An ecological integrity assessment of the lower Amatikulu, Thukela and Umvoti rivers, KwaZulu-Natal, South Africa

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Dissertation submitted in fulfillment of the requirements for the degree *Magister Scientiae* in Zoology at the Potchefstroom Campus of the North-West University

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September 2013

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Summary

The ecosystem services of the lower Amatikulu, Thukela and Umvoti Rivers are used extensively through sugarcane agricultural activities, heavy industries and rural sewage-treatment works. These activities affect the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers. The Umvoti River is already being referred to as a 'working river'. This study aims to determine the current state of ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers and to establish trends between current and historical periods for the evaluation of changing trends in ecological integrity.

Abiotic (driver) and biotic (responder) indicator components were used in order to identify and monitor any changes in the surrounding environment as well as to determine the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers. Driver components include water quality, sediment grain size, moisture and organic content as well as habitat state, whereas responder components involve macroinvertebrates and fish assemblages. Two surveys were carried out; one during the low-flow period (5-11 August 2011) and the other during the high-flow period (20-28 March 2012). Current data and findings together with historical data from 1999 to 2010 were used to establish trends of selected driver and responder components.

Water quality variables selected include general variables such as water temperature, chemical oxygen demand (COD), electrical conductivity (EC), pH and total alkalinity (TAL) as well as salts, nutrients and toxics. These variables provide indications as to the state of the water-quality component of this study. The Target Water Quality Requirements (TWQR) as developed by the Department of Water Affairs and Forestry for domestic use (Volume 1) and Aquatic Ecosystems (Volume 7) were used to evaluate the quality of the water sampled in this study. The water quality as well as quantity was also compared to historical data obtained from previous studies that have been done for the same study area.

The sediment analyses were performed according to the protocol set out by the United States Environmental Protection Agency. Habitat availability, diversity and state were assessed by means of the Integrated Habitat Assessment System Version 2 (IHAS v 2) and the Index of Habitat Integrity (IHI).

The water quality of the lower Amatikulu River was found to be in a slightly modified state with the majority of water quality parameters within the target values as set by the TWQG. Water quality parameters considered on the lower Thukela River such as water temperatures, oxygen levels, nutrient and salt loads occurred at elevated levels and were not within the TWQG requirements. The water quality of the Thukela River wasconsidered to be in a modified state which may cause negative impacts on the structure and function of the river, while the water quality of the lower Umvoti River was seriously modified. Sediment analyses revealed that the organic content of the Lower Amatikulu, Thukela and Umvoti Rivers was low. Sediment grain-size distributions are dominated by well-sorted larger soil grain-sizes (>500 µm) which is not ideal for the biodiversity. This is an indication that erosion and transportation are taking place in the Amatikulu, Thukela and Umvoti Rivers. The removal of riparian vegetation by agricultural activities and water abstraction contributes to the habitat deterioration as well as erosion and transportation of sediments that occurs in lower Amatikulu, Thukela and Umvoti Rivers.

The use of macroinvertabrates as biological indicators in the determination of the ecological integrity, state or health of lotic ecosystems is globally well established. The South African Scoring System, version 5 (SASS 5), the Macroinvertebrate Response Assessment Index (MIRAI) and multivariate statistical analyses were implemented in order to determine the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers. Results revealed that the SASS 5 integrity classes were generally one class higher than the integrity classes of MIRAI. SASS 5 and MIRAI integrity classes of the Amatikulu River ranged from natural (Class A) to largely modified (Class D/E) while the Thukela and Umvoti rivers ranged from natural to seriously modified (Class E/F).

Fish assemblages are commonly used as key indicators to describe the ecological state of aquatic ecosystems. Methods used to sample fish included electronarcosis and a 5m wide 12mm meshed seine net. The Fish Response Assessment Index (FRAI) and multivariate statistical analyses were implemented in order to determine the ecological integrity of the lower Amatikulu, Thukela and Umvoti rivers. Results revealed that the automated FRAI integrity classes were constantly lower than the adjusted FRAI integrity classes. Automated and adjusted FRAI integrity classes of the Amatikulu River ranged from largely natural (Class B) to largely modified (Class D) while the Thukela and Umvoti rivers ranged from natural (Class A) to seriously modified (Class E/F).

The current ecological integrity of the lower Amatikulu River was found to be in a largely natural, with few modifications (Class B) state. The Thukela River was found to be in a moderately modified (Class C) state while the Umvoti River was found to be in a largely modified (Class D) state. The trends in ecological integrity of the selected driver components which include water quality, sediment and habitat availability fluctuated noticeably. The general trend in water quality of the lower Amatikulu, Thukela and Umvoti Rivers slightly recovered towards 2012. Sediment analyses revealed that the sediment grain-size distribution as well as the moisture and organic contents generally remained stable. There was a decline in the general state of habitat integrity towards 2012. As a result of the decline in the habitat ecological integrity the ecological integrity of macroinvertebrates also slightly declined towards 2012. However, a noticeable improvement in the ecological integrity of fish assemblages was observed towards 2012. To conclude, the ecological integrity of water quality and fish assemblages improved towards 2012, while habitat and macroinvertebrates deteriorated and sediment stayed the same. The general and overall state of ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers did not deteriorate nor did it improve, but rather it stayed the same.

Impacts on the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers include a multitude of different sources. To prevent the current ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers from deteriorating further, a collective effort involving all parties is essential.

Key words: Abiotic components; Amatikulu River; Biotic components; Ecological integrity; Thukela River; Umvoti River

Opsomming

Die ekosisteem dienste van die laer Amatikulu-, Thukela- en Umvotiriviere word intensief aangewend deur suikerriet landbou-aktiwiteite, nywerheid- en rioolstelsels. Die ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere word beïnvloed deur hierdie aktiwiteite. Die Umvotirivier word alreeds beskou as 'n "werkende rivier". Die doel van hierdie studie is om die huidige ekologiese toestand van die Amatikulu-, Thukela- en Umvotiriviere asook die verhouding tussen huidige en historiese data te bepaal om sodoende die tendens en verandering in die tendense van die ekologiese integriteit uit te lig.

Abiotiese (respons) en biotiese (drywer) komponente is gebruik om enige veranderinge in die omgewing te identifiseer en te kontroleer sowel as om die ekologiese integriteit van die Amatikulu-, Thukela- en Umvotiriviere te bepaal. Drywerkomponente bestaan uit waterkwaliteit, korrelgrootte van sediment, vog en organiese inhoud en die toestand van die habitat, waar die respons komponente makroinvertebraat- en visgemeenskappe insluit. Twee opnames, een tydens laagvloei tydperk (5-11 Augustus 2011) en een tydens hoogvloei tydperk (20-28 Maart 2012) is uitgevoer. Historiese data van 1999 tot 2010 tesame met huidige data, is gebruik om tendense in die drywer en responskomponente te bepaal.

Waterkwaliteitsveranderlikes insluitend temperatuur, chemiese suurstof vereistes, elektriese geleidingsvermoë, pH, totale alkaliniteit, soute, voedingstowwe en gifstowwe is gebruik om water kwaliteit te bepaal. Bogenoeme veranderlikes dui die toestand van die waterkwaliteit komponent van hierdie studie aan. Die Teiken Water Kwaliteit Vereistes (TWKV) vir Huishoudelike Gebruik (Volume 1) en Akwatiese Ekosisteme (Volume 7) wat deur die Departement van Waterwese en Bosbou ontwikkel is, is in hierdie studie gebruik om die water kwaliteit te evalueer. Waterkwaliteit en kwantiteit is ook vergelyk met historiese data uit vorige studies wat in dieselfde studie area gedoen is.

Sediment-analises is volgens die voorskrifte wat deur die "United States Environmental Protection Agency (USEPA)" vasgestel is, uitgevoer. Habitat beskikbaarheid, diversiteit en status is bepaal deur van die "Integrated Habitat Assessment System Version 2 (IHAS v 2)" en die "Index of Habitat Integrity (IHI)" gebruik te maak.

Daar is gevind dat die waterkwaliteit van die laer Amatikulurivier in ’n redelike goeie, maar geringe verswakte toestand is. Die meerderheid van die waterkwaliteit veranderlikes val binne die teiken waardes soos deur die TWKV vasgestel. Die temperatuur, suurstof vlakke, voedingstof en sout konsentrasies in die laer Thukelariviere het vlakke getoon wat hoër is as die waardes wat deur die TWKV vasgestel. Die waterkwaliteit van die Thukelarivier verkeer in ’n veranderde toestand wat negatiewe invloede op die strukture en funksies van die rivier kan hê. Die waterkwaliteit van die laer Umvotiriver is in ’n ernstige verswakte toestand. Volgens sediment-analises is die organiese inhoud in die laer Amatikulu-, Thukela- en Umvotiriviere laag. Die verspreiding van die sediment korrelgroottes is oorheersend groot (>500 µm), wat nie ideaal vir die biodiversiteit is nie. Dit dui ook op erosie in die laer Amatikulu-, Thukela- en Umvotiriviere. Verwydering van oewerplante en onttrekking van water uit die rivier veroorsaak verswakking van die habitat, erosie en beweging van sediment in die laer Amatikulu-, Thukela- en Umvotiriviere.

Die gebruik van makroinvertebrate as biologies indikators om die ekologiese integriteit, toestand en gesondheid van ’n lotiese ekosisteem te bepaal is wêreldwyd ’n goed ontwikkelde stelsel. Die “South African Scoring System version 5 (SASS 5)”, die “Macroinvertebrate Response Assessment Index (MIRAI)” en multiveranderlike statistiese analises is gebruik om die ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere te bepaal. Vanuit die resultate kan gesien word dat die integriteit klas wat deur SASS5 verkry is telkens ’n klas hoër is as die klas deur MIRAI verkry. Integriteitsklasse soos deur SASS5 en MIRAI bepaal vir die Amatikulurivier wissel tussen natuurlik (Klas A) en grootliks versteur (Klas D/E), terwyl klasse vir die Thukela- en Umvotiriviere wissel tussen natuurlik en ernstig versteur (Klas E/F).

Visgemeenskappe word algemeen gebruik as sleutel indikators om die ekologiese toestand van die akwatiese ekostelsels te beskryf. Visse is gevang deur van elektriese-verdowing en ’n treknet met ’n lengte van 5m en ’n maasgrootte van 12mm, gebruik te maak. Die “Fish Response Assessment Index (FRAI)” en multiveranderlike statistiese analises is gebruik om die ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere te bepaal. Volgens die resultate het die geoutomatiseerde FRAI telkens laer integriteitsklasse aangetoon as die aangepasde FRAI integriteitsklasse. Geoutomatiseerde en aangepasde FRAI integriteitsklasse van die Amatikulurivier het van grootliks natuurlik (Klas B) tot grootliks versteur (Klas D) gewissel, terwyl die Thukela- en Umvotiriviere tussen natuurlik (Klas A) en ernstig versteur (Klas E/F) gewissel het.

Die huidige ekologiese integriteit van die laer Amatikulurivier blyk grootliks natuurlik (Klas B) te wees. Resultate wys dat die Thukelarivier in ’n matig versteurde (Klas C) toestand is terwyl die Umvotirivier grootliks versteur (Klas D) is. Tendense in die ekologiese integriteit volgens die drywer komponente soos waterkwaliteit, sediment en habitat beskikbaarheid het aansienlik gewissel. Die algemene tendens in die laer Amatikulu-, Thukela- en Umvotiriviere ten opsigte van waterkwaliteit het teen 2012 effens verbeter. Volgens sediment-analises het die verspreiding in sediment korrelgrootte, vog en organiese inhoud stabiel en onveranderd gebly. Daar het teen 2012 ’n afname in die algemene toestand in die integriteit van die habitat voorgekom. Die afname in die habitat integriteit het ’n effense afname in die ekologiese integriteit van die makroinvertebraat-populasies tot gevolg gehad. Daar het egter teen 2012 ’n merkbare verbetering in die ekologiese integriteit van die visgemeenskappe voorgekom. Die ekologiese integriteit van waterkwaliteit en visgemeenskappe het teen 2012 verbeter, terwyl die habitatintegriteit en makroinvertebraatgemeenskappe afgeneem en sediment onveranderd gebly het. Die algemene en algehele status in ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere het nie verswak of verbeter nie, maar onveranderd gebly.

Daar is ’n menigte bronne wat ’n effek op die ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere kan hê. Om te voorkom dat die huidige toestand rakende die ekologiese integriteit van die laer Amatikulu-, Thukela- en Umvotiriviere afneem, is die samewerking van alle partye nodig.

Sleutelwoorde: Abiotiese komponente; Amatikulurivier; Biotiese komponente; Ekologiese integriteit; Thukelarivier; Umvotirivier

Acknowledgements

"I lift up my eyes to the hills – where does my help come from? My help comes from the Lord, the Maker of heaven and earth".

Psalms 121: 1 & 2.

To my Lord and Saviour, Jesus Christ, thank You for blessing me with the opportunity to be involved in this project and providing me with strength and courage.

I would like to acknowledge the following people and organisations with sincere gratitude for assisting me in so many ways:

- My farther, Johann, mother, Hanlie, brother, Carel and sisters, Helen and Emmarentia, for all the love, support, motivation and believing in me.
- All my other family and friends for their continual support and motivation.
- Francois Jacobs, my colleague and friend, for all his help, especially with the field work.
- Karien du Plessis for always being willing to help where ever she could as well as for her support and encouragement.
- My supervisor Professor Nico J. Smit, for providing me with the opportunity to continue my post graduate studies in this well organised and challenging project, and for the guidance he provided as well as skills that he taught me.
- Doctor Gordon O'Brien for allowing me to do this project and for sharing his knowledge, as well as for all his advice, guidance and support during field trips and throughout my entire study period.
- The North-West University for allowing me to do this study and for the use of their facilities and equipment as well as financial support.
- Sappi for their generous financial assistance in order to complete this study.
- Everyone else who played a role and contributed to the successful completion of this study. These essential contributions have not gone unnoticed and are greatly appreciated.

CHAPTER 1: INTRODUCTION

1.1. General introduction

Water is our most essential natural resource and sustains all life on planet earth (Vörösmarty *et al*., 2010). It has a major influence on economic and social development in many countries (DWAF, 2009). Freshwater resources provide us with aquatic ecosystems which offer valuable services (e.g. waste assimilation, recreation and fisheries) and goods (e.g. food) and these benefits are known as ecosystem services (DWAF, 2009; Hoeinghaus *et al*., 2009; UNEP, 2009). Hoeinghaus *et al*. (2009) state that (ecosystem) services can be seen as renewable capital in that they may be renewed using a portion of the original stock and solar energy. Ecosystem services and in particular aquatic ecosystem services provide a range of services which include provisioning, regulating, supporting and cultural services which contribute directly and indirectly to economic and social development as well as human welfare (Hoeinghaus *et al*., 2009; UNEP, 2009). According to Costanza (2008) ecosystem services can be defined as 'the benefits people obtain from ecosystems'. Aquatic ecosystems contribute to human welfare in the sense that it provides resources that can be harvested and provides services that include processes regarding water purification, water storage and transport (DWAF, 2009; O'Brien, 2011). Aquatic ecosystem services also include beauty, educational, cultural, spiritual and recreational aspects (DWAF, 2009).

South Africa is considered a water-scarce, semi-arid country with uneven spatial distribution of water resources (DWAF, 2004). Aquatic ecosystems are directly threatened by human activities (Vörösmarty *et al*., 2010). The excessive utilisation of the ecological services of aquatic ecosystems in South Africa leads to a decline in ecological integrity resulting in the loss of key ecosystem services (Arthington *et al.,* 2010). As such it is crucial to manage and protect our freshwater aquatic ecosystems in a sustainable and sound manner due to the fact that these ecosystems are essential to mankind. The South African National Water Act (Act No. 36 of 1998) was promulgated to protect and manage South Africa's water resources. The National Water Act states that the purpose of the Act is to 'ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled' in a sustainable approach. The National Water Act requires that a National Water Resource Strategy (NWRS) must be implemented in order to reach the goal of the Act itself.

According to the Department of Water Affairs and Forestry (DWAF, 2004) the NWRS must provide information regarding the ways in which water resources must be managed, provide quantitative information regarding the present and future availability of and requirements for water in each of the 19 water management areas, as well as propose interventions by which these may be reconciled.

The ecosystem services of the lower Amatikulu, Thukela and Umvoti Rivers are used extensively through sugarcane agricultural activities, heavy industries and rural sewage-treatment works. These activities affect the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers. The Umvoti River is already being referred to as a 'working river' (DWAF, 2004). This study aims to determine the current state of ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers and to establish trends between current and historical periods for the evaluation of changing trends in ecological integrity.

1.1.1. Environmental monitoring

Environmental monitoring refers to the systematic sampling of air, water, soil and biota in order to observe and study the surrounding environment, as well as to derive knowledge from this process (Reece and Richardson, 1999; Artiola *et al.,* 2004; Wiersma, 2004; Weston, 2011). Environmental monitoring can be conducted for a number of reasons, including to establish environmental baselines, trends and cumulative effects, test environmental modelling processes, educate the public regarding environmental conditions, inform policy design and decision-making, ensure compliance with environmental regulations, assess the effects of anthropogenic influences, or to conduct an inventory of natural resources (Mitchell, 2002; Weston, 2011). Environmental monitoring can also be used to measure and evaluate the consequences of human actions on ecosystems (Kleynhans, 2003). Long-term environmental monitoring is the best way to identify measurement parameters that can serve as vital signs of ecosystems and define the limits of their variation (Hohls, 1996).

Aquatic ecosystems, as all other ecosystems, are complex and are exposed to a multitude of stressors at any given time which result in cumulative effects (Dallas, 2007; Davis *et al.,* 2010; Granek *et al.,* 2010; Glaholt *et al.,* 2012). The sampling of abiotic (non-living) and biotic (living) components of aquatic ecosystems through environmental monitoring can produce data in order to detect the baseline patterns as well as patterns of change in the inter- and intra-process relationships between and within the abiotic and biotic components

(Artiola *et al.,* 2004; Wiersma, 2004; Weston, 2011). Abiotic components can also be referred to as ecological driver components and biotic components as ecological responder components. Abiotic (driver) as well as biotic (responder) components are considered to be good indicators of ecosystem health as they are generally sensitive to a low level of disturbance of a wide variety of environmental impacts and have the ability to integrate the responses to environmental change (Roux, 1999). Abiotic and biotic components act as tools used as indicators or lines of evidence of ecosystem health in environmental monitoring (Todd and Roux, 2000; Weston, 2011).

Environmental monitoring is a useful tool to use for monitoring and assessing aquatic ecosystem state or health (Hohls, 1996; Roux, 1999; Artiola *et al.,* 2004; Wiersma, 2004). The overall condition or health of aquatic ecosystems can only be determined if the interaction of all the physical, chemical and biological components are taken into consideration (Hohls, 1996). Therefore it is important to include as many abiotic and biotic lines of evidence as possible when determining the ecological health of aquatic ecosystems (Hohls, 1996). A national monitoring programme, the River Health Programme (RHP), assesses and monitors the ecological integrity state of the rivers in South Africa by using standardised lines of evidence to provide information regarding the ecological health of the country's rivers (Mangold, 2001; DWAF, 2008).

Environmental monitoring can generate large amounts of data due to the fact that it includes various components of abiotic and biotic lines of evidence. This makes it difficult to simplify the amount of data to such a point where it is useful to resource managers, conservationists, politicians and the general public (Hohls, 1996). In order to address this challenge, a number of relatively simple and rapid assessment techniques, by which abiotic and biotic lines of evidence can be numerically presented, have been developed. These techniques are referred to as community metric measures, and are used to quantify the status of aquatic ecosystems by summarising data on the present ecological health or integrity status of aquatic communities of rivers compared to the natural or near-natural reference conditions (Hohls, 1996; Van Eeden, 2003; Kleynhans *et al.,* 2005).

1.1.2. Abiotic lines of evidence

1.1.2.1. Water quality

The term water quality is used to describe the physical, chemical, biological and aesthetic characteristics of water which determine the fitness for a variety of uses as well as for the protection of the health and integrity of aquatic ecosystems (DWAF, 1996a; 1996b). The physical, chemical, biological and aesthetic characteristics are controlled or influenced by constituents that are either dissolved or suspended in water (DWAF, 1996a; 1996b). The monitoring of water quality plays an essential role in the integrity of an ecosystem due to the fact that the response of biotic indicator organisms is linked to the quality of the water of an aquatic ecosystem (Munn *et al.,* 2002). Water quality is monitored and assessed by measuring the fundamental variables which include system variables (temperature, dissolved oxygen, salts, pH and turbidity), nutrients (phosphate, nitrite and nitrate), toxic substances (inorganic substances such as Hg, Cu and NH_4^+ as well as organic substances which include phenol and atrazine) and non-toxic inorganic substances (total dissolved solids and electrical conductivity) (DWAF, 1996a; 1996b; Palmer *et al.,* 2005; Ramollo, 2008).

Water temperature governs the speed at which chemical reactions occur as well as metabolic rates and for this reason controls all aspects of aquatic biology (Laxton and Gittins, 2003). Temperature is one of the major factors controlling the distribution of aquatic organisms (DWAF, 1996b). The water temperature indirectly influences oxygen solubility, nutrient availability and the decomposition rate of organic matter, all of which affect the structure and function of biotic communities (Gallagher, 1999).

Dissolved oxygen (DO) concentration is considered an essential parameter of any water quality assessment (Laxton and Gittins, 2003). The maintenance of adequate DO concentrations is critical for the survival as well as functioning of aquatic biota as it is required for the respiration of all aerobic organisms (DWAF, 1996b). Therefore DO concentrations provide a useful measure of aquatic ecosystem health (DWAF, 1996b). The DO concentration of water can be expressed in three different ways: as a mass of oxygen per litre of water (mg/l), volume of oxygen per litre of water (ml/l) and as percentage saturation (Laxton and Gittins, 2003). Laxton and Gittins (2003) further states that seasonal changes are caused by annual temperature fluctuations and are related to the solubility of oxygen at each temperature.

Chlorine can react with a variety of organic substances to form stable chloro-organic compounds, some of which are harmful even at low concentrations (DWAF, 1996b). Elevated chlorine levels may cause fish to experience adverse changes in the blood chemistry, damage to gills and decreased growth rate while invertebrates become immobile, exhibit reduced reproduction and reduced survival (DWAF, 1996b). Aquatic plants can become chlorotic and reduced rates of photosynthesis and respiration are observed for phytoplankton (DWAF, 1996b).

The pH of water is an important parameter as it presents indications of the origin of water, the geology of the catchment, the type of biological activity occurring in it and the probability that it is contaminated by industrial or domestic waste (Laxton and Gittins, 2003). The water's pH is affected by factors such as temperature, concentrations of inorganic and organic ions as well as biological related activities (DWAF, 1996b). Turbidity is a measure of the extent to which light penetration in water is reduced by the suspended materials carried by the water (Bain and Hynd, 1999; Stevenson and Bain, 1999; Laxton and Gittins, 2003).

Nitrite, nitrate and ammonium are the most common ionic forms of dissolved nitrogen in aquatic ecosystems (Rabalais *et al*., 2002; Camargo and Alonso, 2006). Nutrients, including nitrite and nitrate, are substances carried by water and are essential for the growth of plants and animals (Laxton and Gittins, 2003). Nitrite is the inorganic intermediate and nitrates the end product (DWAF, 1996b). Nitrate is usually more abundant than nitrite in the aquatic environment and nitrate and nitrite are usually measured and considered together (DWAF, 1996b). Ammonia may occur in a free, un-ionised form (NH_3) or in an ionised form as ammonium (NH_4^+) (DWAF, 1996b; Camargo and Alonso, 2006). Both are reduced forms of inorganic nitrogen derived from aerobic as well as anaerobic decomposition of organic material (DWAF, 1996b). Ammonium itself has little or no toxicity on aquatic biota, but does contribute to eutrophication of aquatic ecosystems (DWAF, 1996b; Smith, 2003; Camargo and Alonso, 2006). Phosphorus in surface water occurs in an ionic form, orthophosphate, and is the component of water chemistry that limits plant production and growth in aquatic ecosystems (Bain and Stevenson, 1999; Laxton and Gittins, 2003). DWAF (1996b) states that phosphorus is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems.

Total dissolved solids (TDS) are a measure of the total concentration of all dissolved components in water (DWAF, 1996b; Bain and Stevenson, 1999). The electrical conductivity (EC) of water refers to a measure of the ability to conduct electricity (Laxton and Gittins, 2003). The EC of water increases when the concentration of TDS increases (Bain and Stevenson, 1999; Laxton and Gittins, 2003). The conductivity of fresh water can be used as an indication of the different types of processes that occur in the catchment of the selected aquatic ecosystem (Laxton and Gittins, 2003).

The South African Water Quality Guidelines were developed with the goal to serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems (DWAF, 1996a; 1996b). The criteria set out by the South African Water Quality Guidelines are based on selected key indicator species to represent the different trophic levels and if these species are protected, the other species should be safe as well (Roux *et al.,* 1996).

The South African Water Quality Guidelines have established guidelines for domestic, recreational, industrial and agricultural uses as well as guidelines for the protection of the health and integrity of aquatic ecosystems (DWAF, 1996a; 1996b). For each of these guidelines a Target Water Quality Range (TWQR) has been established. The TWQR is a management objective which has been derived from quantitative and qualitative criteria and refers to the range of concentrations or levels within which no measurable adverse effects are expected on the health of aquatic ecosystems, and should therefore ensure their protection (DWAF, 1996a; 1996b).

1.1.2.2. Sediment

Sediment analysis is regarded as an important factor that should be taken into account when conducting environmental monitoring programmes in a river ecosystem (Charkhabi *et al.*, 2008). The analyses of sediment provide environmentally significant information and indications of the relative degrees of contamination in a sampling area (Roux *et al.*, 1993; IAEA, 2003; Charkhabi *et al.*, 2008). Sediment forms part of an integral component of aquatic ecosystems as it provides habitat, feeding, spawning and rearing areas for numerous aquatic organisms (USEPA, 2001; Goode *et al.,* 2012). The U.S. Environmental Protection Agency (USEPA) (2001) further states that sediment also serves as a reservoir for pollutants and therefore a potential source of pollutants to the water column, organisms and human consumers of those organisms.

Pollutants present in sediment may arise from various sources which include municipal and industrial discharges, urban and agricultural runoff, atmospheric deposition and port operations (USEPA, 2001).

Sediment analysis regarding biological assessments of aquatic ecosystems includes several characteristics. These characteristics include sediment grain size, organic and moisture content. According to the International Atomic Energy Agency (IAEA) (2003) analyses of sediment grain size are used to characterise the physical characteristics of sediment. Sediment grain sizes influence both chemical and biological variables and can therefore be used to normalise chemical concentrations according to sediment characteristics and to account for some of the variability found in biological assemblages (IAEA, 2003). The type of grain size can also provide information on the amount of sediment that is being transported down a river (Venter and Van Vuren, 1997).

Organic material in sediments originates both from aquatic organisms living in the aquatic systems and from organic matter that is derived from the surrounding soils as well as terrestrial sources (Page, 2002). The organic material of sediment can be used as an indicator of the productivity of the system. The total organic carbon (TOC) content of sediment is a measure of the total amount of oxidisable organic material (USEPA, 2001). TOC is the sum of dissolved organic carbon (DOC) or suspended organic carbon (SOC) and colloids (USEPA, 2001). TOC is regarded an important parameter to measure in sediments due to the fact that it is a major determinant of non-ionic organic chemical bioavailability (DiToro *et al.,* 1991).

1.1.2.3. Habitat

The availability and quality of habitat are some of the most important factors determining the survival of biota in an ecosystem (Hubert and Bergersen, 1999; Malherbe, 2006; Carminati, 2008). For this reason it is essential to include a habitat assessment when determining the ecological integrity of a specific riverine system (Mangold, 2001). According to Bain and Stevenson (1999) habitat can be defined as: ‘specific type of place within an ecosystem occupied by an organism, population or community that contains both living and non-living components with specific biological, chemical and physical characteristics including the basic life requirements of food, water and cover or shelter’. Habitat types of rivers include pools, rapids, sandbanks, bedrock, boulders, cobbles, gravel, sand, mud, runs, riffles as well as marginal and aquatic vegetation (Malherbe, 2006).

The availability and diversity of the instream habitat is usually influenced by the type of substrate available; however, some rivers have naturally poor diversity (Mangold, 2001). The riparian zone and riparian vegetation provide habitats for aquatic and terrestrial species and perform several ecological functions which ensure that an aquatic ecosystem stays healthy (Mangold, 2001; Malherbe, 2006). The functions provided by riparian vegetation include the maintaining the river channel, filters light, nutrients and sediment, provide food and provides building material for local communities (Mangold, 2001).

1.1.3. Biotic lines of evidence

1.1.3.1. Macroinvertebrates

Macroinvertebrates are one of the most important organism groups used to evaluate the ecological integrity of rivers (Álvarez-Cabria *et al*., 2010). Macroinvertebrates in aquatic ecosystems include aquatic insects, larvae of insects with terrestrial adult forms, mussels, clams, snails and worms that are aquatic throughout their life cycle (Thirion, 2007; Malherbe *et al.,* 2010). Aquatic macroinvertebrates are commonly used to assess the biological integrity of rivers and streams, more commonly than any other biota (O'Keeffe and Dickens, 2000; Thirion, 2007). Macroinvertebrate communities form an essential part of riverine ecosystems and provide a good indication of the prevailing flow regime and water quality in a river (Thirion, 2007; Álvarez-Cabria *et al*., 2010). They are also important processors of transported organic material and serve a vital function in purifying the water in a river or stream and provide a valuable food source for other animals (Thirion, 2007; Álvarez-Cabria *et al*., 2010). Macroinvertebrate communities adapt to the flow conditions which control temperature, sediment transport and nutrient flows in a system (Thirion, 2007; Álvarez-Cabria *et al*., 2010). If any of these conditions change it will cause changes in the invertebrate community structures through the loss of certain species or the increase of others as well as providing conditions for a range of new or otherwise scarce species to flourish (Thirion, 2007). However, there are some disadvantages related to the use of macroinvertebrates as ecological indicators. These disadvantages include that macroinvertebrate communities are not only influenced by human activities, but their structure and composition change seasonally and with different locations within a selected catchment (Álvarez-Cabria *et al*., 2010). Temporal variation in species composition of macroinvertebrate communities may occur as a consequence of different life cycles (Álvarez-Cabria *et al*., 2010).

The disadvantages of using macroinvertebrate communities as ecological indicators can be overcome by sampling different locations within a selected catchment, sampling during different seasons and developing long-term macroinvertebrate community databases to account for intra- and interannual variability for different river typologies (Álvarez-Cabria *et al*., 2010).

1.1.3.2. Fish

Fish assemblages are commonly used as key indicators to describe the ecological state of aquatic ecosystems (Maceda-Veiga and De Sostoa, 2011). The advantages of fish as environmental indicators rely on key aspects of their biology and ecology, namely their wide distribution in aquatic environments, diversity of functional guilds, their major ecological role in food webs, their relatively long life-span which accounts for long-term effects and their value for mankind as food source (DWAF, 1999; Todd and Roux, 2000; Whitfield and Elliott, 2002; Van der Oost *et al.,* 2003; Harrison and Whitfield, 2004; Maceda-Veiga and De Sostoa, 2011; Cabral *et al.,* 2012; Gamito *et al.,* 2012). However, there are some disadvantages related to the use of fish as indicators of the ecological state of aquatic ecosystems which should be considered (Cabral *et al.,* 2012; Gamito *et al.,* 2012). The disadvantages include the high mobility of fish, their high tolerance to contaminates and physical degradation of habitats as well as the selective nature of sampling gears required for large sampling efforts (Whitfield and Elliott, 2002; Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012). Nevertheless, the majority of these disadvantages are out-weighed by the related advantages (Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012).

1.2. Study area

1.2.1. Amatikulu River

The Amatikulu River is situated north of the Thukela and Umvoti Rivers. The Amatikulu River joins the Nyoni River and flows parallel to the Indian Ocean before it empties into the ocean approximately 105 km north of Durban. Sugarcane agricultural activities, heavy industries (such as the Amatikulu Sugar Mill), rural areas and rural sewage-treatment works occur on the banks of the Amatikulu River. Sand abstraction for irrigation also occurs in this area. All these related impacts may influence the ecological integrity of the lower Amatikulu River.

Literature on historical assessments of the lower reaches of the Amatikulu River is limited. Carminati (2008) assessed the effect of the sugar milling activities on the ecological integrity of the lower Amatikulu River. Results of this study revealed that the water quality in the lower reaches of the Amatikulu River (up- and downstream of the Amatikulu Sugar Mill) were in a relatively good state with only turbidity and chlorides that exceeded the TWQR for domestic use and ammonia for aquatic use. Sediment analyses indicated that upstream of the sugar mill the sediment sizes ranged from fine sand to gravel; however, the site was dominated by coarser particles (Carminati, 2008). Downstream of the Amatikulu Sugar Mill the sediment was characterised by very fine and medium sand particles. As a result of the good habitat and water quality, the macroinvertebrate community structures were also in a fairly good state. The fish community structures in the lower Amatikulu River were in a relatively bad state. Carminati (2008) stated that a flood occurred during the high-flow season in 2006 which may have caused fish species to be washed down. Carminati (2008) concluded that the Amatikulu Sugar Mill is responsible for the majority of the impacts which cause the loss of habitat, decline in water quality and the loss of other biota downstream of the mill.

1.2.2. Thukela River

The Thukela River originates in the Drakensberg Mountain Range above Bergville where it flows in an easterly direction reaching the Indian Ocean approximately 95 km north of Durban (DWAF, 2001a; Stryftombolas, 2008). The major tributaries include the Mlambonya, Little Thukela, Klip, Bushmans, Sundays, Mooi as well as the Buffalo Rivers (DWAF, 2001a). The Thukela catchment covers a total area of 29 039 km² with a natural mean annual runoff (MAR) of 3 799 x 10^6 m³ at the river mouth, which makes the Thukela River the second largest river in South Africa (DWAF, 2004; Rowntree and Wadeson, 2008). The average annual sediment load at the Thukela River mouth has been estimated at 5.5 x 10^6 t/a (DWAF, 2001a).

The lower reaches of the Thukela River catchment are characterised by sugarcane agricultural activities which result in the loss of natural habitat and may cause erosion and siltation to increase. The area also supports some highly industrialised areas including the Mandini and Sundumbili industrial complexes which include Tugela Rail, a textile factory and a vegetable-oil factory (Stryftombolas, 2008). Another major industry that may contribute to the excessive use of the ecosystem services provided by the lower reaches of the Thukela River is the Sappi Tugela Mill. According to DWAF (2004b) the Sappi Tugela Mill is responsible for the largest water use in the area with an estimated water requirement of 24 x 10^6 m³/a. The Sappi Tugela pulp and paper mill has both extraction and discharge points in the same region, accompanied by extensive sugarcane plantation irrigation (Stryftombolas, 2008). The Sappi Tugela Mill discharges its effluent directly into the Thukela River close to the confluence with the eMandeni River. The eMandeni River supports the Isithebe rural area and industrial complex as well as rural sewage treatment works from both Isithebe and Mandini. Previous studies on the lower reaches of the Thukela River have been done by Oliff (1960), Brand *et al.* (1967), Coke (1995), De Moor *et al.* (1999), DWAF (2001a), DWAF (2003), Cloete *et al.* (2008), Ferreira *et al.* (2008); Stryftombolas (2008) and O'Brien (2010a).

Water-quality analysis results of the Reserve Determination revealed elevated levels of magnesium and chloride ions while other salt ions were considered to be in a natural state (DWAF, 2003). The Reserve findings indicated that during low-flow conditions, with relation to a dilution factor, activities associated with the Sappi Tugela Mill impacted the state of the system (DWAF, 2003; Stryftombolas, 2008). The impacts associated with Sappi are related to elevated levels of chemical and biological oxygen demands (CODs and BODs), suspended solids, sodium and temperature (DWAF, 2003).

Results of the studies undertaken in 2005, 2006, 2008 and 2010 revealed similar findings (Cloete *et al.,* 2008; Ferreira *et al.*, 2008; Stryftombolas, 2008; O'Brien *et al.*, 2010a). Stryftombolas (2008) stated that the decreased oxygen levels are caused by a combination of industrial wastewater in the eMandeni River and the Sappi Tugela paper mill effluent. Results from 2008 and 2010 studies (Cloete *et al.*, 2008; Ferreira *et al.*, 2008; O'Brien, 2010a) indicated that the water quality of the lower Thukela River, upstream of the eMandeni River confluence and the Sappi effluent discharge point, were in a fairly natural state. The water quality of the eMandeni River in 2008 was in a severely modified state (Cloete *et al.*, 2008).

