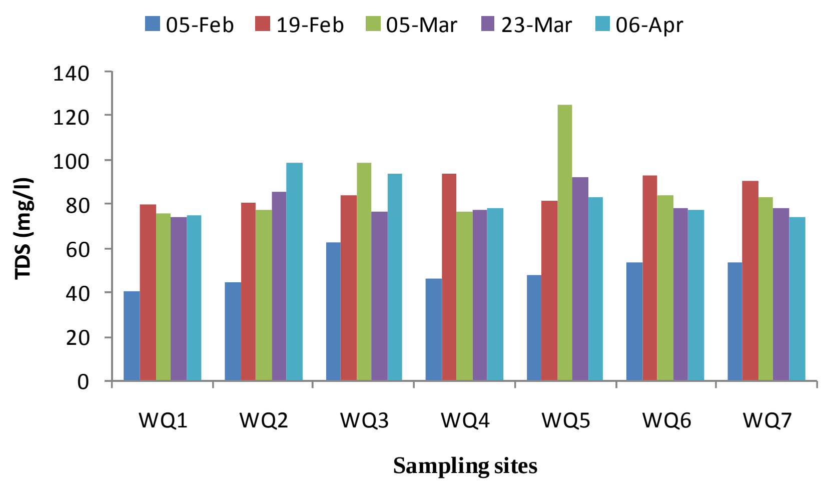


Figure 7.4 Variation of turbidity along sampling sites in 2009



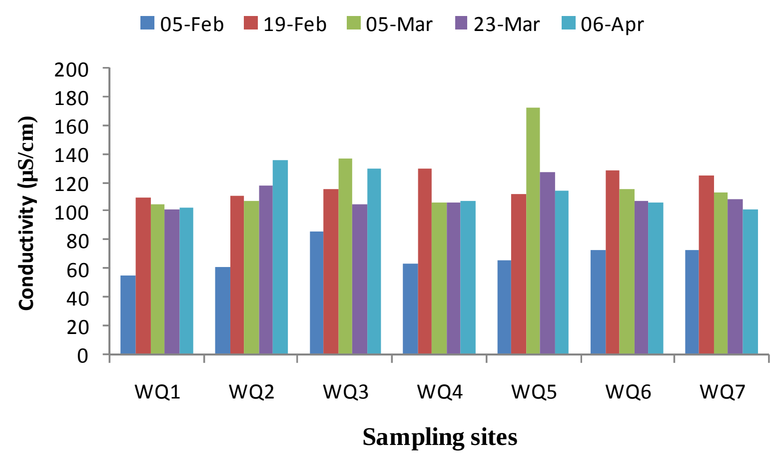


Figure 7.5 Variation of TDS along sampling sites in 2009

Figure 7.6 Variation of conductivity along sampling sites in 2009

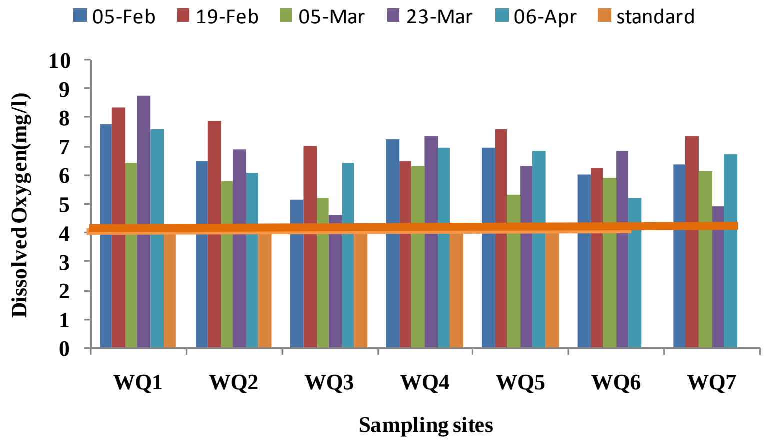


Figure 7.7 Variation of dissolved oxygen along sampling sites

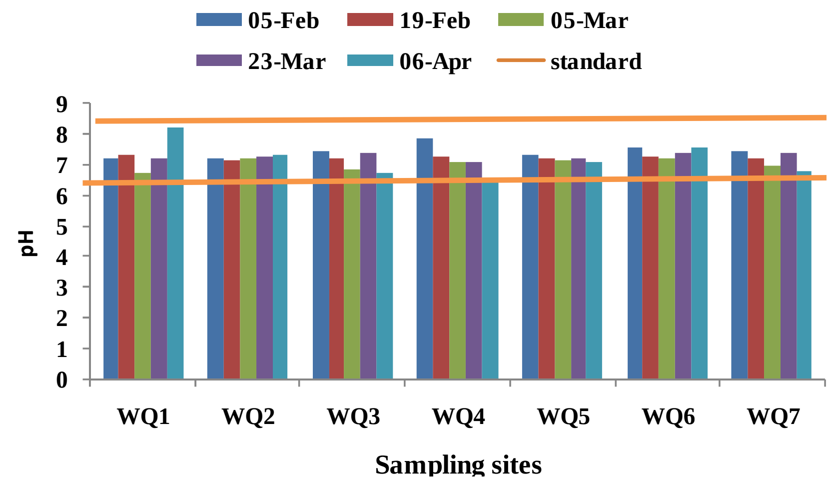


Figure 7.8 Variation of pH along sampling sites

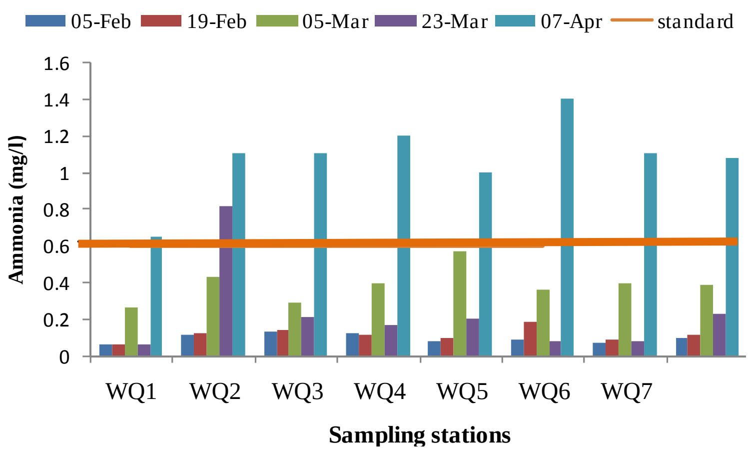


Figure 7.9 Variation of ammonia along sampling sites

