Macroinvertebrates as ecological indicators of the wellbeing of the lower uMvoti and Thukela Rivers, KwaZulu-Natal, South Africa.

Ntombiphumile Perceverence Tenza

Submitted in fulfilment of the academic requirements for the degree of

Master of Science

in the Discipline of Ecological Sciences
School of Life Sciences
College of Agriculture, Science and Engineering
University of KwaZulu-Natal

Pietermaritzburg Campus

2018

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

ABSTRACT

The excessive use of water resources and climate change stressors is impacting the quality and quantity of surface aquatic ecosystems in South Africa, a semi-arid country. Although South Africa is considered to be a developing nation, riverine ecosystems have already been transformed and impacted on to meet human needs. This has altered the ecological characteristics of the rivers of which more than 70% are now threatened. The National Water Act (NWA) of South Africa and associated National Water Resource Strategy (NWRS) advocates the establishment of a suitable balance between the use and protection of water resources to ensure sustainability. The implementation of NWA and NWRS is limited in some South African rivers and the quality of these vulnerable ecosystems continues to deteriorate. Knowledge is needed to evaluate the response of the riverine ecosystems to changes in environmental variables so that we can understand the socio-ecological consequences of the continued deterioration of our resources and best manage them when resource demand exceeds supply. This study focusses primarily on lower uMvoti and Thukela Rivers along with their associated tributaries (Ntchaweni and Mandeni Streams). These rivers are among the highly threatened ecosystems and that can be attributed to water resource use stressors including overexploitation, invasion by exotic species, industrial pollution and effluents, extensive agricultural practices, mining activities, increased urbanization as well as social and economic development in peri-urban and urban centres. These stressors have been identified as determinants of the degradation of aquatic biodiversity and they result in the loss of key ecosystem services.

Aquatic macroinvertebrates are good ecological indicators that have been used internationally to establish robust bio-monitoring lines of evidence or tools for the monitoring and management of river ecosystems. Today a suite of international and local lines of evidence incorporating macroinvertebrates are available to evaluate the wellbeing of macroinvertebrates communities, their response to environmental variable changes and the wellbeing of the rivers they occur in.

To implement the use of macroinvertebrate communities as ecological indicators of the evaluation of the wellbeing of the uMvoti and Thukela Rivers, aquatic insects, mollusks, fresh water crustaceans, annelids, and other aquatic invertebrate communities were characterised. These use of these ecological indicators is well established due to: (1) the knowledge of the tolerances of taxa to different water quality, quantity and habitat stresses, (2) the high diversity of taxa that are representative of a wide range of river ecosystem types and (3) they are abundant, easy to collect (visible to the naked eye) and easy to identify. Two community metric measure tools namely the South African Scoring System (SASS, version 5) and the Macroinvertebrate Response Assessment Index (MIRAI) were used to evaluate the wellbeing of macroinvertebrate communities of the lowland uMvoti and Thukela Rivers in this study. The ecological integrity of both rivers were found to be adversely impacted and their integrity state ranged mostly from class C (moderately modified) to class E/F (seriously or extremely modified). Reduced habitat heterogeneity and altered water quality were found to be driving factors that cause the degradation in macroinvertebrate communities.

Multivariate statistical analyses were used to evaluate the responses of macroinvertebrate communities to water resource use activities associated with the uMvoti and Thukela Rivers. In the early part of the study period many intolerant macroinvertebrate taxa contributed to the structure of communities. However, towards the latter part of the study, pollution tolerant taxa dominated communities. Both rivers also showed a decreasing trend in estimated macroinvertebrates estimated abundance and number of taxa. In the uMvoti River this can be attributed to the combined effect of the urban runoff, effluence discharge from the Gledhow sugar mill and Sappi Stanger Mill, informal settlements and agricultural activities. Results reported from the Thukela River can be ascribed to the synergistic effects of water quality stressors associated with the Isithebe Industrial complex, wastewater treatment works, effluent from the Sappi mill, sugarcane plantations as well as domestic use by local communities.

The outcomes of this study showed that there is not sufficient protection and management measures afforded to the systems. The requirements of the National Water Act to establish a sustainable balance between the use and protection of the water resources in the system is not being achieved. No action is being taken to mitigate pollution from major sources in the study area. Thus, an appropriate management plan and its implementation is urgently needed, with monitoring activities, to mitigate these stressors and attain a balance between use and protection of these socio-ecologically important ecosystems. Failure to implement effective management plans may result in continued deterioration of the wellbeing of the ecosystem and potential loss of biodiversity, ecosystem services and functions that these rivers provide.

PREFACE

The data described in this dissertation were collected in KwaZulu-Natal, Republic of South Africa. This study is part of a long-term river monitoring program which included both historical and present datasets. The historical data was collected from 1999 – 2015. The present data was collected in 2016 while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Colleen T. Downs and Dr. Gordon O'Brien.

This dissertation, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

…………………………….

Ntombiphumile Perceverence Tenza

February 2018

I certify that the above statement is correct and as the candidate's supervisor I have approved this dissertation for submission.

…………………………..

Professor Colleen T. Downs

Supervisor

February 2018

…………………………..

Dr. Gordon O'Brien

Supervisor

February 2018

COLLEGE OF AGRICULTURE, SCIENCE AND ENGINEERING

DECLARATION 1 - PLAGIARISM

I, Ntombiphumile Perceverence Tenza, declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a. Their words have been re-written but the general information attributed to them has been referenced
   b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.

5. This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: ………………………………………

Ntombiphumile Perceverence Tenza

February 2018

COLLEGE OF AGRICULTURE, SCIENCE AND ENGINEERING

DECLARATION 2 - PUBLICATIONS

Details of contribution to publications that form part and/or include research presented in this dissertation:

Publication 1 (Formatted for African Journal of Aquatic Science)

NP Tenza, CT Downs & G O'Brien

Application of community metric measures to evaluate the wellbeing of macroinvertebrate communities in lowland rivers of KwaZulu-Natal

Author contributions:

NPT conceived paper with CTD and GO. NPT collected and analyzed data and wrote the paper. CTD and GO contributed valuable comments to the manuscript.

Publication 2 (Formatted for African Journal of Aquatic Science)

NP Tenza, CT Downs & G O'Brien

Macroinvertebrate communities of lowland rivers in KwaZulu-Natal and their response to water quality, quantity and habitat changes

Author contributions:

NPT conceived paper with CTD and GO. NPT collected and analyzed data and wrote the paper. CTD and GO contributed valuable comments to the manuscript.

Signed:  ………………………………

Ntombiphumile Perceverence Tenza

February 2018

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Almighty God who have given me the power to believe in myself and follow my dreams. He gave me faith, hope, perseverance, strength, knowledge and the opportunity to do this research. I take pride in acknowledging the insightful guidance of my supervisors Professor CT Downs and Dr GC O'Brien, for sparing their valuable time whenever I approached them, creative suggestions and for showing me the way ahead. My sincere appreciation to the National Research Foundation (ZA), Aquatic Ecosystem Research Programme and South African Pulp and Paper Industries Limited (Sappi) for financial support.

I sincerely thank my mother TB Cele and step father TD Mthenbu whose wisdom, love and guidance are with me in everything I pursue. I will also like to thank them and my little sister SA Mthembu for taking care of my son while I was always away studying. Most importantly, I would like to express my gratitude to my wonderful son, LS Hlengwa who provide unending inspiration in everything I do. I have great pleasure in thanking PS Hlengwa for endless support and the encouragement for pursuing this research successfully. I sincerely thank N Senoge and O Agboola in ensuring that I pass my SASS5 accreditation and for assisting me in data collection. I would also like to thank my friends for being my support structure and keeping me motivated always.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

Seventy one percent (%) of earth is covered in water, 97 % of which contains salt, leaving only 3 % as freshwater (William 2014). Very little amount (1%) support total life (readily available surface freshwater). Of that 1%, approximately 68.7% is frozen in icecaps and glaciers while another 30% or so is locked up in the ground (Mishra and Dubey, 2015). Climate change has been gradually causing major concerns about the limited accessible surface freshwater and the impact has been that many countries are water scarce. In addition to being hit by this phenomenon, South Africa is currently classified as a semi-arid and water scarce country that receives an average precipitation of approximately 450 mm per year, less than the world average (approximately 860 mm p.a.) (DWAF 2004; Hill 2007; Otieno and Ochieng 2007; Kohler 2016). Freshwater resources are regarded as the most degraded ecosystems in South Africa and that due to anthropogenic stressors like overexploitation, invasion by exotic species, industrial pollution and effluents, extensive agricultural practices, mining activities, increased urbanisation as well as social and economic development in peri-urban and urban centers (Farrel 2014). Such stressors exacerbate the degradation of aquatic biodiversity and they also result in the loss of key ecosystem services (Deborde et al. 2016). Hence, it is of great importance to protect, manage and conserve freshwater ecosystems.

In 1998, the South African National Water Act (NWA), Act 36 of 1998 (NWA 1998) was formed to protect, manage and conserve South Africa’s water resources in a way that considers human basic needs of the present and the future. The NWA was also aimed at promoting equality to access, efficient use and the beneficial use of water in the public interest (NWA 1998). Additionally, the NWA was developed for ensuring that the current and future ecological integrity of aquatic ecosystems are developed and sustained (NWA 1998). For this to happen, factors that drive the ecological integrity of aquatic ecosystems need to be determined and controlled if possible (Malherbe 2006). Over the years, water quality (physico-chemical parameters) has been the most widely used method for assessing the ecological integrity of aquatic ecosystems. However, the use of this method alone was found to be insufficient, meaning that it cannot provide a precise explanation of the overall condition of an ecosystem, instead it reflects snapshots of the condition (Kenney et al. 2009). Many factors other than water quality have a significant impact on the overall condition of aquatic ecosystems. Such factors include habitat modifications, altered flows as well as invasion by exotic species (Roux 1999). Therefore, the effective method for a comprehensive assessment of aquatic ecosystem must consider the cumulative effect of all these factors (Roux 1999).

Biomonitoring has increasingly been recognised as a crucial method for assessing and monitoring aquatic ecosystems. This assessment method uses biological responses of aquatic communities such as algae, fish and macroinvertebrates to evaluate changes in the aquatic environment (Li et al. 2010). The use of biomonitoring programmes has been adopted in many parts of the world and the most famous existing programs include the British River Invertebrate Prediction and Classification (RIVACS) methodology, the Australian National River Health Programme and the Rapid Bioassessment Protocol for Use in Stream and Rivers of the United States (Roux 1999). Appropriate concepts from these programmes were used in the development of the South African River Health Programme (RHP) in 1994 by the Department of Water Affairs and Forestry (Roux 1999). The RHP development was based on the idea that combined aquatic communities (such as fish, macroinvertebrate and riparian vegetation) reveal the effects of anthropogenic disturbances that occur in rivers over a long period of time (DWAF 2008). Information obtained through the RHP gives an overall condition of the riverine ecosystems (Boulton 1999). It is also used in the development of effective strategies for river protection, conservation and management (Boulton 1999). To further support the management and protection of riverine ecosystems, ecological classification (Eco Classification) was developed. The purpose of Eco classification was to determine and categorise the current ecological integrity of rivers compared to their pristine state (Kleynhans and Louw 2007). This allowed researchers to gain insights and understanding about the causes and sources of the deviation of the current ecological state from the reference/pristine condition (Kleynhans and Louw 2007). The Eco Classification permits the collection of information that is desirable and attainable for developing future ecological objectives for the riverine ecosystems (Kleynhans and Louw 2007).

1.1 Riverine ecosystem drivers

Riverine ecosystems are very important as they provide valuable ecosystem services. They are documented to have rich fauna that have communities with a complex structure and high biological value (Benetti 2012). Riverine ecosystems have special topology which makes them fragile and vulnerable to direct and indirect anthropogenic stressors (Benetti 2012; Maddock 1999). To satisfy human needs, rivers systems have been manipulated over the past years by constructing dams, weirs and reservoirs. This alters the ecological characteristics of the rivers and it has adverse impact on habitat quality and availability. The degradation of habitat itself pose the greatest threat to the biodiversity of aquatic communities (Ferrel 2014). Other important pressures that affects riverine ecosystems include change in land-use, altered flow regimes, loss of river connectivity due to river regulation, excessive nutrient loads inputs, sedimentation through erosion, invasion by exotic species and climate change (Gosselin et al. 2016). All these pressures have been recognised to act simultaneously and somehow, they partially intensify or cancel each other's effect (Gosselin et al. 2016). Rivers are identified as significant and sensitive ecosystems, however, the mitigation opportunities for them are inadequate because the way in which they respond to the water resource use stressors is poorly understood. Thus, it is very importance to do more research that assess the response of the riverine ecosystems to changes in environmental variables.

1.1.1 Water quality

Water quality is fundamental for healthy ecosystems and it is defined by it physical, chemical and aesthetic (appearance and smell) characteristics (Venter 2013). Different land-use can significantly alter both chemical and physical water conditions which can subsequently reduce the biological integrity within riverine ecosystems (Farrel 2014). The physical, chemical and aesthetic characteristics are primarily influenced by the substances that are either suspended or dissolved in water column. Impacts of agriculture and urbanisation particularly in lowland areas are most predominant, placing a significant strain on water quality and quantity. Pesticides and fertilisers containing phosphate and nitrate from cultivated areas cause nutrient enrichment which accelerates the growth of phytoplankton (Johnston and Dawson 2005). Increased growth rates of such species (and bacteria) lead to an increase in water turbidity, macrophyte growth and algal blooms (Chapman 1996). The presence of excessive algae in water results in the reduction of dissolved oxygen which is a vital feature for riverine ecosystems. Low oxygen content in water impacts many aquatic organisms which require high levels of dissolved oxygen to survive (McCartney 2010). For example, stoneflies (Plecoptera) and caddisfly larvae

(Trichoptera) are always abundant in well oxygenated and running waters, suggesting that they are intolerant to pollution and oxygen depletion (Olomukoro and Dirisu 2014).

Water temperature is another important feature which affects water quality (Chapman 1996). An increase in water temperature is correlated with an increase in water chemical reactions, this lead to high evaporation and volatilisation (Chapman 1996). Moreover, solubility of gases like oxygen, carbon dioxide and nitrogen tend to decrease if the water temperature increases (Chapman 1996). As a result, the respiration rate of organisms intensifies causing an increase in oxygen consumption and decomposition of matter (McCartney 2010). Changes in pH also have a significant impact on water quality because higher pH can convert ammonium (NH_4) to a more toxic form, ammonia (NH_3) (McCartney 2010). Low pH also has a negative effect to some aquatic macroinvertebrates, for example, Mayflies and Stoneflies faces an increased loss of sodium in their blood when exposed to low pH (Sutcliffe and Hildrew 1989). Thus, alterations in pH in a system has an adverse impact on the biodiversity of aquatic organisms.

1.1.2 Habitat

Habitat quality and availability are the most considered aspects when assessing habitat integrity of many systems because they determine the survival of different organisms within an ecosystem (Malherbe 2006; Carminati 2008). Habitat types of rivers include pools, rapids, sandbanks, bedrock, boulders, cobbles, gravel, sand, mud, runs and riffles (Malherbe, 2006). Riparian zones and vegetation are known to be extremely important because they promote heathy aquatic ecosystems (Malherbe 2006). For example, shrub and tree roots hold streambanks in place, preventing erosion (Venter 2013). Riparian vegetation filters light and nutrients, provides multiple habitats for aquatic organisms and they are responsible for flood attenuation (Malherbe 2006).

1.2 Freshwater macroinvertebrates

For this study, changes in habitat and water quality are the main aspects that are evaluated using freshwater macroinvertebrates as bioindicators. Freshwater macroinvertebrates are regarded as a fundamental part of aquatic ecosystems. They include aquatic insects (such as stoneflies, mayflies, dragonflies, and rat-tailed maggots), mollusks (snails), fresh water crustaceans (crayfish and scuds), annelids (worms and leeches), and all other organisms that live permanently or during certain periods of their life cycle linked to the aquatic ecosystems (O'Keeffe and Dickens 2000). Freshwater macroinvertebrates have individuals with macroscopic size of normally above 1 mm (Benetti 2012). They are regarded as excellent indicators of anthropogenic impacts and because of that they are highly recommended and frequently used when evaluating the biological integrity of riverine ecosystems. The reliability of using such organisms is based on the idea that there is a vast knowledge of their sensitivity to different stresses, they are abundant, easy to collect (visible to the naked eye) and easy to identify in the laboratory (Bredenhand 2005; Leunda et al. 2009). Other benefits of using freshwater macroinvertebrates as biological indicators include their limited mobility and relatively long-life histories (often live for more than a year) which enables them to integrate the effects of the stressors to which they are exposed to over time (Ferrel 2014).

In the mid-1990s macroinvertebrate community structures were commonly used to assess the ecological integrity of lotic and riverine ecosystems (O'Brien 2011). By the late 1990s many South African researchers had already adopted the frequent use of such communities as biological indicators of ecosystem health (O'Brien 2011, O'Keeffe and Dickens 2000). Reece and Richardson (1999) stated that macroinvertebrate community structures change both temporally and spatially. This is due to alterations that usually occur in the environment within which they inhabit. Such environmental changes are caused by a mixture of geographic factors, water chemistry, habitat stability, and/or land use (Reece and Richardson 1999). Seasonal change was also documented to be one of the major aspects that drive environmental factors (like water temperature and resource availability) which play an important role on the persistence of macroinvertebrate communities. Hence, the present research considered both low flow and high flow seasons when sampling.

1.3 Description of study areas

1.3.1 Thukela River

The Thukela River is the largest river system in KwaZulu-Natal (KZN) Province, South Africa (Stryftombolars 2008). This catchment originates from the Drakensburg escarpment and it meanders 520 km through the central KZN until it reaches the Indian Ocean at approximately 85 km north of Durban (Stryftombolars 2008, Venter 2013). Tributaries of this catchment include the Klip River, Mooi River, Mzinyathi "Buffalo" River, Sundays River, Ingangani River, Blood River and Bushmans River (DWAF 2001a; Stryftombolars

2008; Venter 2013). The catchment area of this river is estimated to be approximately 29 000 km^2 with the MAR (mean annual runoff) of 3 865x10^6 m^3 (Whitfield and Harrison 2003; Stryftombolars 2008). When looking at the MAR alone, Thukela catchment is the second largest river in South Africa, following the Orange River which is in first position (Stryftombolars 2008). Thukela catchment water is transferred to other systems, for example, the Tugela-Vaal Transfer Scheme which was commissioned in November 1974 (Davies 1982). A certain amount of the water from the Tugela River is transferred via canals, pipelines and dams into the Vaal River system (DWS 2014) to provide for increasing water demand due to urbanisation and industrialisation in the Gauteng area.

Water from the Thukela catchment is also used by people that reside within the Thukela basin. The areas that this study focused primarily on included the Sundumbili community, eMandini community and industrial complexes (Stryftombolars 2008, Venter 2013). The hazards generated by these areas (especially industries) include several water quality related impacts and habitat disturbance (Stryftombolas 2008; O'Brien et al. 2009; O'Brien 2010). The Sappi Tugela Pulp and Paper Mill is one of the industries which largely impacts the lower Thukela River as it has the extraction and discharge point for effluents which gives high solid waste (Stryftombolars 2008). The influence of this industry is intensified by the presence of waste water treatment works as well as the prevalent sugar plantations (Stryftombolars 2008) which is responsible for nutrient enrichment and increased siltation.

1.3.2 uMvoti River

The uMvoti River originates from the Natal Midlands, KZN Province, South Africa; it meanders through a south easterly direction past Greytown and Stanger until pours into the Indian Ocean at a point that is close to Blythedale Beach (Malherbe 2006; Venter 2013). The length of this river is approximately 197 km (Shaddock and Wepener 2015). The Hlimbitwa River is regarded as one of the main tributaries of the UMvoti River and they both join near Dhlakati (Malherbe 2006; Venter 2013). In 2004 the Department of Water Affairs and Forestry characterised the uMvoti River as a medium sized river with a total MAR of approximately 595 million m^3/a (DWAF 2004a; Malherbe 2006; Venter 2013). Stanger and Greytown communities depend largely on the uMvoti River and it is regarded as having a high socio-economic value (Carminati, 2008, Swemmer, 2011). This catchment is highly impacted by town and village development, sugarcane plantations as well as heavy industries like Ushukela Sugar Mill, Glendale Distillery and the Sappi Stanger Mill (Carminati 2008). O'Brien (2010) documented that the habitat integrity of the lower uMvoti River had decreased to the lowest rating available, suggesting that this system was highly stressed. As a result, the biodiversity and numerous basic ecosystem functions had been altered negatively. The pulp and paper mill that is found near the lower uMvoti catchment produces large amounts of solid waste which have become deposited into the catchment (Swemmer 2010). Furthermore, informal settlements and intensive poor irrigation and cultivation practices remove riparian vegetation on the uMvoti River banks which promote erosion (Swemmer 2010). Sand mining is another factor that has impacted this catchment by producing lose soils that become eroded to the river channel (Swemmer 2010). This process turns the river into a winding narrow and braided stream with unnatural flow (Carminati 2008; Swemmer 2010).

1.4 Problem statement

The Thukela and uMvoti Rivers (along with their associated tributaries) are among the major rivers in KZN Province. They suffer heavily from anthropogenic disturbances which require the direct or indirect water uptake from the Thukela and uMvoti Rivers. Some of the disturbances discharge partially treated effluence on the streams, which in turn results in the degradation of the ecological integrity. Drought has exacerbated the impact of anthropogenic disturbances; hence, it is of great important to evaluate the potential impacts such disturbances have on the overall ecological integrity of the lowland Thukela and uMvoti Rivers. The present study examined the freshwater macroinvertebrate communities as ecological indicators of historical and current ecological integrity of these study rivers. The outcomes will contribute to the implementation of effective strategies for sustaining these rivers before they reach a point of irreversible changes. The outcomes will also help in developing suitable strategies for maintaining a desirable balance between the water resource use and the protection at the lowland sections of both the Thukela and uMvoti Rivers.

1.5 Hypotheses and predictions

It was hypothesised that macroinvertebrates are suitable ecological indicators of the ecological integrity of the lower uMvoti and Thukela Rivers, KwaZulu-Natal, South Africa. It was predicted that (1) natural and anthropogenic disturbances have an adverse effect on stream ecological integrity, and (2) macroinvertebrate communities decrease due to habitat heterogeneity, changes in water quality parameters and anthropogenic activities on both rivers. It was also predicted that there is significant change in the ecological integrity of the lower Thukela and uMvoti Rivers when comparing current and historical data.

1.6 Aim and objectives

The aim of this study was to use macroinvertebrates as ecological indicators of the wellbeing of lower Thukela and uMvoti Rivers, KZN. The objectives were to:

(1) Assess the freshwater macroinvertebrate communities at the study sites on a spatial and temporal scale.
(2) Identify environmental driver parameters that were strongly associated with the persistence of macroinvertebrates communities.
(3) Evaluate the response of freshwater macroinvertebrate communities to changes in environmental driver parameters.
(4) Determine the link between the macroinvertebrate community changes to the surrounding anthropogenic land-uses in the study area (agriculture and industrial activities)
(5) Evaluate the historical and current ecological integrity of the lowland Thukela and uMvoti Rivers.
(6) Provide river management recommendations.

1.7 Dissertation structure

The dissertation is structured with each data chapter written in a manuscript format for submission to an international peer review journal. Any repetition was unavoidable. The chapters are as follows:

Chapter 1: Literature review

Chapter 2: Application of community metric measures to evaluate the wellbeing of macroinvertebrate communities in lowland rivers of KwaZulu-Natal

Chapter 3: Macroinvertebrate communities of lowland rivers in KwaZulu-Natal and their response to water quality, quantity and habitat changes

Chapter 4: Concluding chapter - Macroinvertebrates as ecological indicators of the wellbeing of lowland rivers of KwaZulu-Natal.

1.8 References

Benetti CJ, Pérez-Bilbao A, Garrido J. 2012. Macroinvertebrates as indicators of water quality in running waters: 10 years of research in rivers with different degrees of anthropogenic impacts. In Ecological Water Quality-Water Treatment and Reuse. InTech.

Boulton AJ. 1999. An overview of river health assessment: philosophies, practices, problems and prognosis. Freshwater Biology 41: 469–479.

Bredenhand E. 2005. Evaluation of macroinvertebrates as bio-indicators of water quality and the assessment of the impact of the Klein Plaas dam on the Eerste River. MSc Dissertation, University of Stellenbosch, Stellenbosch.

Carminati AV. 2008. An Assessment of the Effects of Sugar Mill Activities on the Ecological Integrity of the UMvoti and Amatikulu Rivers, KwaZulu Natal. MSc dissertation, University of Johannesburg, Johannesburg.