Results regarding sediment analyses revealed that the organic content of the lower Thukela River were classified as being low (Ferreira *et al.*, 2008; Stryftombolas, 2008). Organic contents in the sediment of the eMandeni River ranged from moderately low to high (Cloete *et al.*, 2008). Grain-size analyses showed that medium sand dominates the lower Thukela River (Ferreira *et al.*, 2008; Stryftombolas, 2008). Additionally, the grain sizes in the eMandeni River ranged from gravel to fine sand (Cloete *et al.*, 2008). The findings may indicate that sediments are being transported in these systems (Ferreira *et al.*, 2008).

Habitat assessments conducted by DWAF during the Reserve Determination showed that the Instream Habitat Integrity (IHI) was in a moderately modified state and the riparian zone habitat in a largely modified state (DWAF, 2003). Historical results revealed that the habitat status of the lower Thukela River and associated eMandeni River generally deteriorated over time (Cloete *et al.*, 2008; Ferreira *et al.*, 2008; Stryftombolas, 2008).

Macroinvertebrate and fish community structures of the lower Thukela River were found to be in a fairly natural state upstream of the eMandeni River and Sappi effluent discharge point (Ferreira *et al.*, 2008; Stryftombolas, 2008). However, below the confluence of the eMandeni River and Sappi effluent discharge point, the macroinvertebrate as well as the fish community structures were classified to be in a largely modified to a severely modified state. Historical results regarding the overall ecological integrity state of the lower Thukela River and associated eMandeni River revealed that the Thukela River is generally classified to be in a moderately modified and largely modified state (Stryftombolas, 2008; O'Brien *et al.,* 2010a). O'Brien (2010a) concluded that the ecological integrity state of the Thukela River slightly recovered in 2010 from the reduced state in 2008, but was still lower than the outcomes of the assessment carried out in 2006.

Results revealed that the eMandeni River was classified to be in a severely modified ecological integrity state in 2005, 2006, 2008 and 2010 (O'Brien *et al.*, 2010a). The cumulative impacts on both the eMandeni Stream and the Thukela River caused a decline in the EcoStatus of habitat, macroinvertebrates, fish and water quality around the confluence between the eMandeni River and the Thukela River (Stryftombolas, 2008).

1.2.3. Umvoti River

The Umvoti River empties into the Indian Ocean close to Blythedale Beach, about 90 km north of Durban. The Umvoti River rises in the Natal Midlands from where it meanders down in a south-easterly direction towards Greytown and Stanger. One of the main tributaries of the Umvoti River is the Hlimbitwa River which joins the Umvoti River near Dhlakati. DWAF (2004a) categorised the Umvoti River as a medium-sized river with a total natural mean annual runoff (MAR) of 595 million m^3/a. The Umvoti River catchment covers an area of approximately 2 728 km^2 (Carminati, 2008).

The lower reaches of the Umvoti River are characterised by sugarcane agricultural activities, heavy industries, informal settlements, rural areas as well as rural sewage-treatment works. This may cause the loss of natural habitat and biota while sediment transportation is increased. Overgrazing and water abstraction for agricultural, commercial and industrial uses occur in the lower reaches of the Umvoti River (Carminati, 2008). Irrigation accounts for the largest water usage of the area and is followed by the industrial sector and in particular the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi Fine Paper's Stanger Mill (Malherbe, 2006).

The Umvoti River is a highly developed and highly utilised aquatic resource to such an extent that it is referred to as a 'working river' (DWAF, 2004). This status suggests that due to excessive use of the ecosystem services and resources associated with this system the structure and function of the lower Umvoti River is impaired (DWAF, 2004; O'Brien, 2011). The nature and extent of the use of the associated ecosystem services of the lower Umvoti River are well documented in the literature (Tharme, 1996; CRUZ, 2000; DWAF, 2001b; 2004b) O'Brien *et al.,* 2005; Malherbe, 2006; Schüring and Schwientek, 2006; Carminati, 2008; Malherbe *et al.,* 2008; Swemmer, 2008; O'Brien *et al.,* 2009; Malherbe *et al.,* 2010; O'Brien, 2011).

In particular, the water quality of the lower Umvoti River and associated Nchaweni River remained in a severely modified, impacted state (Tharme, 1996; CRUZ, 2000; O'Brien *et al.,* 2005; Malherbe, 2006; Carmanati, 2008; Malherbe *et al.,* 2008; O'Brien, 2010b; O'Brien, 2011). Below the confluence of the Umvoti and Hlimbitwa Rivers, excessive eutrophication, salinisation, and contamination by toxins has resulted in chemically inadequate water-quality conditions with low oxygen levels that are not conducive to maintaining ecosystem health and biodiversity (O'Brien *et al.,* 2005; Malherbe *et al.,* 2008; O'Brien, 2010b). The impaired water quality of the system is considered to be one of the main factors contributing to the severely modified state of the lower Umvoti River (Malherbe, 2006; Carminati, 2008; Malherbe *et al.,* 2008; O'Brien, 2010b; O' Brien, 2011).

Sediment analyses showed that the organic content were generally very low to moderately low (CRUZ, 2000; O'Brien *et al.,* 2005; Malherbe, 2006; Carminati, 2008; Malherbe *et al.,* 2008; O'Brien, 2010b; O'Brien, 2011). This indicates that the productivity of the system is fairly low. Grain-size distribution analyses indicated that the sediment is well sorted, which is not ideal for biodiversity. Results revealed that in 2008 high averages grain size of sediments occurred in the lower Umvoti system, which suggests that the system is being excessively eroded (Malherbe *et al.,* 2008). Malherbe *et al.* (2008) further stated that large quantities of sediment are being deposited into the Umvoti River, which under natural conditions would be trapped by a healthy functioning riparian vegetation zone.

Previous studies concluded that as a result of multiple stressors and impacts, the habitat availability and biodiversity of the lower Umvoti River was found to be in a severely impacted state. According to Tharme (1996) the habitat in this lower section of the Umvoti River was 'modified completely, with an almost total loss of natural habitat'. Sugarcane agricultural activities caused riparian vegetation to be removed, which altered the habitat integrity. Results in 2010 showed that the habitat quality of the lower Umvoti River remained in a modified to severely modified state (O'Brien, 2010b).

As a result of poor water quality, habitat integrity and flow modifications, macroinvertebrate and fish community structures in the lower Umvoti River and associated Nchaweni and Mbozambo Rivers were considered to be in a modified to severely modified state (Tharme, 1996; CRUZ, 2000; O'Brien *et al.,* 2005; Malherbe, 2006; Carminati, 2008; Malherbe *et al.,* 2008; O'Brien, 2010b). The overall ecological integrity of the lower Umvoti River and associated tributary, the Nchaweni River, has remained in a severely modified state since 1999 (O'Brien, 2010b).

1.3. Hypotheses

The hypotheses established for this study state:

1. The ecological integrity of the lower Amatikulu River is significantly better than that of the lower Thukela River and Umvoti River.
2. The ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers experienced a downward trend between current and historical periods.

1.4. Aims and objectives

The aims established for this study include the following:

1. Determine the current state of ecological integrity of selected driver and responder components of the lower Amatikulu, Thukela and Umvoti Rivers in KwaZulu Natal.
   In order to reach this aim the following objectives have been established:
   a. Carry out selected lines of evidence to evaluate the current ecological state of the following ecosystem driver components:
      i. Water quality.
      ii. Sediment physicochemical variables.
      iii. Habitat availability, diversity and state.
   b. Carry out selected lines of evidence to evaluate the current ecological state of the following responder components:
      i. Macroinvertebrates.
      ii. Fish.

2. Compare trends of the current state of ecological integrity of selected driver and responder components to historical data to allow for the evaluation of changing trends in the ecosystem integrity state of the lower Amatikulu, Thukela and Umvoti Rivers in KwaZulu Natal.

   In order to reach this aim the following objectives have been established:

   a. Compare current and historical data of selected lines of evidence to establish the ecological state and trends of the following ecosystem driver components:
      i. Water quality.
      ii. Sediment physicochemical variables.
      iii. Habitat availability, diversity and state.
   b. Compare current and historical data of selected lines of evidence to establish the ecological state and trends of the following ecosystem responder components:
      i. Macroinvertebrates.
      ii. Fish.

1.5. Study layout

- Chapter 1: Introduction.
- Chapter 2: Assessment of the present ecological integrity of selected driver components (water quality, sediment and habitat) of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal.
- Chapter 3: Assessment of the present ecological state and community structures of macroinvertebrates of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal.
- Chapter 4: Assessment of the present ecological state and community structures of fish assemblages of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal.
- Chapter 5: Revisiting hypotheses and recommendations
- Chapter 6: References.

CHAPTER 2: Assessment of the present ecological integrity of selected driver components (water quality, sediment and habitat) of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal

2.1. Introduction

Environmental monitoring refers to the use of abiotic and biotic indicator components in order to identify and monitor any changes in the surrounding environment (Reece and Richardson, 1999; Artiola *et al.,* 2004; Wiersma, 2004; Weston, 2011). Aquatic environmental monitoring involves the application of a range of tools or lines of evidence to identify and monitor any changes in the ecological integrity or state of aquatic ecosystems (Mitchell, 2002; Weston, 2011). These lines of evidence include exposure (driver components) tools which consider how the ecosystem template changes due to ecosystem service use, and effect (responder components) tools which consider how the living or biotic components of the ecosystem respond to the changes in the ecosystem (Roux, 1999; Todd and Roux, 2000; Weston, 2011). Driver components (Chapter 2) include water quality, sediment grain size, moisture and organic content as well as habitat state, whereas responder components involve macroinvertebrates (Chapter 3) and fish assemblages (Chapter 4). The monitoring of water quality plays an essential role in the integrity of an ecosystem due to the fact that the response of biotic indicator organisms is linked to the quality of the water of an aquatic ecosystem (Munn *et al.,* 2002).

Sediment analyses provide environmentally significant information and indications of the relative degrees of contamination in a sampling area (Roux *et al.*, 1993; IAEA, 2003; Charkhabi *et al.*, 2008). Sediment forms part of an integral component of aquatic ecosystems as it provides habitat, feeding, spawning and rearing areas for numerous aquatic organisms (USEPA, 2001). Sediment analyses for biological assessments of aquatic ecosystems include characteristics such as sediment grain size, moisture and organic content.

Habitat quality is an important part of an ecosystem as it forms the basis for the ecosystem. If the habitat quality is affected, it will have an effect on the whole systems integrity (Uys *et al.*, 1996). When the habitat diversity is extensive and un-impacted, the biotic community structures tend to be good.

The aim of this chapter is to assess the current ecological state of the selected driver components and to compare the findings from historical data (from 1999 to 2012) with the results of the current study of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal (Figure 1).

2.2. Materials and methods

2.2.1. Study area, site selection and sampling regime

The study area for this study comprises the lower reaches of the Amatikulu, Thukela and Umvoti Rivers in KwaZulu-Natal, South Africa (Figure 1). Previous studies conducted by CRUZ (2000), O'Brien *et al*. (2005), Malherbe (2006), Schüring & Schwientek (2006), Carminati (2008), Ferreira *et al.* (2008), Malherbe *et al.* (2008), Swemmer (2008), Stryftombolas (2008), O'Brien *et al.* (2009), O'Brien (2010a), O'Brien (2010b) and O'Brien (2011) suggest that the lower reaches of the Amatikulu, the Thukela and Umvoti Rivers are exposed to excessive sugarcane agricultural activities, industrial activities, rural sewage-treatment works and domestic use of urbanised areas which all contribute to the excessive use of ecosystem services and will cause the degradation of the ecological integrity of these rivers.

Two surveys were carried out; one during the low-flow period (5-11 August 2011) and the other during the high-flow period (20-28 March 2012). The low-flow period can be seen as the worst-case scenario due to the fact that water levels are much lower which may cause potential impacts on the rivers to be higher. The high-flow period can be seen as the recovery period as high water levels cause potential impacts on the rivers to be lower.

The sites selected for this study (Figure 1) were based on the aims and objectives of the study as well as on historical sites that had been selected for previous studies done by CRUZ (2000), O'Brien *et al*. (2005), Malherbe (2006), Schüring & Schwientek (2006), Carmanati (2008), Cloete *et al.* (2008), Ferreira *et al.* (2008), Malherbe *et al.* (2008), Swemmer (2008), Stryftombolas (2008), O'Brien *et al.* (2009), O'Brien (2010a), O'Brien (2010b) and O'Brien (2011). For this chapter sampling methods and protocols for assessing the ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers include driver components such as water quality, sediment grain size, moisture and organic content as well as habitat availability.

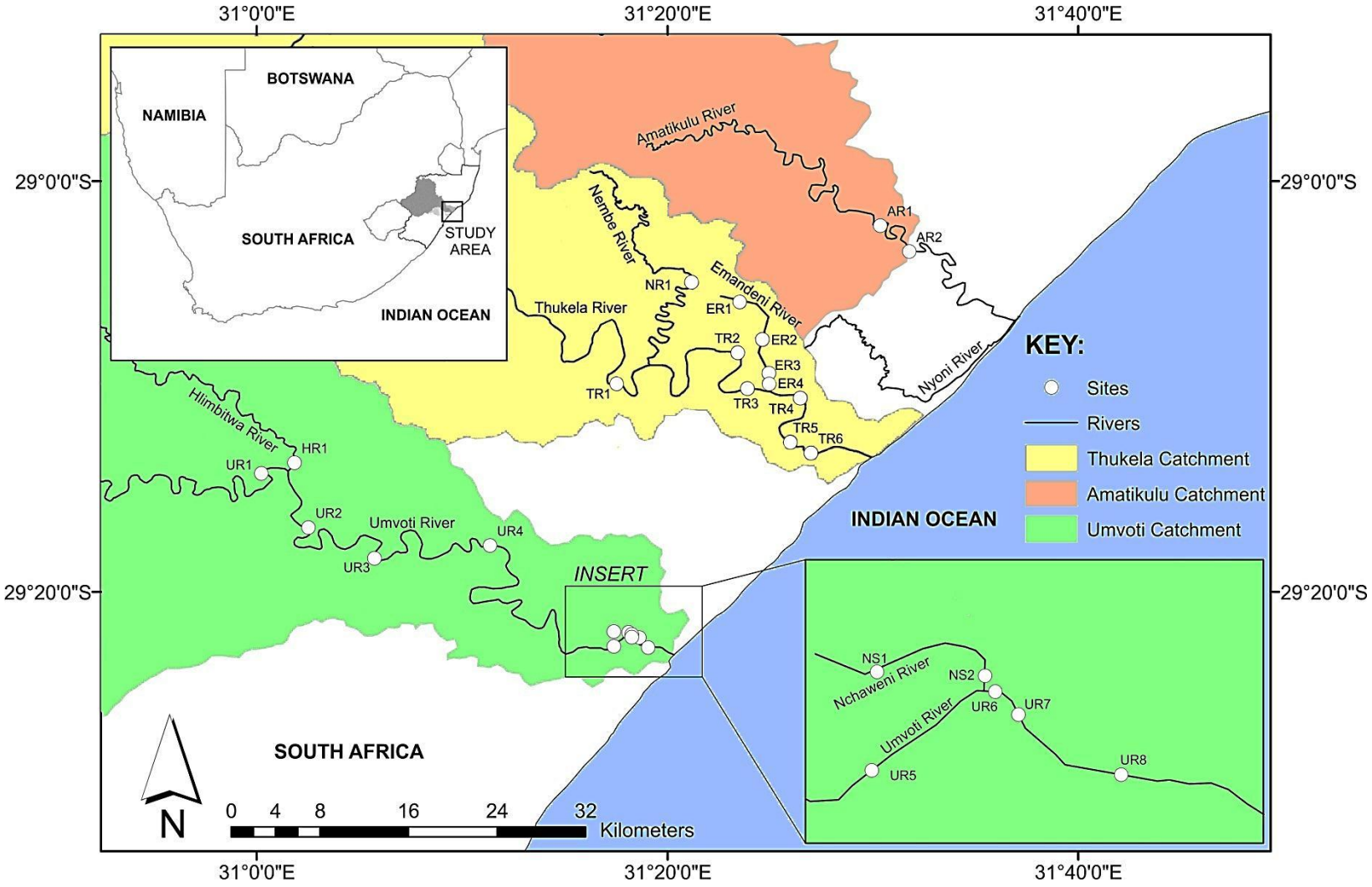


Figure 1: Map of the study area including the sites of the current study as well as historical sites

2.2.2. Site selection on the Amatikulu River

Two sampling sites on the Amatikulu River were selected for this study (Table 1).

Table 1: GPS coordinates of the sites sampled on the Amatikulu River

Site	S	E
AR1	-29.03622	31.50614
AR2	-29.05736	31.52966

2.2.2.1. Amatikulu River (AR1 and AR2)

Site AR1 (Figure 2) is situated upstream of the Amatikulu Sugar Mill. Extensive sugarcane agricultural activities, irrigation as well as sand abstraction occur in this area and may affect the state of the river at this site. The AR2 (Figure 3) site is located downstream of the Amatikulu Sugar Mill and the small urbanised area. A railway bridge is situated just upstream of this site, local communities make use of sand abstraction for irrigation purposes, and a small gravel road passes through the river. Both sites (AR1 and AR2) of the lower Amatikulu River are characterised by lowland river channels. The substrate is dominated by sand (especially at site AR1), gravel and isolated areas of cobbles and boulders. Habitat types include riffle areas, glides and runs with undercut banks and rood wads as well as pools. The marginal vegetation is dominated by reeds; however, isolated areas with sedges and grasses also occur. Impacts associated with the mill and sugarcane agricultural activities as well as the runoff from the surrounding settlements and small urbanised area may occur at these two sites.



A B

Figure 2: Photos of site AR1 on the Amatikulu River during low flow (A) and high flow (B)



A B

Figure 3: Photos of site AR2 on the Amatikulu River during low flow (A) and high flow (B)

2.2.3. Site selection on the Thukela River

A total of seven sampling sites were selected for this study including those on the Thukela River (3 sites), the eMandeni River (3 sites) and the Nembe River (1 site) (Table 2).

Table 2: GPS coordinates of the sites sampled on the Thukela River

Site*	S	E
TR2	-29.16461	31.29211
TR3	-29.17626	31.44097
TR5	-29.21214	31.43292
ER1	-29.09791	31.39208
ER3	-29.14630	31.40750
ER4	-29.17059	31.42154
NR1	-29.08226	31.35300

* TR - Thukela, ER - eMandeni, NR - Nembe

2.2.3.1. Thukela River (TR2)

The TR2 (Figure 4) site on the Thukela River is referred to as the reference site for the lower Thukela River as it is situated upstream of the industrial activities of the town Mandeni. However, the site may be affected by activities associated with the local communities, urbanised area of Sundumbili and sugarcane agriculture upstream. The site is just below a gauging weir where the Department of Water Affairs records daily flow readings of the lower Thukela River. The site is located close to a water-abstraction point for water-treatment works and the paper mill. The substrate of this site is dominated by bedrock with isolated batches of boulders, cobbles and sand. The habitat types include riffle areas and pools as well as areas with undercut banks and root wads.

Marginal vegetation is dominated by reeds. Shrubs, sedges and grasses also occurred as well as large trees on the banks of the river.



A B

Figure 4: Photos of site TR2 on the Thukela River during low flow (A) and high flow (B)

2.2.3.2. Thukela River (TR3)

This site (Figure 5) is located downstream of the Sappi discharge point as well as the confluence of the eMandeni River with the Thukela River. The site is close to the John Ross Bridge on the R102. Mining activities occur close to the site and a brick-making plant is situated nearby. This site will provide information on the impacts that may be caused by the eMandeni River and Sappi Tugela Mill effluent discharge point. The site has lowland river channel characteristics. The substrate consists mainly of sand. The habitat types include undercut banks and root wads, shallow glides and pool areas. Marginal vegetation includes reeds, shrubs, sedges and grasses as well as large trees on the river banks.



A B

Figure 5: Photos of site TR3 on the Thukela River downstream of the John Ross Bridge during low flow (A) and high flow (B)

2.2.3.3. Thukela River (TR5)

Site TR5 (Figure 6) is the lowest site sampled in 2011 and 2012 on the Thukela River. It is situated just downstream of the Harold Johnson Nature Reserve, upstream of the N2 Bridge and the 'Ultimatum Tree' heritage site. The site will provide information on the cumulative impacts caused by the activities associated by the local communities, sugarcane agricultural activities, industrial activities and rural sewage-treatment works which may affect the state of the lower Thukela River. Channel characteristics that are associated with lowland river sections characterise site TR5. The substrate is dominated by sand. Habitat types included shallow glides, large pool areas as well as isolated areas with undercut banks and root wads. Marginal vegetation is characterised by large trees on the river banks as well as reeds, shrubs, sedges and grasses.



A B

Figure 6: Photos of site TR5 on the Thukela River during low flow (A) downstream of the N2 bridge and high flow (B) upstream of the N2 bridge

2.2.3.4. eMandeni River (ER1)

The ER1 (Figure 7) site is referred to as the reference site for the eMandeni River as it is situated upstream of the Isithebe industrial complex and Isithebe rural area. Impacts on this site may be limited and only caused by activities related to the local communities and domestic use. Small-scale agricultural activities also occur on the southern side of the site which may affect the state of the stream at this particular site. The substrate at this site includes boulders, cobbles, sand and isolated batches of gravel and mud. Habitat types consist of low velocity riffle sections and pools. The marginal vegetation is characterised by reeds, shrubs, sedges as well as grasses.



A B

Figure 7: Photos of site ER1 on the eMandeni River during low flow (A) and high flow (B)

2.2.3.5. eMandeni River (ER3)

Site ER3 (Figure 8) is located on the north-eastern side of the eMandeni River, downstream of the Isithebe rural area and industrial complex and the iLembe Wastewater Treatment Works. On the eastern side of the site is a dumping site. The ER3 site will provide information on the impacts on the eMandeni River that may be caused by the industrial complex and rural area of Isithebe as well as the iLembe Wastewater Treatment Works. The habitat types of this site include small riffle sections, glides, runs with undercut banks and root wads as well as pools. The marginal vegetation is dominated by overhanging vegetation which includes large trees, shrubs, sedges and grasses as well as small isolated reed areas. The substrate consists of bedrock, boulders, cobbles and isolated gravel and sand sections.



A B

Figure 8: Photos of site ER3 on the eMandeni River during low flow (A) and high flow (B)

2.2.3.6. eMandeni River (ER4)

This site (Figure 9) is situated just above the Sappi discharge point and the confluence between the eMandeni River and the Thukela River. This site will provide information on the cumulative impacts that may be caused by the industrial activities of Isithebe and Mandeni, the rural wastewater treatment works, agricultural activities and domestic use of Isithebe and Mandeni's rural areas. Marginal vegetation is dominated by large trees; however, reeds, sedges shrubs and grasses also occur. The habitat types include riffles, runs, glides and pools. The substrate consists of boulders, isolated areas of cobbles and mud.



A **B**

Figure 9: Photos of site ER4 on the eMandeni River during low flow (A) and high flow (B)

2.2.3.7. Nembe River (NR1)

The NR1 site (Figure 10) is located approximately 8 km upstream of the confluence between this river and the Thukela River. The confluence of these two rivers is downstream of site TR2. Together with site TR2, this site is also considered a reference site for this study, as there are very few negative impacts on this river. The only impacts that may affect the state of the Nembe River are activities associated with local communities and informal settlements. The site is characterised by diverse habitat, vegetation and substrate types. Habitat types include riffle sections, glides, runs and pools. The marginal vegetation consists of large trees, sedges, shrubs, grasses and reeds. Substrate includes boulders, cobbles, gravel, sand and small isolated bedrock areas.



A **B**

Figure 10: Photos of site NR1 on the Nembe River during low flow (A) and high flow (B)

2.2.4. Site selection on the Umvoti River

A total of six sites were selected for this study, including those on the Hlimbitwa tributary and the Nchaweni River (Table 3).

Table 3: GPS coordinates of the sampled sites on the Umvoti River

Site*	S	E
HR1	- 29.22867	31.03072
UR2	- 29.28119	31.04215
UR5	- 29.37618	31.29228
UR7	- 29.37044	31.30420
NS1	- 29.36569	31.28971
NS2	- 29.36616	31.30183

* HR - Hlimbitwa, UR - Umvoti, NS - Nchaweni

2.2.4.1. Hlimbitwa River (HR1)

This is the uppermost site of the sampling sites on the Umvoti River. The site (Figure 11) is upstream of the confluence of the Hlimbitwa and Umvoti Rivers. This site is upstream of the sugarcane agricultural and industrial activities that occur in Stanger and the only impacts here are caused by local communities. This site was selected as a reference site as well as to determine the ways in which the Hlimbitwa River contributes to the ecological integrity of the Umvoti River. Habitat, vegetation and substrate types of this site and site NR1 on the Nembe River are very similar. Habitat types consist of pools, riffles, runs and glides. The marginal vegetation includes trees, grasses, sedges, shrubs and reeds. Substrate is characterised by boulders, cobbles, gravel and sand.



A **B**

Figure 11: Photos of site HR1 on the Hlimbitwa River during low flow (A) and high flow (B)

2.2.4.2. Umvoti River (UR2)

This site (Figure 12) is the uppermost site on the Umvoti River itself and is downstream of the confluence with the Hlimbitwa River. This site is also upstream of Stanger where the major sugarcane agricultural and industrial activities occur and impacts on the river are mainly caused by local communities. This site was only sampled during the high-flow survey conducted in March 2012. The substrate, marginal vegetation and habitat types of site UR2 include the same characteristics as those of site HR1 on the Hlimbitwa River.



Figure 12: A photo of the UR2 site on the Umvoti River during the high-flow survey

2.2.4.3. Umvoti River (UR5)

The site is situated just upstream of the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi Fine Paper's Stanger Mill. This site (Figure 13) was regarded as a reference site during the CRUZ (2000) study as it is situated upstream of most of the activities that may influence the quality of the Umvoti River. These activities include the industrial activities associated with Stanger, Ushukela, Sappi and the Stanger Wastewater Treatment Works. However, several sugarcane agricultural activities occur upstream of this site and might affect this site. Habitat types of this site include runs and pools. Marginal vegetation is dominated by reeds. The surrounding vegetation which once was coastal Bushveld or coastal grasslands has been replaced by sugarcane plantations. Substrate is dominated by sand.



A B

Figure 13: Photos of site UR5 on the Umvoti River during low flow (A) and high flow (B)

2.2.4.4. Umvoti River (UR7)

The UR7 site (Figure 14) is the lowest site of the sampled sites in 2011 and 2012 on the Umvoti River. It is situated at the bridge on the N2. It is situated below the confluences of both the Nchaweni River and Mbozambo River. Effluents are discharged from the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi's Stanger Mill into the Nchaweni River, which feeds into the Umvoti River. Effluent discharged from the Stanger Wastewater Treatment Works enters the Mbozambo River. The UR7 site is used to assess the change in the state of the Umvoti River which may be caused by the activities between sites UR5 and UR7. Channel characteristics that are associated with lowland river sections are characteristic of Site UR7. The substrate of this site is dominated by sand but very small isolated gravel batches are also present. Habitat types include runs and pools. Marginal vegetation is dominated by reeds and the surrounding vegetation biomes of the area have been replaced by sugarcane plantations.



A B

Figure 14: Photos of site UR7 on the Umvoti River during low flow (A) and high flow (B)

2.2.4.5. Nchaweni River (NS1 and NS2)

The confluence of the Nchaweni River with the Umvoti River is downstream of site UR5 and upstream of site UR7. The Nchaweni River transports the effluent of the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi's Stanger Mill. The site NS1 (Figure 15) is situated just upstream of the Gledhow Sugar Mill and the Sappi Stanger Mill while the site NS2 (Figure 16) is situated downstream just before the confluence with the Umvoti River. Site NS1 is used to indicate the state of this river upstream of these two mills and site NS2 is used to indicate the influence that these two mills and their associated activities may have on the state of the Nchaweni River as well as the contribution of impacts on the state of the Umvoti River. Habitat types of both sites NS1 and NS2 include low velocity riffle sections, glides, runs and pools. The marginal vegetation at site NS1 is dominated by reeds and grasses while at site NS2 the marginal vegetation is also dominated by reeds but includes trees and grasses. Substrate of NS1 is dominated by sand and isolated gravel areas while site NS2 consists of sand and mud.



A B

Figure 15: Photos of site NS1 on the Nchaweni River during low flow (A) and high flow (B)



A B

Figure 16: Photos of site NS2 on the Nchaweni River during low flow (A) and high flow (B)

2.2.5. Water quality

The approach adopted by CRUZ (2000), O'Brien *et al*. (2005), Malherbe (2006), Schüring & Schwientek (2006), Carminati (2008), Stryftombolas (2008), O'Brien *et al*. (2009) and Malherbe *et al*. (2010) for assessing the physicochemical variables for water was implemented in this study. The variables selected include general variables such as temperature, chemical oxygen demand (COD), electrical conductivity (EC), pH and total alkalinity (TAL) as well as salts, nutrients and toxics. These variables provide indications as to the state of the water-quality component of this study.

2.2.5.1. Sampling protocol

During each survey a single sub-surface water sample was collected at all the proposed sites. The water samples were collected in clean polyethylene bottles. Before a water sample was collected the polyethylene bottle was rinsed with water from the site to prevent contamination. Water samples were collected carefully in order to make sure that no air bubbles were present in the sample. After collecting the water sample it was kept cool (4°C), not frozen, until laboratory analyses were performed.

Physical variables were measured *in situ* when the other driver and responder biophysical components were sampled. These physical variables include temperature, pH, oxygen concentration and saturation levels and electrical conductivity. The physical variables were measured with a YSI multi-meter.

2.2.5.2. Laboratory analyses

The sub-surface water samples that were collected in clean polyethylene bottles for laboratory analysis were sent to Eco-Analytica Laboratories, Faculty of Natural Sciences, North-West University, Potchefstroom. Eco-Analytica analysed the following variables:

- General variables:
    - chemical oxygen demand (COD)
    - electrical conductivity (EC)
    - pH
    - Total alkalinity (TAL)

- Salts:
    - chlorides (Cl)
    - sulphates (SO_4)
    - calcium (Ca)
    - sodium (Na)
- Nutrients:
    - nitrates (NO_3)
    - nitrite (NO_2)
    - ortho-phosphates (PO_4)
- Toxics:
    - ammonium (NH_4)

The Target Water Quality Requirements (TWQR) as developed by the Department of Water Affairs and Forestry (DWAF, 1996a) for domestic use (Volume 1) and Aquatic Ecosystems (Volume 7) (DWAF, 1996b) were used to evaluate the quality of the water sampled in this study (Table 4). The water quality as well as quantity was also compared to historical data obtained from previous studies that have been done for the same study area.

Table 4: Target water quality ranges for constituents measured in the lower Amatikulu, Thukela and Umvoti Rivers. Ranges provided in the DWAF (1996a and 1996b) Guidelines for Domestic Use (Volume 1) and Aquatic Ecosystems (Volume 7).

Variable	Units	Abbreviations used	Domestic use	Aquatic ecosystem
Temperature	℃	℃	N/A	<2 ℃, <10% Δ
pH		pH	6.0-9.0	>0.5 or 5% Δ
Oxygen	mg/l	O2	N/A	6-12mg/l
Oxygen	% saturation	O2 %	N/A	80-120%
Conductivity	µS/cm	EC	0-0.7mS/cm	N/A
Total Alkalinity as $CaCO_3$	mg/l	TAL	0-80mg/l	N/A
Nitrate as N	mg/l	NO3	N/A	N/A
Nitrite as N	mg/l	NO2	N/A	N/A
Nitrogen ammonia as N	mg/l	NH4	0-1mg/l	<7µg/l
Soluble ortho-phosphate as PO_4	mg/l	PO4	N/A	15%Δ and no change to trophic status
Chemical oxygen demand as O_2	mg/l	COD	N/A	N/A
Chlorides	mg/l	Cl	100-200mg/l	N/A
Calcium	mg/l	Ca	0-32mg/l	N/A
Sodium	mg/l	Na	100-200mg/l	N/A
Sulphate	mg/l	SO4	0-200mg/l	N/A

Note: Δ refers to maximum allowable change in variable from reference value.

2.2.6. Sediment

2.2.6.1. Sampling protocol

A representative sediment sample was collected at all the proposed sites of this study. The sediment samples were placed in polyethylene zip-lock bags and were kept frozen until analysis of the sediment characteristics could be performed. The sediment samples were frozen in order to prevent any organic material digestion by invertebrate fauna and/or any other organic decomposition.

2.2.6.2. Sediment analyses

The sediment analyses were performed according to the protocol set out by the United States Environmental Protection Agency (USEPA, 2001). This approach has also been implemented by CRUZ (2000), Malherbe (2006), Carminati (2008) and Stryftombolas (2008). In the laboratory a known amount of sediment for each site was dried for a total of 4 days at 60°C, and the water content of each sample was determined. The organic content of each sediment sample was determined by taking a known amount of sediment (accurate to 0.0001g) and incinerating it for a minimum of 6 h at 600°C. The samples were then reweighed to determine the percentage organic content in the sample. The United States Environmental Protection Agency (2001) classification of the percentage of the organic content in sediment is indicated in Table 5.

Table 5: Organic content classification system in sediment (USEPA, 2001)

Classification	**Percentage**
very low	< 0.05%
Low	0.05 - 1%
Moderate low	1 - 2%
Medium	2 - 4%
High	> 4%

The remaining dried sediment was then used to determine the grain size of each sample by using an Endecott sieve system with various sieves ranging from > 4 000 µm to 53 µm. The grain-size categories used to characterise the sediment can be seen in Table 6.

Table 6: Grain-size categories according to Cyrus *et al.* (2000)

Grain size in µm	Categories
> 4 000 µm	Gravel
4 000 µm – 2 000 µm	Very coarse sand
2 000 µm – 500 µm	Coarse sand
500 µm – 212 µm	Medium sand
212 µm – 53 µm	Very fine sand
< 53 µm	Mud

2.2.7. Habitat

The habitat availability, diversity and state were assessed by means of the Integrated Habitat Assessment System Version 2 (IHAS v 2) (McMillan, 1998) and the Index of Habitat Integrity (IHI) (Kleynhans, 1996). The approaches set out by these two indices to assess habitat availability, diversity and state are widely implemented throughout the National River Health Programme. These indices are performed by entering various observations on a provided score sheet in the field. The values of the indices are then calculated and a rating system for each index then describes the habitat quality of the given site (Table 7 and Table 8).

Table 7: Summary of the scoring procedures used to determine the Index of Habitat Integrity (IHI) (Dallas, 2005)

Impact Class	Description	Score
None	No discernible impact or the modification is located in such a way that it has no impact on the habitat quality, diversity, size and variability.	0
Small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability is limited.	1-5
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are fairly limited.	6-10
Large	The modification is generally present with a clearly determinal impact on habitat quality, diversity, size and variability. Large areas are, however, not affected.	11-15
Serius	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	16-20
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	21-25

Table 8: Habitat integrity classes for IHAS and description of each class, adopted from Kleynhans (1999)

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

2.3. Results and Discussion

2.3.1. Water quality

2.3.1.1. Amatikulu River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical water quality variables collected from the Amatikulu River (Figure 1), where available from 2006 to 2012, include water temperature, oxygen, electrical conductivity, pH, nitrate, nitrite, phosphate, ammonia, chlorides, alkalinity, calcium, chemical oxygen demand (COD), sulphates and sodium (Table 9) are presented below.