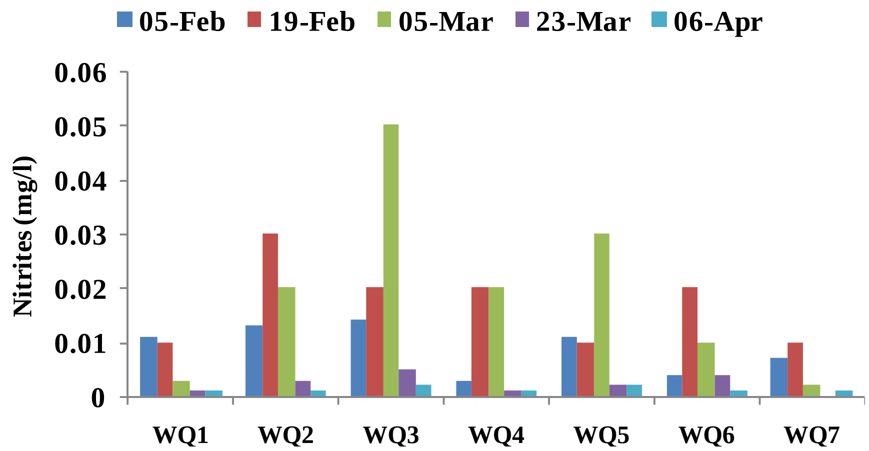


Figure 7.10 Variation of ammonia along sampling sites

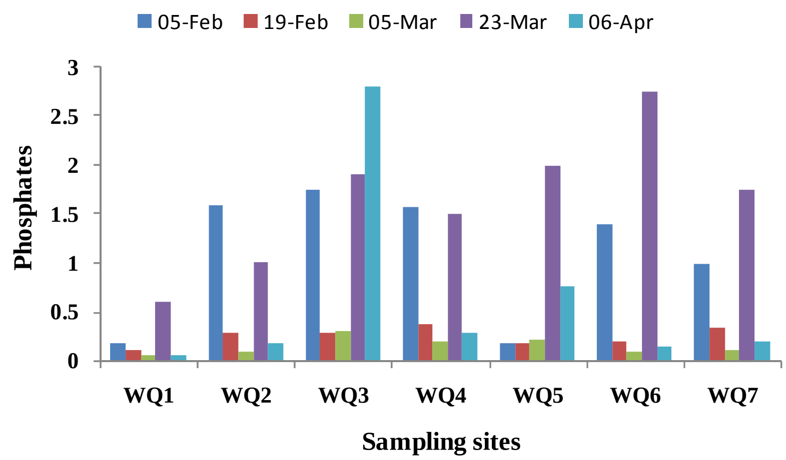


Figure 7.11 Variation of phosphates along sampling sites

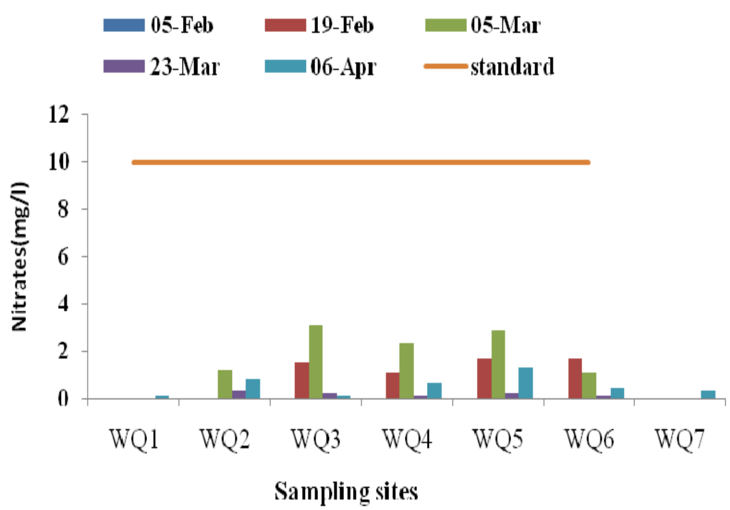


Figure 7. 12 Variation of nitrates along sampling sites

APPENDIX H : Principal Component Analysis (PCA) Extractions

Table7.12: Total Variance Explained

Component	Initial Eigenvalues			Extraction sums of squared loadings		
	Total	%Variance	Cumulative%	Total	%Variance	Cumulative%
1	5.976	59.757	59.757	5.976	59.757	59.757