Chapman DV. (Ed.). 1996. Water quality assessments: a guide to the use of biota, sediments, and water in environmental monitoring. 2nd Ed. F & FN Spon. London

de Castro-Català, N, Kuzmanovic M, Roig N, Sierra J, Ginebreda A, Barceló D, ... Muñoz I. 2016. Ecotoxicity of sediments in rivers: Invertebrate community, toxicity bioassays and the toxic unit approach as complementary assessment tools. Science of the Total Environment 540: 297–306.

Deborde DDD, Hernandez MBM, Magbanua FS. 2016. Benthic macroinvertebrate community as an indicator of stream health: the effects of land use on stream benthic macroinvertebrates. Science Diliman, 28: 5–26

Department of Water Affairs and Forestry (DWAF). 2008. National Aquatic Ecosystem Health Monitoring Programme (NAEHMP): River Health Programme (RHP)

Implementation Manual. Version 2. ISBN No. 978-0-621-383343-0, Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2004. Draft background information: South African Forestry, Pulp and Paper industries: Draft version 1. DWAF, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2004a. National Water Resource Strategy. DWAF, Pretoria, South Africa.

Farrell KT. 2014. Aquatic Macroinvertebrate Community in the Wilge River. PhD dissertation, University of Johannesburg, Johannesburg.

Ferreira M, 2005. A study into the anthropogenic impacts affecting the Elands River, Mpumalanga. PhD dissertation, University of Johannesburg, Johannesburg.

Gosselin MP, Kiesel J, Fohrer N, Langhans S, Jähnig S, Venohr M., Push M. 2016. Analysing the effects of pressures on riverine ecosystems using models in the context of ecosystem-based management. 11th ISE, Melbourne, Australia

Hill L 2007. Focus on CSIR research in pollution waste: The South African river health programme. CSIR, Pretoria.

International Atomic Energy Agency (IAEA). 2003. Collection and Preparation of Bottom Sediment Samples for Analysis of Radionuclides and Trace Elements. Report No. IAEA-TECDOC-1360. IAEA, Vienna.

Johnston AE, Dawson CJ. 2005. Phosphorus in agriculture and in relation to water quality. Peterborough: Agricultural Industries Confederation.

Kenney MA, Sutton-Grier AE, Smith RF, Gresens SE. 2009. Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy. Terrestrial Arthropod Reviews 2: 99.

Kleynhans CJ, Louw MD. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report, Pretoria.

Kleynhans CJ. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41–54.

Kohler M. 2016. Confronting South Africa's Water Challenge: A Decomposition Analysis of Water Intensity. South African Journal of Economic and Management Sciences 19: a1590.

Leunda PM, Oscoz J, Miranda R, Ariño AH. 2009. Longitudinal and seasonal variation of the benthic macroinvertebrate community and biotic indices in an undisturbed Pyrenean river. Ecological Indicators 9: 52–63.

Li L, Zheng B, Liu L. 2010. Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. Procedia Environmental Sciences 2: 1510–1524.

Malherbe CW. 2006. The current ecological state of the lower UMvoti River, KwaZulu-Natal. MSc dissertation, University of Johannesburg, Johannesburg.

McCartney BA. 2010. Evaluation of Water Quality and Aquatic Ecosystem Health in the Mara River Basin East Africa. PhD dissertation, Florida International University, Miami.

McMillan PH. 1998. An Integrated Habitat Assessment System (IHAS v2) for Rapid Biological Assessments of Rivers and Systems. Division of the Environment and Forestry Technology. Report No. Env-P-I 98132. CSIR, Pretoria.

Mishra RK, Dubey, SC. 2015. Fresh Water Availability and its Global Challenge. International Journal of Engineering Science Invention Research and Development 2: 351–407.

National Water Act (Act No. 36 of 1998). Republic of South Africa 1998. Government Gazette, (19182).

Niemirycz E, Gozdek J, Koszka-Maron D. 2006. Variability of organic Carbon in water and sediments of the Odra River and its tributaries. Polish Journal of Environmental Studies 15: 557–563.

O’Brien GC, Swemmer R, Wepener V. 2009. Ecological integrity assessment of fish assemblages of the Matigulu/Nyoni and UMvoti estuaries, KwaZulu-Natal, South Africa. African Journal of Aquatic Science 34: 293–302.

O'Brien GC. 2010. Ecological State Assessment of the Lower Thukela River/Estuary, KwaZulu-Natal. Investigational Report. Rivers of Life: Aquatic Health Services, Potchefstroom.

O'Brien GC. 2011. Regional Scale Risk Assessment Methodology using the Relative Risk Model as a Management Tool for Aquatic Ecosystems in South Africa. Unpublished PhD dissertation. University of Johannesburg, Johannesburg, South Africa.

O'Keeffe J. Dickens C. 2000. Aquatic invertebrates. In: King J.M., Tharme R.E. and De Villiers M.S. (eds.) Environmental Flow Assessments for Rivers: Manual for the

Building Block Methodology. WRC Report No. 576/1/98. Water Research Commission, Pretoria. pp. 231–244.

Olomukoro JO, Dirisu A. 2014. Macroinvertebrate community and pollution tolerance index in Edion and Omodo Rivers in derived savannah wetlands in Southern Nigeria. Jordan Journal of Biological Sciences 7: 19–24.

Otieno FAO, Ochieng GMM. 2007. Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. Water South Africa 30: 120–124.

Page DW. 2002. Characterisation of organic matter in sediment from Corin Reservoir, Australia. Journal for Analytical and Applied Pyrolysis 70: 69–183.

Reece PF, Richardson JS. 1999. Biomonitoring with the reference condition approach for the detection of aquatic ecosystems at risk. In: L.M. Darling (ed.) Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk. 15–19 February 1999, Kamloops, B.C. pp. 549–552.

Roux DJ. 1999. Incorporating Technologies for the Monitoring and Assessment of Biological Indicators into a Holistic Resource-Based Water Quality Management Approach-Conceptual Models and Some Case Studies. PhD dissertation, Rand Afrikaans University, Johannesburg.

Shaddock BF, Wepener V. 2015. An evaluation of the weight of evidence approach to assess sediment quality in the UMvoti Estuary, KwaZulu-Natal, South Africa, African Journal of Aquatic Science 40: 235–246

Stryftombolas IC. 2008. Ecotoxicological Assessment of the Impact of Paper and Pulp Effluent on the Lower Thukela River Catchment, KwaZulu-Natal, South Africa, and the Toxicological Assessment of Similar Effluent from Two Other Mills. MSc Dissertation, University of Johannesburg, Johannesburg.

Sutcliffe DW, Hildrew A.G. 1989. Invertebrate communities in acid streams. Acid toxicity and aquatic animals 34: 13–28.

Swemmer R. 2010. Ecological integrity assessment of the UMvoti Estuary, KwaZulu-Natal, South Africa. MSc dissertation, University of Johannesburg, Johannesburg.

Venter AJ, van Vuuren JHJ. 1997. The effects of gold mine related operations on the physical and chemical characteristics of sediment texture. Water SA 23: 249–256.

Venter JJ. 2013. An ecological integrity assessment of the lower Amatikulu, Thukela and UMvoti Rivers, KwaZulu-Natal, South Africa. PhD dissertation, North-West University, Potchefstroom.

Whitfield AK, Harrison TD. 2003. River flow and fish estimated abundance in a South African estuary. Journal of Fish Biology 62: 1467–1472.

Williams M, 2014. What Percent of Earth is Water. Universe Today. Available at http://www. Universe today. com/65588/what-percent-of-earth-is.

CHAPTER 2

Application of macroinvertebrates bioassessment metrics to evaluate the ecological integrity of lowland Thukela and uMvoti rivers of KwaZulu-Natal

NP Tenza, CT Downs and GC O'Brien

School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg 3209, South Africa

Formatted for African Journal of Aquatic Science

Abstract

Aquatic macroinvertebrates are a fundamental part of aquatic ecosystems and they are frequently used and highly recommended as biological indicators of stream health. This study incorporated the use of macroinvertebrate community structures to evaluate the ecological integrity of the lower uMvoti and Thukela Rivers along with their associated tributaries (Ntchaweni and Mandeni). Two community metric measure approaches namely the South African Scoring System (SASS, version 5) and the Macroinvertebrate Response Assessment Index (MIRAI) were used in this study. The outcomes revealed better ecological integrity state within the two sites situated in the upper reaches of the study area due to minimal human disturbances and adequate habitat heterogeneity which allowed more families to thrive successfully. Results also demonstrated that the ecological integrity of the uMvoti and Ntchaweni Rivers were being degraded and they were dominated by pollution tolerant families. The Thukela and Mandeni Rivers also demonstrated relatively poor ecological integrity throughout the study periods. The SASS5 and MIRAI tools were implemented successfully as they generated suitable trends which indicated the response of macroinvertebrate community to changes in environmental variable conditions due to water resource use. However, the SASS5 tool was to some extent less suitable for the overall assessment of the integrity states as it considered water quality at the primary driver of change. On the other side, the MIRAI tool was found to be more responsive, robust and more informative about the drivers of change. This can be attributed to the fact that it considers multi-metric approach when generating the macroinvertebrates integrity states.

The outcomes of the study further illustrated that macroinvertebrate integrity trends generated by SASS5 tool had high variability whereas the MIRAI trends had less variability. Again, this can be associated with the use of multiple metrics as probably driver of changes in macroinvertebrates communities.

Keywords Macroinvertebrate communities · SASS5 · MIRAI · Anthropogenic activities · Ecological integrity state

2.1 Introduction

Aquatic macroinvertebrate communities are frequently used and highly recommended as biological indicators of the wellbeing of aquatic ecosystems (Oertel and Salánki 2003). The long history of using macroinvertebrates as bioindicators is ascribed to representative taxa preferring sedentary habits, rapid life cycles, taxa occupying varied trophic levels and variable pollution tolerances. This information in turn provides strong evidence for interpreting cumulative effects of natural and anthropogenic disturbances on riverine ecosystems (Li et al. 2010). Macroinvertebrate biological indices have been used as early as 1970's. The implementation of the Clean Water Act in 1972 in the United States paved the way for the development of bioassement methods for assessing conditions of water resources (Fourie et al. 2014). Such bioassement methods were developed based on biological communities including fish, periphyton, benthic macroinvertebrates, plants, birds and amphibians (Jun et al. 2012). From then, benthic macroinvertebrate communities were the commonly used set organisms for assessing the effect of disturbances on riverine ecosystems worldwide (Jun et al. 2012). New biological indices based on macroinvertebrate communities have been developed after the implementation of Water Framework Directive (WFD) in Europe in 2003 (Poikane et al. 2014). These biological indices focus primarily on a multimeric approach. Even before this, community metric measures have been advocated by many aquatic biologists as an efficient tool for biomonitoring (Poquet et al. 2009). These approaches use measures or metrics that represent different characters of biological communities in order assess the effect of natural and anthropogenic disturbances on streams (Yuan and Norton 2003). They also summarize the overall ecological integrity of a system into single index value or score (Poquet et al. 2009). The success of using such an approach has increased over the past years, and that is due to diverse measures it uses which includes taxonomic diversity, compositional estimated abundance, and autecological characteristics (e.g., feeding types, habits, and stressor tolerance values) (Poquet et al. 2009). Each of these measures reveal information that is potentially useful in distinguishing and understanding biological responses of macroinvertebrate communities to disturbances (Poquet et al. 2009).

Although many community metrics have been developed thus far, only few have proven to be robust and have been extensively implemented for assessing effect of disturbances on streams (Chambers and Messinger 2001). They include the RIVPACS implement in Europe (Clarke et al. 2003), AusRivas in Australia (Wright 1995), BEAST in Canada (Reynoldson et al. 1995), Multimetric Macroinvertebrate Index Flanders in Belgium (Flanders) (Gabriels et al. 2010), the I2M2 in France (Mondy et al. 2012), the STARICMi in Italy (Buffagni et al. 2006), the multimetric index (METI) in NW Spain (Pardo et al. 2009) and the South African Scoring System (SASS) version 5 (Dickens and Graham 2002). In 1994, Chutter developed the simple, quick and cost-effective method for sampling macroinvertebrate communities in river systems of South Africa. This SASS method was developed based on the British Biological Monitoring Working Party (BMWP) method as a foundation (Dickens and Graham 2002). The SASS method is similar to rapid bioassessment methods such as RIVPACS (Wright et al. 1984), IBMWP (Alba-Tercedor et al. 2002) and SIGNAL (Chessman 1995) because it also evaluates macroinvertebrate diversity at a family level (Bellingan et al. 2015). This assessment also allocates sensitivity scores to each macroinvertebrate family based on how the organisms within that family are intolerant to water quality alteration or habitat modifications (Bellingan et al. 2015). For example, Oligoneuridae, Blephariceridae and Ephemeridae are given a sensitivity score of 15 suggesting that they are highly intolerant families that require good water quality to survive. The Oligochaeta, Coelenterata and Culicidae possesses a sensitivity score of 1, suggesting that they are highly tolerant families that can survive in poor water quality. Such families have adaptations that enables them to thrive successfully in water with low dissolved oxygen, turbid waters or nutrient-enriched waters. Historically, the SASS method been refined/upgraded (SASS 1 – SASS5), with each upgrade improving robustness (Dickens and Graham 2002). The current method, SASS version 5 (SASS5), has become the backbone of the South African River Health Programme (RHP), River Eco-Status Monitoring Programme (REMP) and other organisations e.g. Umgeni Water and other environmental consultancies. The SASS method relies primarily on water quality and this limit the success of using this method because water quality alone does not identify specific drivers of macroinvertebrate community structure changes and it is insufficient for providing a precise explanation of the overall condition of an ecosystem (Kenney et al. 2009).

In 2007, the macroinvertebrate Response Assessment Index (MIRAI) was developed in South Africa for evaluating riverine ecosystems wellbeing using macroinvertebrates (Thirion, 2007). The MIRAI primarily depends on the SASS5 method as it uses information collected using the standard SASS5 method (Dickens and Graham 2002). The MIRAI offers a habitat-based cause-and-effect foundation of community responses to water quality, flow and habitat variability, to deduce the deviation of the macroinvertebrate communities from the reference or baseline conditions (Venter 2013). The MIRAI tool was built on the notion that macroinvertebrate communities incorporate the effects of the alterations in hydrology, geomorphology and physico-chemical conditions of riverine ecosystems (Thirion 2016). A draft spreadsheet that includes a semi-quantitative rating of the intolerances (based on SASS weights), habitat and velocity preferences is used for MIRAI analysis (Thirion 2007).

The SASS5 and MIRAI tools provide qualitative and quantitative information about the ecological integrity state of riverine ecosystems (Thirion 2007). Such information is necessary for steady management of water resource as continuous satisfaction of human needs pose the greatest threat to the sustainable use of water resources. Creditable data obtained though monitoring using the SASS5 and MIRAI tools will provide better understanding of the riverine ecosystems and that will allow for the implementation of effective strategies for promoting a balance between use and protection rights of South Africa’s water resources.

The aim of this study was to apply the SASS5 and MIRAI tools to evaluate the wellbeing of macroinvertebrate communities of the lower uMvoti and Thukela Rivers of KwaZulu-Natal, South Africa. It was predicted that both indices will exhibit poor macroinvertebrate community states on both rivers demonstrating the synergistic effect of excessive water resource use that has altered water quality, flows and habitat. Results from this study will make an important contribution to understanding the lowland river ecosystems in KwaZulu-Natal. The information gained in this study will also help uMvoti and Thukela Rivers stakeholders to better understand the nature of their water resource, as a means of developing appropriate strategies and/or policies for conserving and managing such rivers and their associated tributaries.

2.2 Methods

2.2.1 Study area

The study area included the lower reaches of the uMvoti and Thukela Rivers in KwaZulu-Natal, South Africa (Fig. 2.1). The forever increasing demand for water resources in the Thukela River pose the greatest threat to the structure and functioning of the river (Whitfield and Harrison 2003). This river is heavily impacted by ecosystem service use that includes water abstraction for domestic use, industries, agricultural activities, mining, recreation, wastewater treatments works and roads and rail networks (Malherbe 2006; Venter 2013; Jacobs 2017). Such ecosystem service negatively impacts natural flow regimes, water quality and quantity as well as habitat quality (Lamberth et al. 2009). The uMvoti River is the second river that this study will focus on and it is also heavily impacted by excessive use of ecosystem services. Activities at the lower uMvoti River include sugarcane plantations, heavy industries, informal settlements, rural areas, and sewage treatment works (Malherbe 2006; Venter 2013).

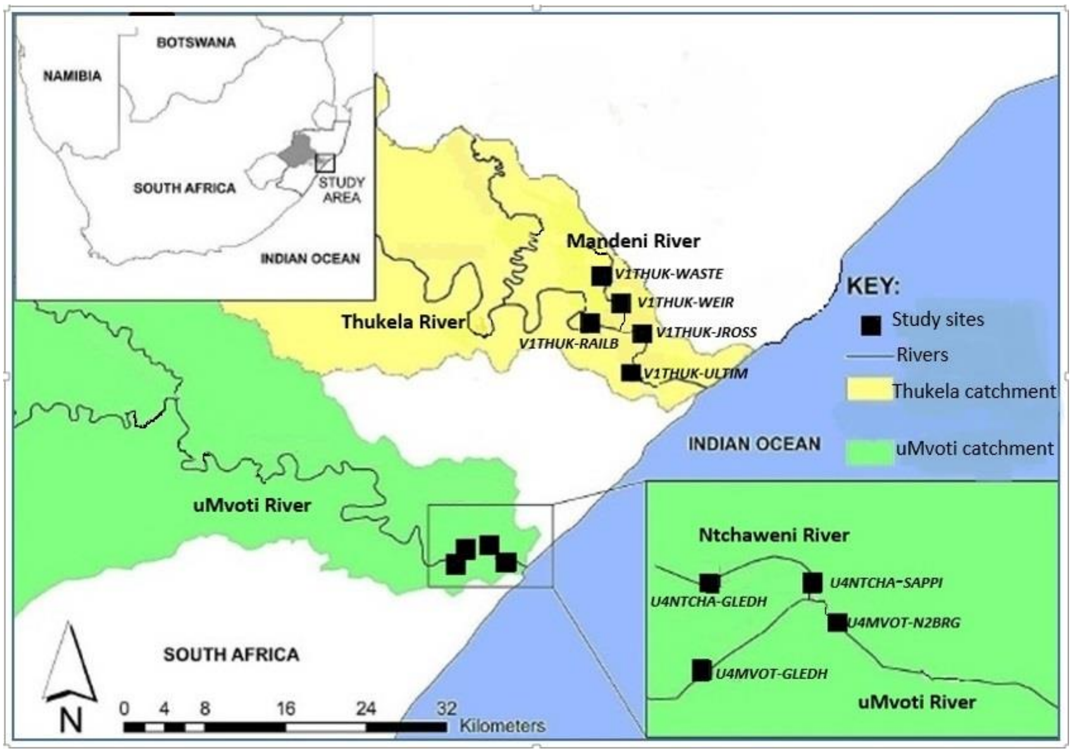


Figure 2. 1: Map of the study area showing all 9 study sites from uMvoti and Thukela Rivers as well as associated tributaries (Ntchaweni and Mandeni Rivers).

2.2.2 Site selection

The study sites selection was based primarily on the aim and objectives of this study as well as the availability of historical data sampled (O'Brien et al. 2005; Malherbe 2006; O'Brien et al. 2009; O'Brien 2010; O'Brien 2012; Venter 2013). This study is part of a long-term river monitoring program which included both historical and present datasets. The historical data was collected almost every year and during both high and low flows periods between 1999 – 2015. The present data was collected in 2016. For the latter dataset two surveys were carried out, the first survey was conducted in April 2016 (high flow period). This period occurs during the wet season and it is associated with increased water flow. The second survey was conducted between September and October 2016 (low flow period). This is regarded as a seasonal phenomenon which is vital for river flow regime and is defined as reduced flow of water in rivers during lengthy dry weather periods (Deksissa et al. 2003).

uMvoti River sites and its associated tributary (Ntchaweni)

U4NTCHA-GLEDH: This site was in the Ntchaweni River and it was positioned upstream of the confluence between Ntchaweni and uMvoti Rivers. This site was heavily impacted by the Gledhow Sugar Mill nearby. The U4NTCHA-SAPPI site was the second site within the Ntchaweni River, it was further downstream, and it was highly impacted by the combine effect of Gledhow Sugar Mill and Sappi Pulp and Paper making activities. The selection of these sites were based on the notion that they will show the effects caused by industrial activities of the Ntchaweni stream wellbeing. The marginal vegetation of both sites was dominated by reeds and grasses. The U4NTCHA-SAPPI was also dominated tress. The substrate of the U4NTCHA-GLEDH site was dominated by sand and remote gravel while the U4NTCHA-SAPPI site consists of sand and mud.

U4MVOT-GLEDH: This site was located upstream of the confluence between Ntchaweni-uMvoti Rivers. This site has minimal human disturbances that may deteriorate the ecological integrity of the uMvoti River. Sugarcane plantations which occurs upstream of this site might pose a threat to the river wellbeing. The sand substrate was dominating, and marginal vegetation was mainly composed of reeds.

U4MVOT-N2BRG: This site was located below the confluence point between Ntchaweni, Mbozano and uMvoti Rivers. The selection of this site was based on the idea that this site can reveal the changes in ecological state of uMvoti River after it has mixed with the Ntchaweni stream. It can also be used to evaluate the effect of pollution originating from the Ntchaweni Stream on the uMvoti River wellbeing. Marginal vegetation was dominated by reeds and the substrate of this site consists mostly of sand and a bit of gravel.

Thukela River sites and its associated tributary (Mandeni)

V1MAND-WASTE: This site is located in Mandeni tributary and it was situated downstream of both Isithebe rural area and Isithebe industrial complex as well as iLembe wastewater treatment works. Furthermore, this site had a lot of solid waste coming from the dumping site nearby. The selection of this site was based on the idea that it will show the effects caused by water resource use activities associated with the Mandeni Stream. The substrate of this site comprised a mixture of bedrock, boulders, and cobbles as well patches of gravel and sand. The marginal vegetation consists of overhanging vegetation that includes trees, shrubs, sedges, grasses and reeds.

V1MAND-WEIR: This site was located downstream of the V1MAND-WASTE and information obtained by monitoring this site will be of great use for revealing the cumulative impacts caused by industrial activities of Isithebe and Mandeni, wastewater treatment works, agricultural activities and domestic use of the local communities on the Mandeni stream. The substrate was dominated by boulders, however, there are isolated areas of cobbles and mud. The marginal vegetation that consists of large trees, reeds, sedges, shrubs and grasses

V1THUK-RAILB: This was located upstream of the confluence between Mandeni and Thukela Rivers. Effluent discharges that originate from the Mandeni Stream does not affect this site. However, sugarcane plantations, urbanised Sundumbili and the local communities may pose a threat to the ecological integrity of this site. This site was dominated by bedrock substrate with few boulders, cobles and sand. Marginal vegetation of this site was comprised of reeds, shrubs, sedges, grasses and large trees. There was poor representation of sand biotope.

V1THUK-JOHNR: This site was located downstream of the SAPPI effluent discharge point and it was also below the confluence between Mandeni and Thukela Rivers. The selection of this site was based primarily on the notion that it will reveal the impacts caused by pollution originating from the Mandeni stream as well as the Sappi Tugela Mill effluent discharges. This site was dominated by sandy substrate and its marginal vegetation consists of reeds, grasses, shrubs, grasses and trees.

V1THUK-ULTIM: This site was in the lower reaches of the Thukela River and it was found further below VITHUK-JOHNR. The selection of this site was based on the idea that it will provide reveal the synergistic effects of local communities, pollution originating from the Mandeni stream, sugarcane plantation and sewage treatment works on the ecological integrity of the lowland Thukela River. This site was dominated by sandy substrate and sparse marginal vegetation that consists of large trees, reeds, sedges and grasses.

2.2.3 Field data collection

The assessment of freshwater macroinvertebrate biota was conducted using the South African Scoring System (SASS) (version 5), the bioassessment protocol designed for the rapid water quality assessments (Dickens and Graham 2002). Different macroinvertebrate families exhibit varied response to pollution and such responses range from highly tolerant families such as Muscidae, Culicidae and Oligochaeta to highly sensitive families like Oligoneuridae and Ephemeridae (Mahlangu 2014). Thus, this method enables aquatic macroinvertebrate communities to indicate the impact of perturbation and habitat modifications. Samples were collected in the following biotopes:

Stones biotopes

(1) Stones in current (SIC): These included movable stones in current (pebbles and cobbles of 2–25 cm average size) and/or bedrock (which includes boulders of >25 cm) which were sampled for approximately 2 minutes (min.). If the bedrock or rocks were highly embedded the maximum sample time was extended up to 5 min. The SASS net (1 mm mesh on a 30 cm square frame) was placed in a position where the water current will transport the dislodged organisms into the net.