Table 9: Water quality data where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys for sites AR1 and AR2 on the Amatikulu River

Sites	Temperature (°C)	Oxygen (mg/l)	Oxygen (% saturation)	Electrical conductivity (µS/cm)	pH	Nitrate (mg/l)	Nitrite (mg/l)	Soluble ortho-phosphate (mg/l)	Nitrogen ammonia (mg/l)	Chloride (mg/l)	Total alkalinity (mg/l)	Calcium (mg/l)	Chemical oxygen demand (mg/l)	Sulphate (mg/l)	Sodium (mg/l)
AR1-06H	25.9	7.57	92.00	147	7.34	1.40	0.16	0.02	0.05	11	42	-	26	0.10	-
AR1-06L	15.4	9.84	97.40	300	7.50	2.40	0.01	0.02	0.01	20	-	-	3	2.00	-
AR1-11L	15.7	6.30	0.65	244	8.70	0.88	2.76	0	0.56	33	25	6.50	119	8.02	40
AR1-12H	25.9	5.03	0.63	246	7.39	0.43	0.00	1.51	0.02	58	38	4.95	-	10.64	28
AR2-06H	26.2	7.05	88.20	7.2	7.20	6.50	0.17	0.02	0.07	19	49	-	26	2.00	-
AR2-06L	14.1	8.94	87.70	377	7.44	0.13	0.01	0.03	0.01	22	-	-	14	0.10	-
AR2-11L	17.5	7.85	0.87	311	8.20	0.32	4.14	0	0.02	1	35.5	11.00	109	10.25	58
AR2-12H	25.6	5.11	0.63	386	7.59	1.16	0.00	0.77	0.01	99	59.5	7.86	-	11.05	47

Water temperature levels (Figure 17) of the sites on the lower Amatikulu River (AR1 and AR2) recorded during current and historical surveys reflect primarily natural seasonal fluctuations (Gallagher, 1999). As expected, during the generally cooler low-flow surveys lower temperatures were recorded in comparison to the generally warmer high-flow surveys. Temperature levels ranged from 14.1°C (AR2 during 2006 low flow) to 25.9°C (AR1) during the high flows of 2006 and 2012.

Temperature differences between the two sites, AR1 and AR2, during both high and low flows were relatively small throughout the time periods (2006, 2011 and 2012) for which data were available. Noticeably higher temperatures at both sites occurred during the low-flow period of 2011 in comparison to the low-flow period in 2006. None of the temperature levels recorded during 2006, 2011 and 2012 at the sites on the lower Amatikulu River (AR1 and AR2) exceeded the TWQG for aquatic ecosystems (DWAF, 1996b).

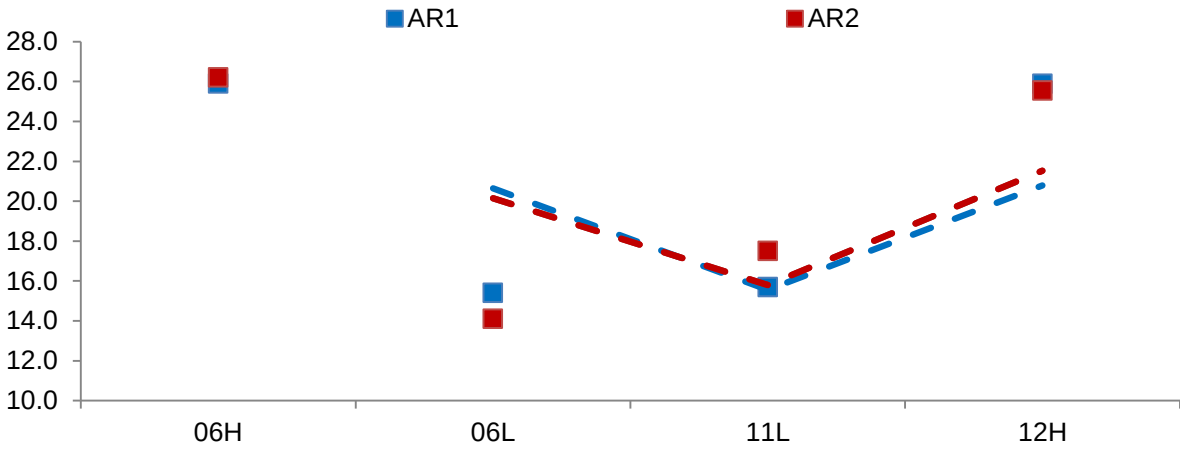


Figure 17: Trends in water temperature (°C) levels (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

Results regarding pH levels (Figure 18) indicate that the levels ranged between pH 7.2 at AR2 during 2006 (high flow) to pH 8.7 for AR1 during the low flow period in 2011. According to DWAF (1996b) fresh water systems in South Africa generally have a pH that ranges between 6 and 8. Trends regarding the pH levels of the lower Amatikulu River show that the levels were relatively stable between 2006 and 2012, except for high levels that occurred at both sites during 2011. These higher levels during 2011 might be caused by an unknown source upstream of site AR1. It is known that elevated pH levels can be caused by increased biological activity in eutrophic systems (DWAF, 1996b). The pH levels of both the sites on the Amatikulu River were within the TWQG requirements for domestic usage as well as aquatic ecosystems (DWAF, 1996a; 1996b).

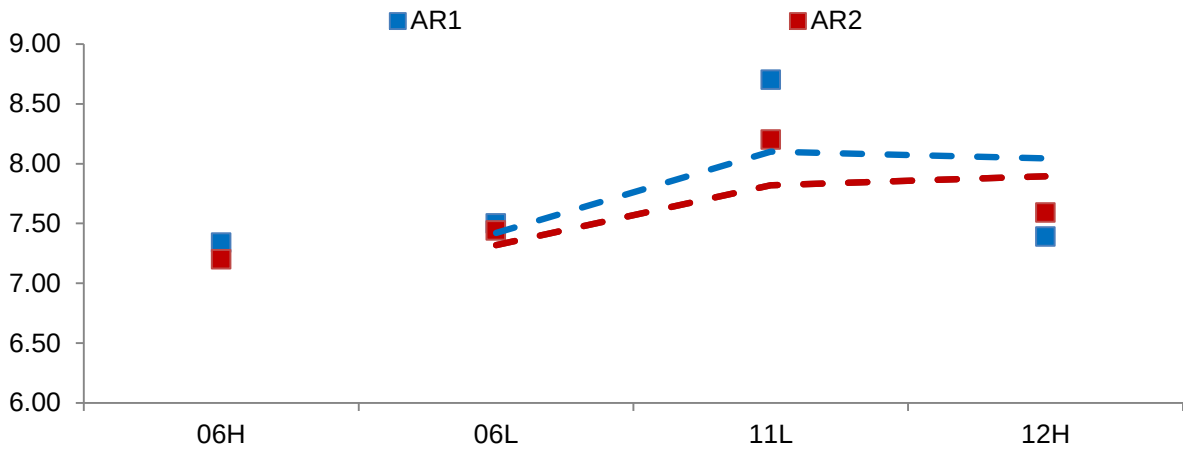


Figure 18: Trends in pH levels (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

Findings of the oxygen (mg/l) levels (Figure 19) of sites AR1 and AR2 reveal that levels ranged from 5.11 mg/l to 9.84 mg/l. Oxygen levels of 2006 and 2011 were all within the TWQG requirements for aquatic ecosystems but during 2012 oxygen levels at both sites (AR1 and AR2) decreased to below the TWQG requirements. Although the oxygen levels recorded in 2012 were not within the TWQG requirements, they were not reduced to such low levels that the structure and functioning of the ecosystem could not be maintained. Carminati (2008) stated that the lower oxygen levels recorded in 2006 high flow compared to 2006 low flow was due to increased chemical oxygen demand (COD) values, which could be caused by decomposition of course alien woody debris present in the river channel. This could also be the case for the low oxygen levels in 2012.

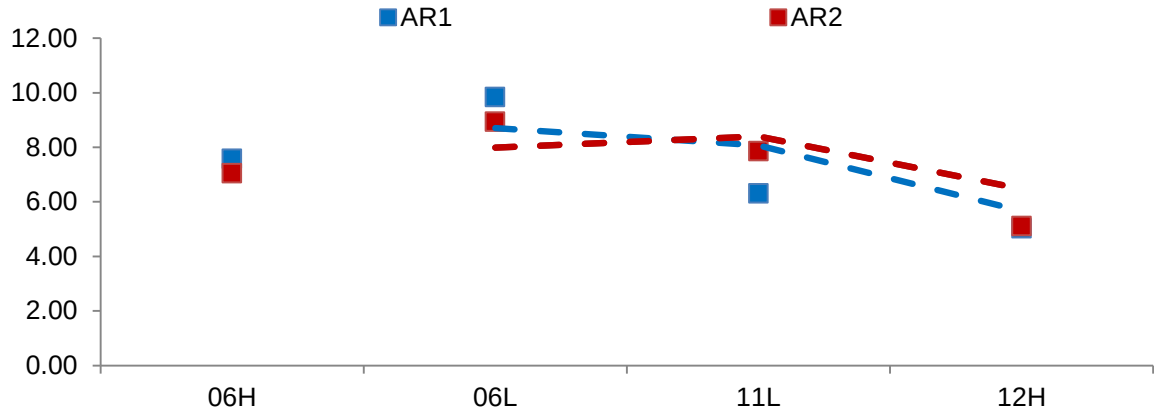


Figure 19: Trends in oxygen (mg/l) levels (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

The COD levels (Figure 20) of the lower Amatikulu River ranged between 3 mg/l and 119 mg/l. The COD trend indicates that relatively low COD levels occurred in 2006 whereafter a noticeable increase towards 2011 was observed. Increased COD levels can be caused by effluent discharges (DWAF, 1996b) and in this case the effluent from the sugar mill which is discharged into the system caused the COD levels to increase noticeably towards 2011. Carminati (2008) also found that effluent discharges from the sugar mill caused COD levels of the Amatikulu River to increase.

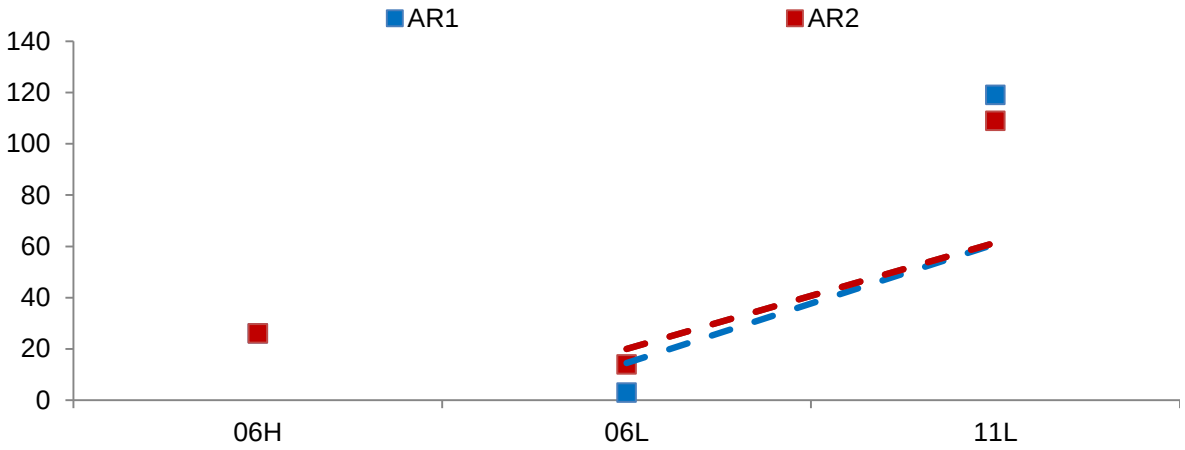


Figure 20: Trends in chemical oxygen demand (mg/l) levels (x axis) where available between 2006 (06) and 2011 (11) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

Much lower electrical conductivity (EC) levels (Figure 21) were recorded during the high-flow period of 2006 in comparison to 2006 (low flow), 2011 and 2012. The electrical conductivity trend of the lower Amatikulu River reveals that AR2 had consistently higher levels than AR1 between 2006 (low flow) and 2012. Domestic and industrial effluent discharges as well as surface runoff from urban, industrial and cultivated areas are all sources that may contribute to increased nutrient levels and salt loads which in return cause elevated EC levels (DWAF, 1996b).

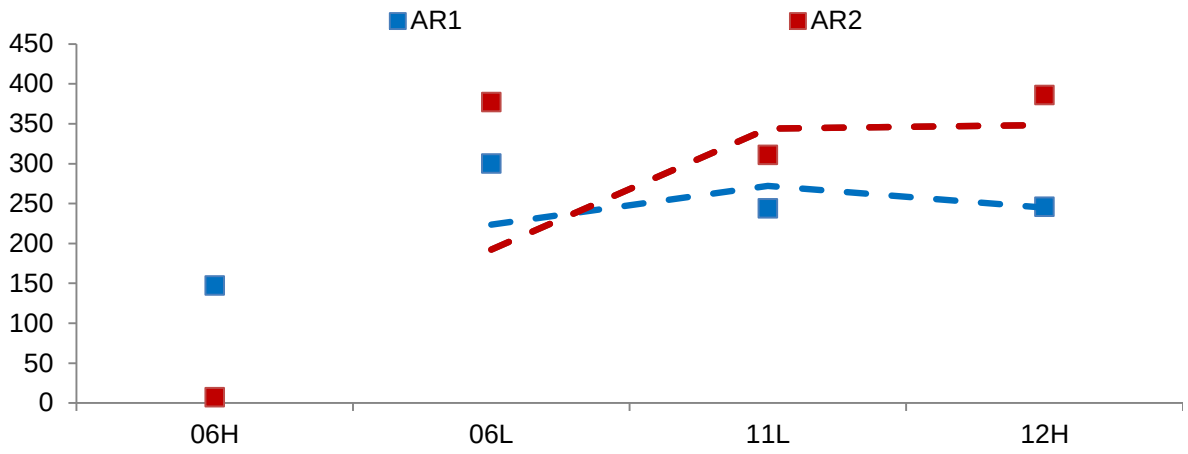


Figure 21: Trends in electrical conductivity (µs/cm) levels (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

Assessment of nutrient loads, using nitrates as a surrogate (Figure 22), indicates that the Amatikulu River contained relatively low levels from 2006 to 2012, except for site AR2 during the high-flow period of 2006. According to Carminati (2008) the elevated nutrient loads at site AR2 during the 2006 low-flow period were caused by the mill's effluent. High loads of nitrates and phosphates are attributed to fertilizers used for agricultural purposes (Cheesman, 2005). There are sugarcane agricultural activities in the surrounding area of the Amatikulu River which could cause elevated nitrate loads however, the decreasing trend suggest that the impact of fertilizers are very low.

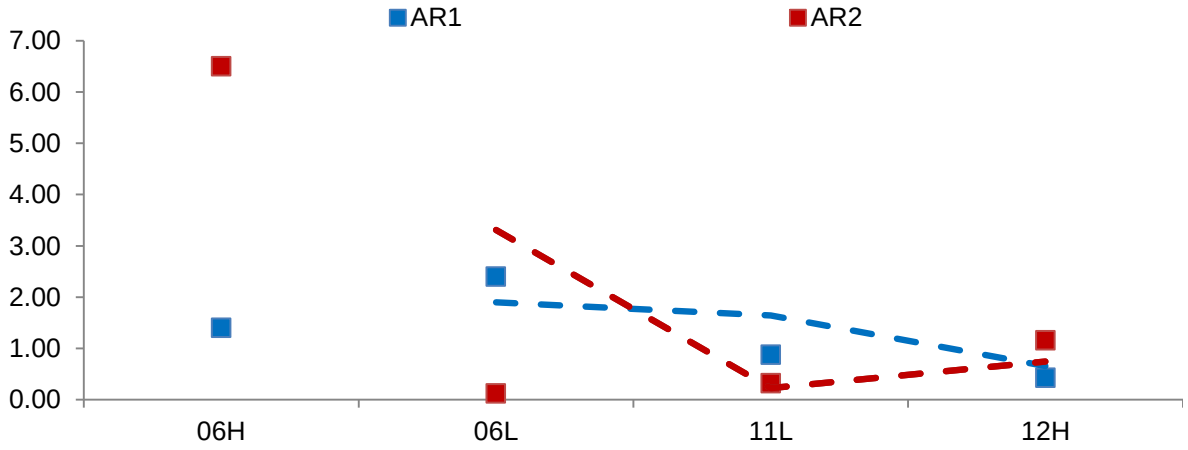


Figure 22: Trends in nitrate (mg/l) loads (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

The salt loads, chloride (Figure 23) and sulphate levels (Figure 24), of the lower Amatikulu River are within the TWQG requirements for domestic usage. The general trends regarding the salt loads indicate that the loads increased between 2006 and 2012 at both AR1 and AR2. The increasing salt loads are consisted with the higher EC levels during 2006 and 2011 low-flow period and the high-flow period of 2012.

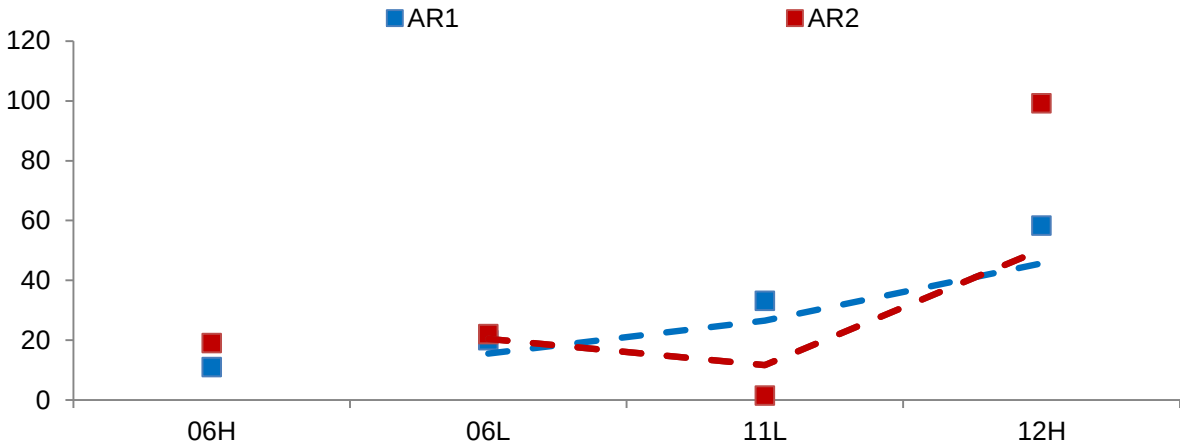


Figure 23: Trends in chloride (mg/l) loads (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

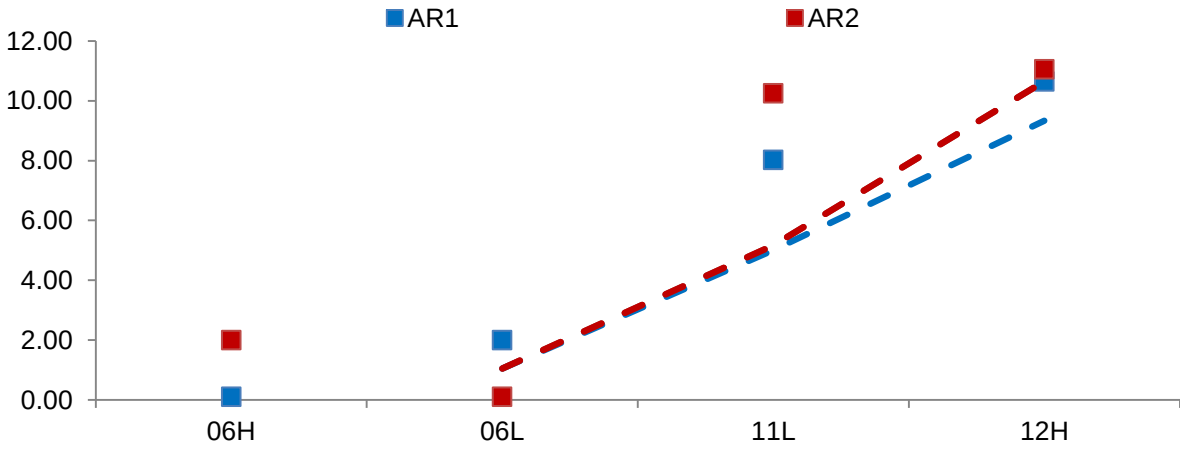


Figure 24: Trends in sulphate (mg/l) loads (x axis) where available between 2006 (06) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Amatikulu River

2.3.1.2. Thukela River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical water-quality variables collected from the Thukela River (Figure 1), where available from 2005 to 2012, include water temperature, oxygen, electrical conductivity, pH, nitrate, nitrite, phosphate, ammonia, chlorides, alkalinity, calcium, chemical oxygen demand (COD), sulphates and sodium (Table 10) are presented below. Results show that the water quality state of the sites varies considerably with many constituents occurring in elevated levels that may result in negative impacts to the structure and function of the aquatic ecosystems considered. In particular, temperature levels, oxygen levels, nutrient and salt loads have been of concern historically and currently.

Table 10: Water quality data where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys for the Thukela (TR), Nembe (NR) and eMandeni (ER) Rivers

Sites	Temperature (°C)	Oxygen (mg/l)	Oxygen (% saturation)	Electrical conductivity (µS/cm)	pH	Nitrate (mg/l)	Nitrite (mg/l)	Soluble ortho-phosphate (mg/l)	Nitrogen ammonia (mg/l)	Chloride (mg/l)	Total alkalinity (mg/l)	Calcium (mg/l)	Chemical oxygen demand (mg/l)	Sulphate (mg/l)	Sodium (mg/l)
TR1-05L	17.8	8.74	92.50	275	7.80	0.01	0.29	0	0.01	3	-	-	0	33.00	-
TR1-06L	15.5	9.95	100.20	275	8.16	0.01	0.02	0.01	0.01	3	-	-	10	22.00	-
TR2-05L	18.6	8.60	91.50	295	8.30	0.01	0.16	0	0.01	0	-	-	1	24.00	-
TR2-06L	16.6	10.35	103.80	264	8.45	0.01	0.05	0.02	0.01	1	-	-	10	5.00	-
TR2-08L	20.5	10.38	124.90	222	7.60	0.10	0.01	0.05	0.04	13	72.3	9.70	8	13.00	18
TR2-10H(1)	24.9	9.40	105.00	166	8.60	0.08	0.01	0.05	0.40	11	72.8	11.30	6	13.54	18
TR2-10H(2)	24.2	7.20	82.30	252	9.30	0.10	0.02	0.05	0.06	19	104.2	15.30	19	34.52	35
TR2-11L	14.5	9.20	0.91	190	7.10	2.60	1.38	0	0.07	15	80.5	22.00	119	20.82	42
TR2-12H	27.3	5.60	0.70	198	7.87	1.66	0.00	0.04	0.001	8	74.5	13.42	-	11.11	16
TR3-11L	21	3.60	0.45	146	8.70	1.15	1.38	0	0.09	11	74	18.00	130	16.99	34
TR3-12H	25.8	5.52	0.68	187	8.57	2.01	0.00	0.00	0.002	8	71	12.32	-	8.95	14
TR4-05L	21.5	7.28	82.30	482	7.35	1.50	0.79	0.09	0.01	4	-	-	36	164.00	-
TR4-06L	27.5	4.60	57.70	900	7.00	0.01	0.06	0.13	0.01	15	-	-	26	86.00	-
TR4-08L	21.8	8.27	96.50	343	7.68	0.10	0.02	0.58	0.14	31	98.7	13.00	15	26.00	44
TR4-10H(1)	36.5	0.70	10.10	1120	8.50	0.47	0.09	0.82	0.45	40.2	142.9	14.00	17	18.84	65
TR4-10H(2)	36.2	1.90	27.00	1127	7.30	0.08	0.02	0.05	0.89	22.1	50.7	67.00	706	483.36	182
TR5-05L	22.9	4.59	52.70	388	7.57	0.01	0.25	0.07	0.01	1	-	-	1	6.00	-
TR5-06L	18.6	10.07	107.00	316	7.89	0.01	0.01	0.04	0.01	2	-	-	10	13.00	-
TR5-08L	23.5	6.02	73.80	249	6.95	0.10	0.02	0.05	0.05	15	76.3	11.10	6	20.00	23
TR5-10H(1)	29.1	1.60	22.80	326	8.50	0.08	0.05	0.05	0.47	9	85	11.00	8	9.02	17
TR5-10H(2)	27.6	3.60	46.00	358	8.80	0.12	0.02	0.05	0.05	20	94.9	17.80	15	32.18	34
TR5-11L	19.4	7.90	0.88	223	8.20	2.32	2.76	0	0.05	14	81	25.00	115	20.89	44
TR5-12H	33	3.55	0.50	370	8.23	0.15	0.00	0.00	0.002	15	104	16.42	-	36.65	39
TR6-05L	20	4.20	47.10	388	7.28	0.01	0.38	0.04	0.01	3	-	-	1	16.00	-
TR6-06L	18.6	10.67	106.00	320	7.97	0.12	0.01	0.02	0.01	1	-	-	10	10.00	-
ER1-11L	18.2	6.60	0.71	359	7.60	0.20	1.84	0	0.20	78	84.5	16.00	105	14.67	100
ER1-12H	23.3	3.00	0.35	436	8.75	0.17	0.00	0.06	0.02	83	120	10.81	-	9.23	56
ER2-05L	18.5	1.95	21.50	2370	7.68	0.01	0.62	4.10	0.48	43	-	-	10	300.00	-
ER2-06L	14.5	0.93	9.40	2000	8.21	0.01	0.04	8.50	26.00	172	-	-	20	256.00	-
ER2-08L	17.1	8.22	92.30	1274	8.62	0.97	0.28	1.91	1.09	174	298	25.20	40	104.00	216
ER3-05L	18.8	5.60	58.00	2310	7.83	0.01	0.66	3.10	0.58	30	-	-	1	166.00	-
ER3-06L	13.7	5.99	60.00	2010	8.01	0.01	0.05	8.00	25.00	176	-	-	23	179.00	-
ER3-08L	21.3	3.98	45.40	1279	9.21	1.11	0.28	2.21	1.03	178	294	25.20	47	2.21	247
ER3-10H(1)	21.6	5.30	65.10	1912	8.50	0.33	0.11	8.23	2.16	183	253.7	19.10	51	37.26	272
ER3-10H(2)	27.5	3.15	39.80	1467	8.50	0.08	0.88	13.80	0.29	200	453	19.60	83	63.47	375
ER3-11L	20.1	3.10	0.31	1025	8.80	1.72	184.94	4.83	1.17	214	189	40.00	155	37.13	310
ER3-12H	24.6	5.05	0.60	1050	8.18	3.77	0.00	5.44	0.001	183	224	19.62	-	48.57	163
ER4-10H(1)	24.2	5.29	76.00	1733	8.70	0.91	0.80	4.02	0.34	116	275.6	20.10	40	29.22	268
ER4-10H(2)	26.3	5.91	74.40	1215	9.00	0.54	0.35	13.30	0.19	235	451.6	23.30	87	56.69	289
ER4-11L	17.1	3.60	0.48	1143	8.50	9.22	86.95	1.17	0.60	182	224.5	54.00	144	75.29	430
ER4-12H	25.8	5.04	0.59	1018	8.36	4.69	0.00	5.90	0.001	156	235.5	20.62	-	110.17	159
NR1-11L	15.1	8.00	1.10	110	7.20	0.27	2.76	0.01	0.09	30	15	3.50	80	7.39	40
NR1-12H	25.6	5.40	0.66	128	8.03	0.11	0.00	0.02	0.01	26	21	2.59	-	2.40	21

Water temperature levels (Figure 25) of the lower Thukela, Nembe and eMandeni Rivers primarily exhibit natural seasonal fluctuations as expected during the generally cooler low-flow survey periods in winter compared with the warmer summer months. In addition, naturally increasing temperatures from the upper reaches of rivers towards lower sites were evident. Temperatures in the Nembe River (NR1) ranged between 15.1°C and 25.6°C and are within the TWQG requirements for aquatic ecosystems. For the Thukela River, water temperature levels for the majority of sites were within the TWQG requirements except for site TR4 during the two high-flow surveys in 2010 as well as at site TR5 during 2012. Temperatures of up to 36.5°C occurred at TR4 during 2010 and 33°C at TR5 during 2012. Stryftombolas (2008) sated that the effluent temperature at the Sappi effluent discharge point were exceptionally high (39.9°C). The effluent discharge point is upstream of sites TR4 and TR5. The elevated temperature levels of the effluent will have an influence on the water temperature of the Thukela River. These unacceptably high water temperatures will result in negative impacts on the function and structure of the Thukela River's aquatic ecosystem. No evidence was obtained to suggest that the temperature levels had been unacceptable at any sites on the eMandeni River (ER1-ER4) during any current and/or historical surveys.

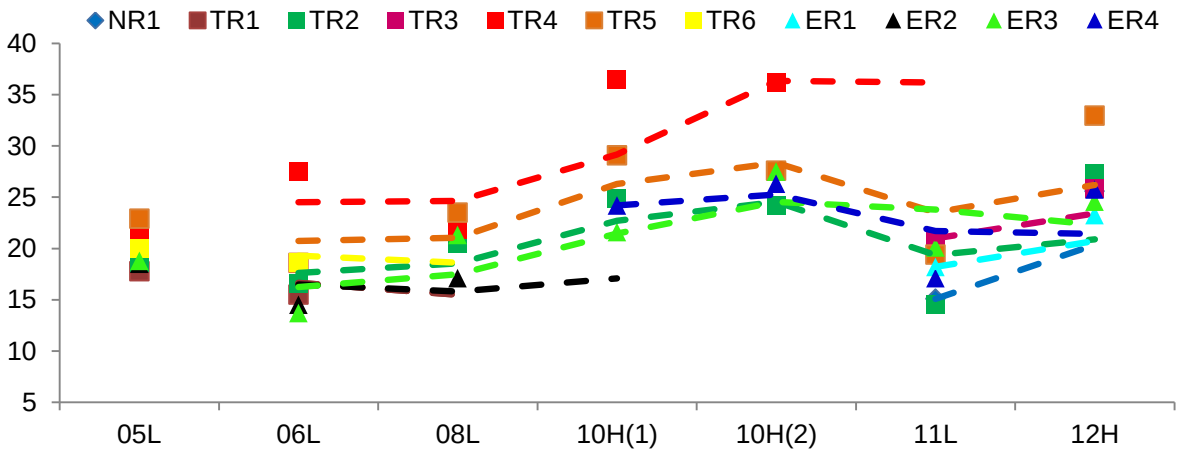


Figure 25: Trends in water temperature (°C) levels (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

The pH levels of the lower Thukela, Nembe and eMandeni Rivers (Figure 26) fluctuated noticeably. The pH levels of the Nembe River ranged between pH 7.2 and pH 8.3 whereas those in the Thukela River ranged from pH 6.95 to pH 9.3 and in the eMandeni River between pH 7.6 and pH 9. Trends regarding the pH levels revealed an increase from 2005 towards 2010 whereafter pH levels stabilised and slightly decreased towards 2012; however, pH levels in the Nembe River (site NR1) and site ER1 on the eMandeni River increased from 2011 to 2012.

Industrial activities generally cause acidification rather than alkalinisation of rivers (DWAF, 1996b). In this case the rivers tend to be slightly more alkaline than acidic. The available pH levels observed in the lower Thukela, Nembe and eMandeni Rivers since 2005 to 2012 may be indicative of water quality-related impacts but pH is not considered to have any direct impacts on the structure and function of the aquatic ecosystem of the study area.

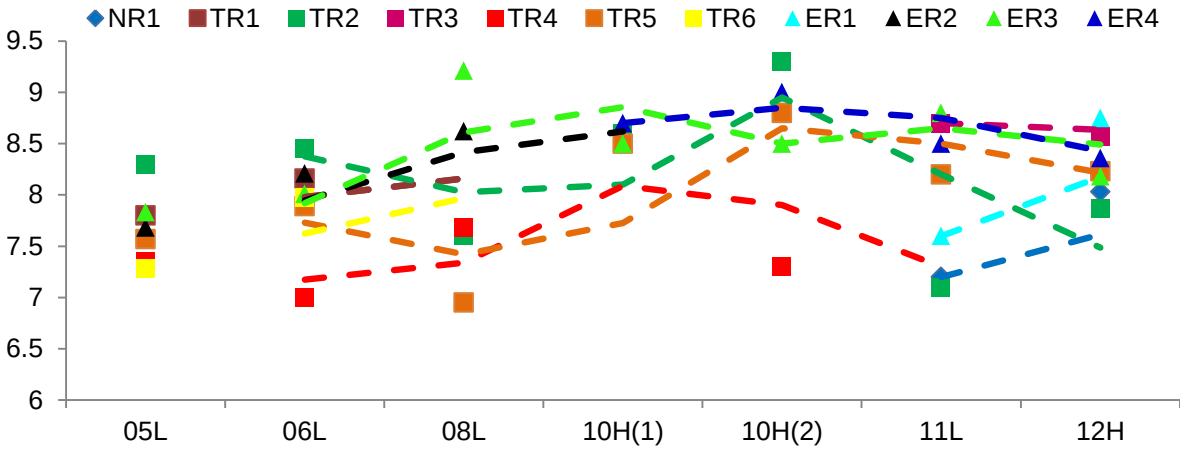


Figure 26: Trends in pH levels (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

Results regarding the oxygen (mg/l) levels obtained from current and historical data fluctuate considerably (Figure 27). According to the TWQG oxygen levels of below 6 mg/l are unacceptable for the maintenance of aquatic ecosystem structure and function (DWAF, 1996b). The maintenance of adequate dissolved oxygen concentrations are essential for the survival and functioning of aquatic organisms (e.g. macroinvertebrates and fish) as they all requires oxygen for respiration purposes (DWAF, 1996b). Oxygen levels of the Nembe River ranged from 5.4 mg/l to 8 mg/l while those in the Thukela River ranged between 0.7 mg/l to 10.67 mg/l and in the eMandeni River they ranged from 0.93 mg/l and 8.22 mg/l. It is clear that oxygen levels at sites TR4 and TR5 of the Thukela River are constantly lower than the sites situated upstream. During the high-flow period of 2010 extremely low oxygen levels of 0.7 mg/l to 1.9 mg/l occurred at TR4 and TR5. Organic waste from the Sappi effluent just upstream of these two sites could cause the oxygen levels to be reduced. However, if organic waste causes the oxygen levels to decline high levels of chemical oxygen demand (COD) should occur at the same time. At site ER2 oxygen levels of 1.95 mg/l and 0.93 mg/l occurred during 2005 and 2006 but recovered in 2008. These extremely low oxygen levels will cause negative impacts on the structure and function of the related ecosystem. The general trend regarding the oxygen levels of the lower Thukela, Nembe and eMandeni Rivers suggest that levels decreased between 2005 and 2012.

This is concerning and should be looked at in order to prevent the oxygen concentrations of these systems to decrease to levels so low that the structure and functioning becomes impaired.

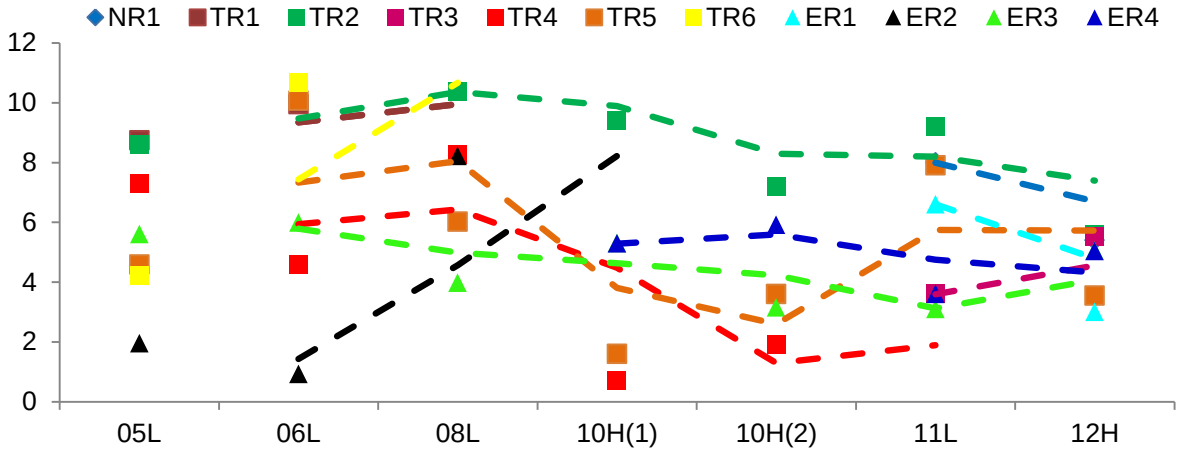


Figure 27: Trends in oxygen (mg/l) levels (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

Findings of the chemical oxygen demand (COD) levels of the lower Thukela, Nembe and eMandeni Rivers indicate that the Nembe (NR1) and Thukela (TR1-TR6) Rivers had relatively low COD levels between 2005 and the first high-flow survey (H1) of 2010 (Figure 28). Since the second high-flow (H2) survey of 2010 up until 2012, the COD levels of the Nembe and Thukela Rivers increased noticeably and reached levels of up to 706 mg/l at TR4. This is confirms the low oxygen levels at site TR4 during the same time period. The increased COD levels are caused by organic waste which comes from industrial and rural sewage-treatment effluent.