2	1.546	15.458	75.215	1.546	15.458	75.215
3	1.051	10.509	85.724	1.051	10.509	85.724
4	.848	8.478	94.202			
45	.504	5.040	99.243			
6	0.76	.757	100.000			
7	6.63E-016	6.63E-015	100.000			
8	4.79E-016	4.79E-015	100.000			
9	1.71E-016	1.71E-015	100.000			
10	-1.24E-016	-1.24E-016	100.000			

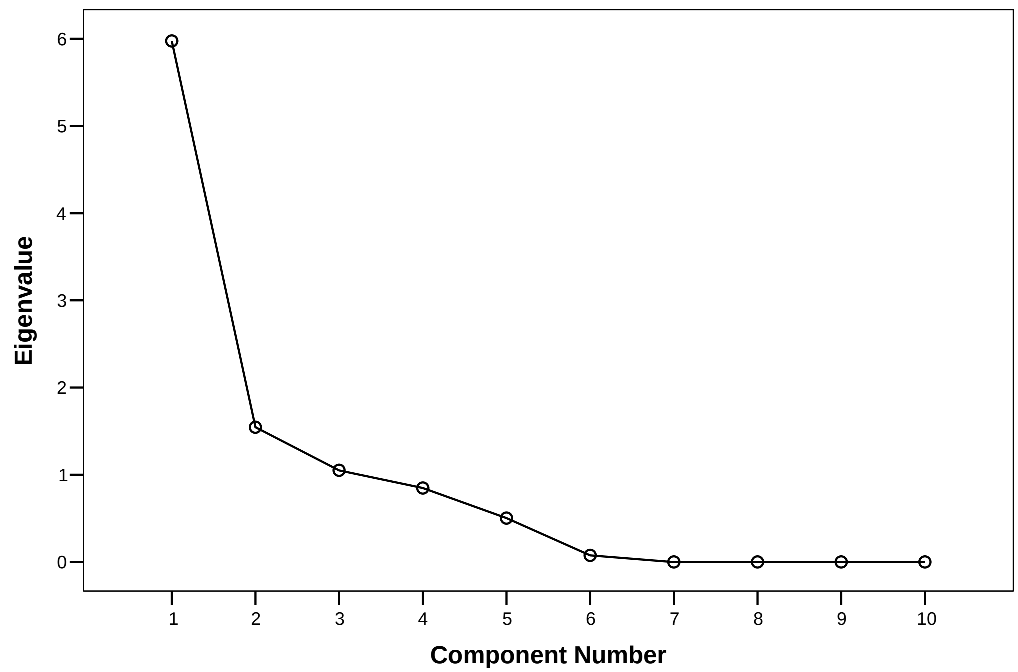


Figure 7.13 Scree plot of the characteristic roots (Eigenvalues) of Principal Component Analysis

Table 7.13 Principal component –variables

site	PC 2 Variable
WQ1	-.36676
WQ2	1.60715
WQ3	-.48031
WQ4	-1.13922
WQ5	.77360
WQ6	-.39446
WQ7	0.6794