(2) Stones out of current: The sampling of stones out of current (SOOC) followed immediately after the SIC were sampled. These were stones out of any noticeable flow and included bedrock or any solid objects out of current such as movable pebbles and cobbles of 2–25 cm average size. This was sampled by 1 min. of kicking, turning or scraping of stones whilst continuously sweeping the net through the disturbed area to collect biota. The dislodged biota was collected into a net and placed inside a SASS tray (30 cm × 45 cm and 10 cm deep) for identification.

Vegetation biotopes

(1) Marginal vegetation (in and out of river current): Any emergent and overhanging vegetation growing at the edge of the stream both in and out of current were marginal vegetation and was sampled for an approximate of 2 m in total length. Macroinvertebrates were sampled by pushing and pulling the net vigorously on the vegetation. (2) Aquatic vegetation: This comprised mainly of submerged vegetation, which included roots, stems and floating aquatics and it was sampled for about 1 m^2. Even here, macroinvertebrates were sampled by pushing and pulling the net vigorously on the vegetation.

Gravel, sand and mud biotopes

Gravel, sand and mud (GSM) biotopes were sampled for approximately 1 min. combined. (1) Gravel: This was mainly small stones of <2 cm in size and these were sampled by continuous shuffling of feet whilst sweeping the net over the disturbed area to catch dislodged biota. (2) Sand: This comprised of particles that were <2 mm diameter in size. Sampling was done by stirring and shuffling the feet in sand whilst continuously sweeping the net over the disturbed area, mostly in slow moving or still water to catch dislodged biota. Shuffling of feet should be about 10 – 20 cm deep. (3) Mud, silt and clay particles: (<0.06 mm diameter) were sampled in the same way as gravel and sand.

Hand picking and visual observation

While sampling different biotopes, approximately 1 min. of "hand picking and visual observation" was carried out to identify specimens that may have been missed by the sampling procedure. Thus, extra taxa were recorded on the SASS sheet. Samples were identified using a macroinvertebrate guide (Dickens and Graham 2002) and total SASS5 score, total number of taxa and ASPT were calculated for each sample. The abundance was also estimated as per SASS5 method,1 = 1, A = 10, B = 100, C = 1000, D = >1000 After sample identification, the voucher specimens were preserved in polyethylene honey jars (350 g) with 70% ethanol and were stained with phloxine.

2.2.4 Habitat integrity

The habitat integrity was determined by means of Invertebrate Habitat Assessment Systems (IHAS) which was developed by McMillan, (1998) and Index of Habitat Integrity (IHI) developed by Kleynhans, (1996). These two indices are very good at assessing habitat availability, diversity and state (Venter, 2013). Such indices are also documented to be frequently used and highly recommended for the National River Health Programme (Venter 2013). The IHAS and IHI have standard score sheets which require to be filled in the field. Habitat quality of each site is then determined by calculating the percentage values of these indices.

Table 2. 1: Habitat integrity assessment categories for the IHAS and IHI habitat quality indices (following Kleynhans 1999; Dallas 2005).

Class	Description	Score (% of Total)
A	Unmodified, natural	90 – 100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged.	80 – 89
C	Moderately modified. A loss or change in natural habitats and biota has occurred, but basic ecosystem functioning appears predominately unchanged.	60 – 79
D	Largely modified. A loss of natural habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred.	40 - 59
E	Seriously modified. The loss of natural habitat, biota and ecosystem functioning is extensive.	20 – 39
F	Modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, the basic ecosystem functioning has been destroyed.	0 – 19

2.2.5 Data analysis

SASS5

The SASS5 score and ASPT values were graphed and placed within the biological bands of Dallas (2007) to assess overall trends in the integrity of the macroinvertebrate assemblages (Fig. 2.3 and 2.6). The SASS5 interpretation guidelines are primarily based at the site location to the broad Ecoregion Level I biomes (Kleynhans et al., 2005; Dallas, 2007). In this study the lower North Eastern Coastal Belt – Lower ecoregion was used in order to assess the SASS results from the lower Thukela and uMvoti Rivers as well as their associated tributaries (Mandeni and Ntchaweni).

MIRAI

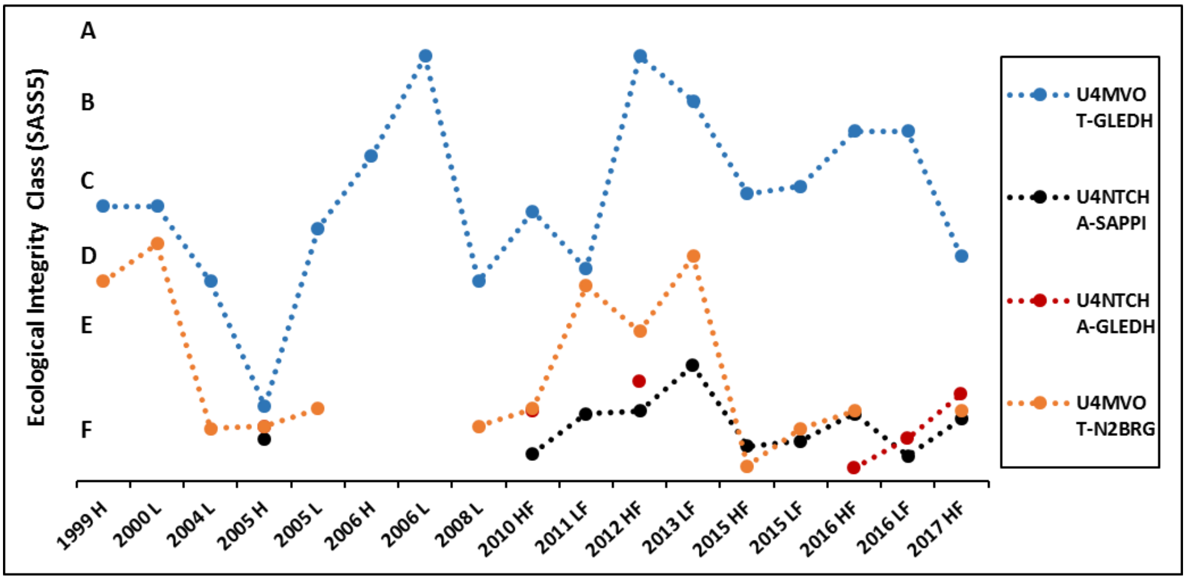
The MIRAI tool was also used for data analysis and it requires macroinvertebrate data that are collected using the SASS5 method (Thirion 2007). The MIRAI is Excel based tool which consist of four different metric groups that measured the change of the present macroinvertebrate assemblages from the reference assemblage in terms of flow-, habitat- and physico-chemical alteration as well as alteration in system's connectivity and seasonality (Thirion 2007). The change in terms of estimated and frequency of occurrence of macroinvertebrate taxa on different metrics were measured on a scale from 0 (no change from reference) to 5 (extreme change from reference). Each metric was ranked and weighted according to its importance in determining the macroinvertebrate assemblages Ecological Category (EC) (Thirion 2007). Preference scores that were higher than 3.5 illustrated a strong preference for a certain metric category (habitat and/or velocity) (Thirion 2007).

2.3 Results

2.3.1 uMvoti River and its associated tributary (Ntchaweni)

In the SASS5 results (Fig. 2.2 a), U4MVOT-GLEDH included better water and habitat quality when compared with the other site as it ecological integrity state mostly ranged from class A (unmodified) – C (modified) (Fig. 2.2 a), except for 2005 high flow, 2008 low flow, 2011 low flow and 2017 high flow where the ecological integrity was class D (largely modified) or class F (extremely modified). The rest of the sites showed high variability overtime and their ecological integrity class predominantly ranged from Class D – E (seriously modified) /F. The Ntchaweni Stream was in an unacceptably poor and unsustainable state and its ecological integrity ranged from class D – E/F. The ecological integrity of the U4NTCHA-SAPPI site exhibited a slight increasing trend from 2011 (class E/F) – 2013 (class D). This was followed by a decrease in 2015 which showed a deterioration in the wellbeing of this site as it returned to class F. The Ntchaweni Stream sites were represented by low number of taxa and they were dominated by tolerant taxa. With regards to MIRAI results, the integrity of classes was generally one class lower than the integrity classes of SASS5 for each site (Fig. 2.2 b).

a)



b)

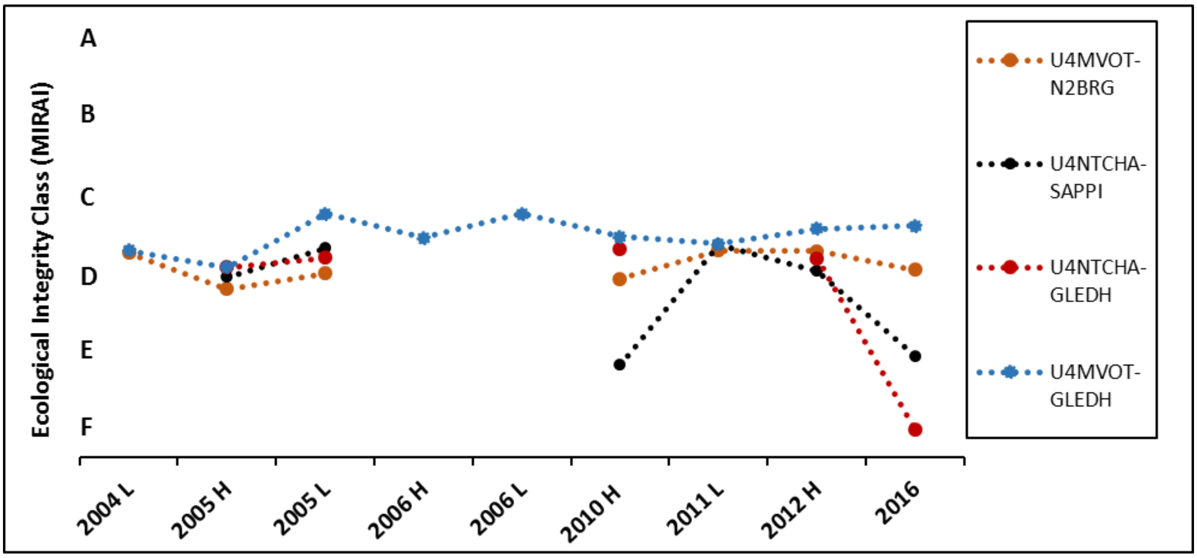


Figure 2. 2: Trends regarding the macroinvertebrate community wellbeing determined by **a)** SASS5 and **b)** MIRAI analysis during the study period (1999 – 2016) for the high (H) and low (L) flow surveys in the four study sites of the uMvoti River.

The Ntchaweni Stream sites had a relatively low SASS5 scores and ASPT (Fig. 2.3). Furthermore, the biological bands developed using the ecoregion indicated that the ASPT and SASS5 scores categorized this stream as class E/F. The U4MVOT-N2BRG site also revealed low SASS5 scores and ASPT as it surveys were scattered around class D-E/F. The ecosystem wellbeing of the U4MVOT-GLEDH showed better ecological states when compared with the three other sites. This site was the only one with predominantly class A, B or C.

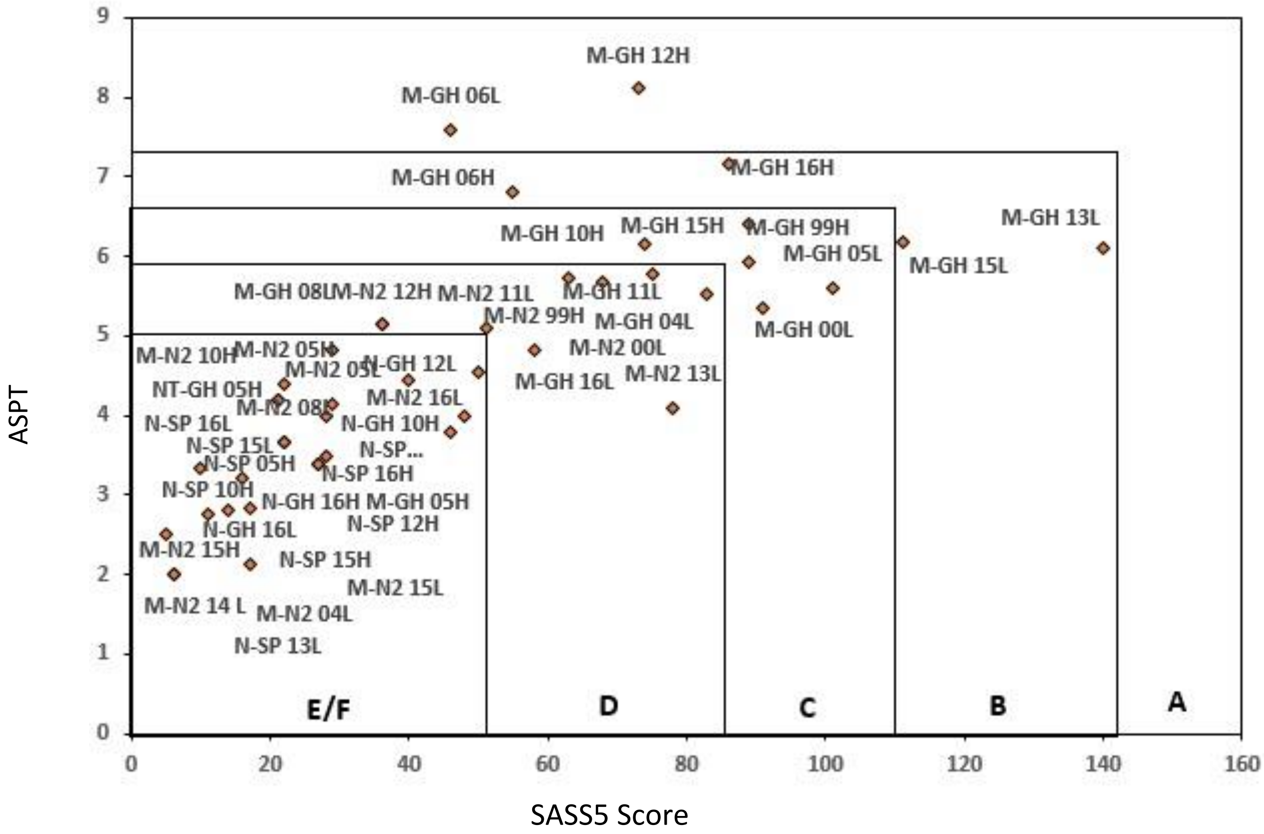


Figure 2. 3: Average score per taxa (ASPT) (y-axis) and South African Scoring System (SASS) score (x-axis) plotted for the lower uMvoti river. This plot is primarily based on the integrity category bands from North Eastern Coastal Belt developed by Dallas (2007). U4MVOT-GLEDH = M-GH, U4MVOT-N2BRG = M-N2, U4NTCHA-SAPPI = N-SP and U4NTCHA-GLEDH = N-GH.

The number of taxa found within each year in all sites varied extensively depending on how favourable conditions were during the surveys. Noticeable fluctuations in number of taxa were observed over the study period (Fig. 2.4). U4MVOT-GLEDH had the highest number of different taxa, followed by U4MVOT-N2BRG, U4NTCHA-SAPPI and U4NTCHA-GLEDH. The highest number of taxa was recorded during the 2013 low flow survey in U4MVOT-GLEDH (23 taxa) whereas the lowest number of taxa was recorded during the 2016 high flow survey in U4NTCH-GLEDH (2 taxa).

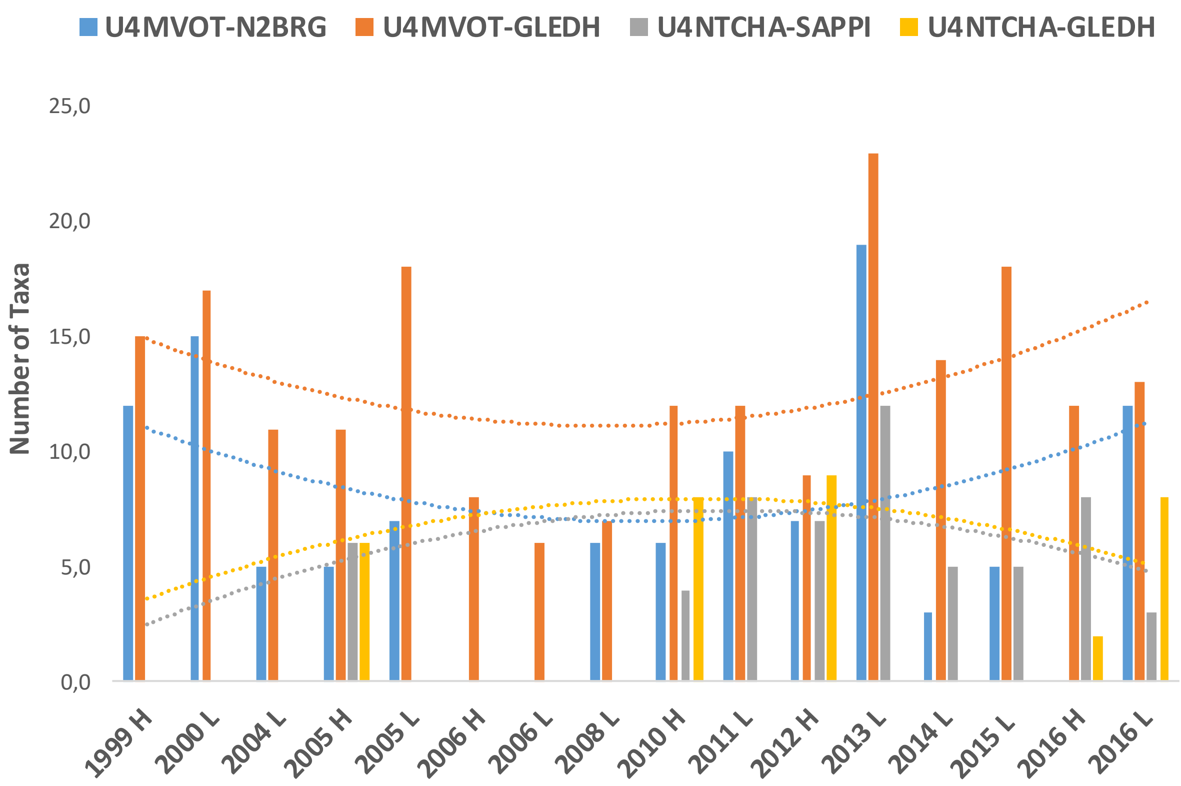


Figure 2. 4: Number of taxa recorded during the study period (1999 – 2016) for the high (H) and low (L) flow surveys in the four study sites of the uMvoti River.

All sites surveyed during the 2005 high flow survey showed better habitat integrity state (class C) when compared with the other surveys. The IHAS results revealed that the Ntchaweni Stream sites were normally in a largely modified state (class D) except for 2005 high flow survey. The uMvoti river sites were predominantly in a largely modified state (class D) throughout the study period. However, the habitat integrity of these site deteriorated in 2016 as they were found to be seriously modified indicating an unacceptable decline in habitat diversity and availability. IHI results revealed that there was an improvement in the habitat integrity state of the sites during the 2011 low flow survey except in site U4NTCHA-GLEDH.

Table 2. 2: The Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) of the lower uMvoti River during the study period (1999 – 2016).

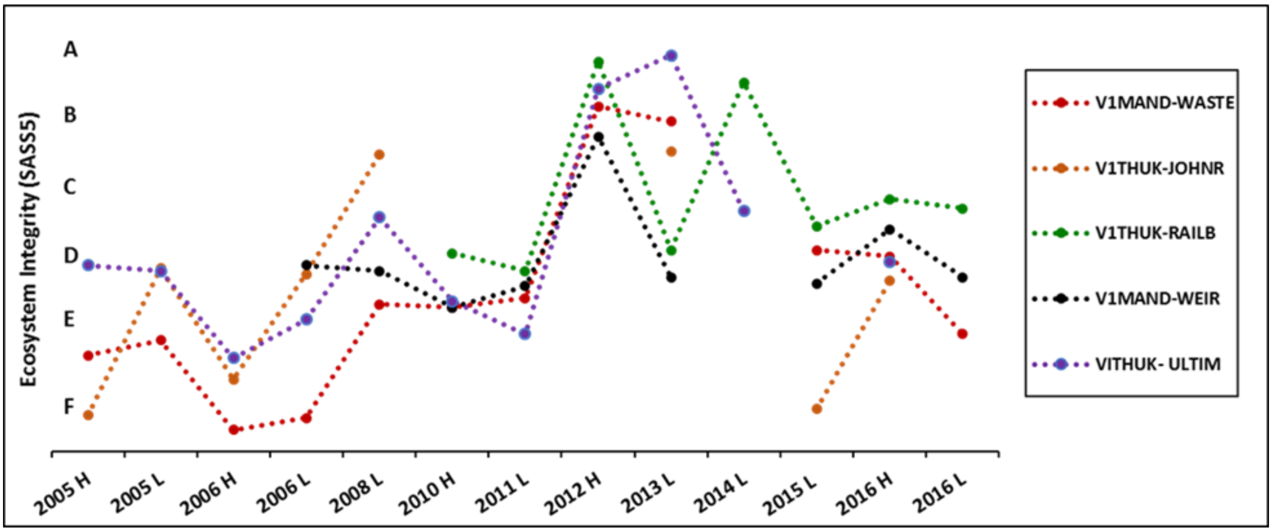
Sites	IHI	IHAS	IHAS Class
U4NTCHA-SAPPI 2005H	60	75	C
U4NTCHA-SAPPI 2012H	45	46	D
U4NTCHA-SAPPI 2011L	120	50	D
U4NTCHA-SAPPI 2016H	-	58	D
U4NTCHA-SAPPI 2016L	48	45	D
U4NTCHA-GLEDH 2005H	73	75	C
U4MVOT-GLEDH 2005L	75	75	C
U4NTCHA-GLEDH 2012L	-	46	D
U4NTCHA-GLEDH 2016H	-	49	D
U4NTCHA-GLEDH 2016L	-	45	D
U4MVOT-GLEDH 1999H	49	46	D
U4MVOT-GLEDH 2000L	48	41	D
U4MVOT-GLEDH 2004L	67	50	D
U4MVOT-GLEDH 2005H	62	70	C
U4MVOT-GLEDH 2006H	79	73	C
U4MVOT-GLEDH 2006L	58	43	D
U4MVOT-GLEDH 2008L	43	48	D
U4MVOT-GLEDH 2011L	190	50	D
U4MVOT-GLEDH 2012H	175	56	D
U4MVOT-GLEDH 2016H	-	41	D
U4MVOT-GLEDH 2016L	63	32	E
U4MVOT-N2BRG 1999H	-	47	D
U4MVOT-N2BRG 2000L	47	40	D
U4MVOT-N2BRG 2004L	48	48	D
U4MVOT-N2BRG 2005H	55	61	C
U4MVOT-N2BRG 2005L	51	65	C
U4MVOT-N2BRG 2008L	65	65	C
U4MVOT-N2BRG 2011L	150	50	D
U4MVOT-N2BRG 2012H	57	56	D
U4MVOT-N2BRG 2016L	48	34	E

2.3.2 Thukela River and its associated tributary (Mandeni)

The results from the Thukela River (along with Mandeni Stream) study sites had an increasing ecological integrity from 2005 – 2012. That was followed up by a decreasing trend which was allied with pollution tolerant taxa and low number of taxa (Fig. 2.5 a). The Thukela River sites included better ecological integrity when compared with the Mandeni Stream sites (Fig. 2.5 a). In the Mandeni Stream, macroinvertebrate communities were in an unacceptably and unsustainable poor state which ranged from Class D – E /F. The ecological integrity of the V1MAND-WASTE site exhibited an increasing trend from 2006 (class F) – 2012 (class B). However, that was followed by a decreasing trend with the dominance of pollution tolerant taxa. The ecological integrity of the V1MAND-WEIR site normally ranged from class D – E over the study period except for 2012 survey where this site was characterized as class B/C (Fig. 2.5 a). The ecological integrity of the Thukela River sites had high variability throughout the study period and it ecological class ranged from class A – F (Fig. 2.5 a). V1THUK-RAILB was the least impacted site of all as it ecological integrity class ranged from class A – D. This site had high number of taxa and it showed both tolerant and intolerant taxa.