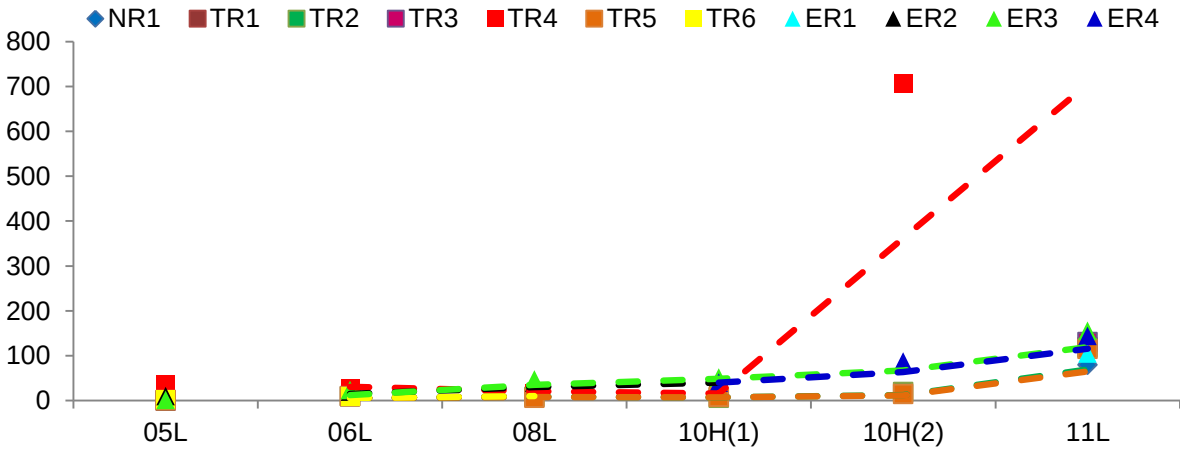


Figure 28: Trends in chemical oxygen demand (mg/l) levels (x axis) where available between 2005 (05) and 2011 (11) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

Trends regarding the electrical conductivity (EC) levels observed in the lower Nembe, Thukela and eMandeni Rivers (Figure 29) indicate noticeable fluctuations between these rivers. The Nembe and Thukela Rivers had relatively low and stable EC levels between 2005 and 2012, except for site TR4 which had exceptionally high levels that ranged from 343 µS/cm to 1 127 µS/cm. Results show that the EC levels of the eMandeni River (ER1-ER3) generally decreased from 2005 towards 2012; however, the EC levels at site ER1 increased slightly between 2011 and 2012. The EC levels of site TR4 on the Thukela River and sites ER2-ER4 of the eMandeni River were noticeably higher compared to the rest of the sites. Domestic and industrial effluent discharges as well as surface runoff from urban and industrial areas in the vicinity of TR4 and ER2-ER4 are all sources that may contribute to increased nutrient levels and salt loads which in return cause elevated EC levels (DWAF, 1996b).

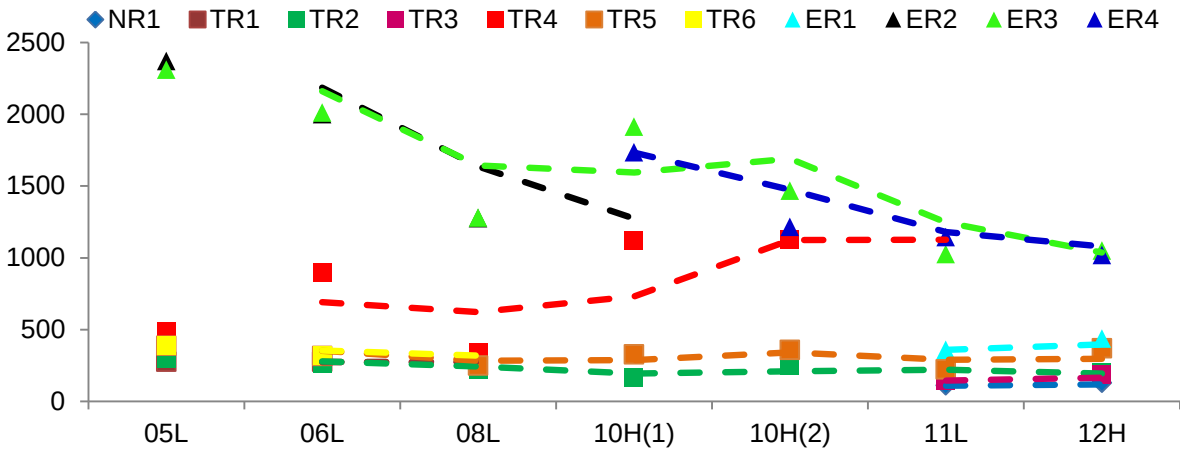


Figure 29: Trends in electrical conductivity (µs/cm) levels (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

The productivity of freshwater ecosystems are nitrogen dependent (Laxton and Gittins, 2003). The surface runoff from the surrounding catchment areas, effluent containing human and animal excrement, agricultural fertilizers and organic industrial waste can all contribute to elevated nutrient loads (DWAF, 1996b). Nutrient loads, considered using nitrates as a surrogate, of the Nembe River (NR1) ranged from 0.11 mg/l to 0.27 mg/l (Figure 30). For the Thukela River (TR1-TR6) nutrient loads ranged between 0.01 mg/l and 2.6 mg/l and on the eMandeni River (ER1-ER4) the loads varied between 0.01 mg/l and 9.22 mg/l (Figure 30). Results indicate that nutrient loads of the Nembe River were stable between 2011 and 2012. Trends reveal that the nutrient loads of the Thukela and eMandeni Rivers were relatively low and stable since 2005 towards the second high flow (H2) period of 2010 whereafter loads increased towards 2012.

Extremely high nutrient loads (9.22 mg/l) occurred at site ER4 during 2011 but recovered to 4.69 mg/l in 2012. The lower parts of river ecosystems are usually based on the fluctuating nutrient loads accumulating in the upper reaches of river ecosystems and therefore it is expected that site ER4 will have higher nutrient loads than sites ER1-ER3. However, the extremely high loads of ER4 are caused by effluent from the industrial complex and rural area of Isithebe as well as the iLembe Wastewater Treatment Works. O' Brien (2010a) stated that the elevated nutrient loads from the eMandeni River cause elevated nutrient loads to occur in the vicinity of site TR5 on the Thukela River which is situated downstream of eMandeni confluence.

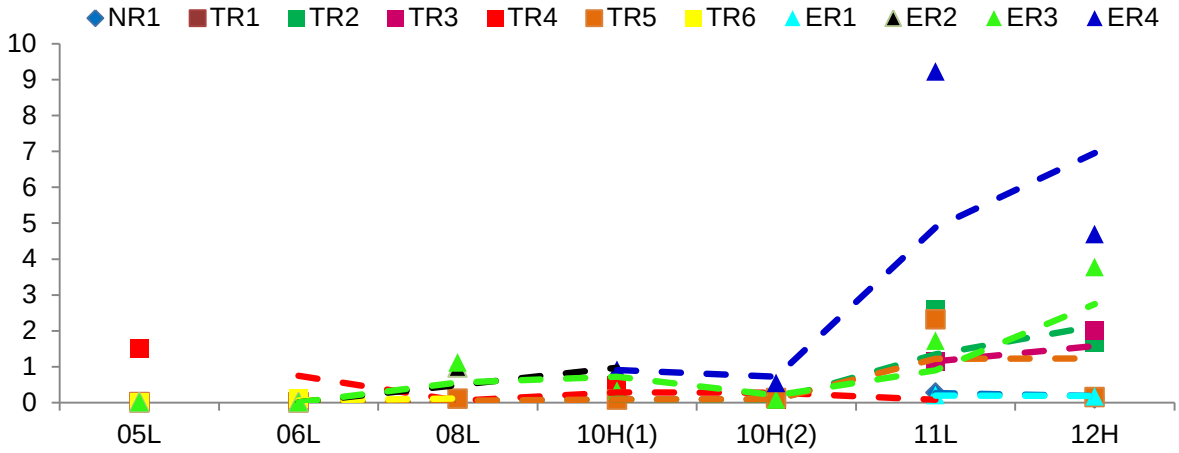


Figure 30: Trends in nitrate (mg/l) loads (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

Chloride loads (Figure 31) of the selected study area were stable at sites NR1 and ER1 during 2011 and 2012. Results reveal that the chloride loads of the Thukela River (TR1-TR6) were relatively low and stable with a slight increase from 2006 towards 2010 but recovered again in 2011 and were stable towards 2012. The chloride loads of the eMandeni River (ER1-ER4) occurred in noticeably elevated loads in comparison with the Thukela River since 2005 and 2012. These elevated chloride loads of the eMandeni River are consistent with the high EC levels that were observed in the eMandeni River and may also influence EC levels in the vicinity of the confluence between the Thukela and eMandeni Rivers.

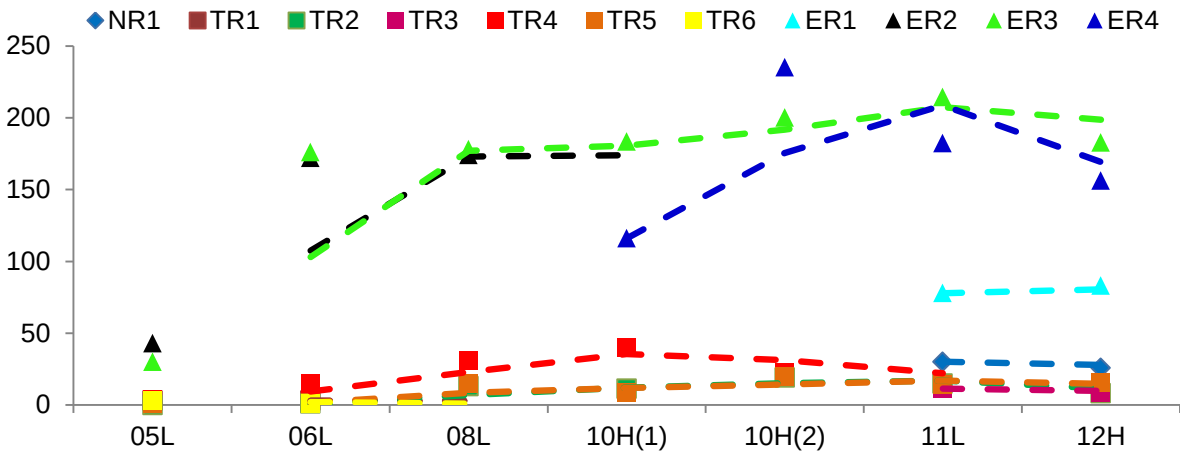


Figure 31: Trends in chloride (mg/l) loads (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

The sulphate loads (Figure 32) of the Thukela, Nembe and eMandeni Rivers were stable at sites TR6 during 2005 to 2008 and at NR1 as well as ER1 between 2011 and 2012. Elevated sulphate loads occurred at TR5, ER2 and ER3 during 2005 but decreased towards the first high-flow survey of 2010. Since 2010 to 2012 sites TR5, ER2 and ER3 slightly increased but were still lower in 2012 than in 2005. TR4 showed a similar trend but sharp elevated levels were recorded during the second high-flow survey of 2010, which together with chlorine loads resulted in elevated EC levels for the same time period.

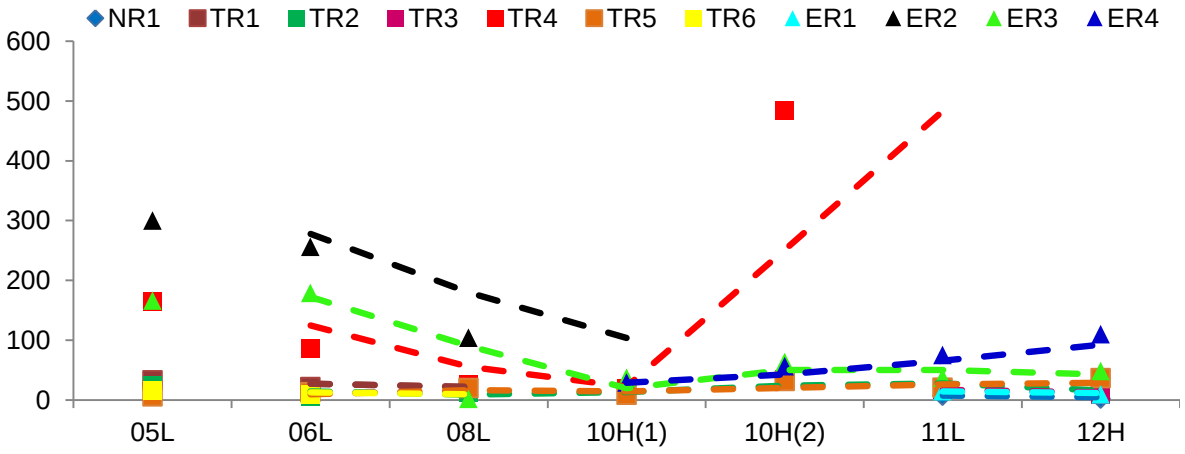


Figure 32: Trends in sulphate (mg/l) loads (x axis) where available between 2005 (05) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Thukela, Nembe and eMandeni Rivers

2.3.1.3. Umvoti River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical water-quality variables collected from the Umvoti River (Figure 1), where available from 1999 to 2012, include water temperature, oxygen, electrical conductivity, pH, nitrate, nitrite, phosphate, ammonia, chlorides, alkalinity, calcium, chemical oxygen demand (COD), sulphates and sodium (Table 11) are presented below. The range of the loads/levels of the water quality constituents considered for the lower Umvoti, Hlimbitwa and Nchaweni Rivers between 1999 and 2012 varies noticeably. Several constituents occurring in elevated levels may result in negative impacts on the structure and function of the aquatic ecosystem. Specifically, the temperature, oxygen levels, nutrient and salt loads are excessive at selected sites, both historically and currently.

Table 11: Water quality data where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys for the Umvoti (UR), Hlimbitwa (HR) and Nchaweni (NS) Rivers

Sites	Temperature (°C)	Oxygen (mg/l)	Oxygen (% saturation)	Electrical conductivity (µS/cm)	pH	Nitrate (mg/l)	Nitrite (mg/l)	Soluble ortho-phosphate (mg/l)	Nitrogen ammonia (mg/l)	Chloride (mg/l)	Total alkalinity (mg/l)	Calcium (mg/l)	Chemical oxygen demand (mg/l)	Sulphate (mg/l)	Sodium (mg/l)
HR1-11L	18.5	8.41	1.05	112	7.70	2.01	1.38	0.02	0.01	12	29.5	7.60	93	10.39	23
HR1-12H	23	6.69	0.85	136	8.04	0.60	0.00	0.04	0.03	16	40	5.11	-	8.98	15
UR1-05H	25.1	8.38	101.00	129	8.13	0.25	0.02	0.01	0.01	12	-	-	10	51.00	-
UR1-05L	15.3	10.29	104.70	173	7.76	0.25	0	0.01	0.01	13	45	8.70	10	4.40	18
UR1-10H	18.2	8.60	105.00	121.2	8.70	0.01	0.66	0.05	0.09	13	50.8	8.20	6	9.93	14
UR1-11L	22.2	8.70	1.11	127	7.80	1.57	1.38	0.00	0.13	21	31	8.40	107	10.67	30
UR2-12H	29.5	6.69	0.88	174	8.51	0.19	0.00	0.01	0.003	19	50	6.63	-	3.61	21
UR3-06H	30.4	8.30	111.20	140	8.20	1.30	0.11	0.04	0.02	4	36	-	20	0.10	-
UR3-06L	12.3	11.13	105.00	183	7.83	0.40	0.01	0.01	0.01	10	-	-	12	0.10	-
UR4-06H	25	7.30	91.00	146	7.44	4.10	0.08	0.05	0.03	5	41	-	22	3.00	-
UR4-06L	14.6	9.96	99.30	203	7.73	0.90	0.01	0.01	0.01	12	-	-	22	2.00	-
UR5-99H	22.4	8.51	98.10	514	8.10	0.21	0.01	0.05	0.05	58	82	15	32	11.60	48
UR5-00L	18.9	6.12	65.48	376.2	7.68	0.24	0.01	0.05	0.16	37.6	73.6	14.10	214	7.60	34
UR5-04L	27.6	7.70	98.00	356	7.95	0.09	0.01	0.13	0.05	48.2	97	13.30	8	10.70	45
UR5-05H	31.1	4.40	90.00	176	7.65	0.23	0.01	0.02	0.03	18.7	48.17	8.78	10.58	7.05	20
UR5-05L	20.5	9.02	99.60	322	7.54	0.22	0.01	0.03	0.03	30.5	85	12.40	11	5.15	39
UR5-06H	25	8.50	102.50	153	7.60	3.00	0.11	0.08	0.02	6	40	-	24	1.00	-
UR5-06L	14.3	11.26	108.50	225	7.66	1.40	0.01	0.02	0.04	6	-	-	8	4.00	-
UR5-08L	20.5	7.47	86.10	227	6.57	0.35	0.01	0.08	0.06	31	46.7	7.20	9	11.00	24
UR5-10H	21.8	7.80	89.35	310	7.66	0.01	0.11	0.05	0.06	28	70.8	8.90	6	13.62	30
UR5-11L	16.5	4.48	0.47	111	8.20	1.10	0.92	0	0.11	19	26.5	7.60	91	5.85	31
UR5-12H	27.8	6.14	0.78	279	7.94	0.78	0.00	0.03	0.004	45	65	8.70	-	7.59	37
UR6-05H	30.4	4.10	84.00	212	7.70	0.25	0.01	0.01	0.32	23	-	-	8	8.00	-
UR6-05L	23.9	8.04	89.40	334	7.68	0.25	0.02	0.18	0.10	58	-	-	39	1.00	-
UR7-99H	26.1	4.80	59.40	878	7.40	0.13	0.01	0.73	0.05	133	153	31	54	15.30	95
UR7-00L	19.4	5.95	64.73	363	7.62	0.24	0.01	0.18	0.80	52.3	84.6	14.80	207	7.20	44
UR7-04L	26.8	3.50	20.00	1630	7.54	0.09	0.02	0.28	0.10	269.5	475	60.70	154	6.90	332
UR7-05H	30.5	4.30	85.00	187	7.54	0.23	0.01	0.02	0.03	20.1	50	9.42	13.75	6.94	26
UR7-05L	20.1	2.26	17.00	919	7.24	0.17	0.02	0.21	0.23	91.8	265	37.00	85	7.35	160
UR7-08L	20	5.67	61.50	385	6.68	0.21	0.01	0.23	0.06	44	85.1	14.00	19	28.00	47
UR7-10H	22.2	2.40	30.25	670	7.77	0.01	0.08	0.33	0.17	49	165	26.90	68	52.23	87
UR7-11L	19.1	3.80	0.42	265	8.20	1.41	1.84	0	0.14	32	39.5	12.00	104	19.99	57
UR7-12H	28.2	4.72	0.61	333	8.04	1.99	0.00	0.01	0.001	38	26	5.47	-	11.31	30
UR8-99H	26.6	3.11	38.00	632	7.56	0.11	0.01	0.35	0.06	100	119	24	24	13.30	77
UR8-00L	19.6	5.43	58.56	417	7.47	0.20	0.01	0.14	0.39	54.3	90	14.80	222	7.05	47
NS1-05H	26.1	0.80	15.00	579	7.47	0.31	0.10	0.22	0.51	64	157.2	22.74	18	9.66	69
NS1-05L	16.4	0.75	16.40	164	7.01	0.25	0.01	1.43	1.50	55	-	-	9	1.00	-
NS1-10H	22.3	2.50	18.05	620	7.55	0.07	0.44	3.27	10.90	66	163.9	17.20	36	9.15	63
NS1-11L	20	4.28	0.52	465	8.00	3.24	19.32	0.04	0.27	50	60	19.00	88	13.48	69
NS1-12H	24.3	3.72	0.45	468	7.36	6.70	0.00	0.11	0.03	103	105	14.59	-	13.15	68
NS2-05H	25.7	2.20	42.00	722	7.47	0.13	0.06	0.15	2.55	68.4	389.7	46.22	78	17.76	156
NS2-05L	20.7	3.18	36.50	1588	7.43	0.17	0.02	0.28	0.53	173.8	432	58.90	17	9.15	272
NS2-10H	24.3	0.70	9.55	2210	7.87	0.02	0.08	1.87	1.70	113	767.6	92.20	458	213.99	388
NS2-11L	-	-	-	-	-	0.16	1.38	0	0.07	118	109	60.00	332	317.69	320
NS2-12H	27.1	3.94	0.50	782	7.70	1.83	4.56	0.06	0.09	101	195	40.61	-	69.39	106

Water temperature levels (Figure 33) of the sites recorded during current and historical surveys reflect primarily natural seasonal fluctuations (Gallagher, 1999). As expected, during the generally cooler low-flow surveys lower temperatures were recorded in comparison to the generally warmer high-flow surveys. In addition, increasing temperatures from the sites situated in the upper reaches of the study area towards the sites located in the lower reaches were observed. For the Hlimbitwa River (HR1) temperatures ranged between 18.5°C and 23°C. Temperature levels of the Umvoti River (UR1-UR8) from 1999 to 2012 ranged from 12.3°C to 31.1°C and for the Nchaweni River (NS1 and NS2) the temperatures ranged between 16.4°C and 27.09°C. Temperatures as high as 30°C and/or higher (UR3 during high-flow period of 2006 as well as sites UR5 and UR6 during the high-flow period of 2005) are concerning and may result in negative impacts on the structure and function of aquatic ecosystems.

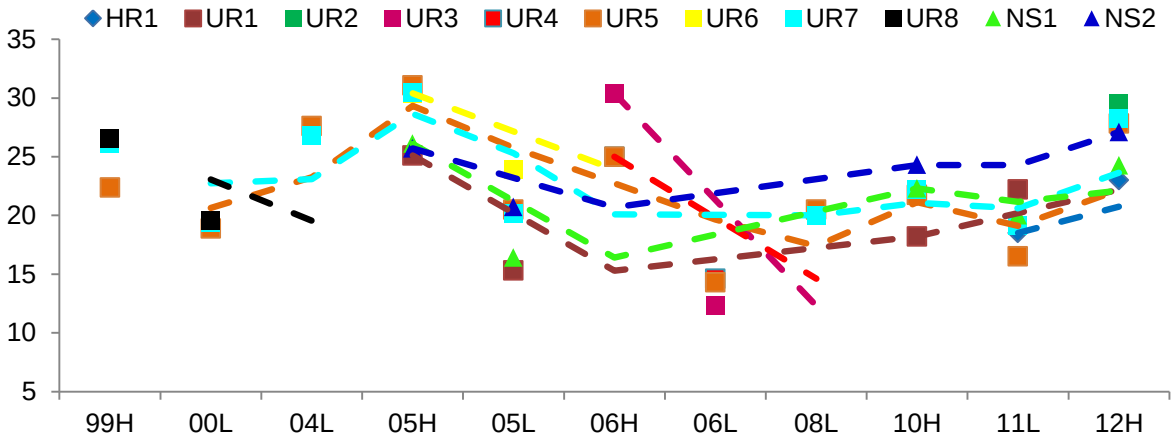


Figure 33: Trends in water temperature (°C) levels (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Findings regarding the pH levels (Figure 34) reveal that all the sites on the lower Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1 and NS2) Rivers were within the TWQG requirements for domestic use and aquatic ecosystems (DWAF, 1996a; 1996b). The pH levels of the Hlimbitwa River ranged from pH 7.7 to pH 8.4 while levels in the Umvoti River fluctuated between pH 6.57 and pH 8.7 and on the Nchaweni River they ranged from pH 7.01 to pH 8. Trends suggest that UR1 had generally higher pH levels than the other sites on the Umvoti River and increased noticeably from 2005 to 2010 whereafter they decreased again in 2011. Findings indicate that pH levels at NS1 were consistently lower than those at NS2 between 2005, 2010 and 2012 although the levels at both sites increased slightly between 2005 and 2012.

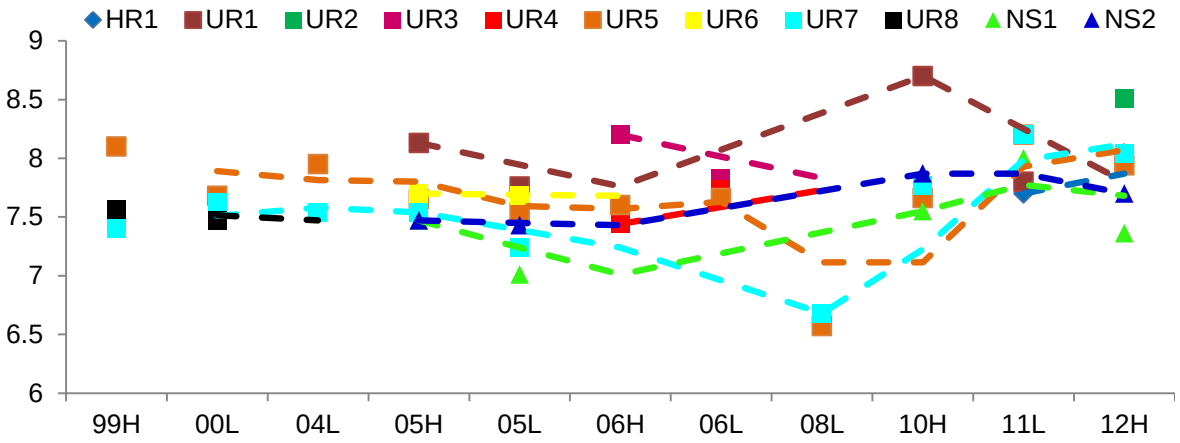


Figure 34: Trends in pH levels (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Results reveal that oxygen levels (Figure 35) of the Hlimbitwa River were within the TWQG levels for aquatic ecosystems (DWAF, 1996b) and ranged from 8.41 mg/l in 2011 to 6.69 mg/l in 2012. Oxygen levels in the Umvoti River fluctuated noticeably since 1999 to 2012 and ranged between 2.26 mg/l and 11.26 mg/l. Findings show that sites UR5 (during 2005 high flow and 2011), UR6 (during 2005 high flow), UR7 (between 1999 and 2012) and UR8 (between 1999 and 2000) had oxygen levels below the required TWQG for aquatic ecosystems (DWAF, 1996b). Malherbe (2006) stated that the low oxygen levels during the 2005 high flow period could be due to high water temperatures at the time however this could not be the case in 2011 as water temperatures were much lower then. According to DWAF (1996b) can reduced oxygen levels be caused by organic matter originating from waste discharges. If this is the case then high chemical oxygen demand (COD) levels should occur at the same time. Site UR5 is situated close to various informal settlements, e.g. Groutville that use the river for various purposes and which could cause oxygen levels to decline. The trends of the oxygen levels of UR5 since 1999 and up to 2012 were consistently higher than the levels of UR7 for the same time period. For the Nchaweni River, oxygen levels ranged from 0.7 mg/l to 4.28 mg/l and were not within the TWQG requirements for aquatic ecosystems (DWAF, 1996b) between 2005 and 2012. The Nchaweni River transports the effluent of the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi's Stanger Mill and together with urban runoff causes oxygen levels to deteriorate. The low oxygen levels of the Nchaweni River may contribute to the low levels that occurred at site UR6 (during 2005 high flow), UR7 (between 1999 and 2012) and UR8 (between 1999 and 2000). Oxygen levels of below 2 mg/l are considered to be unacceptable for the maintenance of ecosystem structure and functioning. Oxygen levels of lower than 2 mg/l occurred at NS1 during 2005 and at NS2 during 2010.

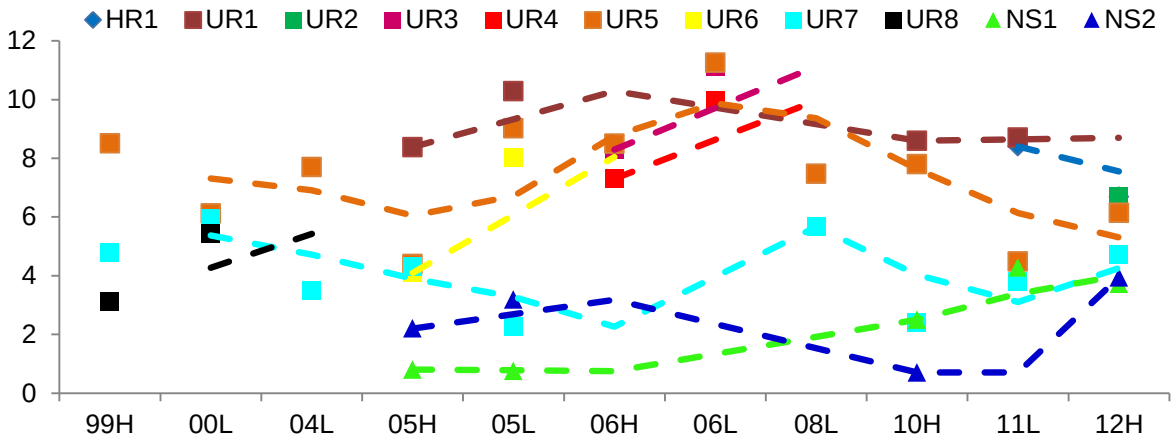


Figure 35: Trends in oxygen (mg/l) levels (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

In terms of chemical oxygen demand (COD) (Figure 36), the general levels of the Umvoti River were relatively stable and low. The COD levels of UR5 were higher than the levels of UR7 during 1999 and 2000, but from 2004 onwards the COD levels of UR7 were consistently higher than the levels of UR5. Chemical oxygen demand levels of site UR5 are not consistent with the low oxygen levels that occurred during the 2005 high-flow period. The COD trend of NS2 is concerning as it dramatically increased since 2005 from a COD level of 16.5 mg/l to a level of 332 mg/l in 2011. High COD levels occurring in the Nchaweni River are consistent with low levels of dissolved oxygen. Chemical oxygen demand levels of all the other sites also showed an increase since 2005 towards 2011, but the trend is much slower compared to NS2. These results indicate that the COD levels entering the Umvoti River from the Nchaweni River are elevated. Malherbe *et al*. (2010) stated that the elevated COD levels of the Nchaweni River are a result of both industrial and urban runoff from Stanger. The general and overall trend indicates that COD levels were high during 1999 and 2000 whereafter they decreased noticeably towards 2005 and since then these levels slowly started to increase again.

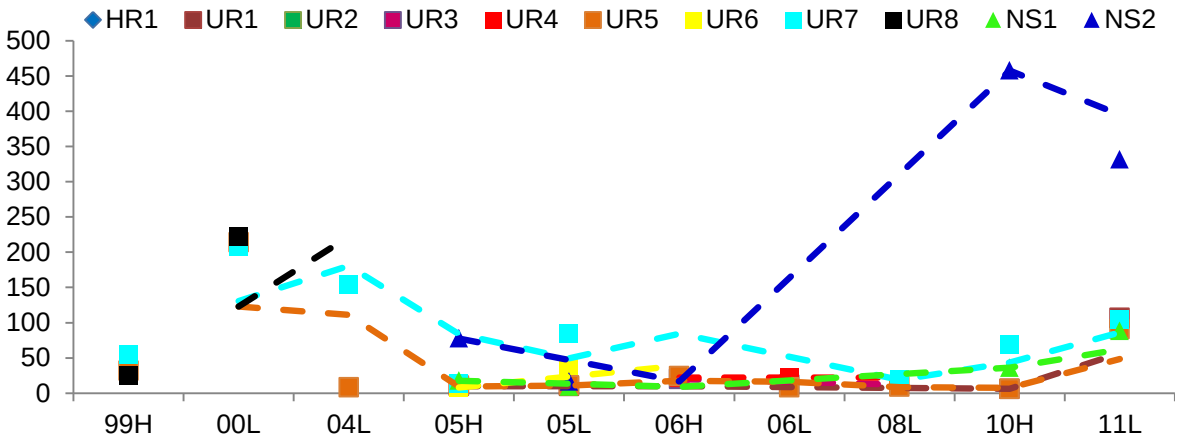


Figure 36: Trends in chemical oxygen demand (mg/l) levels (x axis) where available between 1999 (99) and 2011 (11) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Findings indicate that the electrical conductivity (EC) levels of the lower Umvoti, Hlimbitwa and Nchaweni Rivers fluctuated noticeably (Figure 37). Levels of the Hlimbitwa River ranged between 112 µS/cm and 136 µS/cm and are relatively stable. On the Umvoti River the EC levels fluctuated markedly and ranged from 111 µS/cm to 1 630 µS/cm and on the Nchaweni River the levels ranged between 164 µS/cm and 2 210 µS/cm. Trends indicate that the EC levels of site UR5 were consistently much more stable and lower than levels obtained from UR7 since 1999 to 2012. Electrical conductivity (EC) levels of NS2 fluctuated markedly since 2005 up to 2012 and unacceptably high levels (2 210 µS/cm) occurred during 2010 whereas EC levels at NS1 were much more stable. Domestic and industrial effluent discharges as well as surface runoff from urban and industrial areas in the vicinity of UR6-UR8 as well as NS1 and NS2 are all sources that may contribute to increased nutrient levels and salt loads which in return cause elevated EC levels (DWAF, 1996b).

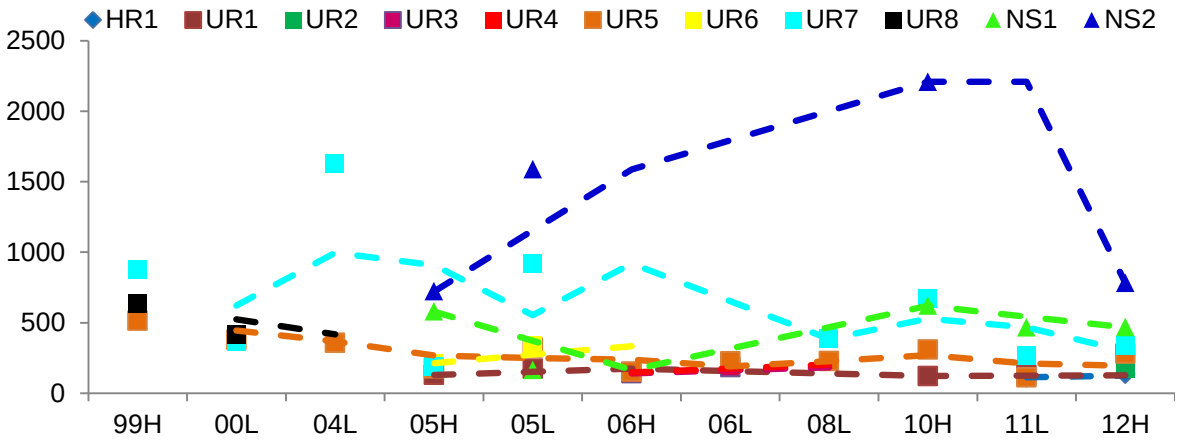


Figure 37: Trends in electrical conductivity (µs/cm) levels (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Nutrient loads (Figure 38) using nitrates as a surrogate, indicate that trends in the Hlimbitwa River remained fairly stable between 2011 and 2012. As for the Umvoti River nitrate loads were stable and at low levels since 1999 up to 2005 whereafter it started to fluctuate noticeably. At site UR5 nitrate loads spiked in 2006 in comparison with the loads at other sites on the Umvoti River but decreased rapidly thereafter. Malherbe (2006), Carminati (2008) and Malherbe *et al*. (2010) all found that elevated nutrient levels in the lower reaches of the Umvoti River (sites UR4-UR7) is a result of cumulative impacts which include fertilizers used on the cultivated sugarcane plantations, urban runoff and effluent discharges from the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi's Stanger Mill. The Nchaweni River contained relatively low levels from 2005 to 2010, but thereafter at NS1 loads increased rapidly towards 2012. This is due to the effluent from the sugar and Sappi mills transported by the Nchaweni River. Elevated nutrient loads in the Nchaweni River resulted in eutrophication and caused the instream channel to be completely covered with reeds (Malherbe, 2006; Carminati, 2008; Malherbe *et al*., 2010). Nitrate loads at NS2 also increased from 2011 towards 2012 but the trend was not as high as that at NS2. The general trend indicates that the nitrate loads of the lower Umvoti, Hlimbitwa and Nchaweni Rivers started to increase since 2006 up to 2012.

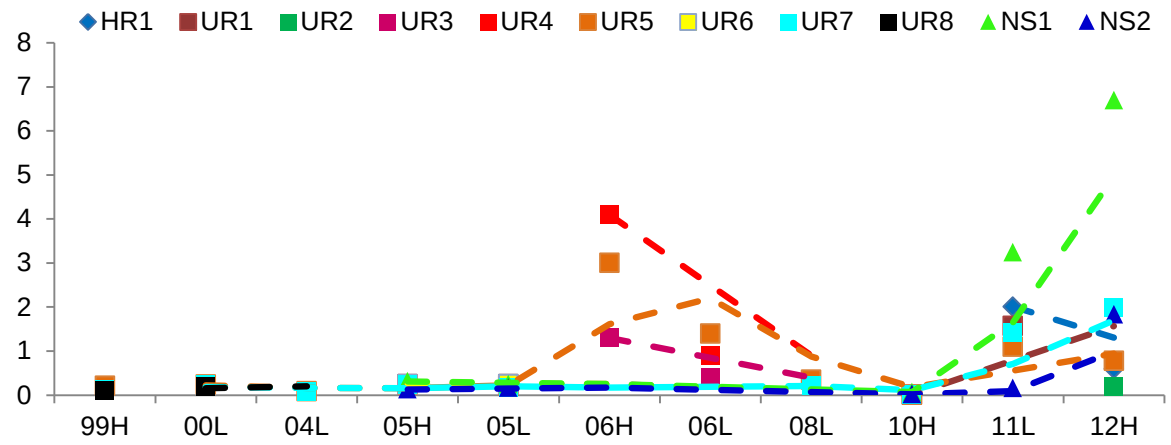


Figure 38: Trends in nitrate (mg/l) loads (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Chloride loads (Figure 39) of the Hlimbitwa River were stable and fairly low. On the Umvoti River the chloride loads fluctuated markedly between 1999 and 2012 with relatively low levels during 2006 at site UR3, UR4 and UR5. At UR7 the loads vary noticeably between 1999 and 2005 whereafter they stabilised from 2008 onwards to 2012. As for the Nchaweni River, chloride loads at NS1 were generally stable and consistently lower than NS2 where levels also fluctuated markedly. Chloride loads at site UR7 and on both sites of the Nchaweni River are consistent with EC levels.

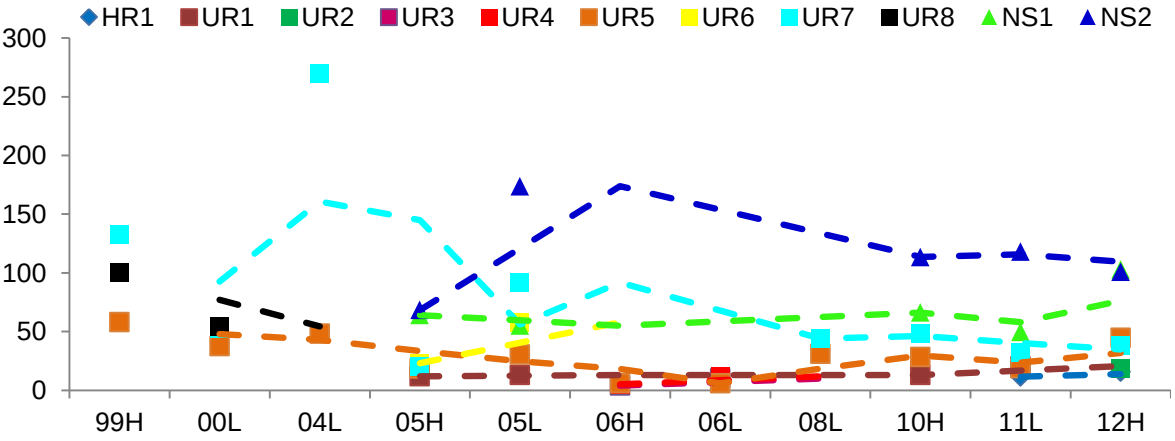


Figure 39: Trends in chloride (mg/l) loads (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

Results regarding the sulphate loads (Figure 40) revealed that loads were stable during 2011 and 2012 at the Hlimbitwa River. On the Umvoti River sulphate loads, as with chloride loads, fluctuated markedly between 1999 and 2012 with relatively low levels during 2006 at site UR3, UR4 and UR5.

At UR7 the loads varied noticeably and trends suggest an increase in sulphate loads between 1999 and 2010 (52.23 mg/l) whereafter it decreased again from towards 2012 (11.31 mg/l). As for the Nchaweni River, loads at NS1 were stable and generally lower than those at NS2. The elevated sulphate loads at NS2 in 2010 (213.99 mg/l) and 2011 (317.69 mg/l) were disconcerting but the levels dropped in 2012 (69.39 mg/l). The results regarding the chloride and sulphate loads suggest that additional salt loads from the Nchaweni River may contribute to elevated loads in the Umvoti River (UR6, UR7 and UR8) below the confluence of the Nchaweni River. No evidence was obtained from current and historical (1999-2012) data of any site on the lower Umvoti, Hlimbitwa and Nchaweni Rivers that salt loads occurred in levels which will cause negative impacts on the structure and function of the aquatic ecosystem.

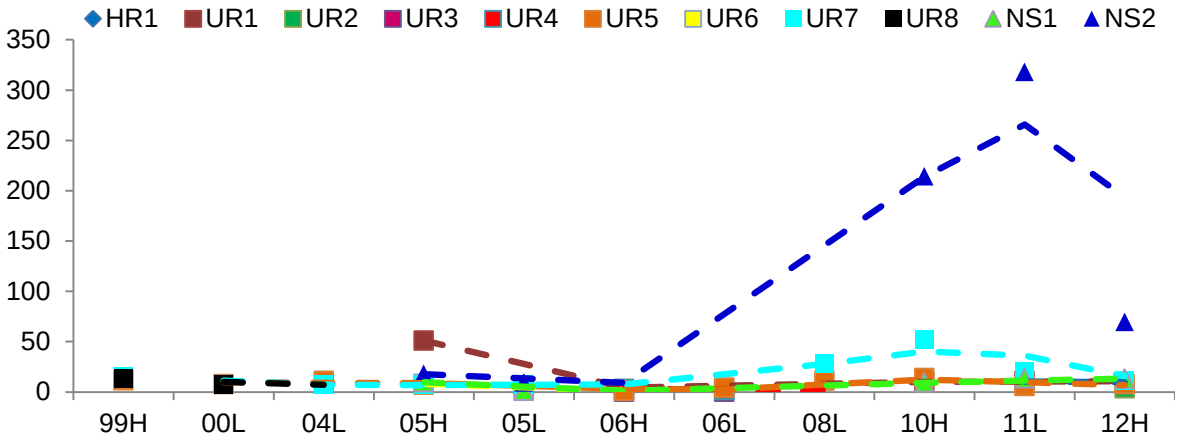


Figure 40: Trends in sulphate (mg/l) loads (x axis) where available between 1999 (99) and 2012 (12) for high (H) and low (L) flow surveys (y axis) for the Umvoti, Hlimbitwa and Nchaweni Rivers

2.3.2. Sediment

2.3.2.1. Amatikulu River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical sediment grain-size, moisture and organic content analyses from the Amatikulu River (Figure 1), where available from 2006 to 2012, are presented in Table 12.

Table 12: Findings of the sediment grain-size distribution analyses (gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M), moisture content and organic content of the lower Amatikulu River (AR1 and AR2) where available for high (H) and low (L) flow surveys during 2006 (06), 2011 (11) and 2012 (12)

Site	G (>4000µm)	VCS (4000µm-2000µm)	CS (2000µm-500µm)	MS (500µm-212 µm)	VFS (212µm-53µm)	M (<53µm)	Moisture content (%)	Organic content (%)
AR1-06H	26.970	7.050	39.220	22.180	4.360	0.190	14.310	0.320
AR1-06L	8.250	15.120	57.260	17.450	0.940	0.940	14.670	0.390
AR1-11L	18.480	36.059	25.561	16.761	1.392	0.370	0.108	0.920
AR1-12H	7.350	40.299	43.577	5.062	0.116	1.862	0.049	0.207
AR2-06H	0.000	0.040	1.690	52.200	45.020	1.030	21.970	0.570
AR2-06L	11.110	9.150	65.590	13.310	0.340	0.480	15.670	0.690
AR2-11L	0.965	7.299	54.659	33.701	1.262	0.448	0.146	0.850
AR2-12H	9.348	43.719	32.625	9.430	1.068	1.972	0.309	0.446

The sediment moisture content (Table 12 and Figure 41) of the Amatikulu River at site AR1 ranged between 14.67% and 0.049% while at AR2 it ranged between 21.970% and 0.146%. Figure 41 shows that the general sediment moisture content trend of both sites on the Amatikulu River decreased from 2006 to 2012. Findings of the sediment analyses of the lower Amatikulu River indicate that the sediment organic content (Table 12 and Figure 42) at both AR1 and AR2 was classified as low during 2006 as well as during 2011 and 2012. The organic content of the lower Amatikulu River ranged from 0.92% to 0.207%. Carminati (2008) revealed that the higher organic content of site AR2 compared to site AR1 during 2006 could be due to flooding conditions where many plants and trees were washed into the river from upstream. Carminati (2008) further stated that it is expected that the Amatikulu River has low organic contents as these two sites are riverine sites at the head of the Amatikulu estuary. Trends of the organic content (Figure 42) showed that AR1 had consistently lower percentages than AR2, except during the low-flow survey in 2011.

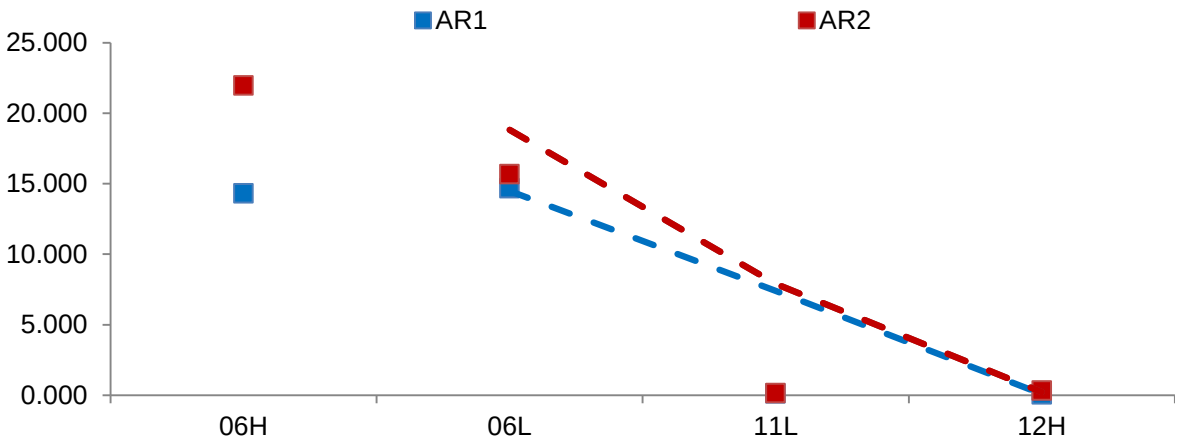


Figure 41: Trends of the sediment moisture (%) content (x axis) of historical and current findings from the Amatikulu River (AR1 and AR2) where available for high (H) and low (L) flow surveys during 2006 (06), 2011 (11) and 2012 (12) (y axis)

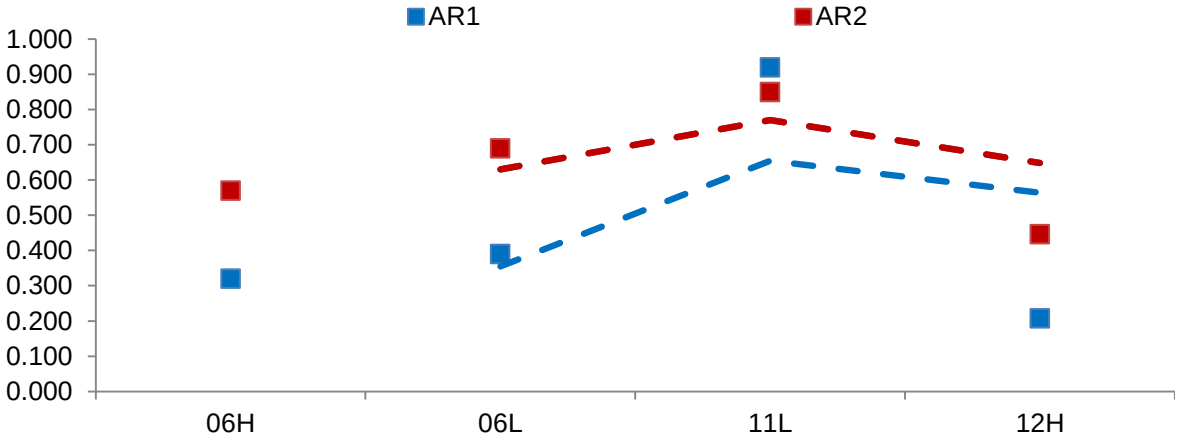


Figure 42: Trends of the sediment organic (%) content (x axis) of historical and current findings from the Amatikulu River (AR1 and AR2) where available for high (H) and low (L) flow surveys during 2006 (06), 2011 (11) and 2012 (12) (y axis)

Results of the sediment grain-size assessment of the lower Amatikulu River indicate that the sediment grain-size distribution at site AR1 as well as AR2 (Figure 43) was composed mainly of larger sediment grain sizes (>500 µm). The sediment grain-size distribution of AR1 was dominated by gravel (>4 000 µm) and coarse sand (2 000 µm to -500 µm) during 2006 (high flow), while during 2006 (low flow) coarse sand was dominant. Fast flowing waters during high flow could scour sediment from the river banks, which are unstable due to erosion caused by sugarcane agricultural activities and resulted in coarser sediments to be transported at site AR1 (Carminati, 2008).

In 2011 the grain-size classes consist mainly of very coarse sand (4 000 µm to 2 000 µm) and in 2012 very coarse sand and medium sand (MS) were the dominant grain sizes. Grain sizes at site AR2 were very similar to the grain sizes of site AR1 with very coarse sand and coarse sand being the dominant soil types during 2006 (low flow), 2011 and 2012. During 2006 (high flow) the sediment grain-size distribution is composed mainly of medium sand and very fine sand (212 µm to 53 µm).

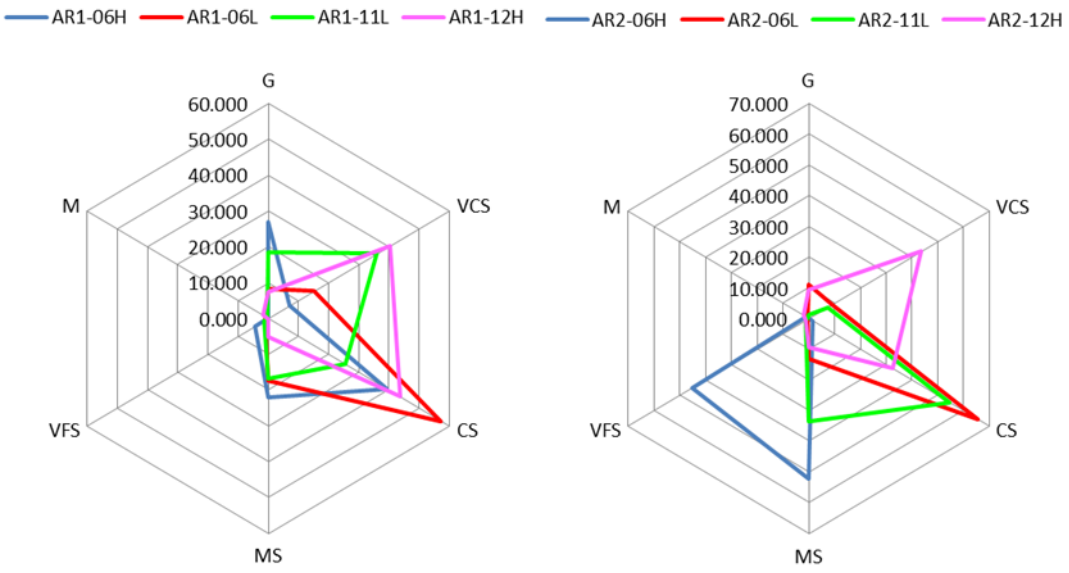


Figure 43: Historical and current sediment grain-size distributions from the Amatikulu River (AR1 and AR2) where available for high (H) and low (L) flow surveys during 2006 (06), 2011 (11) and 2012 (12)

2.3.2.2. Thukela River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical sediment grain-size, moisture and organic content analyses from the Thukela, Nembe and eMandeni Rivers (Figure 1), where available from 2005 to 2012, are presented in Table 13.

Table 13: Findings of the sediment grain-size distribution analyses (gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M), moisture content and organic content of the lower Thukela (TR1-TR6), Nembe (NR1) and eMandeni (ER1-ER4) Rivers where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

Site	G (>4000µm)	VCS (4000µm-2000µm)	CS (2000µm-500µm)	MS (500µm-212 µm)	VFS (212µm-53µm)	M (<53µm)	Moisture content (%)	Organic content (%)
NR1-11L	20.287	20.362	27.374	26.925	2.920	0.452	0.209	0.900
NR1-12H	22.420	25.857	36.376	10.311	0.208	2.500	0.044	0.227
TR1-05L	1.000	3.000	44.000	49.000	3.000	0.000	21.000	0.600
TR1-06L	16.000	5.000	62.000	17.000	0.000	0.000	16.000	0.700
TR2-05L	0.000	0.000	15.000	79.000	5.000	1.000	23.000	0.800
TR2-06L	0.000	0.000	41.000	58.000	0.000	1.000	24.000	0.600
TR2-08L	0.338	0.132	11.740	72.245	9.100	6.532	19.662	0.905
TR2-11L	6.454	17.417	38.125	22.311	5.321	2.524	0.456	1.100
TR3-11L	3.447	30.896	49.873	10.812	3.221	0.371	0.240	0.820
TR3-12H	1.285	21.748	52.867	15.363	4.893	1.990	0.201	0.250
TR4-05L	0.000	0.000	25.000	74.000	1.000	0.000	23.000	0.500
TR4-06L	0.000	1.000	47.000	52.000	0.000	0.000	24.000	0.600
TR4-08L	0.000	0.082	22.456	74.217	2.894	0.302	25.693	1.160
TR5-05L	0.000	1.000	51.000	47.000	1.000	0.000	21.000	0.600
TR5-06L	0.000	1.000	45.000	52.000	0.000	2.000	21.000	0.600
TR5-08L	1.310	0.208	5.187	81.558	10.594	1.398	24.514	0.707
TR5-11L	0.950	14.414	61.519	17.822	3.531	0.374	0.219	0.790
TR5-12H	1.939	28.411	62.641	3.277	0.136	1.862	0.154	0.217
TR6-05L	0.000	3.000	52.000	17.000	15.000	13.000	36.000	4.600
TR6-06L	0.000	0.000	24.000	68.000	0.000	8.000	23.000	0.700
ER1-11L	24.050	26.378	24.050	14.638	3.814	2.925	0.591	1.490
ER1-12H	5.208	15.987	22.890	21.267	8.357	14.437	0.570	0.940
ER2-05L	3.000	8.000	45.000	35.000	7.000	2.000	22.000	2.000
ER2-06L	0.000	1.000	4.000	59.000	0.000	36.000	24.000	1.800
ER2-08L	4.220	12.640	77.100	5.500	1.210	0.180	26.000	5.130
ER3-05L	39.000	14.000	29.000	9.000	7.000	2.000	25.000	5.700
ER3-06L	33.000	30.000	26.000	8.000	0.000	3.000	29.000	5.400
ER3-08L	1.430	1.860	19.000	36.520	33.110	7.720	34.000	4.850
ER3-11L	28.126	51.151	17.717	1.145	0.083	0.377	0.148	0.880
ER3-12H	6.983	22.968	35.167	26.123	4.859	2.019	0.306	0.350
ER4-11L	1.786	1.818	3.030	5.326	8.771	22.903	1.688	2.610
ER4-12H	0.500	1.250	2.468	5.374	6.499	37.370	0.760	1.740

Results show that the sediment moisture content (Table 13 and Figure 44) of the Thukela, Nembe and eMandeni Rivers ranged from 36% to 0.148%. Trends regarding the sediment moisture content showed that noticeably lower percentages occurred at all the sites sampled during 2011 and 2012. Organic material in sediments originates both from aquatic organisms living in the aquatic systems and from organic matter that is derived from the surrounding soils as well as terrestrial sources (Page, 2002). The organic content relates the amount of organic material available for oxidation to the specific ecosystem (USEPA, 2001). Therefore organic content can be used as a measure of the energy available for organisms living in the sediment as well as the productivity of the ecosystem (Stryftombolas, 2008). Figure 45 indicates that the sediment organic content of sites NR1 (2011 and 2012), TR1 (2005 and 2006), TR3 (2011 and 2012) and TR5 (2005 – 2012) is classified as being low in all cases. TR6 ranged from high in 2005 to low in 2006. ER3 followed the same trend and also ranged from high in 2005-2008 to low in 2011 and 2012. The sediment moisture content in other eMandeni River sites (ER1, ER2 and ER4) all ranged from low to moderate low. The general trends shown in Figure 45 suggest that the organic content decreased slightly towards 2012; however, site ER2 showed a noticeable increase between 2005 and towards 2008.

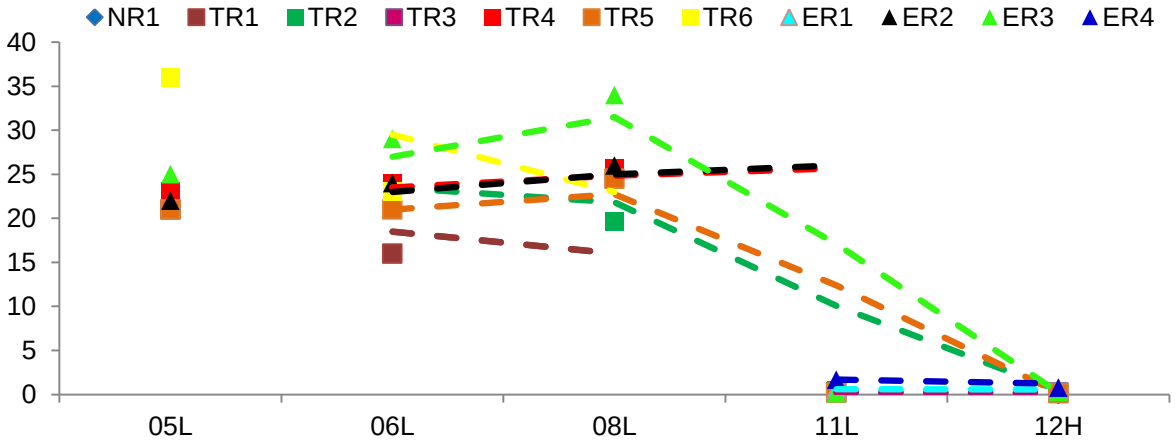


Figure 44: Trends of the sediment moisture (%) content (x axis) of historical and current findings from the Thukela (TR1-TR6), Nembe (NR1) and eMandeni (ER1-ER4) Rivers where available for high (H) and low (L) flow surveys since 2005 (05) to 2012 (12) (y axis)

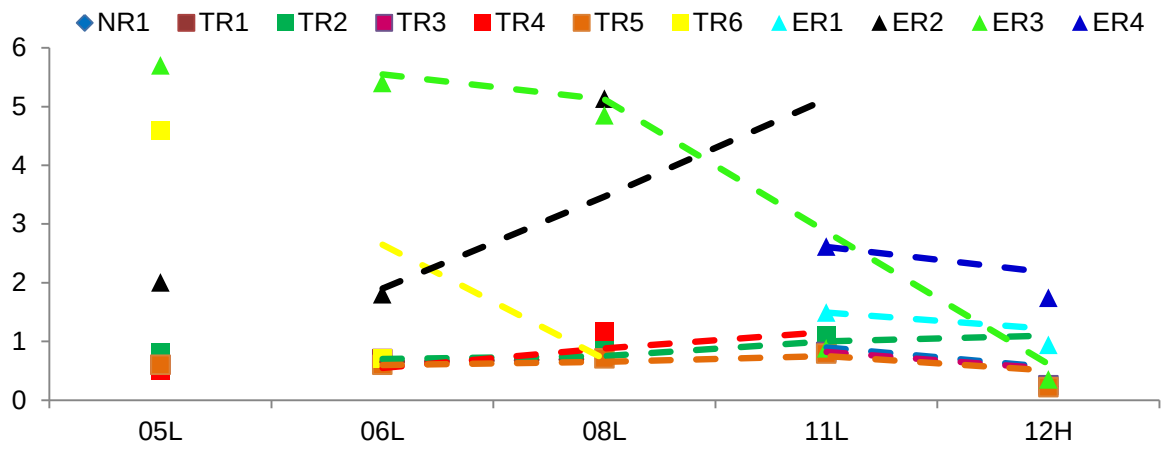


Figure 45: Trends of the sediment organic (%) content (x axis) of historical and current findings from the Thukela (TR1-TR6), Nembe (NR1) and eMandeni (ER1-ER4) Rivers where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12) (y axis)

Results of the sediment grain-size distribution assessment (Figure 46) indicate that the Nembe River (NR1) is dominated by soils composed of gravel (>4 000 µm), very coarse sand (4 000 µm to 2 000 µm), coarse sand (2 000 µm to 500 µm) and medium sand (500 µm to 212 µm). These grain-sizes are too large and are not ideal for the biodiversity of the site. Sediment grain sizes of the Thukela River were generally well-sorted and dominated by coarse sand and medium sand (Figure 46 and Figure 47). According to Stryftombolas (2008) did extensive high flows during 2006, caused the transportation of medium sand from upstream sites and deposited it at the lower sites of the Thukela River (TR4-TR6). Sites TR3 and TR5 were both dominated by very coarse and coarse sand during 2011 and 2012. Sediments in the eMandeni River (Figure 47 and Figure 48) vary from poorly sorted sediments at ER1 to mud-dominated sediments at ER4. Flooding events in 2006 also affected the sediment grain-size distribution of the eMandeni River during that period (Stryftombolas, 2008). The sediment grain-size distribution of ER1 is well-sorted and included soils with larger grains (>500 µm) such as gravel, very coarse sand and coarse sand in 2011, whereas in 2012 the sediment grain-size distribution data indicated poorly sorted coarse sand, medium sand and mud which is associated with healthy habitats. Findings showed that sites ER2 and ER4 had well-sorted sediments composed of coarse sand, medium sand as well as mud. Site ER3 also consists of well-sorted sediment with grains of similar sizes; however, the grain-size distribution in the sediment differed noticeably between 2005 and 2012. During 2008 and 2012 the sediment distribution at site ER3 were in a slightly better state in comparison to other years.

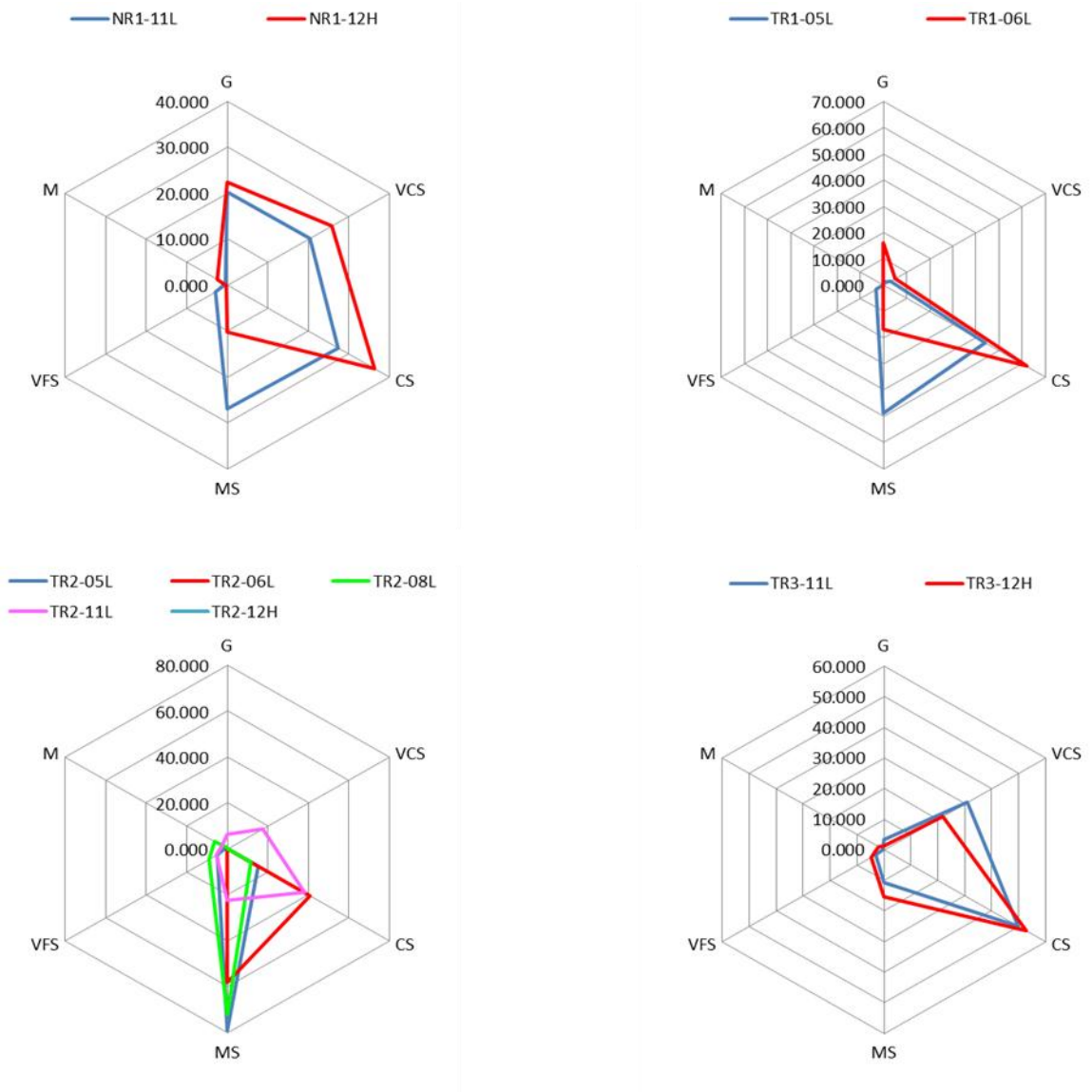


Figure 46: Historical and current sediment grain-size distributions of the Nembe (NR1) and Thukela (TR1-TR3) Rivers where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

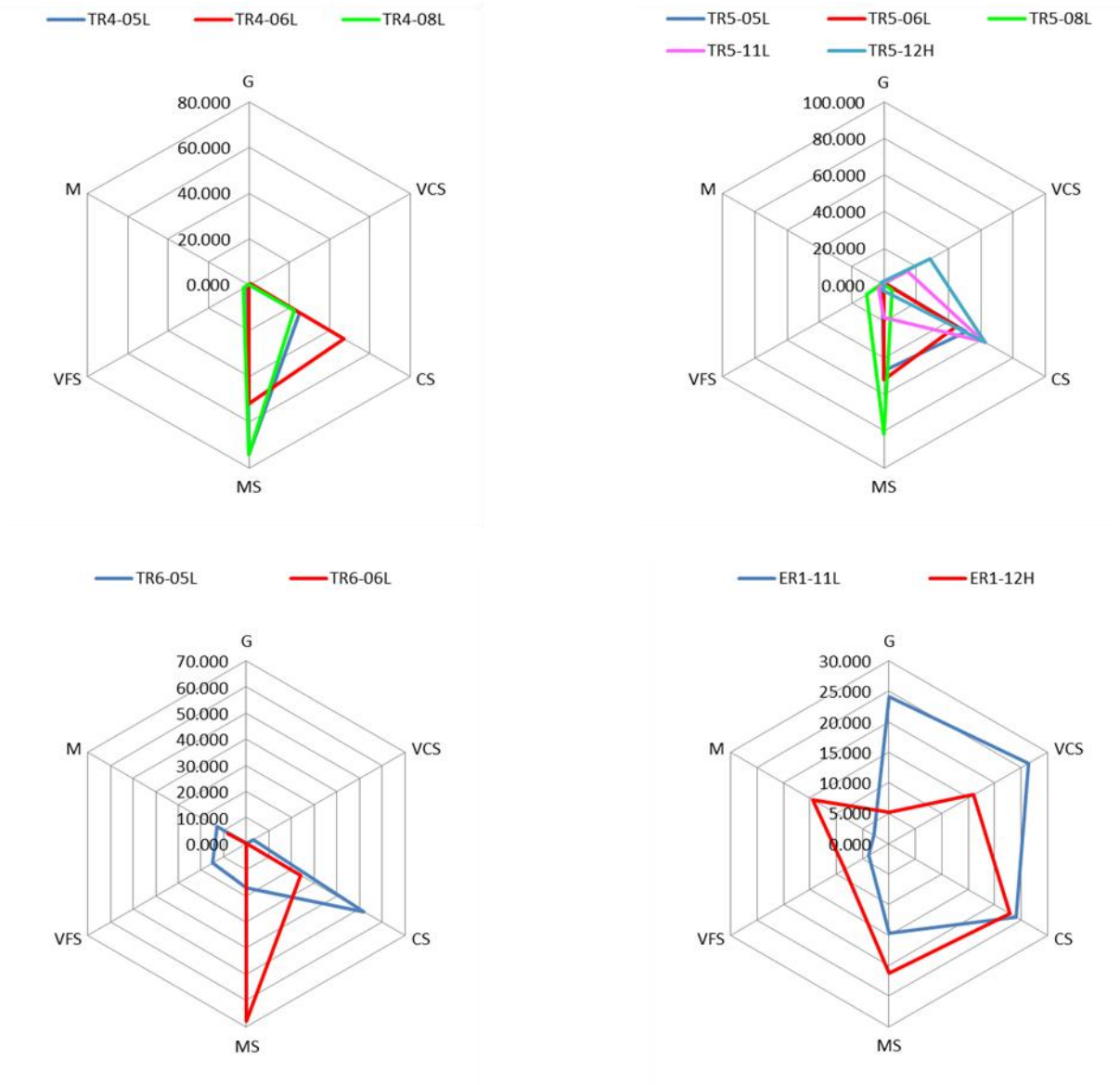


Figure 47: Historical and current sediment grain-size distributions of the Thukela (TR4-TR6) and eMandeni (ER1) Rivers where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

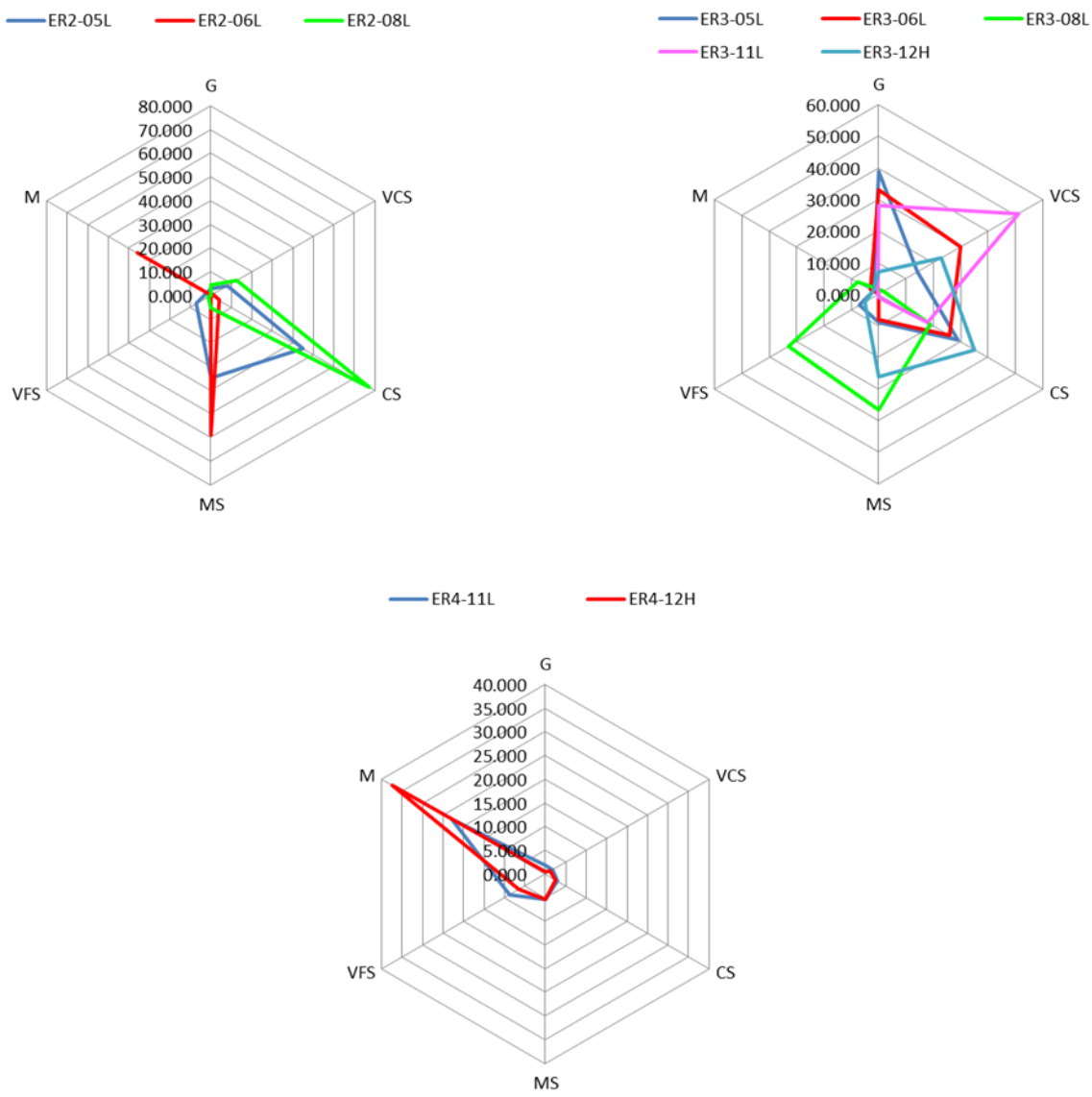


Figure 48: Historical and current sediment grain-size distributions of the eMandeni (ER2-ER4) River where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

2.3.2.3. Umvoti River

Results of current (2011 low-flow and 2012 high-flow surveys) and historical sediment grain-size, moisture and organic content analyses from the Umvoti, Hlimbitwa and Nchaweni Rivers (Figure 1), where available from 1999 to 2012, are presented in Table 14.