Thukela and Mandeni Rivers ranged from largely modified to seriously/critically modified state. The Mandeni sites had a relatively low SASS5 scores and ASPT. Additionally, the biological bands developed indicated that the ASPT and SASS5 scores categorized this stream as class D - E/F in most years except in 2013 and 2014 low flow surveys where some Mandeni sites were characterized a class C (Fig. 2.6). The macroinvertebrate community wellbeing of the V1THUK-RAILB exhibited better ecological states when compared with the three other sites in most years (Fig. 2.6).

a)



b)

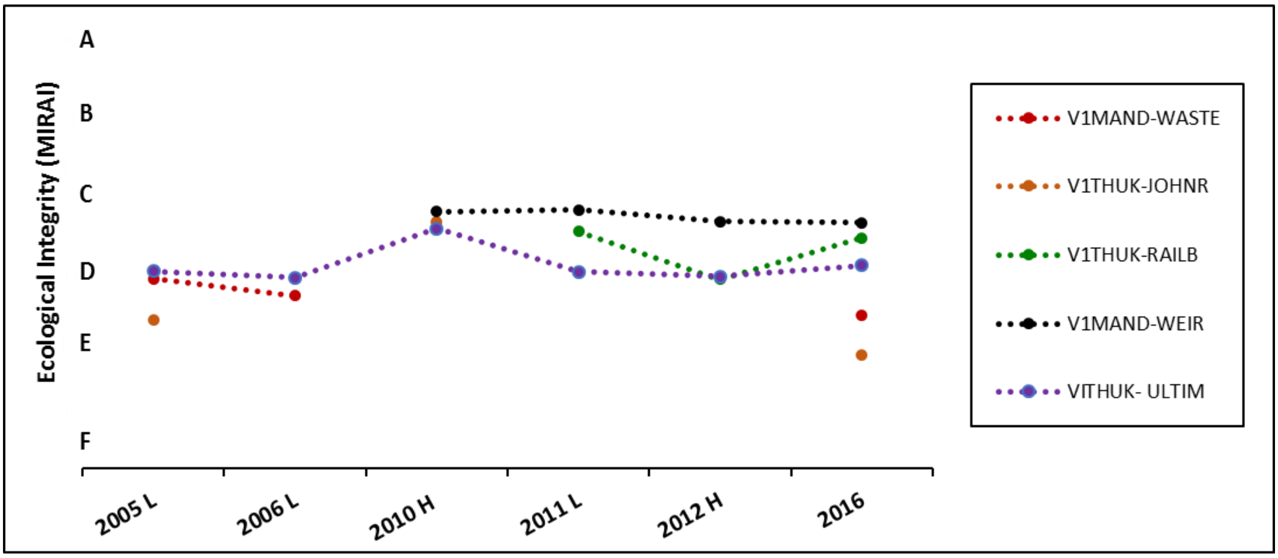


Figure 2. 5: Trends regarding the macroinvertebrate community wellbeing determined by **a)** SASS5 and **b)** MIRAI analysis during the study period (2005 – 2016) for the high (H) and low (L) flow surveys in the four study sites of the Thukela River.

Based on the SASS5 scores and the ASPT, the macroinvertebrate wellbeing of the

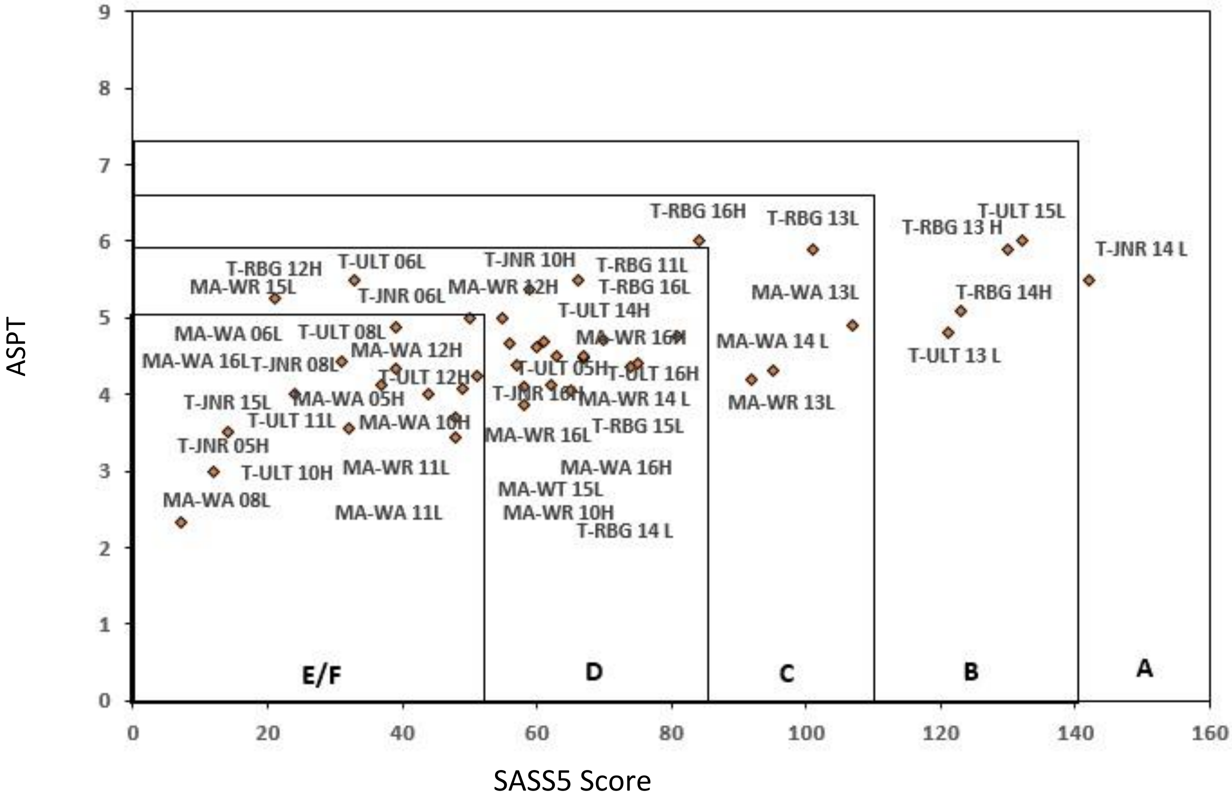


Figure 2. 6*:* Average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (x-axis) plotted for the lower Thukela river. This plot is primarily

based on the integrity category bands from North Eastern Coastal Belt developed by Dallas (2007).

The number of taxa found within each year in all sites varied extensively depending on how favourable the conditions were during the surveys. From 2006 up to 2012, the highest number of different taxa was recorded in the Mandeni stream sites. However, in 2013 – 2016 the highest number of different taxa was observed in the Thukela River sites.

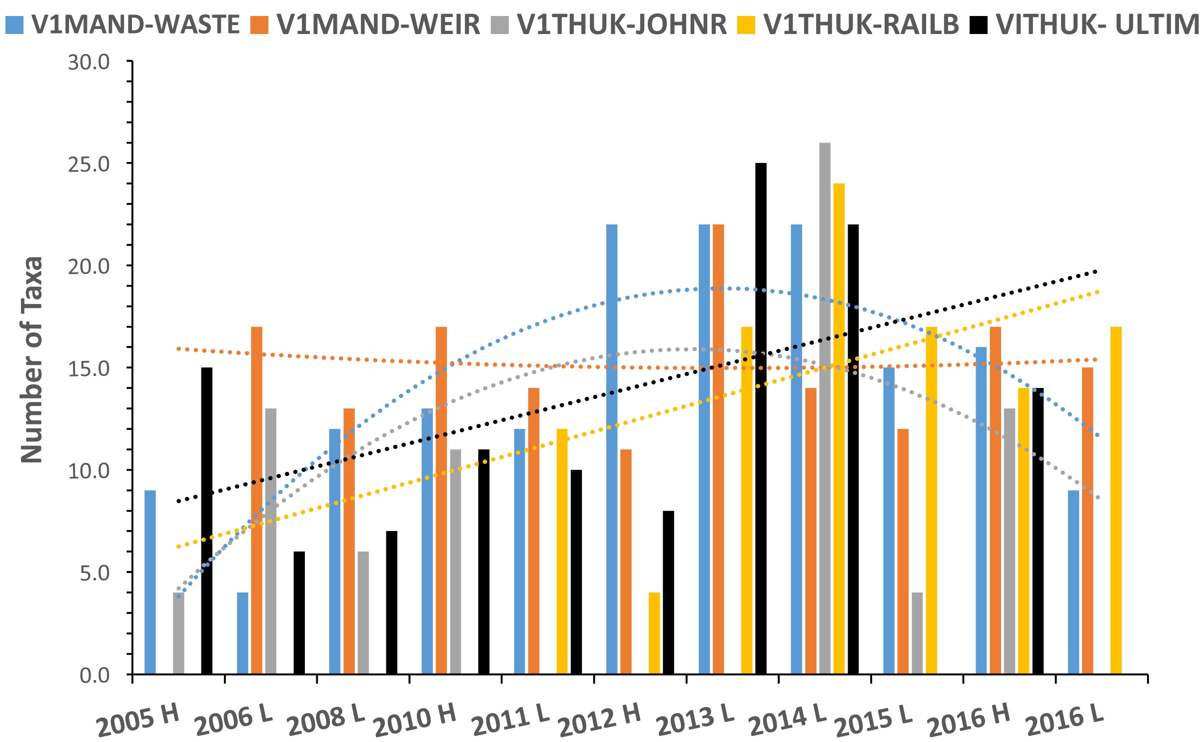


Figure 2. 7: Number of taxa recorded during the study period (2005– 2016) for the high (H) and low (L) flow surveys in the four study sites for Thukela River

The IHAS results revealed that the Thukela and Mandeni rivers sites ranged from modified state (class C) to largely modified state (class D). The Thukela river sites were predominantly in a largely modified (class D) state throughout the study period except for VITHUK-RAILB and V1THUK-JOHNR which was classified as class C in 2005 and 2016 high flow surveys (Table 2.3).

Table 2. 3: The Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) of the lower Thukela River during the study period (2005 – 2016).

Sites	IHI	IHAS	IHAS Class
V1MAND-WASTE 2005H	62	71	C
V1MAND-WASTE 2006L	78	56	D
V1MAND-WASTE 2011L	65	66	C
V1MAND-WASTE 2012H	56	43	D
V1MAND-WASTE 2016H	-	62	C
V1MAND-WASTE 2016L	58	53	D
V1THUK-RAILB 2016H	-	64	C
V1MAND-WEIR 2011L	46	53	D
V1MAND-WEIR 2012H	44	46	D
V1MAND-WEIR 2015L	30	63	C
V1MAND-WEIR 2016H	-	57	D
V1MAND-WEIR 2016L	54	70	C
V1MAND-WASTE 2015L	35	50	D
V1THUK-RAILB 2015L	50	57	D
V1THUK-RAILB 2016L	73	59	D
V1THUK-JOHNR 2005H	53	62	C
V1THUK-JOHNR 2006L	41	50	D
V1THUK-JOHNR 2008L	34	40	D
V1THUK-JOHNR 2010H	126	43	D
V1THUK-JOHNR 2015L	52	50	D
V1THUK-JOHNR 2016H	-	49	D
V1THUK-ULTIM 2005H	46	54	D
V1THUK-ULTIM 2006L	44	54	D
V1THUK-ULTIM 2008L	36	40	D
V1THUK-ULTIM 2011L	45	42	D
V1THUK-ULTIM 2012H	35	46	D
V1THUK-ULTIM 2015L	75	53	D
V1THUK-ULTIM 2016H	-	51	D

2.4. Discussion

2.4.1 uMvoti River and its associated tributary (Ntchaweni)

The ecological integrity of the Ntchaweni Stream sites were found to be in a more degraded state relative to the uMvoti River site. Macroinvertebrate communities from this stream had low number of taxa and they were dominated by pollution tolerant families including Belastomatidae and Chironomidae. This can be attributed to poor water quality caused by effluent discharges from the Gledhow Sugar Mill, Sappi Paper and Pulp making activities as well as domestic use by the local communities (Malherbe 2006; Carminati 2008; Venter

2013). The SASS5 results exhibited high variability of the ecological integrity state of the Ntchaweni River sites whereas the MIRAI results had less variability. This can be attributed to the SASS5 tool considering water quality as the main driver of change in the structure of macroinvertebrate communities (Dickens and Graham 2002) whereas the MIRAI tool considers a combination of different metrics as probable drivers of change (Thirion 2007). The MIRAI tool include habitat availability and heterogeneity, flow regimes, season variations as well as water quality (Thirion 2007). Thus, effective monitoring of the ecological integrity state of macroinvertebrate communities in river ecosystems must consider the cumulative effect of all the metrics included in MIRAI tool. Farrell (2014) documented that the macroinvertebrate communities in the Wilge River normally exhibit low number taxa due to poor availability of habitat. Similar results were obtained in this study and the MIRAI tool revealed that the lack of stone biotopes had an adverse impact on macroinvertebrate communities since habitat heterogeneity and complexity was reduced. As a result, families which were strongly allied with the stone biotopes like Polymitarcyiae, Tricoptera and Plecoptera (Farrell 2014) were not recorded, contributing to lower ASPT scores in Ntchaweni stream sites. The uMvoti and Thukela River sites were mostly dominated by sandy substrate and that had a negative effect on macroinvertebrate communities which exhibited by estimated and low number of different taxa. Low number of macroinvertebrate communities due to sandy substrates has also been documented by several researchers (Quinn and Hickey1990; Brewin et al. 1995; Dallas 2007). The SASS5 and MIRAI results included a decreasing overall trend of the macroinvertebrate community integrity state at the Ntchaweni Stream sites. That suggested that poor habitat heterogeneity as well as anthropogenic activities associated with the Ntchaweni stream negatively impact the overall wellbeing, which in turn will result in the loss of key ecosystem services the stream provides (Deborde et al. 2016).

The severe impact of degraded ecological integrity state at the Ntchaweni Stream sites were further evident at the uMvoti River site (U4MVOT-N2BRG) situated below the Ntchaweni – uMvoti confluence. This site had a low number of taxa and relatively poor ecological integrity state which ranged from class D – E/F when using SASS5 and MIRAI tools. This can be attributed to dominant sandy substrate which reduces the habitat heterogeneity of the stream (Anthony 2001). Other stressors that may be attributed to the degradation of macroinvertebrates integrity state of the U4MVOT-N2BRG site includes excessive water abstraction, sand mining and sugarcane plantations located upstream of this site (Malherbe 2006; Venter 2013). Macroinvertebrate communities in the U4MVOT-

N2BRG site were dominated by pollution tolerant taxa and that may be attributed to Stanger sewage treatment works that originates from the Mbozano River which converge with the uMvoti River upstream of the U4MVOT-N2BRG site (Venter 2013). Sewage treatment works have been documented to have a direct detrimental effect on aquatic organisms by impairing water quality, which in turn alters the biological community structure and ecosystem functioning of many rivers (Aristi et al. 2015). This suggests that changes in water quality plays a major role in macroinvertebrate community structures and that the SASS5 tool was successfully implemented in this study.

The U4MVOT-GLEDH site had minimal human disturbances, good habitat quality and consistently better macroinvertebrates integrity state when compared with the other sites. The pollution intolerant families were prevalent in most years within this site and they included Atydae, Baetidae, Heptageniidae Naucoridae, Oligoneuridae, and many others. It also had high number of taxa which can be associated with adequate habitat availability, heterogeneity and complexity. Baptista et al. (2001) observed a similar association in their study as they observed high habitat heterogeneity and complexity which was allied with high aquatic insect's diversity. This becomes an issue when monitoring rivers using the SASS5 tool alone because it does not include habitat quality and availability as it metric, meaning that this tool accuses water quality as the sole driver of change in macroinvertebrates diversity. However, the biological bands tried to overcome this issue by creating interpretation guidelines for SASS data which considers spatial variation (Dallas 2007). The development of the guidelines was based on the positive correlation that SASS5 score and number of taxa have with the number of biotopes sampled as well as the negative correlation ASPT had with number of biotopes sampled (Dallas 2007). This biological bands interpretation guidelines allows natural variation in the SASS5 biotopes sampled (gravel/sand/mud, vegetation and stone) to be considered (Dallas 2007).

2.4.2 Thukela River and its associated tributary (Mandeni)

The ecological integrity of the Mandeni Stream sites were predominantly found to be in a poor ecological state (class D – E) and they were dominated by pollution tolerant species which included Culicidae, Chironomidae, Sphaeridae, Belastomatidae and a couple of other families with the SASS5 QV scores between 1 – 5. This can be attributed to impaired water quality due to Isithebe industrial complex and iLembe wastewater treatment works

(Venter (2013). The macroinvertebrate community integrity states at the Mandeni Stream sites were probably impacted by cattle grazing and trampling which was excessive. Bracia and Voshel (2006) documented that trampled stream banks faces increased erosion and sedimentation which is not ideal for many aquatic organisms.

The severe impact of anthropogenic stressors associated with the Mandeni Stream was further evident in Thukela River sites (V1THUK-JOHNR and V1THUK-ULTIM) below the Mandeni – Thukela confluence. The ecological integrity of these sites fluctuated markedly (class B – F) when using the SASS5 tool. The degradation of the integrity state observed in the V1THUK-JOHNR and V1THUK-ULTIM sites can be associated with pollution originating from the Mandeni stream sites, exotic vegetation, shallow water column as well as sedimentation caused by intensive sand mining (Venter 2013). These activities affected vulnerable macroinvertebrates. For example, number of Tricoptera, Hydropyschidae, Oligonuerida exhibited a decreasing trend from 1999 – 2016, whereas Chironomidae, Belastomatidae, Simuliidae were found to be predominant in the late study period.

V1THUK-RAILB was situated upstream of the confluence between the Mandeni and Thukela Rivers and it revealed consistently better macroinvertebrates integrity state trend when compared with the other sites. Results also revealed a relatively good species diversity within this site due to adequate habitat heterogeneity which allowed more families to thrive successfully. Several pollution intolerant taxa were recorded in this sites in most years, indicating minimal impact by the anthropogenic stressors. The pollution intolerant families included Atydae, Baetidae, Heptageniidae, Naucoridae, Oligoneuridae, Notonemouridae and Limnichidae

2.4.3 uMvoti and Thukela Rivers (along with their associated tributaries)

The MIRAI and SASS5 tools indicated that the macroinvertebrate communities in this study rivers have suffered a general loss in integrity. The SASS5 tool attributed the possible driver of such trend to water quality states whereas the MIRAI tool attributed such change to a combined effect of habitat quality and availability, river flow regimes, seasonal variations and alterations in water quality. The reduced macroinvertebrate communities in the study rivers indicates that the overall ecological integrity of most lower uMvoti and Thukela Rivers are in a poor state and that can have adverse effect on sustainable use of ecological services associated with these rivers. Hence, protection measures are required in order attain sustainable use of such ecosystem services. Both indices (SASS5 and MIRAI) played a role in generating suitable trends for the uMvoti and Thukela Rivers, as well as their associated tributaries. The SASS5 tool was able to integrate the effects of multiple pollutants or types of impacts on the macroinvertebrate community structures. However, it overall assessment was primarily based on water quality and that resulted in high variability of macroinvertebrates integrity states of both rivers.

The MIRAI classification indicated lower class from what was observed from the SASS5 results. With regards to MIRAI results for uMvoti and Thukela Rivers, there was a steady ecological integrity in most years and this may be due to added metrics which assisted in identifying specific drivers of change and they also gave a more refined ecological integrity.

2.4.5 Conclusions

The use of freshwater macroinvertebrate community metrics revealed a more robust framework for evaluating both the short-term and long-term effects of anthropogenic activities in riverine ecosystems. The tools were implemented successfully as they generated suitable trends which indicated the ecological integrity state of the study rivers. The SASS5 tool was observed to be less effective when monitoring the overall ecological integrity because it depends primarily on water quality as the main driver of change. Many factors other than water quality impact the ecological integrity of river systems. The MIRAI tool on the other side was found to be the better, more responsive, robust and more informative tool.

The outcomes of this study illustrated that the uMvoti River ecological integrity was decreasing. This can be attributed to both poor habitat quality and excessive anthropogenic stressors which results in the uMvoti River being in a seriously modified state. The SASS5 and MIRAI results indicated that ecological integrity of the Ntchaweni Stream sites were largely modified. This could probably be due to water resource use stressors like Gledhow Sugar Mill, Sappi Pulp and Paper making activities and agricultural practices. The Thukela and Mandeni Rivers also exhibited poor ecological integrity. This can be attributed to major industrial activities, wastewater treatment works, and excessive water abstraction and sugarcane plantations. Also low habitat heterogeneity at the uMvoti and Thukela study sites had an adverse effect on the streams ecological integrity. Because of this, it is very important to monitor these rivers in order to get information that is will be of great use in the development of effective strategies for management, protection and conservation. This will help in reaching the sustainable use of water resources and it will promote the balance between the water resource use and protection.

2.5 Acknowledgements

We thank the Aquatic Ecosystem Research Program (AER) and South African Pulp and Paper Industries Limited (Sappi) for the opportunity to do this research and for providing running costs. Our sincere gratitude to the National Research Fund (ZA) for funding as well the Ezemvelo KZN Wildlife for permits. We are grateful to N Senoge and O Agboola for assisting in data collection. We thank Christine for helping with laboratory work.

2.6 References

Alba-Tercedor J, Jáimez-Cuéllar P, Álvarez M, Avilés J, Bonada N, Casas J, Mellado A, Ortega M, Pardo I, Prat N, Rieradevall M, Robles S, Sáinz-Cantero CE, Sánchez-Ortega A, Suárez ML, Toro M, Vidal-Abarca MR, Vivas S, Zamora-Munoz C. 2002. Caracterización del estado ecológico de ríos mediterráneos ibéricos mediante el índice IBMWP (antes BMWP'). Limnetica 21: 175–185.

Anthony DJ. (Ed.). 2001. Applying geomorphology to environmental management. Water Resources Publication.

Arimoro FO, Ikomi RB, Erebe E. 2007. Macroinvertebrate community diversity in relation to water quality status of River Ase, Niger Delta, Nigeria. Journal of Fisheries and Aquatic Science 2: 337–344.

Aristi I, Schiller D, Arroita M, Barceló D, Ponsatí L, García-Galán, M. J., ... Acuña V. 2015. Mixed effects of effluents from a wastewater treatment plant on river ecosystem metabolism: subsidy or stress? Freshwater biology 60: 1398–1410.

Aura CM, Raburu PO, Herrmann J. 2010. A preliminary macroinvertebrate Index of Biotic Integrity for bioassessment of the Kipkaren and Sosiani Rivers, Nzoia River basin, Kenya. Lakes & Reservoirs: Research & Management, 15: 119–128.

Baptista DF, Buss DF, Dorvillé LFM, Nessimian JL. 2001. Diversity and habitat preference of aquatic insects along the longitudinal gradient of the Macaé river basin, Rio de Janeiro, Brazil. Revista Brasileira de Biologia 61: 249–258.

Bellingan TA, Woodford DJ, Gouws J, Villet MH, Weyl OLF. 2015. Rapid bioassessment of the effects of repeated rotenone treatments on invertebrate assemblages in the Rondegat River, South Africa. African Journal of Aquatic Science 40: 89–94.

Braccia A, Voshell Jr JR. 2006. Benthic macroinvertebrate fauna in small streams used by cattle in the Blue Ridge Mountains, Virginia. Northeastern Naturalist 13: 269–286.

Buffagni A, Erba S, Cazzola M, Murray-Bligh J, Soszka H, Genoni P. 2006. The STAR common metrics approach to the WFD intercalibration process: Full application for small, lowland rivers in three European countries. In The Ecological Status of European Rivers: Evaluation and Intercalibration of Assessment Methods (pp. 379–399). Springer Netherlands.

Brewin PA, Newman TML, Ormerod SJ. 1995. Patterns of macroinvertebrate distribution in relation to altitude, habitat structure and land use in streams of the Nepalese Himalaya. Archiv für Hydrobiologie 135: 79–100.

Carminati AV. 2008. An Assessment of the effects of sugar mill cctivities on the ecological integrity of the UMvoti and Amatikulu Rivers, KwaZulu Natal. MSc Dissertation, University of Johannesburg, Johannesburg.

Chambers DB, Messinger T. 2001. Benthic invertebrate communities and their responses to selected environmental factors in the Kanawha River Basin, West Virginia, Virginia, and North Carolina. US Department of the Interior, US Geological Survey.

Chessman BC. 1995. Rapid assessment of rivers using macroinvertebrates: a procedure based on habitat-specific sampling, family-level identification and a biotic index. Australian Journal of Ecology 20: 122–129.