Table 14: Findings of the sediment grain-size distribution analyses (gravel - G, very coarse sand - VCS, coarse sand - CS, medium sand - MS, very fine sand - VFS and mud - M), moisture content and organic content of the lower Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1-NS2) Rivers where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12)

Site	G (>4000µm)	VCS (4000µm-2000µm)	CS (2000µm-500µm)	MS (500µm-212 µm)	VFS (212µm-53µm)	M (<53µm)	Moisture content (%)	Organic content (%)
HR1-11L	19.319	45.472	24.369	5.609	1.246	2.538	0.364	1.080
HR1-12H	14.807	47.386	28.298	4.727	0.647	2.141	0.123	0.237
UR1-05H	24.360	20.840	44.970	9.210	0.400	0.040	16.540	0.330
UR1-05L	22.220	22.490	52.780	2.190	0.090	0.020	16.940	0.310
UR1-11L	7.237	7.753	9.983	10.564	6.784	26.430	2.500	2.750
UR2-12H	8.066	29.177	48.277	9.796	0.351	2.244	0.118	0.228
UR3-06H	0.610	4.490	66.920	24.860	3.050	0.050	18.990	0.270
UR3-06L	8.030	20.150	63.700	7.960	0.130	0.006	14.510	0.220
UR4-06H	0.600	1.390	50.650	41.940	5.260	0.130	15.230	0.320
UR4-06L	0.190	3.380	81.680	12.120	2.450	0.150	18.920	0.210
UR5-99H	10.300	13.600	42.300	33.600	0.100	0.100	0.000	0.186
UR5-00L	0.000	8.100	42.300	47.700	0.800	0.400	0.000	0.135
UR5-04L	0.000	0.548	54.471	45.154	0.581	0.017	22.825	0.268
UR5-05H	0.990	2.520	49.270	41.780	4.240	0.890	25.580	1.080
UR5-05L	2.360	7.810	44.240	38.700	5.820	0.190	20.100	0.350
UR5-06H	1.090	69.700	5.870	23.000	0.240	0.030	11.420	0.240
UR5-06L	1.410	10.990	65.130	21.050	0.850	0.550	16.080	0.290
UR5-08L	0.094	0.857	32.879	63.268	7.034	0.726	22.541	4.662
UR5-10H	0.431	1.547	63.067	34.721	0.021	0.117	0.000	0.000
UR5-11L	5.299	19.927	57.280	15.322	0.476	0.359	0.060	0.780
UR5-12H	0.745	2.980	14.869	18.565	3.094	28.535	0.420	1.550
UR6-05H	1.610	6.820	70.280	20.460	0.380	0.010	23.840	2.360
UR6-05L	0.210	6.260	71.220	21.500	0.270	0.000	21.060	0.250
UR7-99H	18.300	20.200	51.000	8.700	0.200	0.100	0.000	0.180
UR7-00L	0.500	6.500	34.000	51.600	0.500	0.200	0.000	0.145
UR7-04L	0.253	2.773	58.708	36.068	1.314	0.013	21.834	0.264
UR7-05H	0.000	0.000	3.740	65.220	28.990	1.540	26.000	0.590
UR7-05L	0.800	3.210	48.080	44.730	2.180	0.050	20.180	0.320
UR7-08L	0.292	2.112	20.946	56.301	15.016	5.285	21.550	1.042
UR7-10H	0.081	3.969	61.980	30.484	2.278	1.197	0.000	0.000
UR7-11L	0.665	13.441	66.943	16.041	1.189	0.365	0.176	1.000
UR7-12H	1.722	15.870	60.954	16.731	1.096	1.879	0.121	0.250
UR8-99H	1.900	9.500	44.100	43.200	1.100	0.200	0.000	0.303
UR8-00L	0.000	2.400	14.300	61.600	2.300	0.200	0.000	0.241
UR8-04L	0.000	1.654	55.329	40.708	0.837	0.000	23.473	0.330
NS1-05H	0.020	0.520	62.860	29.380	4.760	0.350	27.210	1.490
NS1-05L	26.460	5.780	16.290	33.750	15.090	2.350	34.440	8.990
NS1-10H	3.374	8.222	54.327	30.878	1.013	2.085	0.000	0.000
NS1-11L	1.565	14.568	58.229	15.277	2.317	4.552	0.804	1.910
NS1-12H	2.530	27.543	62.580	3.679	0.058	1.869	0.049	0.207
NS2-05H	0.010	0.970	48.300	47.740	3.860	0.380	27.890	1.760
NS2-05L	0.340	2.260	55.590	31.370	9.540	0.670	23.350	2.550
NS2-10H	0.589	2.346	61.214	33.036	1.228	1.586	0.000	0.000
NS2-11L	5.164	12.438	26.225	22.715	5.850	10.635	1.783	3.160
NS2-12H	0.958	3.612	21.379	27.891	9.657	14.646	1.100	2.170

The sediment moisture content of the Hlimbitwa River (HR1) ranged between 0.123% and 0.364% (Table 14 and Figure 49) whereas in the Umvoti River (UR) it ranged between 0.06% (UR5 in 2011) and 26% (UR7 during 2005 high flow). The Nchaweni River's moisture content ranged from 0.049% to 34.440%. Figure 49 suggests that the general trend regarding the moisture content of the Umvoti, Hlimbitwa and Nchaweni Rivers decreased towards 2011 and 2012.

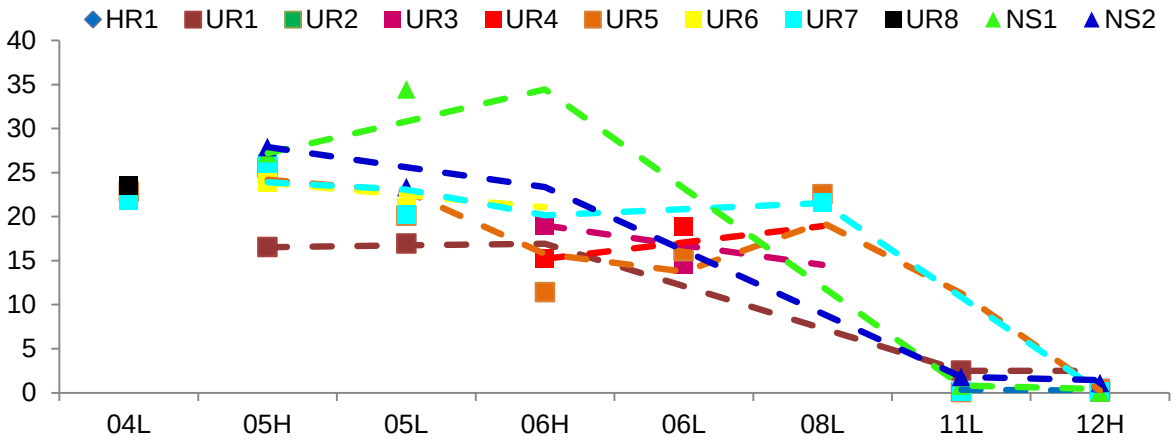


Figure 49: Trends of the sediment moisture (%) content (x axis) of historical and current findings from the Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1-NS2) rivers where available for high (H) and low (L) flow surveys between 2004 (04) and 2012 (12) (y axis)

The sediment organic content (Table 14 and Figure 50) of the Hlimbitwa River as well as the Umvoti River at sites HR1, UR1, UR2, UR3 and UR4 ranged from low to moderate low. Results revealed that the sediment organic content at UR5 was low (0.05% to 1%) during 1999 – 2004, 2005 (low flow) and 2006 (low flow), 2011 and 2012, moderate low (1% to 2%) in 2005 (high flow) and high (>4%) during 2008. High organic content at site UR5 during 2008 is probably due to the decomposition of plant material remaining after the removal of riparian vegetation. Sites UR6 and UR7 ranged between low and moderate low. Organic content of the Nchaweni River at site NS1 ranged from moderate low in 2005 (high flow) and 2011 to high in 2005 (low flow) and back to low during 2012. NS2 ranged from moderate low during the high flows of 2005 and 2012 to medium during the low flows of 2005 and 2011. Figure 50 revealed that the general trend regarding the organic content of the Umvoti, Hlimbitwa and Nchaweni Rivers slightly increased towards 2011 whereafter it decreased again in 2012; however, the organic content at site NS1 increased noticeably between the high and low flows in 2005 and then decreased again towards 2012.

Malherbe (2006) stated that the high organic content at site NS1 during the 2005 low-flow period could be explained by the decreased flow which causing more deposition of sediment with higher organic content. Trends show that the organic content of the Nchaweni River are generally higher compared to the Umvoti River. The discharge of organic effluent from the Gledhow Sugar Mill (owned by Ushukela Milling (Pty) Ltd) and Sappi's Stanger Mill contributes to the organic content of the Nchaweni River.

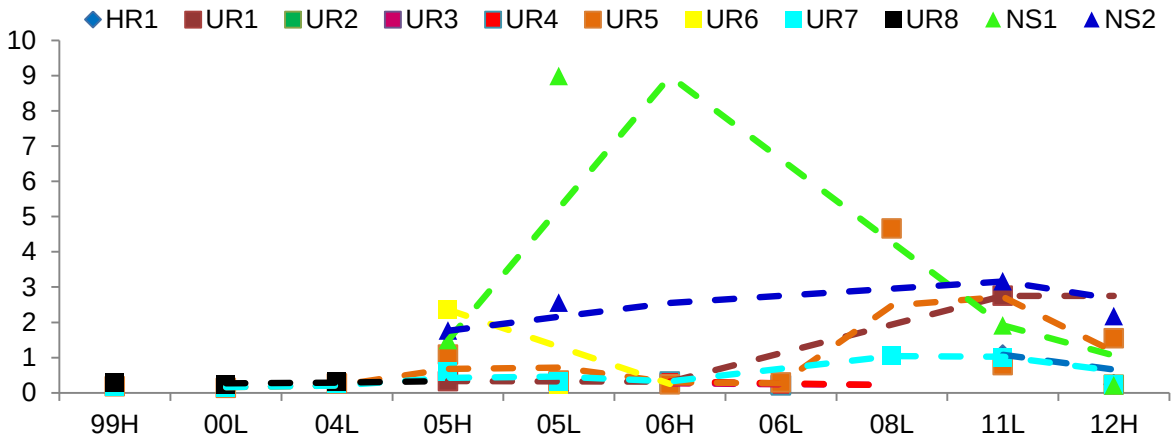


Figure 50: Trends of the sediment organic (%) content (x axis) of historical and current findings from the Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1-NS2) Rivers where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12) (y axis)

Sediment transport increases as the coarseness of the sediment increases, resulting in lower biodiversity of aquatic organisms due to the fact that the availability of several biotopes decreases (Carminati, 2008). The Hlimbitwa River is characterised by well-sorted sediment grain sizes which are mainly composed of very coarse sand (4 000 µm to 2 000 µm) as well as small amounts of gravel (>4 000 µm) and coarse sand (2 000 µm to 500 µm) (Table 14 and Figure 51). Site UR1 on the Umvoti River was dominated by well-sorted coarse sand during 2005 but also included gravel and very coarse sand (Figure 51). In 2011 the sediment grain-size distribution at site UR1 was still well-sorted but was dominated by mud (<53 µm). This can be explained by slower flowing water during the low-flow period which resulted in sediment transportation to decrease. Sites UR2-UR4 and UR6 are dominated by coarse sand (Figure 51 and Figure 52). Site UR5 is dominated by coarse sand and medium sand (500 µm to 212 µm) except for 2006 (high flow) when it was dominated by well-sorted very coarse sand and in 2012 by mud (Figure 51). As for site UR7 (Figure 52) coarse sand and medium sand are dominant; however, during 1999 and 2005 (high flows) gravel and very fine sand (212 µm to 53 µm) also occurred. Site UR8, the lowest site on the Umvoti River, was dominated by coarse sand in 1999 and 2004 while medium sand was dominant in 2000 (Figure 52).

Sugarcane agricultural activities increases siltation of aquatic ecosystems and can be detected when finer sediments are dominant (Venter and van Vuren, 1997; Cheesman, 2005). This explains the dominance of finer sediments which occurred at the lower reaches of the Umvoti River (sites UR5-UR8).

At site NS1 the sediment grain-size distribution was very similar over the years, dominated by well-sorted coarse sand but also included very coarse sand and medium sand; however, in 2005 (low flow) the sediment grain-size distribution was different and included gravel, coarse sand, medium sand and very fine sand (Figure 52). In addition, site NS2 (Figure 52) was dominated by well-sorted coarse sand and medium sand in 2005 and 2010, but in 2011 and 2012 mud and very coarse sand also occurred. Findings regarding the sediment grain-size analyses suggest that the sediments of the majority of the lower Umvoti River sites as well as the sites on the Hlimbitwa and Nchaweni Rivers are well-sorted soils composed of coarse sand (Table 14, Figure 51 and Figure 52). The coarser sediment grain-sizes which dominated the Umvoti, Hlimbitwa and Nchaweni Rivers are an indication that the system is very erosional and large amounts of sediment transportation is taking place. CRUZ (2000) as well as Malherbe (2006) also found that a lot of sediment transportation is taking place in the Umvoti River.

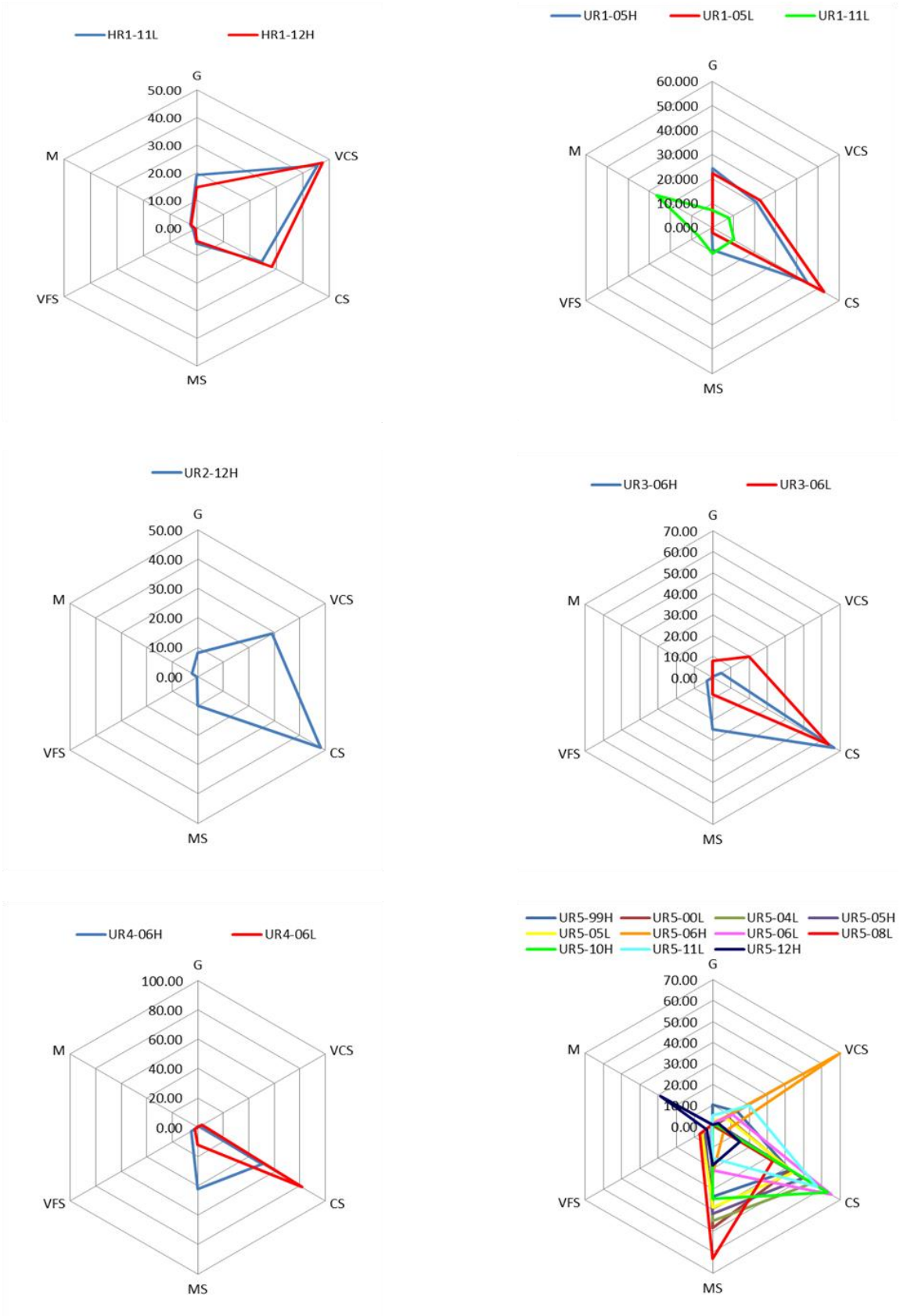


Figure 51: Historical and current sediment grain-size distributions of the Hlimbitwa (HR1) and Umvoti (UR1-UR5) Rivers where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12)

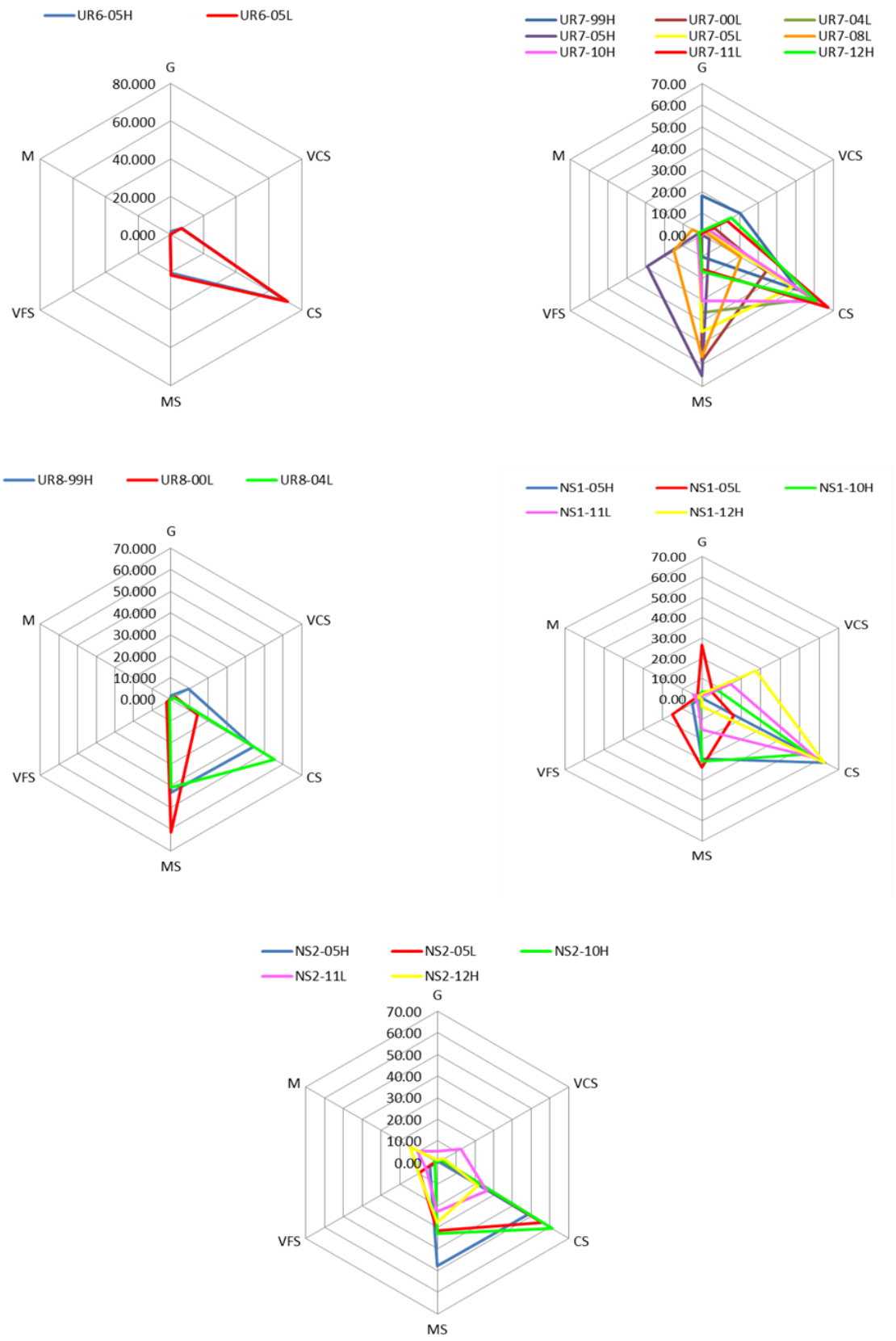


Figure 52: Historical and current sediment grain-size distributions of the Umvoti (UR6-UR8) and Nchaweni (NS1-NS2) Rivers where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12)

2.3.3. Habitat

2.3.3.1. Amatikulu River

Habitat results which include Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System Version 2 (IHAS) scores as well as IHAS integrity classes from the sites sampled on the Amatikulu River (Figure 1) of current and historical data, where available from 2006 to 2012, are presented in Table 15.

Table 15: Results of the current and historical data of the Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the lower Amatikulu River (AR1 and AR2) where available for high (H) and low (L) flow surveys during 2006 (06), 2011 (11) and 2012 (12)

Sites	IHI Score	IHAS Score	IHAS Integrity Class
AR1-06H	-	57	D
AR1-06L	-	70	C
AR1-11L	105	52.08	D
AR1-12H	139	54.17	D
AR2-06H	-	58.7	D
AR2-06L	-	70	C
AR2-11L	70	55.41	D
AR2-12H	55	58.11	D

Results of the Integrated Habitat Assessment System (IHAS), which represents invertebrate specific habitat states, revealed that the lower Amatikulu River (AR1 and AR2) were generally in a largely modified (Class D) state except during the 2006 low-flow period were it was found to be in a moderately modified (Class C) state (Table 15). According to Carminati (2008), the improved habitat state is due to the fact that during the low-flow period a greater diversity of habitat is available. Findings from applying IHAS revealed that trends of the lower Amatikulu River (AR1 and AR2) were similar between 2006 and 2012 (Figure 53). A general decreasing trend in the habitat abundance and diversity was observed in the lower Amatikulu River between 2006 and 2012. The habitat state slightly recovered from 2011 to 2012. The trend further shows that site AR2 had a noticeable better IHAS score compared to site AR1 between 2011 and 2012. Site AR1 was dominated by gravel and sand while boulders and riffle areas were absent during 2011 and 2012. This caused the habitat availability and diversity to deteriorate which resulted in low IHAS scores.

At site AR2 a greater habitat diversity which included isolated areas of cobbles and boulders, forming small riffle sections, were available and is the reason why site AR2 had better IHAS scores compared to AR1 during 2011 and 2012.

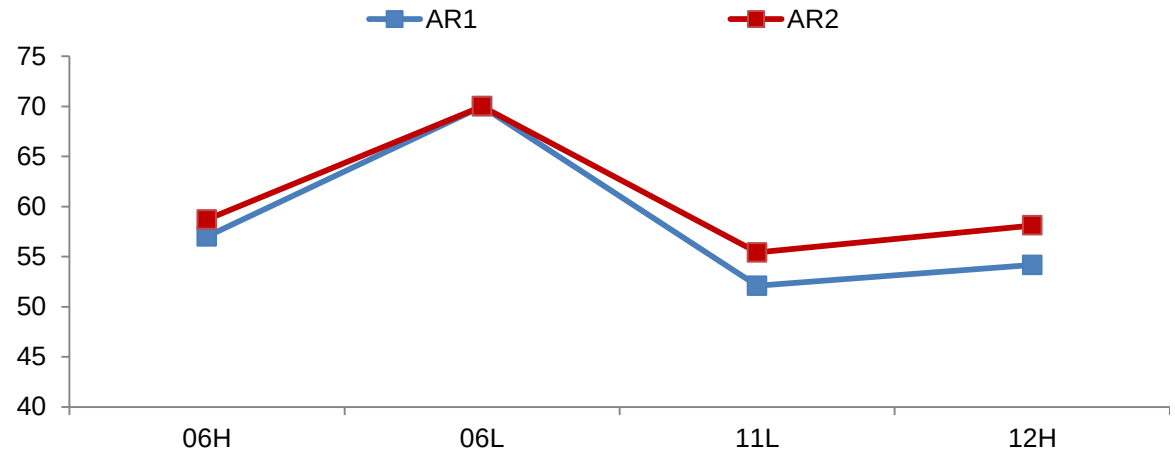


Figure 53: Trends regarding the integrated habitat assessment (IHAS) scores (x axis) from current (2011 and 2012) and historical (2006) data where available of the Amatikulu River (AR1 and AR2) for high (H) and low (L) flow surveys (y axis)

A high Index of Habitat Integrity (IHI) score reveals that that habitat availability and diversity are impaired while low scores indicate that impacts on the habitat is low (Table 15). Results regarding the application of IHI show that the IHI trend of AR1 increased from 2011 to 2012 while AR2 experienced a decreasing trend (Figure 54). Sugarcane agricultural activities in the surrounding area as well as water abstraction at the site are some of the main impacts that increase siltation which cause the habitat diversity and availability to be impaired. Decreasing IHI scores of site AR2 between 2011 and 2012 showed that the habitat diversity and availability improved, which is consistent with increasing IHAS scores also indication improved habitat.

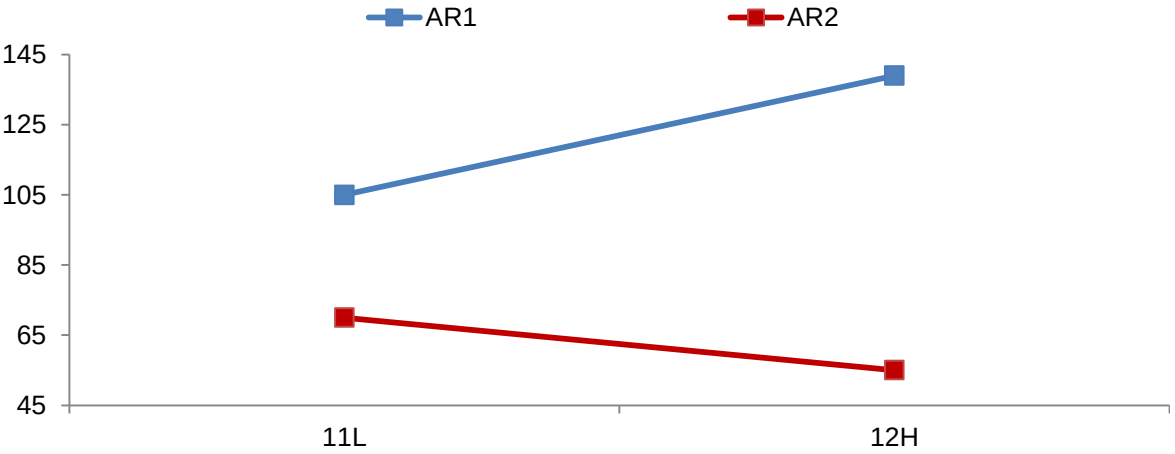


Figure 54: Trends regarding the index of habitat integrity (IHI) scores (x axis) of the Amatikulu River (AR1 and AR2) for high (H) and low (L) flow surveys during 2011 (11) and 2012 (12) (y axis)

2.3.3.2. Thukela River

Habitat results which include Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System Version 2 (IHAS) scores as well as IHAS integrity classes from the sites sampled on the Thukela, Nembe and eMandeni Rivers (Figure 1) of current and historical data, where available from 2005 to 2012, are presented in Table 16 and Table 17.

Table 16: Results of the current and historical data of the Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the lower Thukela River (TR1 – TR6) where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

Sites	IHI Score	IHAS Score	IHAS Integrity Class
TR1-05L	-	68	C
TR1-06L	-	57	D
TR2-05L	-	81	B
TR2-06L	-	98	A
TR2-08L	-	76	C
TR2-10H	68	60.8	C
TR2-11L	55	47.3	D
TR2-12H	45	50	D
TR3-11L	70	50	D
TR3-12H	63	54.17	D
TR4-05L	-	62	C
TR4-06L	-	50	D
TR4-08L	-	40	D
TR4-10H	126	43.2	D
TR5-05L	-	54	D
TR5-06L	-	54	D
TR5-08L	-	40	D
TR5-10H	112	40.5	D
TR5-11L	45	41.67	D
TR5-12H	35	45.83	D
TR6-05L	-	62	C
TR6-06L	-	48	D

Table 17: Results of the current and historical data of the Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the lower eMandeni River (ER1 – ER4) and Nembe River (NR1 and NR2) where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12)

Sites	IHI Score	IHAS Score	IHAS Integrity Class
ER1-11L	55	50	D
ER1-12H	47	56.25	D
ER2-05L	-	71	C
ER2-06L	-	78	C
ER2-08L	-	57	D
ER3-05L	-	66	C
ER3-06L	-	66	C
ER3-08L	-	57	D
ER3-10H	146	68.9	C
ER3-11L	175	66.22	C
ER3-12H	105	59.46	C
ER4-10H	189	67.6	C
ER4-11L	105	52.7	D
ER4-12H	88	50.7	D
NR1-11L	60	68.92	C
NR1-12H	35	60.81	C

Results from applying the Integrated Habitat Assessment System (IHAS), which represents invertebrate specific habitat states, showed that trends of the lower Thukela, Nembe and eMandeni Rivers fluctuated noticeably (Table 16-Table 17 and Figure 55). The habitat state at site TR2 has noticeably declined from being in a natural (Class A) state during the low-flow period of 2006 to a largely modified (Class D) state in 2012. Site TR5 was found to be stable between 2005 and 2006 and then declined in 2008 whereafter the habitat state slightly recovered towards 2012. Between 2011 and 2012 the habitat states of the Nembe (NR1) and eMandeni (ER3 and ER4) Rivers deteriorated while habitat states of sites TR2 and TR3 on the Thukela River as well as ER1 on the eMandeni River recovered slightly. The general trend suggests that the habitat state deteriorated between 2005 and 2012. Stryftombolas (2008) and O'Brien (2010a) found that the deterioration of habitat diversity and availability are caused by constant elevated flows.

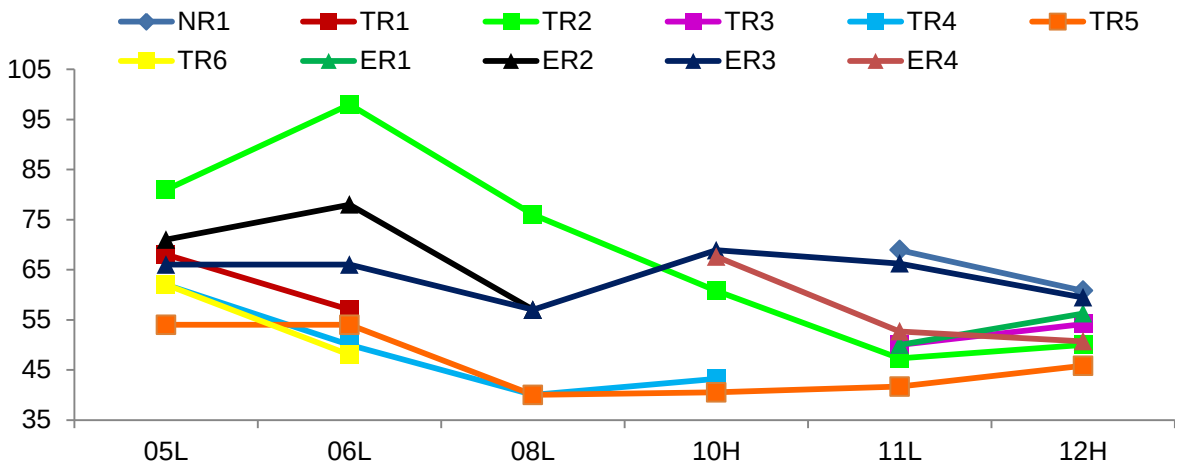


Figure 55: Trends regarding the integrated habitat assessment (IHAS) scores (x axis) from current and historical data of the Thukela (TR1-TR6), Nembe (NR1) and eMandeni (ER1-ER4) Rivers where available for high (H) and low (L) flow surveys between 2005 (05) and 2012 (12) (y axis)

Findings from applying the Index of Habitat Integrity (IHI) revealed that all the sites associated with the lower Thukela, Nembe and eMandeni Rivers experienced a decreasing trend between 2010 and 2012 (Table 16-Table 17 and Figure 56). This indicates that the habitat state recovered between 2010 and 2012. Both IHAS and IHI show that the habitat state of the lower Thukela, Nembe and eMandeni Rivers started to recover from historical flooding events.