Chutter FM. 1994. The rapid biological assessment of streams and river water quality by means of macroinvertebrate communities in South Africa. In: Uys, M.C. (ed.) Classification of Rivers and Environmental Health Indicators. WRC Report No. TT 63/94. Water Research Commission, South Africa. pp 217–234.

Clark DL. 2015. Effects of livestock grazing on aquatic macroinvertebrates in southerninterior wetlands of British Columbia, Canada. PhD Dissertation, Thompson Rivers University.

Clarke RT, Furse MT, Wright JF, Moss D. 2003. Derivation of a biological quality index for river sites: comparison of the observed with the expected fauna. Journal of Applied Statistics 1996: 311–332.

Dallas H.F. 2007. The effect of biotope-specific sampling for aquatic macroinvertebrates on reference site classification and the identification of environmental predictors in Mpumalanga, South Africa. African Journal of Aquatic Science, 32:165–173.

Dallas HF. 2007. River health programme: South African scoring system (SASS) data interpretation guidelines. Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Institute of Natural Resources.

Dallas HF. 2007. The influence of biotope availability on macroinvertebrate assemblages in South African rivers: implications for aquatic bioassessment. Freshwater biology 52: 370–380.

Davies AG. 1982. The construction of the Tugela-Vaal Project dams. Civil Engineer in South Africa, 24(8), 385-388.

Deborde DDD, Hernandez MBM, Magbanua FS. 2016. Benthic macroinvertebrate community as an indicator of stream health: the effects of land use on stream benthic macroinvertebrates. Science Diliman 28.

Deksissa T, Ashton PJ, Vanrolleghem PA. 2003. Control options for river water quality improvement: A case study of TDS and inorganic nitrogen in the Crocodile River (South Africa). Water SA 29: 209–218.

Dickens CW, Graham PM. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. African Journal of Aquatic Science 27: 1–10.

Farrell KT. 2014. Aquatic Macroinvertebrate Community in the Wilge River. PhD Dissertation, University of Johannesburg, Johannesburg.

Fourie HE, Thirion C, Weldon CW. 2014. Do SASS5 scores vary with season in the South African Highveld? A case study on the Skeerpoort River, North West province, South Africa. African journal of aquatic science 39: 369–376.

Gabriels W, Lock K, De Pauw N, Goethals PL. 2010. Multimetric Macroinvertebrate Index Flanders (MMIF) for biological assessment of rivers and lakes in Flanders (Belgium). Limnologica-Ecology and Management of Inland Waters 40: 199–207.

Hammer DA. 1996. Creating freshwater wetlands. CRC Press.

Jacobs PG. 2017. Hydrological assessment to predict velocity-flow classes in the lower Thukela River. PhD Dissertation, North-West University, Potchefstroom.

Jun YC, Won DH, Lee SH, Kong DS, Hwang SJ. 2012. A multimetric benthic macroinvertebrate index for the assessment of stream biotic integrity in Korea. International Journal of Environmental Research and Public Health 9: 3599–3628.

Kenney MA, Sutton-Grier AE, Smith RF, Gresens SE. 2009. Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy. Terrestrial Arthropod Reviews 2: 99.

Kleynhans CJ, Louw MD, Thirion C, Rossouw N, Rowntree K. 2005. River Ecoclassification: Manual for EcoStatus determination (Version 1). Joint Water Research Commission (WRC) and Department of Water Affairs and Forestry (DWAF) report. WRC Report No. KV 168/05. Water Research Commission, Pretoria, South Africa

Lamberth SJ, Drapeau L, Branch GM. 2009. The effects of altered freshwater inflows on catch rates of non-estuarine-dependent fish in a multispecies nearshore line fishery. Estuarine, Coastal and Shelf Science 84:527–538.

Li L, Zheng B, Liu L. 2010. Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. Procedia environmental sciences 2: 1510–1524.

Mahlangu SE. 2014. Aquatic health assessment of the Klip River System, Gauteng, South Africa (Doctoral dissertation, University of Johannesburg).

Malherbe CW. 2006. The current ecological state of the lower UMvoti River, KwaZulu-Natal. MSc Dissertation, University of Johannesburg.

Mondy CP, Villeneuve B, Archaimbault V, Usseglio-Polatera P. 2012. A new macroinvertebrate-based multimetric index (I 2 M 2) to evaluate ecological quality of French wadeable streams fulfilling the WFD demands: A taxonomical and trait approach. Ecological Indicators 18: 452–467.

Nakano D, Nagayama S, Kawaguchi Y, Nakamura F. 2008. River restoration for macroinvertebrate communities in lowland rivers: insights from restorations of the Shibetsu River, north Japan. Landscape and Ecological Engineering 4: 63–68.

O'Brien GC, Swemmer R, Wepener V. 2009. Ecological integrity assessment of fish assemblages of the Matigulu/Nyoni and UUMvoti estuaries, KwaZulu-Natal, South Africa. African Journal of Aquatic Science 34: 293–302.

O'Brien GC, Wepener V, Malherbe W, Swemmer R, Von Bratt C. 2005. Ecological Integrity Assessment of the Lower Mvoti River/Estuary, KwaZulu-Natal: Update of the 2000 Ecological Evaluation of the Lower Mvoti River and Estuary. Report prepared for the Sappi Stanger Environmental Liaison Committee (SSELC). Report No. 2005/06/001. Stanger, South Africa.

O'Brien GC, Venter H. 2012. Evaluation of eight years (2005 to 2012) of ecological integrity data from the lower Thukela River/Estuary and associated systems with management considerations based on the risk of hazards affecting ecosystem structure and function, KwaZulu-Natal., Water Research Group, North West University, Potchefstroom.

O'Brien GC. 2010. Ecological State Assessment of the Lower Thukela River/Estuary, KwaZulu-Natal. Investigational Report. Rivers of Life: Aquatic Health Services, Potchefstroom, South Africa.

Oertel N, Salánki J. 2003. Biomonitoring and bioindicators in aquatic ecosystems. In Modern trends in applied aquatic ecology (pp. 219-246). Springer, Boston, MA.

Poikane S, Zampoukas N, Borja A, Davies SP, van de Bund W, Birk S. 2014. Intercalibration of aquatic ecological assessment methods in the European Union: Lessons learned and way forward. Environmental Science & Policy 44: 237–246.

Poquet JM, Alba-Tercedor J, Puntí T, del Mar Sánchez-Montoya M, Robles S, Alvarez M, Toro M. 2009. The Mediterranean Prediction and Classification System (MEDPACS): an implementation of the RIVPACS/AUSRIVAS predictive approach for assessing Mediterranean aquatic macroinvertebrate communities. Hydrobiologia 623: 153–171.

Quinn JM, Hickey CW. 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. New Zealand Journal of Marine and Freshwater Research 24: 387–409.

Reynoldson TB, Bailey RC, Day KE, Norris RH. 1995. Biological guidelines for freshwater sediment based on BEnthic Assessment of SedimenT (the BEAST) using a multivariate approach for predicting biological state. Austral Ecology 20: 198–219.

Thirion C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission (WRC) and Department of Water Affairs and Forestry (DWAF) report. WRC Report No. TT332/08. Water Research Commission, Pretoria, South Africa.

Thirion C. 2016. The determination of flow and habitat requirements for selected riverine macroinvertebrates. PhD Dissertation, North-West University, Potchefstroom.

Venter JJ. 2013. An ecological integrity assessment of the lower Amatikulu, Thukela and UMvoti Rivers, KwaZulu-Natal, South Africa. PhD Dissertation. North-West University, Potchefstroom.

Wallace JB, Webster JR. 1996. The role of macroinvertebrates in stream ecosystem function. Annual review of entomology 41: 115–139.

Wright JF, Moss D, Armitage PD, Furse MT. 1984. A preliminary classification of running-water sites in Great Britain based on macroinvertebrate species and the prediction of community type using environmental data. Freshwater Biology 14: 221–256.

Wright JF. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20: 181–197

Yuan LL, Norton SB. 2003. Comparing responses of macroinvertebrate metrics to increasing stress. Journal of the North American Benthological Society 22: 308–322.

2.7 Appendices

Appendix 2.1: Photos of the study site in the UMvoti and Ntchaweni Rivers **a)** U4NTCHA-GLEDH **b)** U4UNTCHA-SAPPI **c)** U4MVOT-GLEDH and **d)** U4MVOT-N2BRG

a)

b)

c)

d)

Appendix 2.2: Photos of the study site in the Thukela and Mendini Rivers **a)** V1MAND-WASTE **b)** VAMAND-WEIR **c)** V1THUK-RAILB **d)** V1THUK-JOMHR and **e)** V1THUK-ULTIM

a)

b)

c)

d)

e)

CHAPTER 3

Macroinvertebrate communities of lowland rivers in KwaZulu-Natal and their response to water quality, quantity and habitat changes

NP Tenza, CT Downs and GC O'Brien

School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg 3209, South Africa

Formatted for African Journal of Aquatic Science

Abstract

Water serves as a natural resource that is crucial to humankind and all the other life forms on earth. Anthropogenic natural stressors including climate change threatens limited freshwater resources, especially in water scares areas. South Africa is currently classified as a water scarce and semi-arid country that receives an average precipitation of approximately 450 mm per year, less that the world's average. Hence, it is of great importance to assess, monitor and understand the environmental changes that affect South Africa's aquatic ecosystems. The aim of this study was to evaluate the responses of macroinvertebrate communities to water resource use stressors at the lowland uMvoti and Thukela Rivers, South Africa. A redundancy analysis (RDA) approach using Canoco for Windows version 4.5 was used to statistically analyze all data. Results demonstrated that the prevalence of pollution tolerant families and less diverse macroinvertebrate communities at the uMvoti and Ntchaweni Rivers was ascribed to effluent discharges from the industries, Stanger sewage treatment works as well as domestic use by the local communities. The Thukela and Mandeni Rivers also exhibited pollution tolerant families and relatively poor macroinvertebrate communities. This can be attributed synergistic effect of effluent discharges from industries, wastewater treatment works, solid waste, water abstraction and sedimentation. Both uMvoti and Thukela Rivers are highly impacted by water resource use stressors and they require urgent management and protection interventions.

3.1 Introduction

Water resources are currently facing unprecedented threats from multiple stressors arising from both anthropogenic activities and natural events (Wheater and Gober 2015). Such stressors include a decrease in river flows, loss of habitat, reduction in groundwater levels as well as a rapid increase pollution (King and Pienaar 2011). The Food and Agriculture Organization (FAO) has predicted that in 2050, the world will be required to feed 9 billion people and that will demand a 60 percent (%) increase in the agricultural production (Wise 2013). That alone will cause serious concerns to the limited amount of freshwater available as the agricultural sector accounts for the total of 70% of freshwater withdrawal (UN-Water 2014). Countries like South Africa will be impacted heavily by these developments since it is currently classified as a semi-arid and water scarce country that receives an average precipitation of approximately 450mm per year (Hill 2007; Otieno and Ochieng 2007), making it the 30th driest country on the world (Kohler 2016).

The earth's temperature continues to increase and that promote greater evaporation rate which cause devastating effects of frequent and severe drought as well as flooding on different regions of the world (Cassardo 2014). The combination of anthropogenic stressors results in the loss of many significant ecosystem services (Venter 2013). Globally, it has been predicted that if high water utility rates continue, water demand will exceed supply (Kohler 2016). Therefore, it is of great importance to protect water as a natural resource that sustains all life on earth (Malherbe 2006; Venter 2013; Vörösmarty et al. 2010). The recognition of the vital role played by water in South Africa resulted in the formation of National Water Act (NWA), Act 36 of 1998 (NWA, 1998). This act was aimed at ensuring that South African water is used, protected, conserved, managed and controlled in a way that considers human basic needs of the present and the future (NWA, 1998). The NWA was also aimed at promoting equality to access, efficient use and the beneficial use of water in the public interest (NWA, 1998). Additionally, the NWA was developed for ensuring that the current and future ecological integrity of aquatic ecosystems are developed and sustained (NWA, 1998). For this to happen, factors that drive the ecological integrity of aquatic ecosystems need to be determined through biomonitoring, and controlled if possible (Malherbe, 2006). Biomonitoring is a valuable assessment tool that is frequently applied when evaluating the ecological status of aquatic ecosystems (Li et al. 2010). This assessment tool uses biological responses of aquatic plants and animals to evaluate changes in the environment (Li et al. 2010).

This study focused primarily on freshwater macroinvertebrate communities. Such communities have been established as ecological indicators of the wellbeing of aquatic ecosystems and they are frequently used when assessing the ecological health of many systems because they reveal the impact of perturbation and habitat modifications (Arimoro et al. 2007). Aquatic macroinvertebrates are regarded as fundamental part of aquatic ecosystems and they include aquatic insects (such as stoneflies, mayflies, dragonflies, and rat-tailed maggots), mollusks (snails), fresh water crustaceans (crayfish and scuds), annelids (worms and leeches), and all other macroinvertebrates that reside in water for all or part of their life (O'Keeffe and Dickens 2000). Worldwide, macroinvertebrates are highly recommended and frequently used (Oertel and Salánki 2003) when assessing the biological integrity of riverine ecosystems, mainly because there is vast knowledge of their intolerant to different stresses. In addition, they are abundant, easy to collect (visible to the naked eye), easy to identify, have rapid life cycles and they have large sedentary habits (Bredenhand 2005; Leunda et al. 2009).

In this study the spatial and temporal composition of freshwater macroinvertebrate communities were quantified and compared in the lower uMvoti and Thukela Rivers in KwaZulu-Natal (KZN) Province, South Africa. The overall aim was to evaluate the responses of macroinvertebrate communities to water quality, quantity and habitat changes. It was predicted that macroinvertebrates estimated abundance and diversity will change due to both natural and anthropogenic stressors altering their aquatic environment. Results from this study will make an important contribution to the development of macroinvertebrates protection plans, which in turn will result in the protection, management and conservation of the uMvoti and Thukela Rivers water resources during this ongoing drought period.

3.2 Methods

3.2.1 Study sites

The study area included the lower reaches of the uMvoti and Thukela Rivers in KwaZulu-Natal, South Africa (Fig. 3.1). The uMvoti and Thukela Rivers are heavily impacted by water resource use activities. The uMvoti River originates from the Natal Midlands, KZN Province, South Africa; it meanders through a south easterly direction past Greytown and Stanger until pours into the Indian Ocean at a point that is close to Blythedale Beach. The lower uMvoti River catchment is characterised by commercial dry land agriculture and subsistence farming that includes excessive sugarcane plantations, industrial activities, sewage treatment works, excessive water abstraction and domestic use by surrounding households (Venter 2013). The synergistic effect these anthropogenic stressors progressively worsen the ecological integrity of the uMvoti River, resulting the dominance of tolerant families such Chironomidae, Belastomatidae and Simuliidae in this stream. The Thukela River is the second largest river in South Africa (DWAF, 2004). This catchment originates from the Drakensburg escarpment and it meanders 520 km through the central KZN until it reaches the Indian Ocean at approximately 85 km north of Durban (Stryftombolars 2008, Venter 2013). The lower reaches of the Thukela River are characterised by excessive sugarcane plantations and highly industrialised areas which pose the greatest threat to the persistence of intolerant taxa as they normally exhibit estimated and diversity in this stream.

This study is part of a long-term river monitoring program which included both historical and present datasets. The historical data was collected almost every year and during both high and low flows periods between 1999 – 2015 (O'Brien et al. 2005; Malherbe 2006; O'Brien et al. 2009; O'Brien 2010; O'Brien 2012; Venter 2013). The present data was collected in 2016. For the latter dataset two surveys were carried out, the first survey was conducted in April 2016 (high flow period). This period occurs during the wet season and it is associated with increased water flow. The second survey was conducted between September and October 2016 (low flow period). This is regarded as a seasonal phenomenon which is vital for river flow regime and is defined as reduced flow of water in rivers during lengthy dry weather periods (Deksissa et al. 2003).

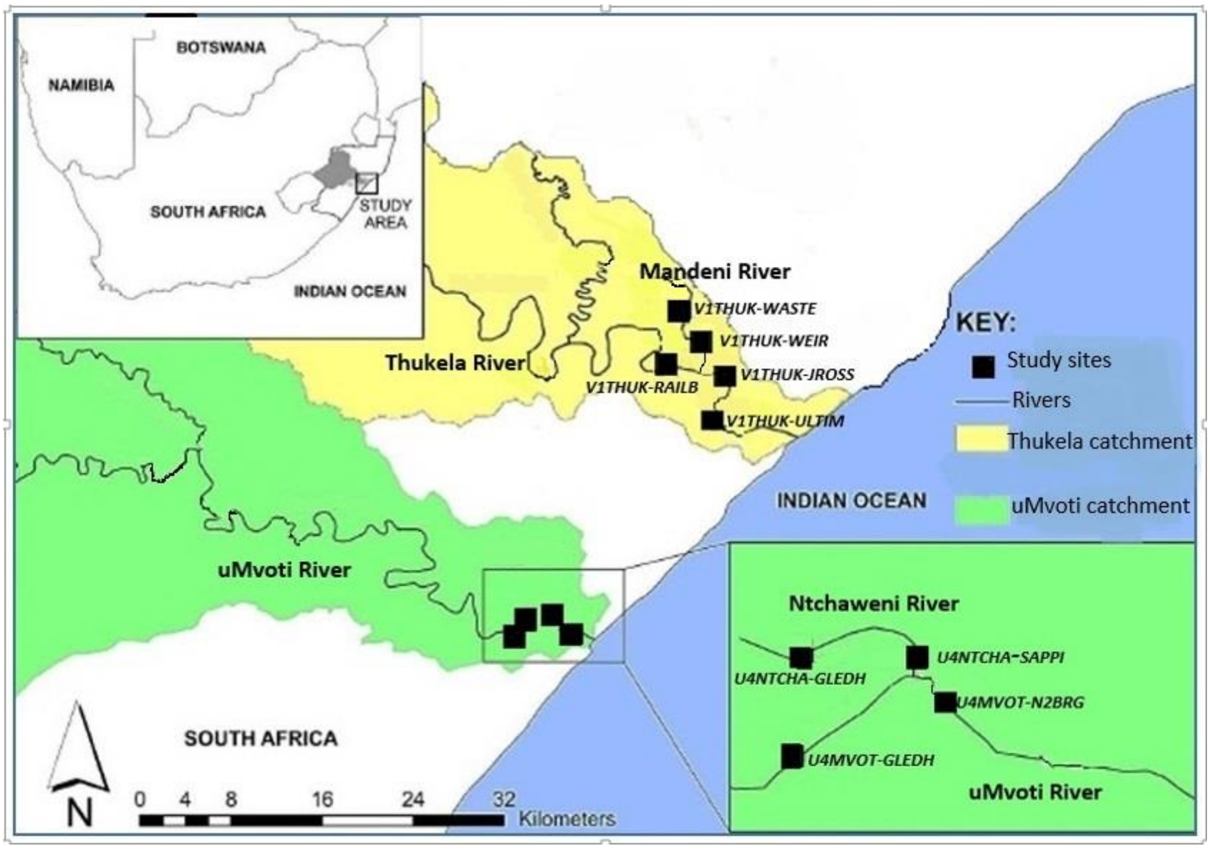


Figure 3.1: Map of the study area showing all 9 sites from uMvoti and Thukela Rivers as well as associated tributaries (Ntchaweni and Mandeni Rivers).

3.2.2 Field data collection

The data collection was undertaken according to the method defined by Dickens and Graham (2002). Data collection was done by accredited SASS5 practitioners. The SASS net (1 mm mesh on a 30 cm square frame) was used to collect macroinvertebrates. For each site, three biotopes were selected and they included stones, vegetation as well as gravel, sand and mud. 1) Stones included movable pebbles, cobbles (970 of 2–25 cm average size) as well as bedrock which includes boulders of >25 cm. Stones were sampled according to the SASS5 method which stipulates that they should be sampled for approximately 3 minutes (min.). The maximum sample time was extended up to 5 min in sites with highly embedded bedrock or rocks. 2) Vegetation biotope was divided into two (marginal and aquatic). Marginal vegetation includes emergent and overhanging vegetation growing at the edge of the stream. Marginal vegetation was sampled for an approximate of 2 m in total length. Aquatic vegetation comprised mainly of submerged vegetation, which included roots, stems and floating aquatics and it was sampled for about 1 m^2. 3) Gravel, sand and mud included small stones (<0.06 mm - 2 cm in size). This biotope was sampled for approximately 1 min on each site.

Samples were identified using a macroinvertebrate guide (Dickens and Graham 2002) and total SASS5 Score, total number of taxa and ASPT were calculated for each sample. The abundance was also estimated as per SASS5 method,1 = 1, A = 10, B = 100, C = 1000, D = >1000

3.2.3 Physico-chemical variables

A range of physico-chemical parameters were assessed following the proposed ecological reserve determination methodology that was developed by the South African Department of Water Affairs and Forestry in 1999 (DWAF 1999). Water quality was assessed for all site and the sampling procedure was undertaken during the high/low flow surveys. The collection of *in situ* physico-chemical variables measured in this study was primarily based on the variables selected in the historical assessments which were conducted by CRUZ 2000; O'Brien et al. 2005; Malherbe 2006; O'Brien et al. 2009; O'Brien 2010; O'Brien 2012 and Venter 2013. A calibrated portable meter (Eutech instruments CyberScan series 600, Thermo Fisher, USA) was used to measure physical *in situ* data which include temperature, pH, conductivity, total dissolved solids (TDS) and dissolved oxygen concentration and saturation. In addition, sub-surface water samples were collected using polyethylene bottles for laboratory analysis. The water samples collected were kept frozen until the analysis was done. Samples were further analysed at the Umgeni Water Laboratory (an accredited laboratory with the South African National Accreditation System and the International Standard ISO/IEC 17025:2005). Variables analyses included nutrients (ammonium, nitrites, nitrates, phosphate and sulphates), salts (chloride, sodium, calcium and total alkalinity), Chemical Oxygen Demand (COD), chlorophyll *a* and microbiological assessments of faecal coliforms, total coliforms and heterotrophic plate count.

3.2.4 Data analysis

The multivariate statistical analysis approaches have been frequently used to evaluate the structure and patterns of biological communities in diverse ecosystems (Van den Brink et al 2003; Malherbe 2006; O'Brien et al. 2009). In this study, a redundancy analysis (RDA) approach using Canoco for Windows version 4.5 was utilised to statistically analyse all data obtained throughout the study period (1999 – 2016). The RDA approach is regarded as a linear response model (Van den Brink et al 2003, Chahourki 2011). Two datasets were required to run RDA, the first dataset include response variables (macroinvertebrate communities) whereas the second dataset consists of explanatory variable (environmental data) (Paliy and Shankar 2016). The RDA approach linked macroinvertebrate communities with explanatory environmental data. The sites, seasons, systems, water quality parameters, sediment and habitat were environmental data. In this study the RDA evaluated changes in macroinvertebrate community structures and then tested the statistical significance of differences in communities after incorporated with Monte Carlo permutation testing (Van den Brink et al., 2003; Ter Braak and Smillauer, 2004). The output of the RDA ordination was a map of samples analysed on a two-dimensional (2D) bases, showing both macroinvertebrate communities and environmental data overlain (biplot) (Farrel 2014). The environmental variables were symbolised by arrows whereas the macroinvertebrate communities were represented by points (Chahourki 2011). The RDA ordination plots summarised the patterns of alterations in the macroinvertebrate communities which can be explained by selected environmental variables in this study (Chahourki 2011). Since SASS5 only provides a relative indication of the estimated abundance, the macroinvertebrates community estimated abundance was estimated as follows: 1 = 1, A = 10, B = 100, C = 1000, D = >1000. All the estimated macroinvertebrate community data were transformed using Log transformation (Van den Brink et al., 2003). Additionally, site codes were modified in order to avoid too much wording on the RDA biplots, thus, U4NTCH-SAPPI = NS-P, U4NTCH-GLEEDH = N-GH, U4MVOT-N2BRG = M-N2, U4MVOT-GLEDH = M-GH, V1MAND-WASTE = M-WA, V1MAND-WEIR = M-WR, V1THUK-RAILB = T-RBG, V1THUK-JOHNR = T-JNR and V1THUK-ULTIM = T-ULT.

3.3 Results

Macroinvertebrate community structures were evaluated to determine whether anthropogenic and/or natural stressors drive their changes. The number of taxa and estimated were compared within sites, between sampling periods as well as between rives. The water quality parameters were also considered as drivers of macroinvertebrate changes at the lower uMvoti and Thukela Rivers (appendix 3.1 and 3.2).

3.3.1. Multivariate Statistical Analysis

The RDA bi-plot was constructed using log transformed data and it separated macroinvertebrates data into four distinct faunal assemblages representing the four rivers studied (uMvoti and Thukela Rivers along with their associated tributaries) (Fig. 3.2). The lower uMvoti River site situated above the Ntchaweni – uMvoti confluence (on the lower left quadrant) had high number of taxa which was dominated by intolerant taxa whereas the sites below this confluence formed one cluster (up left quadrant) and they had low number of taxa associated with tolerant taxa. The Thukela River sites had a mixture of tolerant and intolerant taxa whereas the Mandeni stream sites were dominated by tolerant taxa which were allied with low number of taxa.

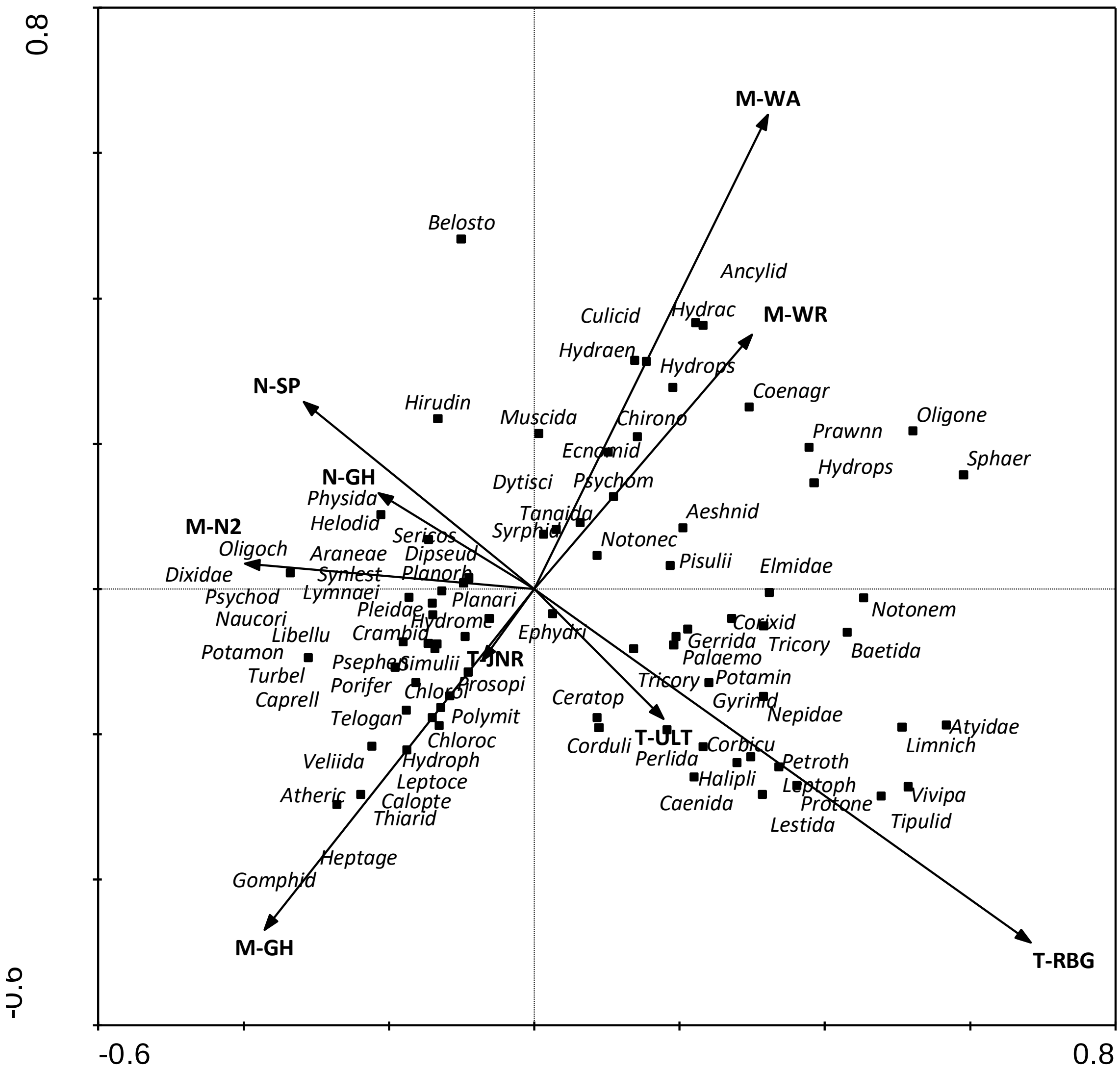


Figure 3. 2: Redundancy analysis bi-plots of the macroinvertebrate community structures, displaying dissimilarity among sites evaluated in this study. The points on the RDA ordination diagram represented the variation in macroinvertebrate

communities whereas the arrows represented sites. The first two axes of the RDA accounted for 70.3% of the total variation explained by the different sites, 50% on the first axis and an additional 19.5% on the second axis. Key: U4NTCH-SAPPI = NS-P, U4NTCH-GLEEDH = N-GH, U4MVOT-N2BRG = M-N2, U4MVOT-GLEDH = M-GH, V1MAND-WASTE = M-WA, V1MAND-WEIR = M-WR, V1THUK-RAILB = T-RBG, V1THUK-JOHNR = T-JNR and V1THUK-ULTIM = T-ULT.

Temporal changes had a significant influence (P = 0.0270, F = 2.317) on the macroinvertebrate community structures from the study area. Intolerant families were closely related to the historical data whereas moderate to highly tolerant families were associated with the present data.

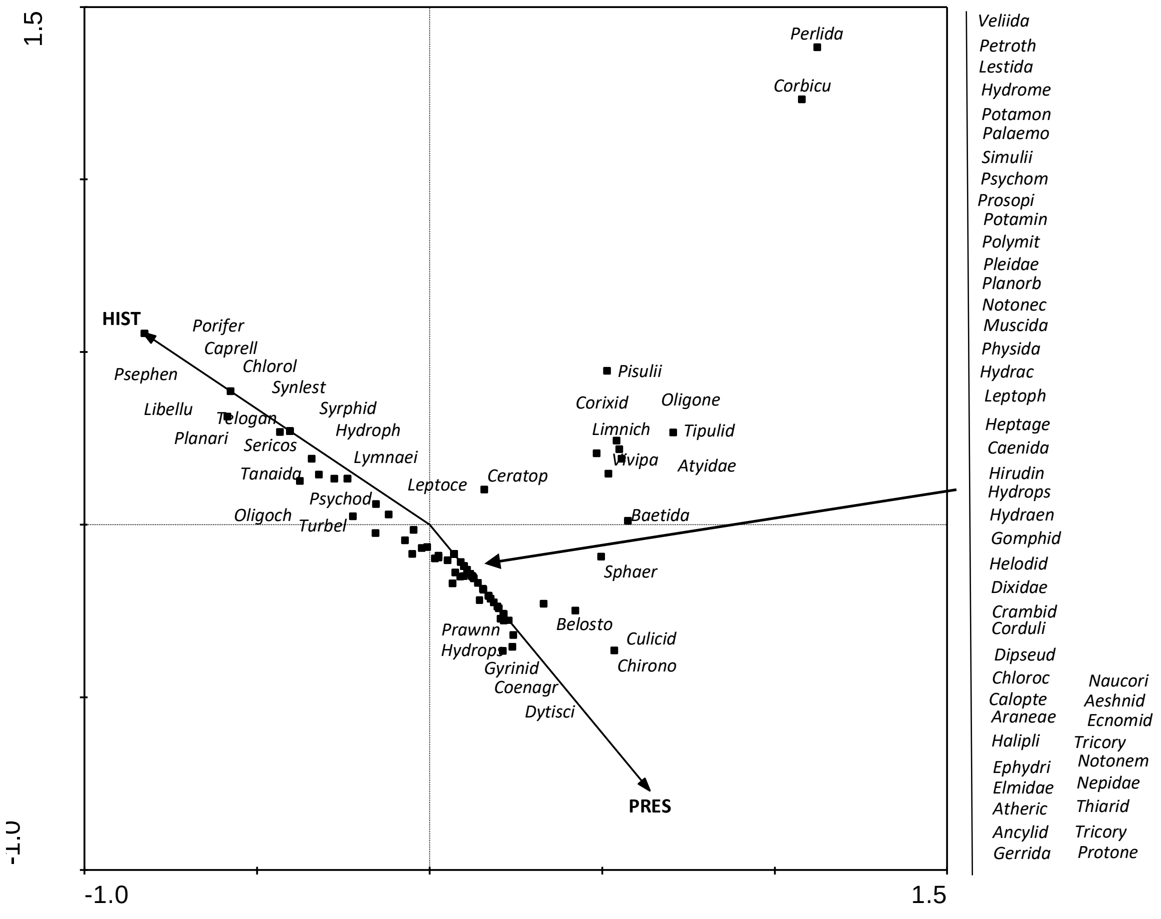


Figure 3. 3: Redundancy analysis bi-plots of the macroinvertebrate communities and temporal changes (historical and present). The points on the RDA ordination diagram represented the variation in macroinvertebrate communities whereas the arrows represented and temporal changes. In the ordination bi-plot, 100% of the variation within the data is represented, 71.3% on the first axis and an additional 28.7% on the second axis.

The Monte Carlo permutation test revealed significant different (P-value of 0.0010, F-ratio of 4.827) (Fig. 3.4). The three SASS5 variables that were hypothesised to represent significant changes in macroinvertebrate communities were the number of taxa (P = 0.001, F= 10.90), estimated (P = 0.001, F = 6.67) and SASS5 scores (P = 0.002, F = 3.53). There was no statistical significance between the macroinvertebrate communities and the ASPT (P = 0.535, F = 0.9).The results further revealed that the SASS5 scores had a correlation with number of taxa and ASPT.

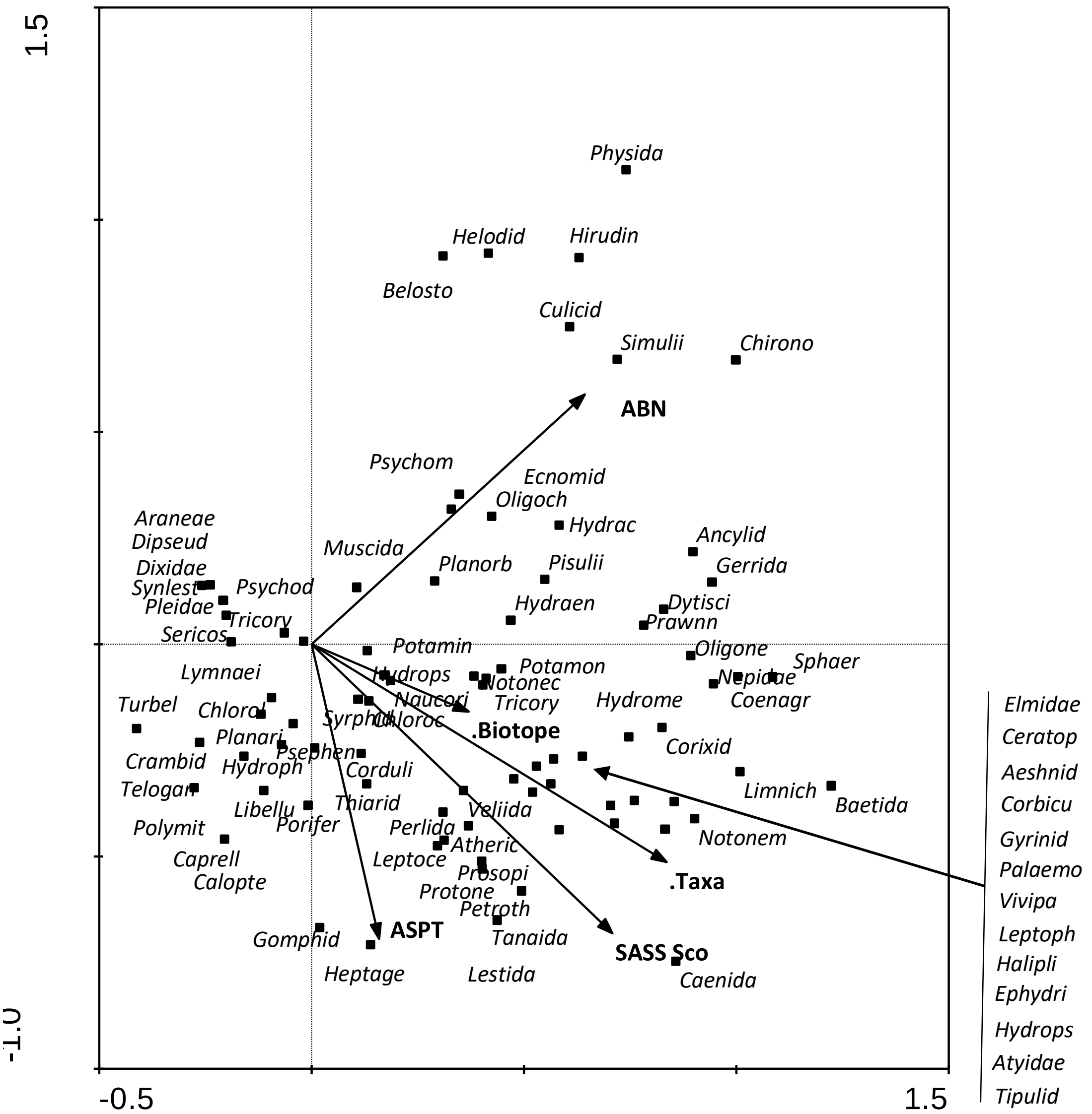
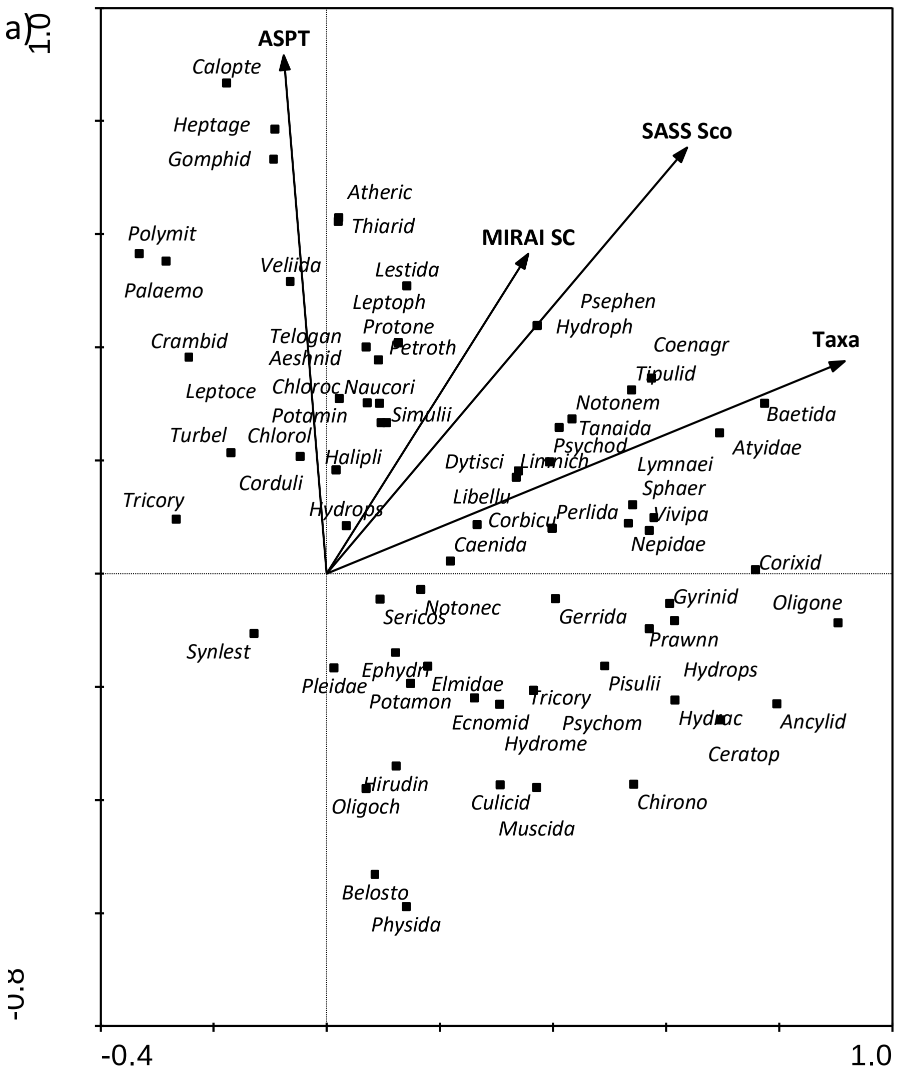


Figure 3. 4: Redundancy analysis bi-plots of the uMvoti and Thukela Rivers macroinvertebrate communities and SASS5 variables. The points on the RDA ordination diagram represented the variation in macroinvertebrate communities whereas the arrows represented SASS5 variables. In total, the RDA summarized 84.2% of the total variation in the first two axes, with axis one explaining 63.1%

and an additional 48.1% on the second axis. Key: ABN = estimated estimated abundance, Tax = number of taxa, SASS Sco = SASS5 Scores and Biotope = number of biotopes.

The South African Scoring System (SASS) and Macroinvertebrate Response Assessment Index (MIRAI) scores (Fig. 3.5 a) were significant different (P = 0.001 and F = 2.717). Another analysis was done to further assess the relationship between macroinvertebrate communities, SASS5 and MIRAI ecological classes (Fig. 3.5 b**)**. The RDA bi-plot, separated macroinvertebrates data into three distinct faunal assemblages (Fig. 3.5). The SASS5 class B and MIRAI class C formed one group that had low number of taxa and it was dominated by tolerant macroinvertebrate families including Heptageniidae, Athericidae, Calopterygidae. The second faunal assemblage was formed by the SASS5 class E/F and MIRAI class D and they were associated with many tolerant families including Oligochaeta, Belastomatidae, Hirudinea and Ephydridae. The last grouped was represented by the SASS5 class C – D and MIRAI class CD – EF. This faunal assemblage was allied by a mixture of tolerant and intolerant families with low number of taxa.


a)
1.0
-0.8
-0.4
1.0
ASPT
SASS Sco
MIRAI SC
Taxa
Calopte
Heptage
Gomphid
Atheric
Thiarid
Polymit
Palaemo
Veliida
Lestida
Leptoph
Protone
Petroth
Psephen
Hydroph
Coenagr
Tipulid
Crambid
Telogan
Aeshnid
Leptoce
Chloroc
Naucori
Potamin
Simulii
Notonem
Tanaida
Baetida
Turbel
Chlorol
Halipli
Psychod
Atyidae
Dytisci
Limnich
Lymnaei
Corduli
Tricory
Libellu
Sphaer
Hydrops
Corbicu
Perlida
Vivipa
Caenida
Nepidae
Corixid
Gyrinid
Oligone
Sericos
Notonec
Gerrida
Prawnn
Synlest
Ephydr
Elmidae
Hydrops
Pleidae
Potamon
Tricory
Pisulii
Ecnomid
Psychom
Hydrac
Ancylid
Hydrome
Ceratop
Hirudin
Oligoch
Culicid
Chirono
Muscida
Belosto
Physida

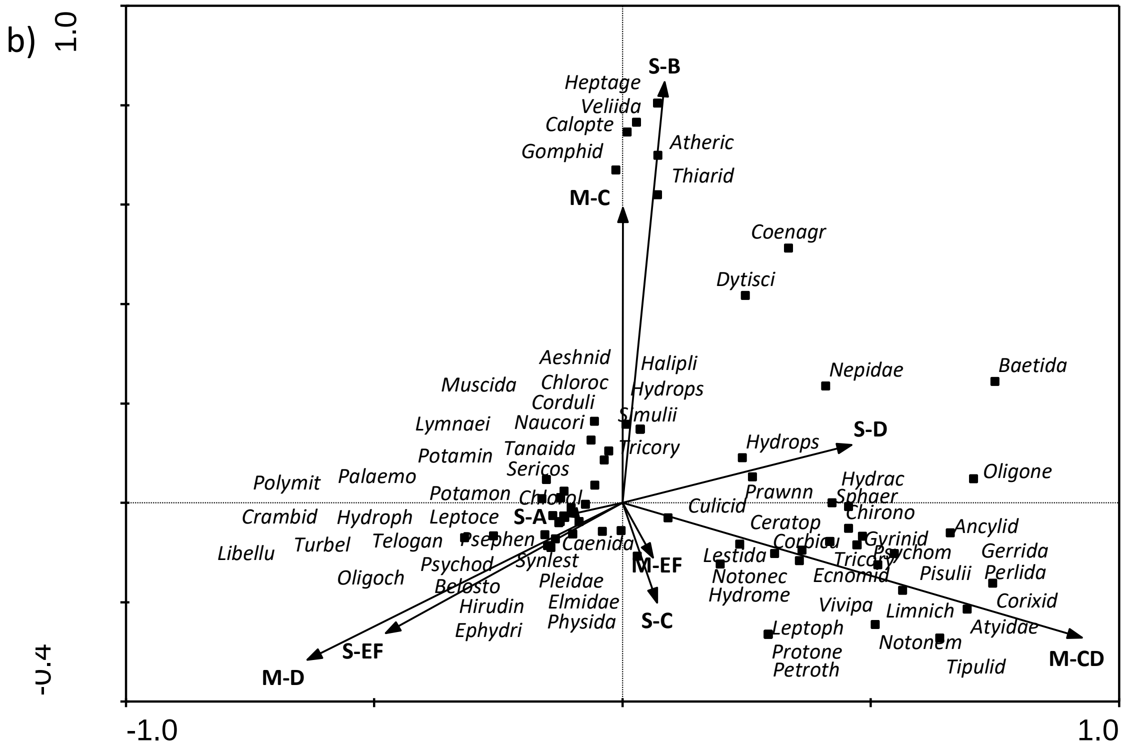


Figure 3. 5: a) Redundancy analysis bi-plots of the macroinvertebrate communities, MIRAI scores and SASS5 outcomes. In the ordination bi-plot, 75.8% of the variation within the data is represented, 52% on the first axis and an additional 23.8% on the second axis. **b**) Redundancy analysis bi-plots of the macroinvertebrate communities, MIRAI and SASS5 ecological classes. The first two axes of the RDA account for 76.6% of the total variation explained by the different sites, 55.6% on the first axis and an additional 22% on the second axis. On both ordination bi-plots, the points represented the variation in macroinvertebrate communities whereas the arrows represented SASS5 and MIRAI variables.

Water quality parameters accountable for structuring the macroinvertebrate community assemblages in the uMvoti and Thukela Rivers are shown in Fig. 3.5. Results showed a significant difference (P = 0.0010, F = 1.890) between macroinvertebrate communities when looking at the different preferences to water quality. The oxygen levels (both percentages and mg/l) were not significance. An increase in pH exhibited a correlation with an increase in COD and such parameters were associated with tolerant families. The pH exhibited similar correlation with the electricity conductivity (EC). Chloride and alkalinity demonstrated a correlation and they were allied with families that require good water quality to persist successfully.

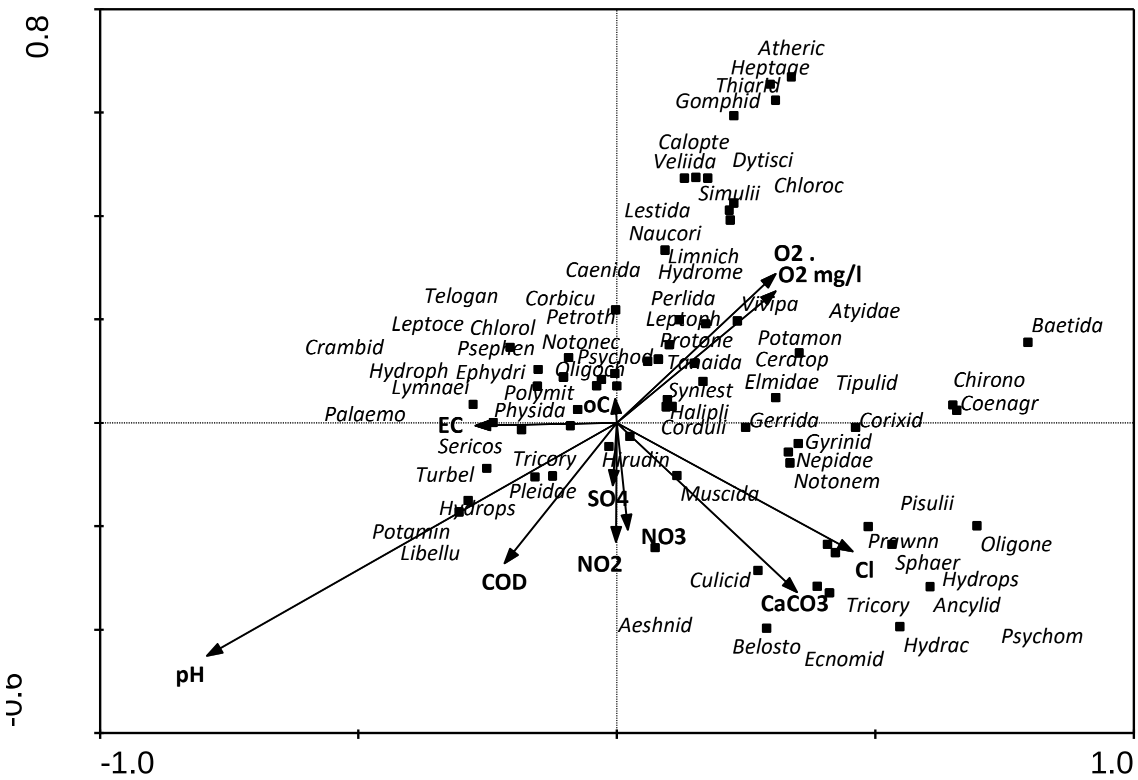


Figure 3. 3: Redundancy analysis bi-plot of macroinvertebrate communities and water quality variables. The points on the RDA ordination diagram represented the variation in macroinvertebrate communities whereas the arrows represented water quality variables. In the ordination plot 69.7% of the variation within the data was presented, 51.3% on the first axis and an additional 18.4% on the second axis.