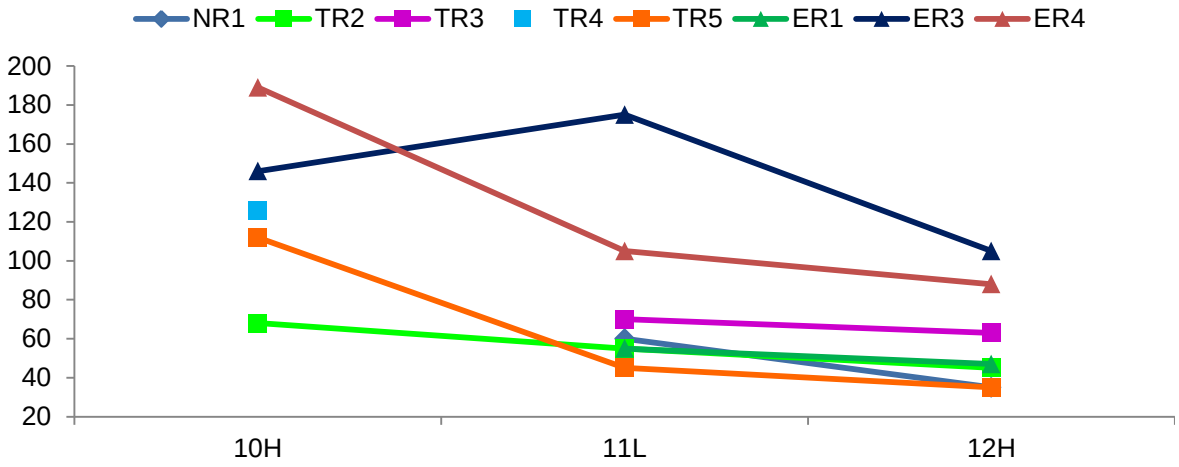


Figure 56: Trends regarding the index of habitat integrity (IHI) scores (x axis) from current and historical data of the Thukela (TR1-TR6), Nembe (NR1) and eMandeni (ER1-ER4) Rivers where available for high (H) and low (L) flow surveys between 2010 (10) and 2012 (12) (y axis)

2.3.3.3. Umvoti River

Habitat results which include Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System Version 2 (IHAS) scores as well as IHAS integrity classes from the sites sampled on the Umvoti, Hlimbitwa and Nchaweni Rivers (Figure 1) of current and historical data, where available from 1999 to 2012, are presented in Table 18 and Table 19.

Table 18: Results of the current and historical data of the Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the lower Umvoti River (UR1 – UR6) where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12)

Sites	IHI Score	IHAS Score	IHAS Integrity Class
UR1-05H	-	74	C
UR1-05L	-	75	C
UR2-12H	45	56.76	D
UR3-06H	-	52.5	D
UR3-06L	-	72	C
UR4-06H	-	52	D
UR4-06L	-	67	C
UR5-99H	-	48	D
UR5-00L	-	49	D
UR5-04L	-	65	C
UR5-05H	-	70	C
UR5-05L	-	75	C
UR5-06H	-	42.5	D
UR5-06L	-	72.5	C
UR5-08L	-	47.5	D
UR5-10H	245	60.42	C
UR5-11L	190	50	D
UR5-12H	175	56.25	D
UR6-05H	-	63.75	C
UR6-05L	-	67.5	C
UR6-08L	-	47	D

Table 19: Results of the current and historical data of the Index of Habitat Integrity (IHI) and Integrated Habitat Assessment System (IHAS) as well as IHAS Integrity Classes of the lower Umvoti River (UR7 and UR8), the Nchaweni River (NS1 and NS2) and the Hlimbitwa River (HR1) where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12)

Sites	IHI Score	IHAS Score	IHAS Integrity Class
UR7-99H	-	47	D
UR7-00L	-	49	D
UR7-04L	-	50	D
UR7-05H	-	61.3	C
UR7-05L	-	65	C
UR7-08L	-	65	C
UR7-10H	230	58.33	D
UR7-11L	150	50	D
UR7-12H	57	56.25	D
UR8-99H	-	47	D
UR8-00L	-	48	D
UR8-04L	-	54	D
NS1-05H	-	75	C
NS1-05L	-	75	C
NS1-10H	154	55.41	D
NS1-12H	60	52.7	D
NS2-05H	-	67	C
NS2-05L	-	72	C
NS2-10H	145	41.89	D
NS2-11L	120	52.08	D
NS2-12H	30	52.7	D
HR1-11L	30	52.7	D
HR1-12H	30	50	D

Results of the Integrated Habitat Assessment System (IHAS), which represents invertebrate specific habitat states, revealed that the habitat state of the lower Umvoti, Hlimbitwa and Nchaweni Rivers ranged from a moderately modified (Class C) to a largely modified (Class D) state (Table 18 and Table 19).

Findings from applying IHAS fluctuated markedly with an upward trend in habitat abundance and diversity during 1999 and 2005 at sites UR5, UR6, UR7, UR8 and NS2 while UR1 and NS1 were relatively stable (Figure 57). During 2005 the IHAS trends clearly show that the habitat integrity of the lower Umvoti River deteriorated as one moves downstream from site UR5 to UR7. The same can be said about the Nchaweni River as site NS1 had higher IHAS scores than NS2. Although the IHAS trend suggests that the highest IHAS scores were obtained during 2005 compared to the other years, Malherbe (2006) revealed that impacts that cause the habitat integrity state to deteriorate include the removal of indigenous riparian vegetation and water abstraction. During the high-flow period of 2006 site UR5 experienced a major decrease and then noticeably recovered towards the low-flow period. The same trend is associated with sites UR3 and UR4. Carminati (2008) sated that this noticeable fluctuations of the habitat integrity are due to the fact that there were very little habitat available during the high-flow compared to the low-flow period. Carminati (2008) also found that the removal of indigenous vegetation causing alien vegetation encroachment resulting in increased bank erosion which also contributes to impaired habitat availability.

Since the low-flow period of 2006 towards 2012 the habitat integrity state of the lower Umvoti and Nchaweni Rivers decreased. Current findings reveal that the habitat abundance and diversity of the Umvoti and Nchaweni Rivers slightly recovered towards 2012 while the Hlimbitwa River experienced a decreasing trend. On the Nchaweni River, site NS1 was consistently higher than NS2, but in 2012 the habitat state was the same for both sites. Cumulative impacts caused by the various land users of the area result in the deterioration of habitat diversity and availability in the lower Umvoti and Nchaweni Rivers. These impacts include the removal of indigenous vegetation which together with sugarcane agricultural activities, water abstraction and channel modifications, especially at site UR5, caused the habitat integrity state to deteriorate. The habitat integrity state of the Hlimbitwa River is mainly affected by rural communities.

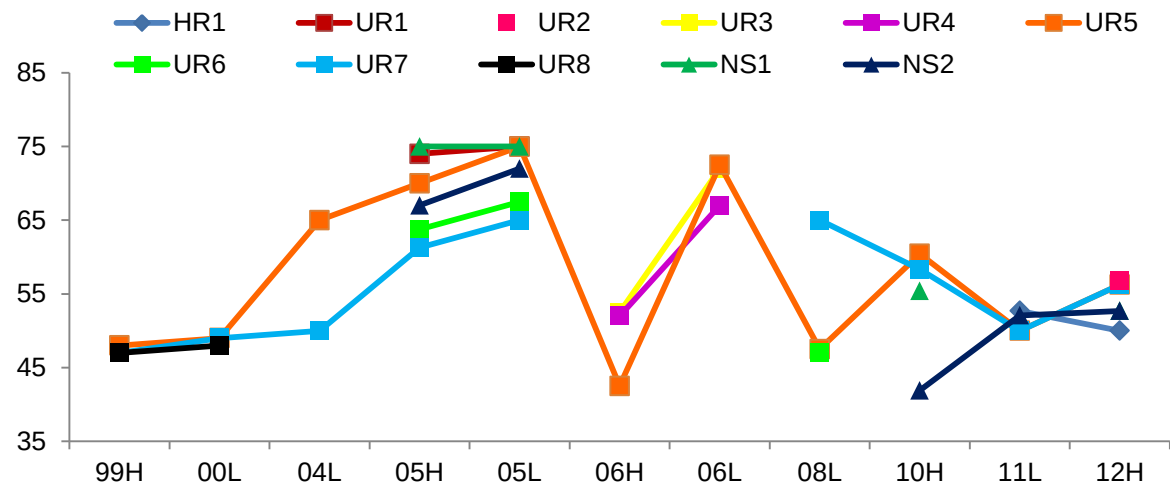


Figure 57: Trends regarding the integrated habitat assessment (IHAS) scores (x axis) from current and historical data of the Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1-NS2) rivers where available for high (H) and low (L) flow surveys between 1999 (99) and 2012 (12) (y axis)

Results from applying the Index of Habitat Integrity (IHI) indicated that the sites associated with the lower Umvoti and Nchaweni Rivers experienced a decreasing trend between 2010 and 2012 whereas the Hlimbitwa River remained stable (Table 18-Table 19 and Figure 58). The decreasing trend suggests that the habitat diversity and availability recovered towards 2012 and is consistent with the IHAS trends. Site UR5 on the Umvoti River had higher IHI scores compared to site UR7. This is because of the extensive channel modifications that occurred at site UR5. Construction and bulldozing of a lagoon that has been artificially constructed in order to accommodate water abstraction for the Gledhow Sugar Mill resulted in channel modifications which also contribute to flow modifications as well as increased sedimentation. As a result of this the only biotopes available include vegetation and sandbanks. The IHI trend of the Hlimbitwa River was stable and is consistent with the IHAS trend.

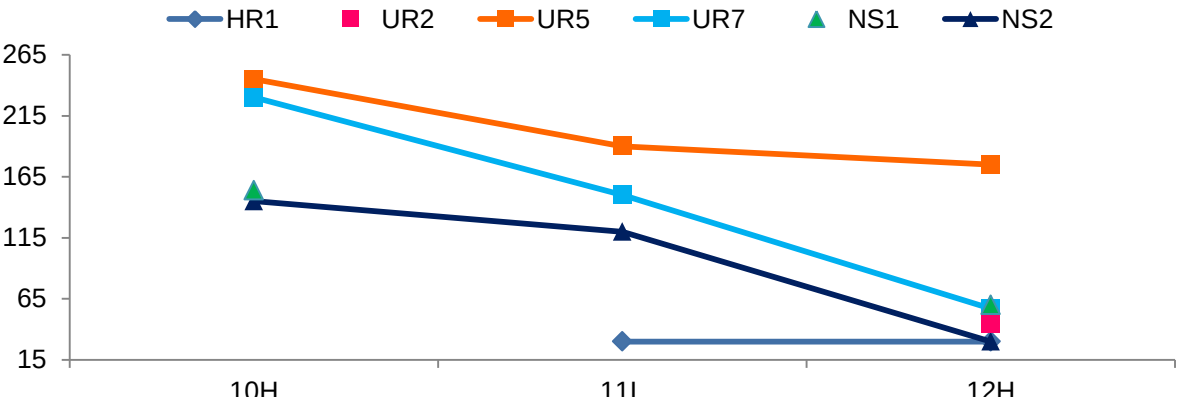


Figure 58: Trends regarding the index of habitat integrity (IHI) scores (x axis) from current and historical data of the Umvoti (UR1-UR8), Hlimbitwa (HR1) and Nchaweni (NS1-NS2) Rivers where available for high (H) and low (L) flow surveys between 2010 (10) and 2012 (12) (y axis)

2.4. Conclusion

The water quality of the lower Amatikulu River was found to be in a fairly good, slightly modified state and the majority of water quality parameters considered were within the target values as set by the TWQG. Water quality parameters considered on the lower Thukela River such as temperatures, oxygen levels, nutrient and salt loads were found to occur at elevated levels and were not within the TWQG requirements. In general, the water quality of the Thukela River is considered to be in a modified state which may cause negative impacts on the structure and function of the river. The water quality of the lower Umvoti River was found to be in a seriously modified state. Sediment analyses revealed that the organic content of the Lower Amatikulu, Thukela and Umvoti Rivers is low. Sediment grain-size distributions are dominated by well-sorted larger soil grains (>500 µm) which is not ideal for the biodiversity. This is an indication that erosion and transportation are taking place in the Amatikulu, Thukela and Umvoti Rivers. The removal of riparian vegetation by agricultural activities and water abstraction contributes to the erosion and transportation of sediments that occurs in lower Amatikulu, Thukela and Umvoti Rivers.

The ecological state of the selected driver components of the lower Amatikulu, Thukela and Umvoti Rivers is a cause for concern as it may negatively impact the macroinvertebrate and fish community structures which in return will cause the overall ecological integrity to deteriorate.

CHAPTER 3: Assessment of the present ecological integrity and community structures of macroinvertebrates of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal

3.1. Introduction

The use of macroinvertebrates as biological indicators in the determination of the ecological integrity, state or health of lotic ecosystems is globally well established (Resh *et al*., 1988; Rosenberg and Resh, 1993; Barbour *et al*., 1996; Thirion, 2007). Changes in aquatic macroinvertebrate community structures have provided valuable information on cumulative stressors such as water quality, pollution, hydrological and geomorphological processes, as well as habitat alterations (Rosenberg and Resh, 1993; Dallas, 2000; Álvarez-Cabria *et al*., 2010; Holt and Miller, 2011). Macroinvertebrates are good ecological indicators as they are also widely distributed, easily sampled, sensitive to subtle changes in ecosystem states, have a large-scale applicability and can be used across regions (Álvarez-Cabria *et al*., 2010). In South Africa several methodologies incorporate aquatic macroinvertebrates as biological indicators when determining the ecological state or health of lotic ecosystems. The South African Scoring System, Version 5 (SASS 5) (Dickens and Graham, 2002), the Macroinvertebrate Response Assessment Index (MIRIA) (Thirion, 2007) and the use of multivariate statistical analysis have been widely used throughout South Africa. These methods have been used to address specific information requirements regarding the response of macroinvertebrate assemblages to changes in ecosystem variables. These ecosystem variables usually include water quality and habitat variables which are referred to as ecological driver components (Dickens and Graham, 2002; Thirion, 2007).

The South African Scoring System is an accredited protocol that has been tested and widely used in South Africa as a biological index of water quality (Dickens and Graham, 2002). The South African Scoring System (SASS) was originally developed by Chutter (1994) to act as a rapid and cost-effective method to assess the macroinvertebrate response to water-quality changes in river ecosystems (Dallas, 1997). The technique also provides valuable information regarding the current state of ecological integrity of the aquatic macroinvertebrate communities of the system being assessed and as such has been widely incorporated into the river health monitoring programmes (Dickens and Graham, 2002; Thirion, 2007).

The South African Scoring System has been revised since it was developed in 1994 and is now in its 5th revision (Dickens and Graham, 2002). Different families show different tolerances to pollution and range from highly tolerant families (e.g. Muscidae and Psychodidae) to less tolerant families (e.g. Oligoneuridae).

The MIRAI method was designed to use the information generated by SASS to allow for the evaluation of water-quality and -quantity impacts as well as habitat suitability for aquatic macroinvertebrates (Thirion, 2007). MIRAI aims to provide users with a habitat-based cause-and-effect foundation to interpret the deviation of the aquatic macroinvertebrate assemblage attributes from a pre-established reference condition (Thirion, 2007). Both the SASS and MIRAI methods are widely implemented as biomonitoring tools and form part of several national ecosystem integrity classification programmes; however, the MIRAI methodology is the preferred approach (Thirion, 2007). Additionally, several multivariate statistical techniques have been used to evaluate the structure of aquatic macroinvertebrate assemblages as well as their response to different altered ecosystem driver components (Van den Brink *et al*., 2003).

3.2. Materials and methods

3.2.1. South African Scoring System (SASS)

Macroinvertebrates were sampled from the sites situated on the Amatikulu, Thukela and Umvoti Rivers (see Chapter 2 for sites) during the low flow (2011) and high flow (2012) surveys using the SASS 5 method. The method involves the collection of macroinvertebrates according to the standardised SASS protocol at three different habitat types or biotopes (Dickens and Graham, 2002). The three different biotopes include stones (in current, out of current and bedrock) sampled for 2 min, marginal vegetation (total length of 2 m), and gravel, sand and mud (GSM) sampled for 30 s to 60 s. These three biotopes are sampled with a standard SASS net (1 mm mesh and dimensions of 30 x 30 x 30 cm) and analysed separately according to the standardised protocol in order to be able to consider habitat availability which may affect the distribution of macroinvertebrates. For accurate identification of specimens, samples were preserved in 10% neutral buffered formaldehyde and stained with phloxine dye, transported back to the laboratory and identified with the aid of a dissection microscope. The preserved macroinvertebrate specimens were identified using a macroinvertebrate guide (Dickens and Graham, 2002).

SASS results are expressed both as an index score (SASS score) and the average score per recorded taxon (ASPT) (Dallas, 2007). Interpretation of the SASS outcomes involves considering the habitat availability and state at the sampled sites. Habitat availability and state were considered by applying the Integrated Habitat Assessment System Version 2 (IHAS) (McMillan, 1998) as well as the Index of Habitat Integrity (IHI) (Kleynhans, 1996). In this study 27 SASS assessments were carried out at 15 sites during the low-flow survey in 2011 and the high-flow survey in 2012 and compared to historical data obtained from studies conducted by CRUZ (2000), O'Brien *et al*. (2005), Malherbe (2006), Carmanati (2008), Cloete *et al.* (2008), Ferreira *et al.* (2008), Malherbe *et al.* (2008), Stryftombolas (2008), O'Brien *et al.* (2009), O'Brien (2010a) and O'Brien (2010b). In total 98 SASS assessments, carried out at 30 sites throughout the study area during 12 surveys from 1999 to 2012, were considered. The SASS results (SASS scores and ASPT values) were analysed using the SASS data interpretation guidelines (Dallas, 2005; Dallas, 2007). The SASS interpretation guidelines are based on the location of the sites within the study area to broad Ecoregion Level I biomes (Kleynhans *et al*., 2005; Dallas, 2007). In this study the North Eastern Coastal Belt-Upper and Lower as well as the North Eastern Uplands-Lower biomes were used in order to assess the SASS results from the lower Amatikulu, Thukela and Umvoti Rivers. The ecological integrity state of macroinvertebrate communities sampled in the lower Amatikulu, Thukela and Umvoti Rivers were determined according to the classification set out by Kleynhans (1999) (Table 20).

Table 20: Classification system used to assess the macroinvertebrate community integrity state of the lower Amatikulu, Thukela and Umvoti Rivers with a description of each class, adopted from Kleynhans (1999)

Ecological category	Description of category	Acceptable / Unacceptable
A	Unmodified, natural state. macroinvertebrate communities compare with reference assemblages	Acceptable
B	Largely natural with few modifications. A small change in the natural habitats and macroinvertebrate communities have taken place but the ecosystem functions are essentially unchanged.	Acceptable
C	Moderately modified. Loss and change of natural habitats and moderate change in macroinvertebrate community structures, ecosystem functions are still predominantly unchanged.	Acceptable
D	Largely modified. A large loss of natural habitat and large change in macroinvertebrate community structures. Ecosystem functions are impaired.	Unacceptable
E	Seriously modified. Extensive loss in natural habitats and change to macroinvertebrate community structures. Ecosystem function disruptions are extensive.	Unacceptable
F	Critically or extremely modified. Modifications have reached a critical level resulting in almost complete loss of natural habitat and macroinvertebrate species. In worst cases basic ecosystem functions have been completely removed and changes may be irreversible.	Unacceptable

3.2.2. Macroinvertebrate Response Assessment Index (MIRAI)

The MIRAI approach or methodology was designed to provide a habitat-based cause-and-effect foundation to interpret the deviation of the aquatic macroinvertebrate community from pre-established reference conditions (Thirion, 2007). Macroinvertebrate data, collected by means of the SASS 5 protocol can be used to determine MIRAI (Thirion, 2007). The approach uses a multi-criteria decision analyses Microsoft® Excel-based model comprising several macroinvertebrate attribute metrics which allow for the evaluation of flow modifications, habitat availability and diversity, water quality and connectivity as well as seasonality (Thirion, 2007). Outcomes regarding the MIRAI assessment include the determination of the present ecological category of the macroinvertebrate community within the study area, relevant to each site, and then the assessment of flow and non-flow related impacts that may be influencing the state of the macroinvertebrate community (Thirion, 2007). The MIRAI index requires that reference macroinvertebrate community conditions, site selection and the method used to sample macroinvertebrate communities must be justified in order to validate the results.

In addition, assessments regarding the state of the habitat as well as other driver components such as water quality and sediment (Chapter 2) which may affect macroinvertebrate communities were also carried out. For the purpose of this study the reference macroinvertebrate communities used, was derived from communities observed at minimally impacted sites within the same Ecoregion level I biome as the sampling sites and historical data. Data used for the SASS assessment were also used for the MIRAI assessment. The habitat suitability for macroinvertebrates was assessed by considering the habitat availability, diversity and potential impacts to habitat state using the RHP's habitat approach presented in Dallas (2005). This included the use an Integrated Habitat Assessment System (IHAS) approach which was developed by McMillan (1998).

3.2.3. Multivariate statistical analyses

Multivariate statistical analyses techniques have been widely utilised to assess biological community structures and patterns in various ecosystems (Ter Braak, 1994; Van den Brink *et al.,* 2003; O'Brien *et al.,* 2009). A principal component analysis (PCA) approach, using Canoco for Windows Version 4.53 was used to statistically analyse all the data obtained from this study as well as historical data. The PCA is based on a linear response model relating species and environmental variables (Van den Brink *et al.,* 2003). The results of the ordination are illustrated as two-dimensional maps of the samples and variables that have been analysed and where the placements of the samples reflect the similarities or dissimilarities between the samples (O'Brien *et al.,* 2009). In order to determine which species, guilds or environmental variables were possibly responsible for the structure and groupings presented by the PCA maps, various redundancy analyses (RDAs) were conducted. For this study the species, guilds and physicochemical variables sampled were overlaid onto the original PCA. An RDA is a derivative of a PCA with one additional feature which, when using Canoco for Windows Version 4.53 (Ter Braak and Smilauer, 2004), allows for the selection of the driving variables that are intended to be overlaid onto the PCA (O'Brien *et al.,* 2009). The values that are entered into the RDA analyses are not the original data, but the best-fit values estimated from a multiple linear regression between each variable in turn and a second matrix of complementary biological or environmental data (O'Brien *et al.,* 2009). The represented RDA plots are then interpreted through two-dimensional bi-plots which present the similarities and dissimilarities between the samples analysed (Shaw, 2003; O'Brien *et al.,* 2009).

In the tri-plots that contain the overlaid environmental and species data, each arrow represents a variable and points in the direction of the steepest increase of values for the corresponding variable (O'Brien *et al.,* 2009). The angles between the arrows indicate the sign (+ or -) of the correlation between the variables where the approximated correlation is positive when the angle is acute and negative when the angle is larger than 90° (O'Brien *et al.,* 2009). The distance between the sampling sites in the diagram approximates the dissimilarity of the variables as measured by their Euclidean distance (Shaw, 2003; O'Brien *et al.,* 2009).

3.3. Results and Discussion

3.3.1. South African Scoring System (SASS) and Macroinvertebrate Response Assessment Index (MIRAI)

3.3.1.1. Amatikulu River

Results of the SASS and MIRAI findings of the lower Amatikulu, River between 2006 and 2012 are presented below in Table 21 and Figure 59. From the eight macroinvertebrate surveys carried out on the lower Amatikulu River, 45 taxa were found (Table 21). The diversity of taxa ranged from 28 (AR1 during 2006 low flow) to 8 (AR1 in 2012 high flow). This reflects the state of macroinvertebrate community integrity which ranged from natural or pristine (Class A) to seriously modified or impacted (Class D/E), as indicated by the SASS scores (Table 21) (Figure 59).

Table 21: Diversity and abundance of macroinvertebrates collected from the lower Amatikulu River during 2006 (06), 2011 (11) and 2012 (12) for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes

Macroinvertebrates	AR1-06H	AR1-06L	AR1-11L	AR1-12H	AR2-06H	AR2-06L	AR2-11L	AR2-12H
Aeshnidae	1	-	1	-	-	-	-	-
Ancylidae	-	1	-	-	-	-	-	-
Atyidae	204	16	-	84	281	5	1	1000
Baetidae	154	383	100	30	81	204	100	1000
Belostomatidae	1	-	-	3	4	-	-	10
Caenidae	-	12	10	-	-	1	1	-
Ceratopogonidae	-	2	10	-	-	-	10	-
Chironomidae	156	360	-	1	79	156	100	100
Coenagrionidae	5	10	10	5	8	-	100	100
Corbiculidae	-	-	-	-	-	-	10	-
Corixidae	-	-	-	-	-	-	10	-
Culicidae	1	-	-	-	81	-	-	-
Dytiscidae	-	-	-	-	-	-	10	-
Ecnomidae	-	1	-	-	-	1	-	-
Elmidae	5	4	-	-	-	-	-	1
Gerridae	-	-	-	-	-	-	10	-
Gomphidae	2	19	10	-	4	3	10	1
Gyrinidae	2	18	100	-	1	13	10	-
Heptageniidae	3	1	-	4	12	6	10	100
Hydracarina	-	-	-	-	-	-	1	1
Hydrophilidae	14	-	-	-	-	-	-	-
Hydropsychidae	-	58	-	-	-	14	-	10
Leptoceridae	15	93	-	-	13	6	-	-
Leptophlebidae	9	-	1	-	-	5	-	-
Lestidae	1	-	10	-	-	-	10	-
Libellulidae	2	-	1	-	3	-	10	-
Lymnaeidae	1	1	-	-	-	-	100	-
Notonectidae	-	-	-	-	-	-	10	-
Oligochaeta	-	4	-	1	-	-	100	1000
Oligoneuridae	-	1	-	-	-	-	-	-
Palaemonidae	-	-	-	-	-	-	1	-
Parecnomina	2	4	-	-	-	-	-	-
Perlidae	15	20	-	-	9	-	-	10
Philopotamidae	3	7	-	-	3	5	-	-
Planorbidae	-	-	-	-	1	-	-	-
Potamonautidae	2	3	-	-	1	-	-	-
Psephenidae	-	-	-	-	-	-	-	1
Psychodidae	-	2	-	-	-	-	-	1
Pyralidae	-	-	-	-	-	-	-	1
Simuliidae	24	15	1	-	22	134	10	-
Tabanidae	-	2	-	-	-	-	1	-
Teloganodidae	-	1	-	-	-	-	-	-
Thiaridea	8	32	-	-	34	1	10	-
Tipulidae	1	1	-	-	-	-	-	-
Veliidae	2	7	-	4	1	-	-	10
NO. OF TAXA	26	28	11	8	18	14	23	16
SASS SCORE	150	171	72	40	103	98	129	101
ASPT	5.77	6.11	6.55	5.00	5.72	7.00	5.61	6.31
SASS CLASS	A	A	B/C	D/E	C	B	B	C
MIRAI SCORE	84.0994	84.3333	63.966	62.9177	77.7667	73.5033	77.6953	77.9625
MIRAI CLASS	B	B	C	C	C	C	C	C

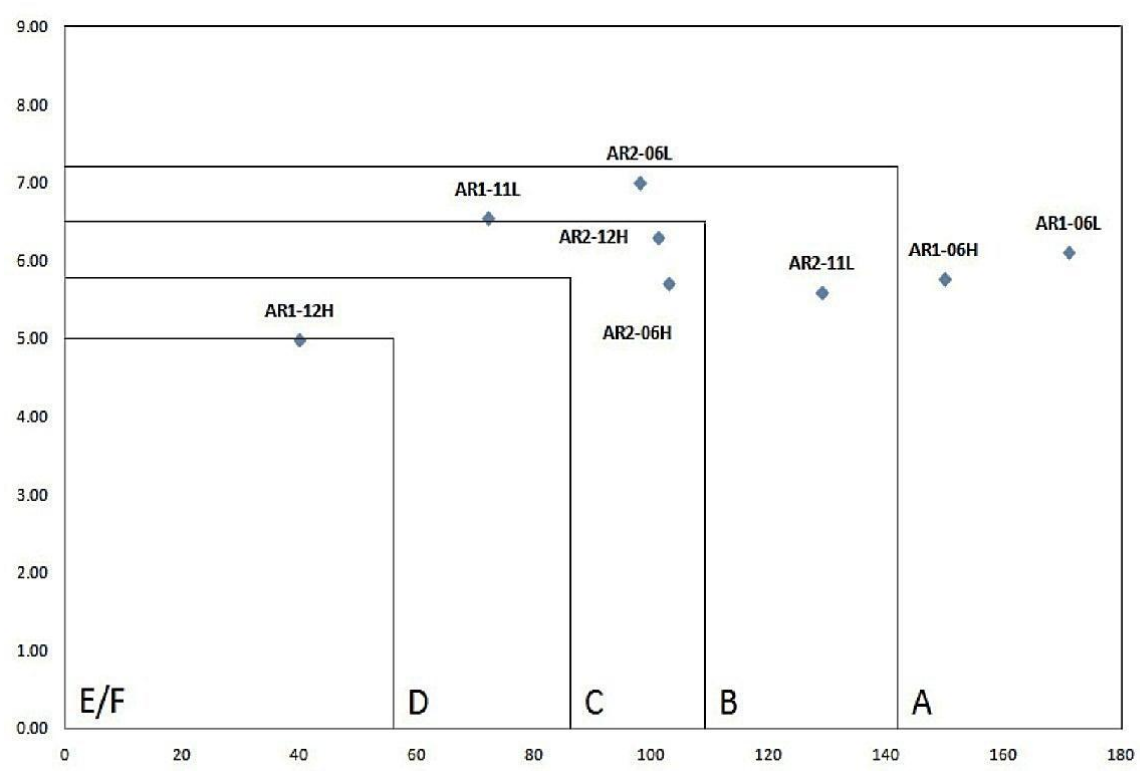


Figure 59: Historical and current average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (y axis) plotted relationships for the lower Amatikulu River (AR) with integrity category bands from North Eastern Coastal Belt – Lower zone reference data, adopted from Dallas (2007)

Trends regarding the SASS scores (Figure 60) indicate that during 2006 AR1 had better scores than AR2, but in 2011 and 2012 this trend was reversed and better scores were observed at AR2 than at AR1. Carminati (2008) found that the better SASS scores of AR1 compared to AR2 during 2006 was due to the fact that the stones biotope was absent at site AR2. This was caused by increased sedimentation from water abstraction by the Amatikulu Sugar Mill which also caused flow modifications. The trend further shows that the macroinvertebrate community structure of AR1 deteriorated from natural (Class A) in 2006 to seriously modified (Class D/E) in 2012. The SASS scores of AR2 were fairly stable and ranged from largely natural with a few modifications (Class B) to moderately modified (Class C) between 2006 and 2012. During 2011 and 2012 site AR1 was dominated by vegetation and GSM biotopes while site AR2 consists out of all three biotopes including stones, vegetation and GSM. Impacts associated with sugarcane agricultural activities and water abstraction which resulted in flow modifications and increased sedimentation caused site AR1 to be dominated by GSM. This caused the reversed trend observed in Figure 60. SASS scores of both sites AR1 and AR2 decreased between 2011 and 2012.

Decreasing oxygen levels together with increasing COD levels and chloride loads could caused the macroinvertebrate community integrity state to deteriorate between 2011 and 2012. Findings show that although the IHAS scores of the Amatikulu River increased between 2011 and 2012 it did not resulted in better SASS scores.

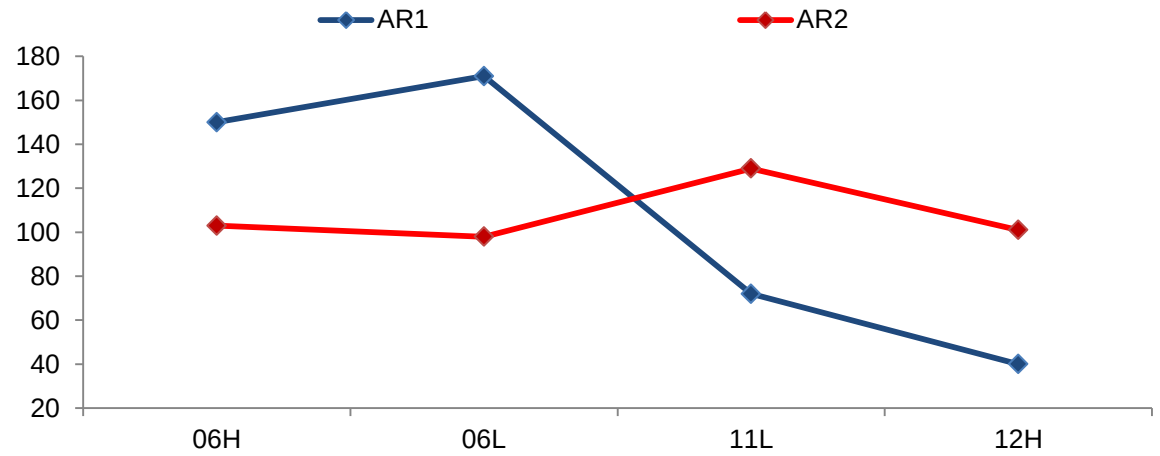


Figure 60: Trends of the South African Scoring System (SASS) scores (x axis) during 2006 (06), 2011 (11) and 2012 (12) collected from the lower Amatikulu River (AR1 and AR2) during high (H) and low (L) flow sampling surveys (y axis)

Results from MIRAI ranged between largely natural with a few modifications (Class B) and moderately modified (Class C) (Table 21). Site AR1 was found to be in a Class B state during 2006 whereafter it went to a Class C in 2011 and 2012 while AR2 was found to be in a Class C state between 2006 and 2012. Findings revealed that the general trends of the MIRAI scores (Figure 61) were similar to those of the SASS scores. MIRAI trends suggest that AR1 and AR2 stayed fairly stable (Class C) between 2011 and 2012. Both trends of the SASS and MIRAI scores showed a decreasing trend, which indicate that the macroinvertebrate community structures of the lower Amatikulu River have deteriorated between 2006 and 2012. This is the result of impaired habitat availability and state in the lower Amatikulu River.

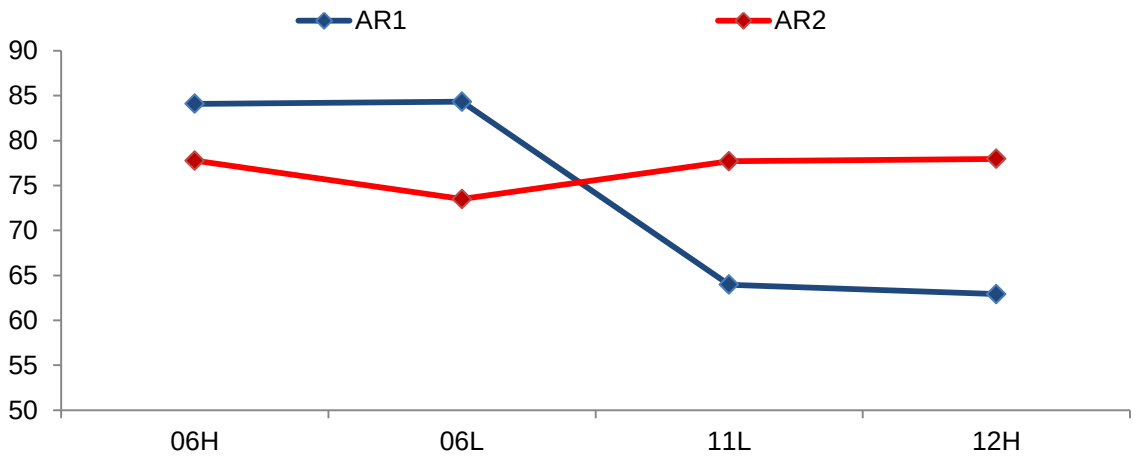


Figure 61: Trends of the Macroinvertebrate Response Assessment Index (MIRAI) scores (x axis) during 2006 (06), 2011 (11) and 2012 (12) collected from the lower Amatikulu River (AR1 and AR2) during high (H) and low (L) flow sampling surveys (y axis)

3.3.1.2. Thukela River

Results of the SASS and MIRAI findings of the lower Thukela, Nembe and eMandeni Rivers between 2005 and 2012 are presented below in Table 22-Table 24 and Figure 62-Figure 63. From 43 macroinvertebrate assessments carried out in the lower Thukela, Nembe and eMandeni Rivers between 2005 and 2012, a total of 63 taxa were found (Table 22-Table 24). The most taxa collected at a site was 34 at NR1 (Nembe River) in 2011 and the least were collected from the Thukela River at site TR4 during the 2006 low-flow period when no macroinvertebrates were found. The macroinvertebrate community integrity or state ranged from natural (Class A) to seriously modified (Class E/F) according to SASS scores (Table 22-Table 24) (Figure 62 and Figure 63). Results clearly show that better SASS scores obtained from the upper reaches of the Thukela River at sites TR1 and TR2 (between 2005 and 2006) as well as on the Nembe River and were found to be in a natural (Class A) state. SASS scores of the lower reaches of the Thukela River (sites TR3 – TR6) were generally found to be in a largely modified (Class D) state. Lower SASS scores are expected at the lower Thukela River sites (TR3-TR6) as they are naturally characterised to be dominated by sandy habitats and the absence of the stones biotope. For the eMandeni River, SASS scores of the majority of the sites were in a seriously modified (Class E/F) state except for site ER1 which ranged between moderately modified (Class C) state to a largely modified (Class D) state. Poor water quality contributed to the low SASS scores of the eMandeni River. The poor water quality of the eMandeni River together with combined impacts, including effluent discharges from Sappi, affects the macroinvertebrate community structure in the vicinity of sites TR4 and TR5 on the Thukela River.