The relationship between macroinvertebrate communities when looking at the different preferences to sediment grain-size distribution had no significant difference (P-value of 0.0.510, F-ratio of 1.697) (Fig. 3.7). Although the complete statistical analyses were not significant, coarse grain-size was found to have a significant difference (P = 0.001, F = 5.86). Findings also reveal that the coarse grain-size sediments were characterised by unique macroinvertebrate community structure. Medium, fine and very fine sediments had unique macroinvertebrate communities. The outcomes further revealed that fine and very fine sediments were positive correlation.

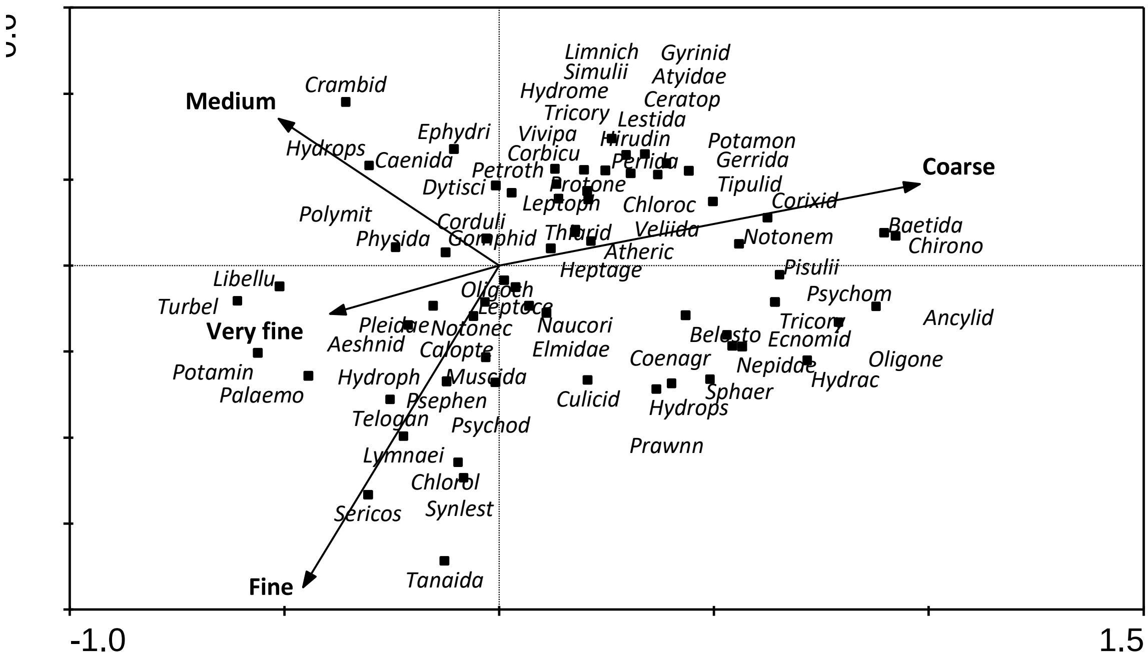


Figure 3. 4: Redundancy analysis bi-plot of macroinvertebrates and sediment grain-size variables. The points on the RDA ordination diagram represented the variation in macroinvertebrate communities whereas the arrows represented sediment grain-size. The first two axes of the RDA accounted for 93.6% of the total variation explained by the different sites, 85.7% on the first axis and an additional 7.9% on the second axis.

3.3.2 Physico-chemical parameters

High water temperatures (31 and 30 ^{o}C) were recorded in the uMvoti River sites during the 2005 high flow survey (Appendix 3.1) whereas the minimum temperature of 14.3 ^{o}C was recorded during the 2006 low flow survey. In the Thukela River, minimum water temperature of 13.7 ^{o}C was recorded during the 2006 low flow survey whereas the maximum water temperature of 32.97 ^{o}C was recorded during the 2012 high flow survey (Appendix 3.2).

The DO levels of the showed a generally decreasing trend from upper to lower reaches of the study area. In the uMvoti River, high DO levels O (9.0 and 11.3 mg/l) were recorded during the 2005 and 2008 low flow surveys. Such values were allied with reduced water temperatures shown on Appendix 3.1. In the Thukela River, the minimum DO level of 0.6 mg/l was recorded during the 2008 low flow whereas the maximum of 10.1 mg/l was recorded during the 2006 low flow survey (Appendix 3.2).

The uMvoti River had low nitrate loads and ammonium between 1999 – 2005. Afterwards, nitrate loads fluctuated noticeably (Appendix 3.1). High nitrate (6.7 mg/l) was recorded during the 2012 low flow survey whereas high ammonium level of 10.9 mg/l was recorded during the 2010 high flow survey. In the Thukela River, the minimum nitrate load of 0.01 mg/l was recorded during the 2005 high flow survey and 2006 low flow survey whereas the maximum level of 4.69 mg/l was recorded during the 2012 high flow survey (Appendix 3.2).

In the uMvoti River, the highest chloride level of 269 mg/l was measured during the 2004 low flow survey whereas the lowest chloride level (0.4 mg/l) was measured during the 2008 low flow survey. Sodium was another salt parameter that influenced the ecological integrity of the study sites. Highest sodium value of 270 mg/l was recorded during the 2016 high flow survey whereas the lowest value of 0.1 mg/l was recorded during the 2008 low flow survey. In the Thukela River, the minimum chloride level of 0.1 mg/l was recorded during the 2010 high flow survey whereas maximum of 373 mg/l was obtained during the high 2016 flow survey.

3.4. Discussion

Temporal changes on both lowland rivers had a significant influence (P = 0.0270) on macroinvertebrate community structures of the study area. Low number of macroinvertebrate taxa were associated with the present dataset whereas high diversity was allied with historical dataset. This suggests that the trend is getting worse with time. In most sites, this can be ascribed to poor water quality, reduced habitat heterogeneity and complexity as well as anthropogenic influences. The uMvoti and Thukela Rivers had the prevalence of pollution tolerant families like Chironomidae and Oligochaeta, that was indicative of how polluted these systems are (Rae 1989). The uMvoti River water quality condition has been reported to be highly impacted by anthropogenic stressors associated with this stream (Malherbe 2006; Venter 2013). The severe impact of these activities was reflected in the water quality, which in turn was reflected in the macroinvertebrate communities by containing low number of taxa and estimated abundance s. The uMvoti River has been documented to be seriously modified, with nearly total loss of its ecosystem services (Tharme 1996). Even the Department of Water Affairs and Forestry referred this river as a ‘working river’ (DWAF, 2004).

The lower Thukela River has been characterised as an ecologically important section of the Thukela catchment with numerous ecosystem services (DWAF 2004). Increasing demand for such ecosystem services has resulted in the degradation of the integrity of this river. The Thukela River has been categorised as the moderately modified (Class C) river (IWR 2004), suggesting that some structure and function aspects of this catchment are negatively impacted by water resource use stressors associated with this river (DWAF 2004).

3.4.1 uMvoti River and its associated tributary

The macroinvertebrate communities at the Ntchaweni Stream sites were relatively in a poor integrity state (class D – F) throughout the study period. This site was dominated by tolerant families like Physidae, Planorbinae, Chironomidae and Belastomatidae (per.obs.) and it had a decreasing trend for macroinvertebrates estimated estimated abundance and number of taxa. This can be attributed to low dissolved oxygen concentrations which were mostly found to be below the TWQG required for aquatic ecosystems (DWAF, 1996b). Relatively high-water temperatures were also recorded in the Ntchaweni Stream sites and that had an adverse effect on macroinvertebrate communities as high-water temperatures are reported to lower the organism’s resistance to pollution, diseases and parasites (Kale 2016). The decrease in macroinvertebrates estimated abundance at the Ntchaweni Stream sites were also driven by the combined effect of the urban runoff as well as effluence discharge from the Gledhow sugar mill and Sappi Stanger Mill (Malherbe 2006; Venter 2013). The nitrate and ammonium concentrations of this stream exhibited an increasing trend throughout the study period and they were normally above the recommended aquatic ecosystem guidelines (DWAF 1996 e). Such increase can be attributed to fertilisers used for intensive sugarcane plantations as in other studies (Pawar and Shaikh 1995). Sanseveriono (2016) reported that high nitrate levels promote algal blooms as well as the release of toxic substances that can cause death of many aquatic species.

The severe impact of water resource use activities at the Ntchaweni Stream sites were further evident at the lower reach site (U4MVOT-N2BRG) of the uMvoti River (below the Ntchaweni – uMvoti confluence). In most surveys, this site consistently had low macroinvertebrates estimated abundance and diversity which was dominated by pollution tolerant families including Oligochaeta, Psychodidae, and Chironomiade (per.

obs.). This can be ascribed to the increased organic and inorganic pollution originating from the Ntchaweni River sites (Venter 2013). The informal settlements and agricultural activities situated upstream of this site worsened water quality condition (Malherbe 2006), which in turn created unfavourable conditions for many tolerance families. Chloride was found to be an important parameter for explaining the biological variation observed in macroinvertebrate community structures (P = 0.046) and in the lower reach site of the uMvoti River, high levels such parameter of were recorded and they were attributed to the combined effect of industrial effluence as well as Stanger sewage treatment works originating from the Mbozano stream which meets the uMvoti River upstream of this site. The chloride levels are reported to enhance excess ions on water column, causing major concerns to the river wellbeing (Gillis 2011) as well as the persistence of tolerant macroinvertebrates.

The upper reach study site (M-GH) at the uMvoti River had more diverse macroinvertebrate communities and they were dominated by intolerant families including Atydae, Baetidae, Heptageniidae, Naucoridae, Oligoneuridae, Heptageniidae Chlorocyphidae, Calopterygidae, Athericidae and others. These families were prevalent in most years and that can be attributed to relatively good dissolved oxygen levels which were normally within the target water quality guidelines (TWQG) of 6 – 9 mg/l (DWAF 1996b). This site was also characterised by low sodium, calcium and chloride levels which promoted the persistence of intolerant families obtained. Some number of pollution tolerant families like Chironomidae, Oligochaeta, Thiaridae and Corixidae were also recorded in this study site and that may be attributed to water quality related stressors that occurs upstream of this site and they include sugarcane plantations, water abstraction for industrial use as well as domestic use by local communities. Despite the occurrence such families, macroinvertebrate communities revealed a relatively better condition throughout the study period in this site.

3.4.2 Thukela River and its associated tributary

Throughout the study period, the Mandeni stream sites were dominated by of pollution tolerant taxa which included Culicidae, Chironomidae, Ancylidae, Coenagrionidae, Sphaeridae, Belastomatidae and a couple of other families. This may be due to the synergistic effects of water quality stressors associated with the Isithebe Industrial complex and wastewater treatment works and the Sappi Mill (Malherbe 2006; Venter 2013). The dissolved oxygen concentrations at the Mandeni Stream sites were normally found to be below the acceptable TWQR requirement of > 6 mg/l (DWAF 1996b) and this contributed to the poor macroinvertebrate communities observed. The Mandeni Stream sites also had high electrical conductivity and Chemical Oxygen Demand levels which have been found to cause the biological variation in macroinvertebrate communities (DWAF, 2003). Other important environmental variables driving macroinvertebrate communities in this stream includes high nitrate, chloride and sulphate levels.

The impact of anthropogenic stressors associated with the Mandeni Stream was further evident at the sites (T-JNR and T-ULT) situated downstream of the Thukela – Mendini confluence ((Stryftombolas 2008).). These sites had relatively high electrical conductivity and that may be attributed to the Mandeni Stream and the Sappi Pulp and Paper Mill and this affect the availability of oxygen in the system. The most important variables driving macroinvertebrate communities in these sites include domestic use, industries, agriculture, mining, recreation, wastewater treatment and road and rail networks (Malherbe 2006; Stryftombolas 2008; O'Brien 2010; Venter 2013). The dissolved oxygen concentration trends in these sites showed a considerable decreasing trend which was associated with increased temperature levels. This resulted in the prevalence of pollution tolerant families which were allied with low number of taxa. The T-JNR is situated at proximity to the Thukela – Mandeni confluence and its macroinvertebrate communities included highly tolerant families like Planaria, Ephydridae and Simulidae. On the other hand, the T-ULT (further down the confluence) had a mixture of pollution tolerant and intolerant families. The tolerant families were attributed to pollution originating from the Mandeni River as well as the land-use activities associated with the upper Thukela River reaches. Despite this, tolerant families like Oligoneuridae, Limnichidae and Baetidae were prevalent in this site and it can be ascribed to the assimilation capacity of the Thukela River which decreased the effect of such stressors as you move down stream of the study area.

Water temperature levels recorded in the upper reach study site (T-RBG) of the Thukela River were mostly within the acceptable range of the TWQG requirements (DWAF 1996b) except for the 2012 high flow survey where relatively high temperature level of 32.97 ^{o}C were recorded. This high temperature tied with low dissolved oxygen content which had an adverse effect on macroinvertebrate communities as a low number of taxa were obtained during this survey (pers. obs.) Normally this site exhibit high levels of dissolved oxygen when compared with the other sites and that can be attributed to this site being located upstream of the Mandeni – Thukela confluence (Ferreira et al. 2008;

Stryftombolas 2008). This may also be ascribed to minimal human pressure and that promoted the persistence of tolerant families like Protoneuridae, Lestidae, Leptophlebiidae, Petrothrincidae, Atydae, Baetidae, Heptaganidae, Naucoridae, Oligoneuridae, Notonemouridae and Limnichidae in this site.

3.4.3 Conclusions

The macroinvertebrate community structures of the Ntchaweni Stream sites were largely modified due to water resource use stressors like the Gledhow Sugar Mill, Sappi Pulp and Paper making activities, agricultural activities and domestic uses by local communities. In most surveys this stream was dominated by tolerant families (like Chironomidae, Oligochaeta, Planaria, Simuliidae and many others) which were associated with a low estimated abundance and number of taxa. The severe impact of the water resource use stressors in the Ntchaweni River was further evident at the site below uMvoti – Ntchaweni confluence as this site also exhibited low macroinvertebrate estimated abundance throughout the study period. With regards to the Thukela River, poor macroinvertebrates diversity and low estimated abundance was observed in most surveys and that can be ascribed to major industrial activities associated with Isithebe industrial complex, the wastewater treatment works of Sundumbili, excessive water abstraction and sugarcane plantations. Again, the impacts of Mandeni Steam associated stressors were observed in the Thukela River sites situated below the Thukela – Mandeni confluence. The spatial and temporal variation in the physico-chemical parameters of the studied rivers had significant effect on the diversity and estimated abundance of macroinvertebrate community structures. The water quality state of the uMvoti river was in a seriously modified state which is why the Department of Water Affairs and Forestry referred this river as a 'working river' (DWAF 2004). Water resource stressors associated with the Ntchaweni streams worsens the ecosystem wellbeing of uMvoti River. Hence, appropriate management plans are urgently needed for this river to minimise these stressors and for attaining a balance between use and protection rights. The Thukela River is categorised as the moderately modified (Class C) river (IWR 2004). Stressors associated with the Mandeni stream worsens the Thukela River, so, urgent management and protection interventions are required.

Both uMvoti and Thukela Rivers along with their associated tributaries need to be monitored and properly managed to reduce stressors that negatively impacts macroinvertebrate communities. This will promote the protection of river ecosystems themselves. Failure to implement effective plans for these river ecosystems may results in a complete loss of ecosystem services and functions that these rivers provide, and rivers might reach a point of irreversible changes.

3.5 Acknowledgements

We thank the Aquatic Ecosystem Research Program (AER) and South African Pulp and Paper Industries Limited (Sappi) for the opportunity to do this research and for providing running costs. We thank the National Research Fund (ZA) for funding. Thanks are also extended to Ezemvelo KZN Wildlife for permits. Also, we are grateful to the Umgeni Water for the use of their facilities to perform water quality analyses.

3.6 References

Arimoro FO, Ikomi RB, Erebe E. 2007. Macroinvertebrate community diversity in relation to water quality status of River Ase, Niger Delta, Nigeria. Journal of fisheries and Aquatic Science 2: 337–344.

Biswas AK. 2008. Integrated Water Resources Management: Is It Working? International Journal of Water Resources Development 24: 5–22

Bouwer H. 2000. Integrated water management: emerging issues and challenges. Agricultural water management 45: 217–228.

Bredenhand E. 2005. Evaluation of macroinvertebrates as bio-indicators of water quality and the assessment of the impact of the Klein Plaas dam on the Eerste River. MSc Dissertation, University of Stellenbosch, Stellenbosch.

Carminati AV. 2008. An Assessment of the Effects of Sugar Mill Activities on the Ecological Integrity of the UMvoti and Amatikulu Rivers, KwaZulu Natal. MSc dissertation, University of Johannesburg, Johannesburg.

Cassardo C. 2014. Global warming and water sustainability. In E3S Web of Conferences (Vol. 2). EDP Sciences.

Chahouki MAZ. 2011. Multivariate analysis techniques in environmental science. In Earth and Environmental Sciences. InTech.

Chutter FM. 1998. Research on the rapid Biological Assessment of Water Quality Impacts in Streams and Rivers. Water Research Commission (WRC) Report No 422/1/98. Water Research Commission, Pretoria.

Coastal Research Unit of Zululand (CRUZ). 2000. Ecological evaluation of the lower Mvoti River and Estuary. CRUZ Environmental Report No. 4, CRUZ, University of Zululand, Empangeni, South Africa.

Daniels SM, Evans MG, Agnew CT, Allott THE. 2012. Ammonium release from a blanket peatland into headwater stream systems. Environmental pollution 163: 261–272.

Deksissa T, Ashton PJ, Vanrolleghem PA. 2003. Control options for river water quality improvement: A case study of TDS and inorganic nitrogen in the Crocodile River (South Africa). Water SA 29: 209–218.

Department of Water Affairs and Forestry (DWAF). 1996b. South African Water Quality Guidelines. 2nd edn. Volume 7: Aquatic Ecosystems. DWAF, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF). 2004. Draft background information: South African Forestry, Pulp and Paper industries: Draft version 1. DWAF, Pretoria.

Department of Water Affairs and Forestry, 1996e. South African water quality guidelines, Volume 5, Agricultural Water Use: Livestock Watering. 2nd Edition. Pretoria, South Africa.

Dickens CW, Graham PM. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. African Journal of Aquatic Science 27: 1–10.

Farrell KT. 2014. Aquatic Macroinvertebrate Community in the Wilge River (Doctoral dissertation, University of Johannesburg).

Ferreira M, Malherbe W, Cloete Y, Wepener V, O'Brien G. 2008. Ecological integrity assessment of the lower UMvoti River/Estuary, KwaZulu-Natal: 2008 update of the 2005 ecological integrity assessment of the lower Thukela River/Estuary, KwaZulu-Natal. University of Johannesburg, Auckland Park, Johannesburg, South Africa.

Ferreira M. 2005. A study into the anthropogenic impacts affecting the Elands River, Mpumalanga.

Gillis PL. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: Implications for salinization of surface waters. Environmental Pollution 159: 1702–1708.

Harvey R, Lye L, Khan A, Paterson R. 2011. The Influence of air temperature on water temperature and the concentration of dissolved oxygen in Newfoundland Rivers. Canadian Water Resources Journal 36: 171–192.

Hill L. 2007. Focus on CSIR research in pollution waste: The South African river health programme.

Kale VS. 2016. Consequence of Temperature, pH, Turbidity and Dissolved Oxygen Water Quality Parameters. Organization (WHO), 3(8).

King J Pienaar H. 2011. Sustainable use of South Africa’s inland waters: a situation assessment of resource directed measures 12 years after the 1998 National Water Act. Water Research Commission Report No. TT, 491: 1–245.

Kleynhans CJ. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41–54.

Kleynhans CJ. 1999. The development of a fish index to assess the biological integrity of South African Rivers. Water SA 25: 265–278.

Kohler M. 2016. Confronting South Africa’s Water Challenge: A Decomposition Analysis of Water Intensity. ERSA (Economic Research Southern Africa) working paper 605.

Leunda PM, Oscoz J, Miranda R, Ariño AH. 2009. Longitudinal and seasonal variation of the benthic macroinvertebrate community and biotic indices in an undisturbed Pyrenean river. Ecological Indicators 9: 52-63.

Li L, Zheng B, Liu L. 2010. Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. Procedia environmental sciences 2: 1510–1524.

Malherbe CW. 2006. The current ecological state of the lower UMvoti River, KwaZulu-Natal. MSc Dissertation, University of Johannesburg, Johannesburg.

Mathebula B. 2016. Assessment of the surface water quality of the main rivers feeding at Katse Dam Lesotho. PhD Dissertation, University of Pretoria, Pretoria

McMillan PH. 1998. An Integrated Habitat Assessment System (IHAS v2) for Rapid Biological Assessments of Rivers and Systems. Division of the Environment and Forestry Technology. Report No. Env-P-I 98132. CSIR, Pretoria, South Africa.

National Water Act (Act No. 36 of 1998). Republic of South Africa 1998. Government Gazette, (19182).

O'Brien GC, Swemmer R, Wepener V. 2009. Ecological integrity assessment of fish assemblages of the Matigulu/Nyoni and UMvoti estuaries, KwaZulu-Natal, South Africa. African Journal of Aquatic Science 34: 293–302.

O'Brien GC, Wepener V, Malherbe W, Swemmer R, Von Bratt C. 2005. Ecological Integrity Assessment of the Lower Mvoti River/Estuary, KwaZulu-Natal: Update of the 2000 Ecological Evaluation of the Lower Mvoti River and Estuary. Report prepared for the Sappi Stanger Environmental Liaison Committee (SSELC). Report No. 2005/06/001. Stanger, South Africa.

O'Brien GC, Venter H. 2012. Evaluation of eight years (2005 to 2012) of ecological integrity data from the lower Thukela River/Estuary and associated systems with management considerations based on the risk of hazards affecting ecosystem structure and function, KwaZulu-Natal., Water Research Group, North West University, Potchefstroom.

O'Brien GC. 2010. Ecological State Assessment of the Lower Thukela River/Estuary, KwaZulu-Natal. Investigational Report. Rivers of Life: Aquatic Health Services, Potchefstroom, South Africa.

Oertel N, Salánki J. 2003. Biomonitoring and bioindicators in aquatic ecosystems. In Modern trends in applied aquatic ecology (pp. 219-246). Springer, Boston, MA.

O'Keeffe J, Dickens C. 2000. Aquatic invertebrates. In: King J.M., Tharme R.E. and De Villiers M.S. (eds.) Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. WRC Report No. 576/1/98. Water Research Commission, Pretoria, South Africa. pp. 231–244.

Otieno FAO, Ochieng GMM. 2007. Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. Water South Africa 30: 120–124.

Paliy O, Shankar V. 2016. Application of multivariate statistical techniques in microbial ecology. Molecular Ecology 25: 1032–1057.

Pawar NJ, Shaikh IJ. 1995. Nitrate pollution of ground waters from shallow basaltic aquifers, Deccan Trap Hydrologic Province, India. Environmental Geology 25(3): 197–204.

Rae JG. 1989. Chironomid Midges as indicators of organic pollution in Scioto River Basin, Ohio. Ohio Journal of Science 89: 5–9.

Sanseverino I, Conduto D, Pozzoli L, Dobricic S, Lettieri T. 2016. Algal bloom and its economic impact. EUR 27905 EN; doi: 10.2788, 660478.

Shaw PJA. 2003. Multivariate Statistics for the Environmental Sciences. London, UK: Arnold Publishers.

Stryftombolas IC. 2008. Ecotoxicological Assessment of the Impact of Paper and Pulp Effluent on the Lower Thukela River Catchment, KwaZulu-Natal, South Africa, and the Toxicological Assessment of Similar Effluent from Two Other Mills. Unpublished M.Sc. Dissertation, University of Johannesburg, Johannesburg.

Swemmer, R., 2011. Ecological integrity assessment of the UMvoti Estuary, KwaZulu-Natal, South Africa. PhD Dissertation, University of Johannesburg, Johannesburg.

Ter Braak CJF, Smilauer F. 2004. Canoco for Windows Version 4.53. © 1997-2004 Biometrics – Plant Research International, Wageningen, The Netherlands

Tharme R. 1996. Rivers of southern Africa: UMvoti River. African Wildlife 50: 31.

UN Water, 2014. http://www.unwater.org/statistics/statistics-detail/ar/c/246663/

United Nations, 2017. https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html

Van den Brink PJ, Van den Brink NW, Ter Braak, CJF. 2003. Multivariate analysis of ecotoxicological data using ordination: Demonstrations of utility on the basis of various examples. Australasian Journal of Ecotoxicology 9: 141–156.

Venter JJ. 2013. An ecological integrity assessment of the lower Amatikulu, Thukela and UMvoti Rivers, KwaZulu-Natal, South Africa. North-West University, Doctoral dissertation, Potchefstroom.

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM. 2010. Global threats to human water security and river biodiversity. Nature 467: 555–561.

Wheater HS. Gober P. 2015. Water security and the science agenda. Water Resources Research 51: 5406–5424.

Wise TA. 2013. Can we feed the world in 2050? A scoping paper to assess the evidence. Global Development and Environment Institute Working Paper: 13–04.

WR (Institute for Water Research), 2003. Thukela water project decision support phase. Reserve determination Thukela system water quality report, Department of Water Affairs and Forestry, Pretoria.

3.7 Appendices

Appendix 3.1: Water quality multiparameters collected during the study period (1999 and 2016) for the high (H) and low (L) flow surveys in four study sites of the uMvoti River and its associated tributary (Ntchaweni).

River	Year	Site code	Temperature (◦C)	Oxygen(mg/l)	Conductivity (mS/m)	pH	Nitrate (mg/l)	Phosphate	Ammonium	Chloride (mg/l)	Total alkalinity (mg/l)	Calcium (mg/l)	COD (mg/l)	Sulphate (mg/l)	Sodium (mg/l)
uMvoti	1999	U4MVOT-N2BRG 1999H	18.5	6.1	360.0	7.7	0.3	-	0.1	38.0	76.5	13.0	177.5	7.1	34.5
uMvoti	2000	U4MVOT-N2BRG 2000L	18.5	6.1	360.0	7.7	0.3	-	0.1	38.0	76.5	13.0	177.5	7.1	34.5
uMvoti	2004	U4MVOT-N2BRG 2004L	26.8	3.5	1630.0	7.5	0.1	-	0.1	269.5	475.0	60.7	154.0	6.9	332.0
uMvoti	2005	U4MVOT-N2BRG 2005H	30.0	4.3	187.0	7.5	0.2	-	0.1	18.4	50.0	8.3	16.5	5.8	19.5
uMvoti	2005	U4MVOT-N2BRG 2005L	20.1	2.3	919.0	7.2	-	-	0.0	91.8	264.0	9.4	84.5	7.4	160.0
uMvoti	2008	U4MVOT-N2BRG 2008L	20.0	5.7	385.0	6.7	-	0.2	4.4	0.6	14.0	19.0	28.0	47.0	1.3
uMvoti	2010	U4MVOT-N2BRG 2010H	22.2	2.4	0.7	7.8	0.1	-	0.2	48.5	-	-	68.0	52.2	-
uMvoti	2011	U4MVOT-N2BRG 2011L	19.1	3.8	265.0	8.2	0.0	-	0.0	0.9	39.5	-	104.0	0.2	-
uMvoti	2012	U4MVOT-N2BRG-2012H	28.2	4.7	333.0	8.0	2.0	-	0.0	37.9	26.0	-	-	11.3	-
uMvoti	2013	U4MVOT-N2BRG 2013L	25.7	5.9	61.5	7.4	-	-	-	94.2	92.0	52.0	100.0	-	60.0
uMvoti	2015	U4MVOT-N2BRG 2015H	28.5	3.0	0.6	6.0	-	-	-	-	-	-	-	-	-
uMvoti	2015	U4MVOT-N2BRG 2015L	24.0	2.5	115.0	7.6	-	-	-	-	303.0	83.5	101.0	-	-
uMvoti	2016	U4MVOT-N2BRG 2016H	-	-	101.0	-	0.1	-	-	105.0	276.0	72.2	46.0	100.0	136.0
uMvoti	2016	U4MVOT-N2BRG 2016L	21.1	2.6	90.0	-	0.1	-	-	94.2	196.0	53.2	72.0	86.7	98.1
uMvoti	1999	U4MVOT-GLEDH 1999H	18.1	6.2	360.0	7.7	0.2	-	0.1	38.5	72.5	13.0	216.5	7.3	35.0
uMvoti	2000	U4MVOT-GLEDH 2000L	18.1	6.2	360.0	7.7	0.2	-	0.1	38.5	72.5	13.0	216.5	7.3	35.0
uMvoti	2004	U4MVOT-GLEDH 2004L	27.6	7.7	356.0	8.0	0.1	-	0.1	48.2	97.0	13.3	8.0	10.7	45.0
uMvoti	2005	U4MVOT-GLEDH 2005H	31.0	4.4	176.0	7.7	0.2	-	0.1	18.2	50.0	7.9	14.0	5.8	19.5
uMvoti	2005	U4MVOT-GLEDH 2005L	20.5	9.0	322.0	7.5	0.2	-	-	30.5	85.0	12.4	11.0	5.2	39.0
uMvoti	2006	U4MVOT-GLEDH 2006H	25.0	8.5	153.0	7.6	3.0	0.1	0.0	6.0	40.0	-	24.0	1.0	-
uMvoti	2006	U4MVOT-GLEDH 2006L	14.3	11.3	225.0	7.7	1.4	0.0	0.0	6.0	-	-	8.0	4.0	-
uMvoti	2008	U4MVOT-GLEDH 2008L	20.5	7.5	227.0	6.6	-	0.1	3.1	0.4	7.2	9.0	11.0	24.0	1.0
uMvoti	2010	U4MVOT-GLEDH 2010H	21.8	7.8	0.3	7.7	0.1	-	0.1	28.2	-	-	6.0	13.6	-
uMvoti	2011	U4MVOT-GLEDH 2011L	16.5	4.5	111.4	8.2	0.0	-	0.0	0.5	26.5	-	91.0	0.1	-
uMvoti	2012	U4MVOT-GLEDH 2012H	27.8	6.1	279.0	7.9	0.8	-	0.0	44.8	65.0	-	-	7.6	-
uMvoti	2013	U4MVOT-GLEDH 2013L	25.0	7.9	35.3	7.4	-	-	-	-	-	26.0	50.0	-	30.0
uMvoti	2015	U4MVOT-GLEDH 2015H	28.6	7.1	283.0	6.0	-	-	-	-	-	-	-	-	-
uMvoti	2015	U4MVOT-GLEDH 2015L	22.6	6.7	38.9	7.1	-	-	-	-	83.8	15.9	20.0	-	-
uMvoti	2016	U4MVOT-GLEDH 2016H	27.4	6.9	74.4	-	0.1	-	-	105.0	186.0	33.5	27.0	18.9	91.0
uMvoti	2016	U4MVOT-GLEDH 2016L	21.5	6.9	38.7	-	0.1	-	-	57.9	73.0	16.3	20.0	18.0	51.0
Ntchaweni	2005	U4NTCHA-SAPPI 2005H	25.7	2.2	722.0	7.5	0.1	0.2	2.6	68.4	389.7	46.2	77.6	17.8	155.5
Ntchaweni	2010	U4NTCHA-SAPPI 2010H	24.3	0.7	2.2	7.9	0.1	-	1.7	113.5	-	-	458.0	214.0	-
Ntchaweni	2012	U4NTCHA-SAPPI 2012H	27.1	3.9	782.0	7.7	1.8	-	0.1	100.9	195.0	-	-	69.4	-
Ntchaweni	2011	U4NTCHA-SAPPI 2011L	-	-	-	-	-	-	-	3.3	109.0	-	332.0	3.3	-
Ntchaweni	2013	U4NTCHA-SAPPI 2013L	26.7	5.0	208.0	7.5	-	-	-	-	96.0	228.0	230.0	-	242.0
Ntchaweni	5015	U4NTCHA-SAPPI 2015H	32.0	3.6	1.7	6.0	-	-	-	-	-	-	-	-	-
Ntchaweni	2015	U4NTCHA-SAPPI 2015L	27.1	1.9	19.2	8.0	-	-	-	-	-	-	-	-	-
Ntchaweni	2016	U4NTCHA-SAPPI 2016H	31.2	1.9	185.0	-	0.1	1.8	-	-	491.0	135.0	128.0	226.0	270.0
Ntchaweni	2016	U4NTCHA-SAPPI 2016L	23.8	3.4	-	-	0.1	-	1.8	149.0	490.0	-	-	120.0	-
Ntchaweni	2005	U4NTCHA-GLEDH 2005H	26.1	0.8	579.0	7.5	0.3	0.2	0.5	64.0	157.2	22.7	17.6	9.7	69.4
Ntchaweni	2010	U4NTCHA-GLEDH 2010H	22.3	2.5	0.6	7.6	0.4	-	10.9	66.2	-	-	36.0	9.2	-
Ntchaweni	2012	U4NTCHA-GLEDH 2012L	24.3	3.7	468.0	7.4	6.7	-	0.0	102.9	105.0	-	0.0	13.2	-
Ntchaweni	2013	U4NTCHA-GLEDH2013H	24.9	2.8	74.6	7.3	-	-	-	-	118.0	46.0	-	-	88.0
Ntchaweni	2015	U4NTCHA-GLEDH2015H	24.4	4.2	0.6	6.0	-	-	-	-	-	-	-	-	-
Ntchaweni	2015	U4NTCHA-GLEDH 2015L	21.0	8.7	78.9	7.1	-	-	-	-	177.0	27.7	39.0	-	-
Ntchaweni	2016	U4NTCHA-GLEDH 2016H	-	-	-	6.9	0.1	-	-	-	186.0	-	-	18.9	98.1
Ntchaweni	2016	U4NTCHA-GLEDH 2016L	-	-	88.6	-	0.1	-	-	107.0	205.0	32.6	37.0	23.2	51.0
Ntchaweni	2016	U4NTCHA-GLEDH 2016H	23.8	1.9	730.0	6.6	0.1	-	-	105.0	-	-	-	100.0	-
Ntchaweni	2016	U4NTCHA-GLEDH 2016L	29.6	-	-	-	0.1	-	-	-	-	-	-	86.7	-

Appendix 3.2: Summary of water quality multiparameters recorded at the lower uThukela River and associated tributary (Mandeni River) during low (L) and high (H) river flow periods from 2005 – 2016

River	Year	Site code	Temperature (◦C)	Oxygen(mg/l)	Conductivity (mS/m)	pH	Nitrate (mg/l)	Phosphate (mg/l)	Ammoniuum (mg/l)	Chloride (mg/l)	Calcium (mg/l)	COD (mg/l)	Sulphate (mg/l)	Sodium (mg /l)
Mandeni	2005	V1MAND-WASTE 2005H	18.8	5.6	2310.0	7.8	0.0	-	0.5	43.0	-	10.0	300.0	-
Mandeni	2006	V1MAND-WASTE 2006L	13.7	6.0	2010.0	8.0	-	-	-	-	-	-	-	-
Mandeni	2008	V1MAND-WASTE 2008L	20.1	0.6	853.0	8.7	0.1	-	3.2	76.0	25.0	54.0	212.0	218.0
Mandeni	2010	V1MAND-WASTE 2010H	27.5	3.2	146.7	8.5	0.1	-	0.3	200.1	19.6	83.0	63.5	375.0
Mandeni	2011	V1MAND-WASTE 2011L	20.1	3.1	1025.0	8.8	0.0	-	0.1	6.1	-	155.0	0.4	-
Mandeni	2012	V1MAND-WASTE 2012H	24.6	5.1	1050.0	8.2	3.8	-	0.0	182.8	-	-	48.6	-
Mandeni	2013	V1MAND-WASTE 2013L	21.7	4.1	256.0	7.7	-	-	-	-	50.0	170.0	-	364.0
Mandeni	2015	V1MAND-WASTE 2015L	22.1	4.6	226.3	7.5	-	-	-	-	21.5	72.0	-	-
Mandeni	2016	V1MAND-WASTE 2016H	24.7	3.9	2.3	7.4	-	-	-	-	-	-	-	-
Mandeni	2016	V1MAND-WASTE 2016L	22.6	3.6	1.7	6.9	-	-	-	-	-	-	-	-
Mandeni	2010	V1MAND-WEIR 2010H	26.3	5.9	121.5	9.0	0.5	-	0.2	235.1	23.3	87.0	56.7	289.0
Mandeni	2011	V1MAND-WEIR 2011L	17.1	3.6	1143.0	8.5	0.2	-	0.0	5.1	-	144.0	0.8	-
Mandeni	2012	V1MAND-WEIR 2012H	25.8	5.0	1018.0	8.4	4.7	-	0.0	156.3	-	-	110.2	-
Mandeni	2013	V1MAND-WEIR 2013L	23.7	7.6	221.0	8.3	-	-	-	-	48.0	180.0	-	292.0
Mandeni	2015	V1MAND-WEIR 2015L	21.7	7.9	190.1	7.3	-	-	-	-	21.6	51.0	-	-
Mandeni	2016	V1MAND-WEIR 2016H	25.6	8.3	215.0	-	3.3	-	-	373.0	38.8	51.0	49.6	668.0
Mandeni	2016	V1MAND-WEIR 2016L	21.9	7.8	1.3	6.9	-	-	-	-	-	-	-	-
Thukela	2005	V1THUK-JOHNR 2005H	21.5	7.3	482.0	7.4	1.5	-	-	4.0	-	36.0	164.0	-
Thukela	2006	V1THUK-JOHNR 2006L	27.5	4.6	900.0	7.0	-	0.0	-	-	-	26.0	86.0	-
Thukela	2008	V1THUK-JOHNR 2008L	21.8	8.3	343.0	7.7	-	98.7	0.6	31.0	15.0	26.0	44.0	3.9
Thukela	2010	V1THUK-JOHNR 2010H	27.1	6.8	33.4	9.0	0.2	0.2	-	0.1	14.8	17.0	31.9	47.0
Thukela	2013	V1THUK-JOHNR 2013L	24.2	8.3	49.9	8.2	-	-	-	-	48.0	20.0	-	24.0
Thukela	2015	V1THUK-JOHNR 2015L	27.0	7.6	24.0	7.3	-	-	-	-	15.8	38.0	-	-
Thukela	2016	V1THUK-JOHNR 2016H	24.8	7.2	34.5	-	0.1	0.1	-	-	25.3	27.0	35.7	76.7
Thukela	2016	V1THUK-JOHNR 2016L	29.0	7.2	239.4	7.0	-	-	-	-	-	-	-	-
Thukela	2005	V1THUK-ULTIM 2005H	22.9	4.6	388.0	7.6	0.3	0.3	-	-	-	1.0	6.0	-
Thukela	2006	V1THUK-ULTIM 2006L	18.6	10.1	316.0	7.9	0.0	0.0	-	-	-	10.0	13.0	-
Thukela	2008	V1THUK-ULTIM 2008L	23.5	6.0	249.0	7.0	-	76.3	0.1	15.0	6.0	20.0	23.0	8.1
Thukela	2010	V1THUK-ULTIM 2010H	27.6	3.6	35.8	8.8	0.1	0.1	-	0.1	17.8	15.0	32.2	34.0
Thukela	2011	V1THUK-ULTIM 2011L	19.4	7.9	223.0	8.2	0.0	0.0	-	-	-	115.0	0.2	-
Thukela	2012	V1THUK-ULTIM 2012H	33.0	3.6	370.0	8.2	0.2	0.2	-	0.0	-	-	36.7	-
Thukela	2014	V1THUK-ULTIM 2014H	26.5	4.1	38.8	7.7	-	-	-	-	-	-	-	-
Thukela	2015	V1THUK-ULTIM 2015L	23.1	5.4	29.7	7.0	-	-	-	-	18.7	20.0	-	-
Thukela	2016	V1THUK-ULTIM 2016H	-	2.4	65.4	-	0.1	0.1	-	109.0	24.3	20.0	43.6	62.9
Thukela	2016	V1THUK-ULTIM 2016L	27.2	2.4	672.4	7.0	-	-	-	-	-	-	-	-
Thukela	2011	V1THUK-RAILB 2011L	14.5	9.2	190.0	7.1	0.0	0.0	-	-	-	119.0	0.2	-
Thukela	2012	V1THUK-RAILB 2012H	27.3	5.6	198.0	7.9	1.7	1.7	-	-	-	-	11.1	-
Thukela	2013	V1THUK-RAILB 2013L	23.3	8.6	40.1	8.1	-	-	-	-	50.0	110.0	-	22.0
Thukela	2014	V1THUK-RAILB 2014H	25.8	6.2	39.5	7.8	-	-	-	-	-	-	-	-
Thukela	2015	V1THUK-RAILB 2015L	24.8	9.5	19.8	8.0	-	-	-	-	14.3	20.0	-	-
Thukela	2016	V1THUK-RAILB 2016H	24.5	6.7	30.0	-	0.1	0.1	-	-	22.8	20.0	25.6	23.9
Thukela	2016	V1THUK-RAILB 2016L	21.4	8.4	29.6	7.0	-	-	-	-	-	-	-	-

CHAPTER 4

Conclusions

4.1 Conclusions

The outcomes of this dissertation contribute to the monitoring and management of water resource in the lower uMvoti and Thukela Rivers. The macroinvertebrate communities were successfully used as ecological indicators representing the response of the ecosystem to changes in environmental variable conditions. The uMvoti and Thukela Rivers along with their associated tributaries (Ntchaweni and Mandeni) were rivers of interest. Both rivers are faced with increased water resource use and that greatly impact their ecosystem wellbeing.

Two community metric measure tools namely the South African Scoring System (SASS, version 5) and the Macroinvertebrate Response Assessment Index (MIRAI) were used to evaluate the ecological integrity of the lowland uMvoti and Thukela Rivers (Chapter 3). The use of these tools was a success as they were able come up with appropriate trends indicating the response of macroinvertebrate communities to environmental changes. The SASS5 tool was observed to be a good tool for monitoring. However, it had some limitations due to primarily focusing on water quality as the driver of change. The MIRAI tool was found to be the best at monitoring because it considered the cumulative impact of different metrices that are important drivers of macroinvertebrate communities (Thirion 2007). The Ntchaweni River had a poorer ecological state than the uMvoti River. This can be attributed to water resource use stressors which include effluent discharges from the Gledhow Sugar Mill, Sappi Paper and Pulp making activities as well as domestic use (Malherbe 2006). Impacts of such stressors were observed in the uMvoti River below the confluence point. The Thukela and Mandeni Rivers also had poor ecological integrity state due to major industrial activities, wastewater treatment works, excessive water abstraction and sugarcane plantations (Venter 2013). The lack of stone biotopes in the lower uMvoti and Thukela Rivers reduced heterogeneity and complexity, and this had a huge impact on macroinvertebrate communities observed. Poor macroinvertebrate communities observed indicated that the ecological wellbeing of these river systems has deteriorated over the year and that have a huge impact on the availability of freshwater resources. Therefore, the water resources of the uMvoti and Thukela River need to be properly administered in a suitable manner.

Multivariate statistical analysis was used to evaluate the responses of macroinvertebrate communities to water resource use activities associated with the uMvoti and Thukela Rivers (Chapter 3). This multimeric analysis has been widely used and highly recommended for evaluating the structure and patterns of biological communities in diverse ecosystems (Van den Brink et al 2003; Malherbe 2006; O'Brien et al. 2009). The RDA bi-plot exhibited temporal changes of macroinvertebrate community structures throughout the study period. High number of taxa and estimated abundance was associated with historical dataset whereas the current dataset was allied with low number of taxa and estimated abundance. Also, historical data had an association with intolerant families including Psephenidae, Chlorocyphidae, Teloganodidae and others. However, such families have been replaced by intolerant families which dominated in the current dataset. This indicated that macroinvertebrate community trend is getting worse with time. The uMvoti River showed a decreasing trend of macroinvertebrate communities. That was not surprising because studies have already reported this river to be seriously modified, with nearly total loss of its ecosystem services (Tharme 1996; DWAF, 2004). With regards to the Thukela River, poor macroinvertebrates communities and estimated was observed in most surveys and that can be ascribed to water resource use stressors. The impact of such stressors was not only evident in macroinvertebrate communities, however, the overall ecological integrity of this river has been categorized as moderately modified (Class C) (IWR 2004). This threatens biodiversity and key ecosystem processes. Thus, proper management strategies need to be implemented on this river system.

4.2 Degree to which the hypothesis and objectives were met

The hypothesis that macroinvertebrates are suitable ecological indicators of the ecological integrity of the lower uMvoti and Thukela Rivers, KwaZulu-Natal, South Africa was accepted. Three predictions were established for this study and they were all achieved. 1) Natural and anthropogenic disturbances exhibited adverse effect on stream ecological integrity, and (2) Macroinvertebrate communities varied through time due to habitat heterogeneity, changes in water quality parameters and anthropogenic activities on both rivers. 3) There was also a significant change in the ecological integrity of the lower Thukela and uMvoti Rivers when comparing current and historical data.

4.3 Recommendations

From the outcomes of the study we make the following recommendations:

- More studies that assess impacts of water resource use on these systems should be implemented in the study area. Such studies should consider the use of ecological indicators including macroinvertebrates and other useful indicators including; fish, diatoms and riparian vegetation. This will provide a better holistic view on how the ecosystem is being affected by multiple-stressors.
- Water resource management policies and principles that are currently exist such as the National Water Resource Strategy (Version 2) should be implemented for each of the rivers in the study. This will ensure that the management and protection plans consider the land-use activity scenarios on each river.
- Industries that use water resources from uMvoti and Thukela Rivers must obtain water use licenses. Industries without licenses should face legal action. The polluter pays principle of the National Water Act should be implemented so that these polluters pay for the mitigation of the wellbeing of the river ecosystems Environmental performance of all activities should be monitored. The results should be integrated by regional regulators.
- Monthly water quality monitoring should be undertaken at the effluent discharge points to ensure that industries comply with their licences. Industries that fail to do so should face legal action. The polluter pays principle of the National Water Act should be implemented so that these polluters pay for the mitigation of the wellbeing of the river ecosystems.
- The dumping of physical waste should be managed by local municipalities who should make polluters accountable.
- Management plans should include the development of riparian buffers which will decrease the rate of sedimentation and erosion. This will also encourage natural filtration (assimilation) of runoff from sugarcane plantations and improve the status and function of the ecosystem
- Also, political support is required to enhance information collection that can be used for better decision making about the management and use of water.

4.4 References

Department of Water Affairs and Forestry (DWAF). 2004. Draft background information: South African Forestry, Pulp and Paper industries: Draft version 1. DWAF, Pretoria.

IWR (Institute for Water Research), 2004. Thukela water project decision support phase. Reserve determination study. Thukela estuarine flow requirements, Department of Water Affairs and Forestry, Pretoria

Malherbe CW. 2006. The current ecological state of the lower UMvoti River, KwaZulu-Natal. MSc Dissertation, University of Johannesburg, Johanesburg.

O'Brien GC, Swemmer R, Wepener V. 2009. Ecological integrity assessment of fish assemblages of the Matigulu/Nyoni and UMvoti estuaries, KwaZulu-Natal, South Africa. African Journal of Aquatic Science 34: 293–302.

Tharme R. 1996. Rivers of southern Africa: UMvoti River. African Wildlife 50: 31.

Thirion C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission (WRC) and Department of Water Affairs and Forestry (DWAF) report. WRC Report No. TT332/08. Water Research Commission, Pretoria, South Africa.

Van den Brink PJ, Van den Brink NW, Ter Braak, CJF. 2003. Multivariate analysis of ecotoxicological data using ordination: Demonstrations of utility on the basis of various examples. Australasian Journal of Ecotoxicology 9: 141–156.

Venter JJ. 2013. An ecological integrity assessment of the lower Amatikulu, Thukela and UMvoti Rivers, KwaZulu-Natal, South Africa. PhD Dissertation, North-West University, Potchefstroom