Table 22: Diversity and abundance of macroinvertebrates where available between 2005 (05) and 2012 (12) from the lower Thukela (TR1 and TR2) and Nembe (NR1) Rivers for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes. The 'x' indicates presence of macroinvertebrates where abundance data were not available.

Macroinvertebrates	NR1-11L	NR1-12H	TR1-05L	TR1-06L	TR2-05L	TR2-06L	TR2-08L	TR2-10H(1)	TR2-10H(2)	TR2-11L	TR2-12H	TR3-11L	TR3-12H
Aeshnidae	1	-	-	-	-	-	-	-	-	1	-	1	-
Atyidae	100	10	10	10	10	10	x	100	1000	10	143	10	147
Baetidae	1000	1000	15	15	15	15	x	100	100	1000	100	10	2
Belostomatidae	-	10	-	-	-	-	-	-	-	-	-	1	-
Caenidae	10	-	-	10	10	10	-	-	-	10	-	-	-
Calopterygidae	-	10	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	-	-	-	5	5	-	-	-	1	-	-	-	-
Chironomidae	10	100	5	5	5	5	x	-	-	100	-	1	-
Chlorocyphidae	10	1	-	-	10	-	x	-	-	-	-	-	-
Coenagrionidae	100	1	5	-	5	-	x	10	1	-	-	1	-
Corbiculidae	-	-	5	5	5	-	-	1	100	-	-	-	-
Corixidae	1	-	-	-	-	-	-	-	10	1	-	10	-
Culicidae	-	-	-	5	-	-	-	-	-	1	-	-	-
Dytiscidae	-	-	5	-	5	5	-	-	-	-	-	10	-
Ecnomidae	10	-	-	-	-	-	-	-	1	-	-	-	-
Elmidae	-	-	-	-	-	-	-	-	-	1	2	-	-
Gerridae	10	-	-	-	5	-	x	-	100	1	1	-	-
Gomphidae	10	100	-	10	10	10	x	10	1	100	1	100	-
Glossomatidae	10	-	-	-	-	-	-	-	-	-	-	-	-
Gyrinidae	10	1	5	5	5	5	-	-	100	10	-	10	-
Heptageniidae	100	10	15	15	15	15	-	-	-	-	-	-	-
Hydraenidae	10	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsychidae	100	100	15	15	15	15	-	1	-	-	19	-	-
Leptoceridae	100	-	5	-	5	5	-	-	1	10	-	-	-
Leptophlebidae	100	-	5	-	5	5	-	10	-	100	-	-	-
Libellulidae	1	-	5	-	5	-	-	1	1	10	-	-	1
Lymnaeidae	1	-	-	-	-	-	-	-	-	-	-	-	-
Muscidae	-	-	-	-	5	5	-	-	-	-	-	-	-
Naucoridae	-	-	-	10	-	-	-	1	-	-	-	-	-
Nepidae	100	-	-	-	-	-	-	-	-	-	-	-	-
Notonectidae	1	-	-	-	-	-	-	10	100	-	-	-	-
Oligochaeta	10	100	-	-	5	5	x	100	-	1	3	-	-
Palaemonidae	-	-	10	-	10	-	x	1000	100	100	-	-	-
Perlidae	10	100	15	15	15	15	-	10	-	10	-	-	-
Petrothrincidae	-	-	-	15	15	-	-	-	-	-	-	-	-
Philopotamidae	1	-	-	15	15	-	-	-	-	-	-	-	-
Pleidae	-	-	-	-	-	-	-	-	-	-	9	-	-
Polymitarcyidae	-	-	-	15	-	-	-	-	-	-	-	-	-
Porifera	1	-	5	-	5	-	-	-	-	-	-	-	-
Potamonautidae	10	-	-	-	5	-	x	10	100	-	-	-	-
Prosopistomatidae	-	-	15	15	15	15	-	10	-	10	1	-	-
Psephenidae	10	10	-	-	-	-	-	-	-	-	-	-	-
Psychodidae	-	10	-	-	-	-	-	-	-	-	1	-	-
Psychomyiidae	-	-	-	-	-	-	-	1	-	-	-	-	-
Pyralidae	-	10	-	-	-	-	-	-	-	-	1	-	-
Simuliidae	10	-	5	5	5	5	x	1	100	100	-	10	-
Synlestidae	1	-	-	-	-	-	-	-	-	-	-	-	-
Tabanidae	10	10	-	-	5	-	-	-	-	-	1	-	-
Teloganodidae	10	-	-	-	-	-	-	-	-	-	-	-	-
Thiaridea	-	-	-	-	5	5	x	1001	1001	-	-	-	-
Tipulidae	1	1	-	-	-	-	-	-	-	-	-	-	-
Tricorythidae	-	-	-	10	10	10	-	-	-	-	-	-	-
Veliidae	100	10	5	-	5	-	x	100	100	10	1	10	23
NO. OF TAXA	34	19	18	19	31	18	13	19	18	20	13	12	4
SASS SCORE	224	122	142	151	212	135	72	114	100	131	86	66	21
ASPT	6.59	6.42	7.89	7.95	6.84	7.50	5.54	6.00	5.56	6.55	6.62	5.50	5.25
SASS CLASS	A	A	A	A	A	A	D	B	C	B	B	D	D
MIRAI SCORE	91.9119	79.6218	77.4763	82.7525	76.2147	67.1811	-	72.0441	71.0212	73.5652	70.2595	59.6172	50.6645
MIRAI CLASS	A	B	C	B	C	C	-	C	C	C	C	C	D

Table 23: Diversity and abundance of macroinvertebrates where available between 2005 (05) and 2012 (12) from the lower Thukela River (TR4 – TR6) for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes. The 'x' indicates presence of macroinvertebrates where abundance data were not available.

Macroinvertebrates	TR4-05L	TR4-06L	TR4-08L	TR4-10H(1)	TR4-10H(2)	TR5-05L	TR5-06L	TR5-08L	TR5-10H(1)	TR5-10H(2)	TR5-11L	TR5-12H	TR6-05L	TR6-06L
Aeshnidae	-	-	-	-	-	-	-	-	-	1	1	-	-	-
Ancylidae	-	-	-	-	10	10	-	-	-	-	-	-	10	-
Atyidae	-	-	-	100	1000	10	10	x	100	1000	-	225	10	10
Baetidae	-	-	-	10	100	15	15	x	100	100	10	34	15	15
Belostomatidae	-	-	-	-	-	5	-	-	-	1	1	-	-	-
Caenidae	-	-	-	-	-	-	10	-	-	1	-	-	-	-
Ceratopogonidae	5	-	-	-	-	5	-	-	-	-	-	-	-	5
Chironomidae	5	-	x	100	-	5	5	x	1001	100	100	-	5	5
Coenagrionidae	-	-	-	10	100	5	-	-	-	100	10	1	5	-
Corixidae	-	-	-	-	-	5	-	x	-	-	-	-	-	-
Culicidae	-	-	-	-	-	5	-	x	100	-	10	-	5	5
Dytiscidae	-	-	-	-	100	-	-	-	1	100	-	-	-	-
Gerridae	-	-	-	10	10	-	-	-	10	-	-	1	-	-
Gomphidae	-	-	-	1	100	-	-	x	-	10	100	5	10	10
Gyrinidae	-	-	-	-	10	-	-	x	100	100	1	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	5	-
Leptoceridae	-	-	-	1	10	-	5	-	-	-	-	-	-	-
Libellulidae	-	-	-	-	-	-	-	-	-	-	1	3	5	-
Naucoridae	-	-	-	-	100	10	-	-	-	10	-	-	10	-
Notonectidae	-	-	-	-	-	-	-	-	10	-	-	-	5	-
Oligochaeta	5	-	-	-	-	5	-	-	-	-	-	-	5	5
Palaemonidae	-	-	-	100	100	-	-	-	-	1000	-	-	-	-
Physidae	-	-	-	-	-	5	-	-	-	-	-	-	5	5
Potamonautidae	-	-	-	10	100	5	-	-	10	100	-	4	5	-
Simuliidae	5	-	-	-	-	5	-	-	-	-	-	-	-	-
Thiaridea	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Veliidae	-	-	-	1000	1000	5	5	-	10	100	1	16	5	5
NO. OF TAXA	4	0	1	11	13	15	6	7	10	14	10	8	15	9
SASS SCORE	12	0	2	59	82	62	33	31	43	78	50	39	62	37
ASPT	3.00	0.00	2.00	5.36	6.31	4.13	5.50	4.43	4.30	5.57	5.00	4.88	4.13	4.11
SASS CLASS	E/F	E/F	E/F	D	C	D	D	E/F	E/F	D	D/E	E/F	D	E/F
MIRAI SCORE	43.7679	-	-	60.5661	65.1485	57.9778	56.1467	-	60.4245	64.9702	57.7518	56.4481	58.5536	56.3885
MIRAI CLASS	D	-	-	C	C	D	D	-	C	C	D	D	D	D

Table 24: Diversity and abundance of macroinvertebrates where available between 2005 (05) and 2012 (12) from the lower eMandeni River (ER1 – ER4) for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes. The 'x' indicates presence of macroinvertebrates where abundance data were not available.

Macroinvertebrates	ER1-11L	ER1-12H	ER2-05L	ER2-06L	ER2-08L	ER3-05L	ER3-06L	ER3-08L	ER3-10H(1)	ER3-10H(2)	ER3-11L	ER3-12H	ER4-10H(1)	ER4-10H(2)	ER4-11L	ER4-12H
Aeshnidae	1	-	-	-	-	10	-	-	-	1	10	1	-	-	-	1
Atyidae	1000	60	-	-	-	10	-	-	-	-	-	67	-	-	-	100
Baetidae	1000	-	15	-	-	15	-	-	-	10	1	8	100	10	10	10
Belostomatidae	-	-	-	-	-	5	5	-	1	1000	1	9	10	10	-	-
Ceratopogonidae	1	-	-	-	-	-	-	-	-	-	-	-	10	1	1000	-
Chironomidae	1000	-	5	5	x	5	5	x	1001	1001	1000	2	100	100	1000	-
Coenagrionidae	100	3	-	-	x	5	5	-	-	-	1000	12	100	10	100	17
Corixidae	10	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-
Culicidae	-	-	5	5	-	5	5	x	100	1000	10	-	-	-	1000	-
Dytiscidae	100	-	5	-	-	-	-	-	-	10	10	2	10	100	10	-
Elmidae	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-
Gerridae	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Gomphidae	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Gyrinidae	10	-	-	-	-	-	-	-	-	-	10	-	1	10	-	-
Helodidae	-	-	-	-	-	15	15	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	5	-	-	-	-	100	5	1001	1000	100	3
Hydracarina	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Hydrophilidae	-	-	5	-	-	-	-	-	-	10	-	-	-	-	-	-
Hydropsychidae	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	2
Leptoceridae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lestidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Libellulidae	10	2	5	-	-	5	-	-	-	-	100	-	-	-	1	-
Lymnaeidae	-	-	-	-	-	-	-	-	-	-	-	-	-	10	1000	-
Muscidae	-	-	-	-	-	-	-	-	-	10	-	-	1	-	-	-
Naucoridae	-	-	10	-	-	10	-	-	-	100	-	-	10	100	-	-
Nepidae	-	-	-	-	-	-	5	-	-	1	-	-	-	-	1	-
Notonectidae	-	-	5	-	-	-	-	-	-	-	-	-	10	-	-	-
Oligochaeta	-	1	5	-	x	-	5	-	-	-	100	10	1000	1000	1000	1000
Palaemonidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Philopotamidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physidae	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-
Planorbidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamonautidae	1000	3	-	-	-	5	5	x	-	10	10	5	10	-	10	11
Psychomyiidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sericostomatidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	1000	-	-	5	x	-	-	-	-	-	-	-	1001	1000	100	-
Syrphidae	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-
Tabanidae	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Thiaridea	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Veliidae	-	-	-	-	x	-	-	-	1	-	-	-	10	-	-	9
NO. OF TAXA	17	9	9	4	5	12	9	3	4	12	13	12	17	13	14	12
SASS SCORE	92	51	32	9	15	59	37	7	11	49	48	51	62	60	48	58
ASPT	5.41	5.67	3.56	2.25	3.00	4.92	4.11	2.33	2.75	4.08	3.69	4.25	3.65	4.62	3.43	4.83
SASS CLASS	C	D	E/F	E/F	E/F	D	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	D/E
MIRAI SCORE	66.1052	56.9086	55.7721	50.7492	-	57.2004	59.1181	-	48.337	65.1085	61.7583	55.4662	65.4727	63.0385	63.9614	60.4997
MIRAI CLASS	C	D	D	D	-	D	D	-	D	C	C	D	C	C	C	C

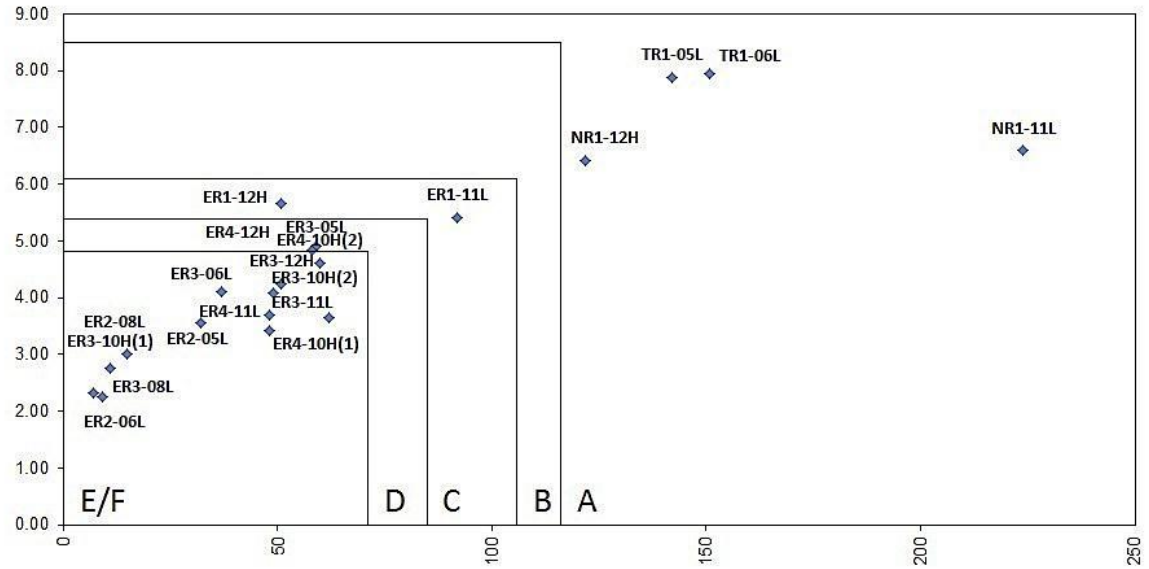


Figure 62: Historical and current average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (y axis) plotted relationships for the lower Thukela (TR), Nembe (NR) and eMandeni (ER) Rivers with integrity category bands from North Eastern Uplands – Lower zone reference data, adopted from Dallas (2007)

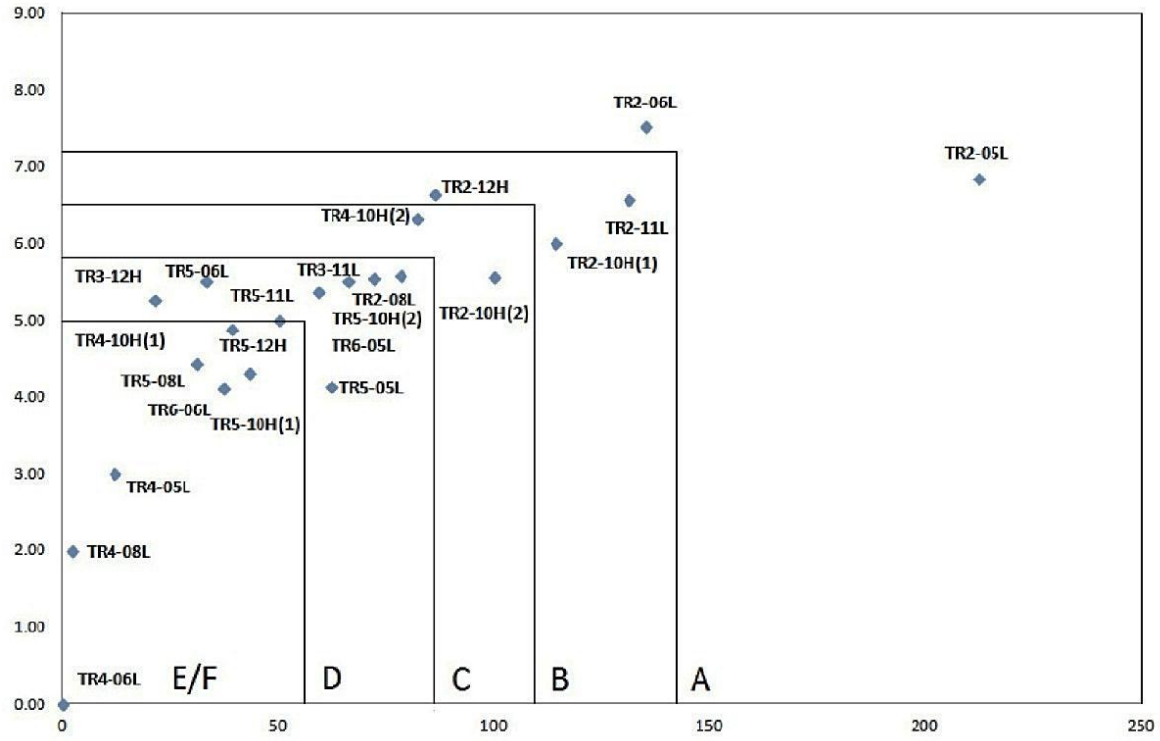


Figure 63: Historical and current average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (y axis) plotted relationships for the lower Thukela (TR), Nembe (NR) and eMandeni (ER) Rivers with integrity category bands from North Eastern Coastal Belt – Lower zone reference data, adopted from Dallas (2007)

Trends regarding the SASS scores (Figure 64) revealed that SASS scores generally decreased from 2005 towards 2008 and then slightly recovered from 2008 to 2011 whereafter they decreased again towards 2012. The decreasing trend of SASS scores between 2011 and 2012 is caused by deteriorating water quality of the lower Thukela, Nembe and eMandeni Rivers. Studies done by Stryftombolas (2008) and O'Brien (2010a) also found that impaired water quality caused SASS scores of the eMandeni River to deteriorate. The trends further indicate that the temporal SASS scores fluctuate noticeably and that there is no clear evidence that the state of the macroinvertebrate communities generally decreases during low-flow periods and recovers in the high-flow periods.

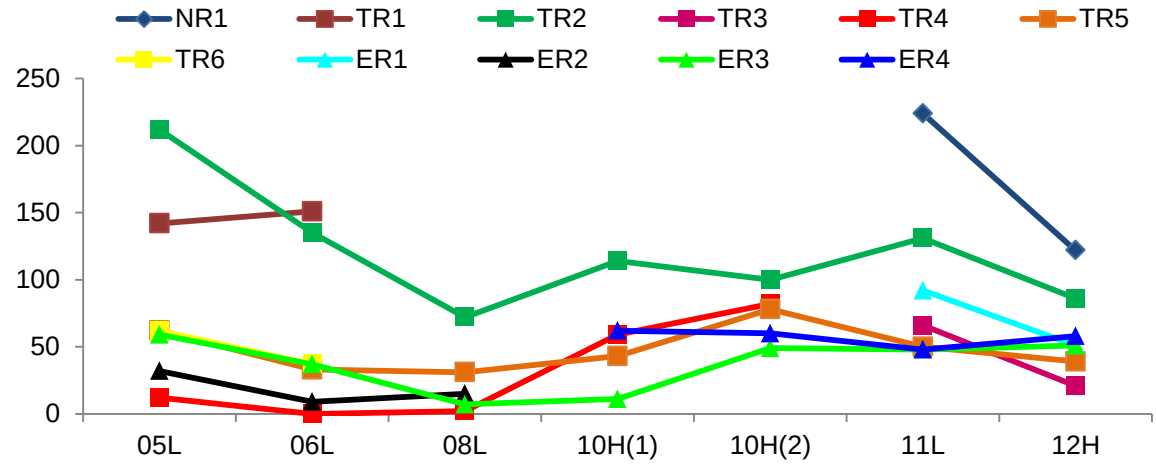


Figure 64: Trends of the South African Scoring System (SASS) scores (x axis) where available between 2005 (05) and 2012 (12) collected from the lower Thukela (TR1 – TR6), Nembe (NR1) and eMandeni (ER1 – ER4) Rivers during high (H) and low (L) flow sampling surveys (y axis)

The MIRAI assessment scores revealed that the Nembe River ranged between a natural (Class A) state (NR1 in 2011) to a largely natural with a few modifications (Class B) state (NR1 in 2012) where the rest of the upper reaches on the Thukela River (sites TR1 and TR2) were generally found to be in a moderately modified (Class C) state (Table 22). For the lower reaches of the Thukela River (TR3 – TR6) the MIRAI scores ranged between a moderately modified (Class C) to a largely modified (Class D) state. The majority of these sites were in a Class D state. The eMandeni River (ER1 – ER4) was generally also found to range between a moderately modified (Class C) to a largely modified (Class D) state (Table 24). Results suggest that the general trends of the MIRAI scores (Figure 65) were similar to those of the SASS scores (Figure 64); however, fluctuations were not as evident and more stable in comparison to the trends regarding the SASS scores.

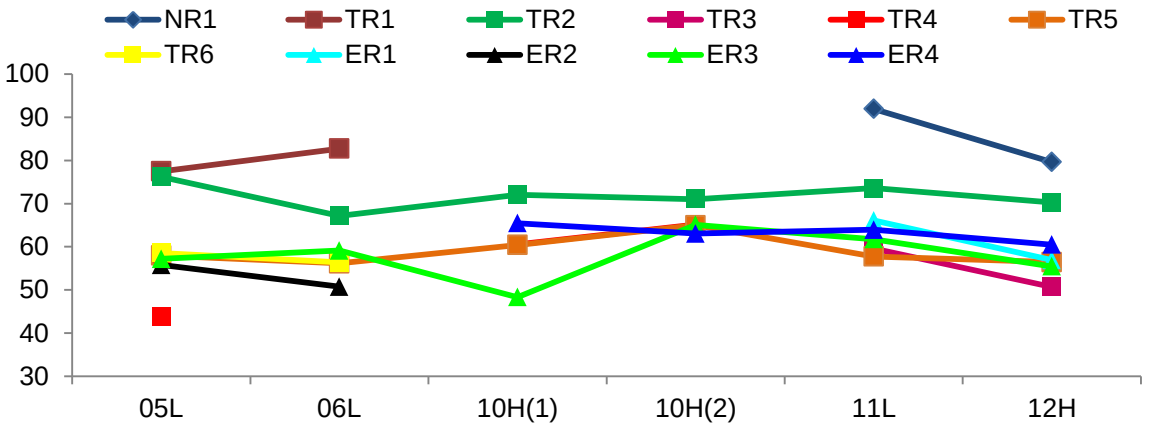


Figure 65: Trends of the Macroinvertebrate Response Assessment Index (MIRAI) scores (x axis) where available between 2005 (05) and 2012 (12) collected from the lower Thukela (TR1 – TR6), Nembe (NR1) and eMandeni (ER1 – ER4) Rivers during high (H) and low (L) flow sampling surveys (y axis)

3.3.1.3. Umvoti River

Results of the SASS and MIRAI findings of the lower Umvoti, Hlimbitwa and Nchaweni Rivers between 1999 and 2012 are presented below in Table 25-Table 26 and Figure 66-Figure 67. A total of 68 taxa were observed from 48 macroinvertebrate assessments carried out on the lower Umvoti, Hlimbitwa and Nchaweni Rivers between 1999 and 2012 (Table 25 and Table 26). The most taxa collected at a site were 31 taxa from site UR1 on the Umvoti River during the low-flow period in 2005 and the high-flow period in 2010 while the least were collected from the Nchaweni River at site NS2 during the second high-flow survey in 2010. This reflects the range of macroinvertebrate community states from natural or pristine (Class A) to seriously modified or impacted (Class E/F), as indicated by the SASS scores (Table 25 and Table 26) (Figure 66 and Figure 67). Findings revealed that consistently better SASS scores were obtained from the upper reaches of the Umvoti River at sites UR1 and UR2 as well as on the Hlimbitwa River. These sites ranged between a natural (Class A) state and a largely natural with a few modifications (Class B) state. These upper sites consist out of diverse habitats and fairly good water quality. The middle reaches of the Umvoti River (UR3 and UR4) were characterised by largely natural with a few modifications (Class B) and largely modified (Class D) states while the lower reaches (UR5–UR8) were generally in a largely modified (Class D) state. Lower SASS scores are expected from sites UR5-UR8 as they are dominated by vegetation and GSM biotopes.

The Nchaweni River (sites NS1 and NS2) was consistently found to be in a seriously modified or impacted (Class E/F) state except for NS2 during the low-flow period in 2005 which was in a Class D state. This is a result of the poor water quality caused by the effluent discharges of the Gledhow Ushukela sugar and Sappi Stanger pulp and paper mills. Previous studies done by Malherbe (2006), Carminati (2008) and O'Brien *et al*. (2010b) all found that the cumulative impacts from the Nchaweni River negatively affected the macroinvertebrate community structures of the lower Umvoti River in the vicinity of sites UR4 and UR5 which are situated below the confluence between the Umvoti and the Nchaweni Rivers.

Table 25: Diversity and abundance of macroinvertebrates where available between 1999 (99) and 2012 (12) from the lower Umvoti (UR1 – UR5) and Hlimbitwa (HR1) Rivers for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes. The 'x' indicates presence of macroinvertebrates where abundance data were not available.

Macroinvertebrates	HR1-11L	HR1-12H	UR1-05H	UR1-05L	UR1-10H	UR2-12H	UR3-06H	UR3-06L	UR4-06H	UR4-06L	UR5-99H	UR5-00L	UR5-04L	UR5-05H	UR5-05L	UR5-06H	UR5-06L	UR5-08L	UR5-10H(1)	UR5-10H(2)	UR5-11L	UR5-12H
Aeshnidae	100	-	-	-	10	-	-	-	-	-	x	-	1	-	1	-	-	-	-	-	10	-
Amphipoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Athericidae	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atyidae	10	-	5	1	100	10	9	-	-	-	x	x	-	10	34	11	17	x	10	100	100	22
Baetidae	1000	100	46	271	1000	1000	10	90	10	21	x	x	150	30	248	6	82	-	100	100	100	23
Belostomatidae	-	100	1	-	10	10	-	-	3	1	x	-	-	-	-	2	-	-	-	-	10	-
Caenidae	-	-	-	27	-	-	-	-	-	1	x	x	-	-	1	-	1	-	-	1	-	-
Calopterygidae	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	10	-	-	2
Ceratopogonidae	10	-	1	2	10	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Chironomidae	10	1	50	99	100	-	86	120	56	24	x	x	-	6	18	65	135	-	-	100	-	-
Chlorocyphidae	-	-	-	4	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coenagrionidae	10	10	2	20	10	10	6	10	-	8	x	x	1	8	3	-	3	-	1	-	10	-
Corduliidae	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Corixidae	100	-	-	1	100	-	-	-	-	-	x	x	-	-	-	-	-	x	1	10	-	-
Culicidae	-	-	-	7	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Dytiscidae	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	10	-	-	-
Ecnomidae	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elmidae	10	10	1	83	1	10	1	9	4	6	-	-	-	-	-	-	-	-	-	-	-	-
Ephydridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Gerridae	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	100	100	-	-
Gomphidae	100	10	-	3	100	10	-	-	-	4	x	x	1	1	-	-	-	x	100	1	100	-
Gyrinidae	1000	-	-	-	10	10	4	3	-	4	-	x	-	-	-	-	1	-	-	-	10	-
Heptageniidae	100	10	2	3	10	10	2	3	7	-	x	x	-	-	-	1	-	-	-	-	-	1
Hydraenidae	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	2	-	-	-	-	-
Hydrophilidae	-	-	-	2	-	-	1	-	-	-	-	-	-	-	1	-	-	x	-	-	-	-
Hydropsychidae	100	100	57	571	1000	100	-	93	10	17	-	-	-	-	-	-	-	-	-	-	-	-
Hydroptilidae	-	-	-	-	-	-	-	-	-	1	-	x	-	-	-	-	-	-	-	-	-	-
Lepidostomatidae	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leptoceridae	100	-	-	5	10	-	2	29	1	1	-	-	-	-	1	-	-	-	-	-	-	-
Leptophlebidae	10	-	-	17	10	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Libellulidae	100	1	-	9	100	-	-	5	1	2	-	x	-	-	1	-	-	-	-	1	10	-
Limnichidae	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Lymnaeidae	-	-	-	1	-	-	2	-	-	-	-	-	-	-	3	-	-	x	-	-	-	-
Muscidae	-	-	-	-	10	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Naucoridae	-	-	-	-	10	-	2	-	1	-	-	-	1	2	-	-	-	x	-	-	1	-
Nepidae	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Notonectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	100	-	-	-
Oligochaeta	-	-	17	11	10	10	-	1	-	-	x	x	1	10	4	-	1	-	-	-	-	1
Oligoneuridae	-	-	2	-	-	1	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-
Palaemonidae	-	-	-	-	1	-	-	-	-	-	-	-	6	-	2	-	-	-	100	100	-	2
Perlidae	-	100	35	38	100	100	-	-	5	3	-	-	-	-	-	-	-	-	-	-	-	-
Philopotamidae	10	-	-	1	10	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physidae	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Pisuliidae	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planorbidae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Polymitarcyidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Potamonautidae	100	-	-	1	10	-	-	-	2	-	x	x	-	-	7	-	-	-	10	1	1	-
Protoneuridae	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Psephenidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Psychodidae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Pyralidae	-	1	-	4	1	-	-	2	-	3	-	-	-	-	1	-	-	-	-	-	-	2
Sericostomatidae	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	100	-	-	27	10	-	1	21	6	11	-	-	7	-	-	-	-	-	-	-	-	-
Sphaeriidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Synlestidae	100	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1	-	-	-	-	-
Tabanidae	100	10	2	5	10	100	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Tanaidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Teloganodidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Thiaridea	-	-	-	-	-	-	-	-	4	2	-	-	3	141	49	-	-	-	-	-	-	-
Tipulidae	-	100	3	5	1	10	-	1	-	1	-	-	1	-	1	-	-	-	-	-	-	-
Turbellaria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-
Tricorythidae	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Veliidae	-	100	4	41	10	100	-	-	9	-	x	x	-	5	5	7	3	-	10	10	10	10
NO. OF TAXA	23	14	16	31	31	16	12	16	17	19	15	17	12	10	23	6	13	7	12	13	12	9
SASS SCORE	163	99	113	185	195	115	76	97	121	113	84	88	77	50	143	37	70	36	74	73	68	73
ASPT	7.09	7.07	7.06	5.97	6.29	7.19	6.33	6.06	7.12	5.95	5.60	5.18	6.42	5.00	6.22	6.17	5.38	5.14	6.17	5.62	5.67	8.11
SASS CLASS	B	B	B	A	A	B	C	C	B	B	D	C	C	D	A	C	D	D	C	D	D	A
MIRAI SCORE	78.6957	70.2797	72.6761	82.7511	81.9692	84.878	68.7821	80.5924	75.7297	79.2194	-	-	58.117	53.3599	68.3158	61.6634	57.6999	-	60.686	60.8198	59.9269	64.1314
MIRAI CLASS	C	C	C	B	B	B	C	B	C	C	-	-	D	D	C	C	D	-	C	C	C	C

Table 26: Diversity and abundance of macroinvertebrates where available between 1999 (99) and 2012 (12) from the lower Umvoti (UR6 – UR8) and Nchaweni (NS1 and NS2) Rivers for high (H) and low (L) flow surveys with SASS Scores, SASS Classes, MIRAI Scores and MIRAI Classes. The 'x' indicates presence of macroinvertebrates where abundance data were not available.

Macroinvertebrates	UR6-05H	UR6-05L	UR6-08L	UR7-99H	UR7-00L	UR7-04L	UR7-05H	UR7-05L	UR7-08L	UR7-10H(1)	UR7-10H(2)	UR7-11L	UR7-12H	UR8-99H	UR8-00L	UR8-04L	NS1-05H	NS1-05L	NS1-10H	NS1-12H	NS2-05H	NS2-05L	NS2-10H(1)	NS2-10H(2)	NS2-11L	NS2-12H
Aeshnidae	-	-	-	x	x	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-
Ancylidae	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atyidae	-	74	-	x	x	-	28	9	-	10	10	-	105	x	x	-	1	-	-	-	-	-	-	-	-	10
Baetidae	23	20	x	x	x	-	59	3	-	-	100	100	44	-	x	-	-	-	100	1000	-	-	-	-	-	100
Belostomatidae	1	1	-	x	-	-	1	-	x	-	10	-	-	x	x	2	-	-	10	10	-	-	-	10	100	100
Caenidae	-	2	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	-	-	-	x	x	-	-	-	-	-	-	10	-	-	x	-	-	-	10	-	-	-	-	-	-	-
Chironomidae	18	10	-	x	x	52	2	280	x	100	100	100	3	x	x	53	2	46	1001	1000	35	2091	1	10	1000	1000
Coenagrionidae	3	1	-	-	x	-	-	-	-	-	-	100	14	-	-	-	-	-	1	1	-	-	-	-	-	-
Corixidae	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	10	-	-	-	-	-	-	-
Culicidae	1	-	-	-	-	-	-	-	x	100	-	-	-	-	-	-	-	1	1000	-	-	-	-	-	100	-
Dixidae	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dytiscidae	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	5	2	-	-	1	-	-	-	-	-
Ecnomidae	-	-	-	-	-	1	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Elmidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Ephydridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Gerridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	100	-
Gomphidae	-	2	-	x	x	-	-	2	-	-	-	10	2	x	x	-	-	-	1	-	-	-	-	-	-	-
Gyrinidae	-	1	-	x	-	-	-	-	x	-	10	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heptageniidae	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	51	6	-	10	-	-	-	-	-	-
Hydrophilidae	-	1	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsychidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
Hydroptilidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Libellulidae	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Lymnaeidae	-	-	x	-	x	-	-	-	-	-	-	-	-	-	x	-	1	1	-	-	1	-	-	-	-	-
Muscidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-
Naucoridae	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Notonectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	10
Oligochaeta	3	3	-	x	x	12	-	10	-	-	-	-	-	x	x	50	249	128	-	1000	202	98	-	-	-	100
Palaemonidae	-	-	-	-	-	-	-	-	-	10	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physidae	-	-	-	-	-	55	-	-	-	-	-	-	-	-	-	50	-	-	-	-	2	-	-	-	-	-
Planorbidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	1	-	-	-	-
Pleidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Potamonautidae	-	3	-	x	x	-	-	1	-	1	-	-	-	-	x	-	-	-	-	1	-	-	-	-	-	-
Psychodidae	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Pyralidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Simuliidae	-	-	-	-	-	-	-	1	-	-	-	1000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Syrphidae	-	-	-	-	-	-	-	-	x	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tabanidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	3	-	-	-	-	-	-	-	-
Thiaridea	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	2	-	x	-	-	-	-	-	-	-	-	-	-	-
Turbellaria	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Veliidae	1	4	-	-	x	-	2	-	-	10	-	10	41	-	x	-	-	-	-	-	-	-	-	100	1	10
NO. OF TAXA	9	13	3	12	15	5	5	7	6	6	7	10	7	7	19	4	6	8	8	9	6	4	1	4	8	7
SASS SCORE	35	59	12	58	82	21	24	36	22	29	33	51	36	26	89	9	22	33	28	40	17	12	2	11	27	28
ASPT	3.89	4.54	4.00	4.83	5.47	4.20	4.80	5.14	3.67	4.83	4.71	5.10	5.14	3.71	4.68	2.25	3.67	4.13	3.50	4.44	2.83	3.00	2.00	2.75	3.38	4.00
SASS CLASS	E/F	D	E/F	D	D	E/F	E/F	D	E/F	E/F	E/F	D	D	E/F	C	E/F	E/F	E/F	E/F	E/F	E/F	D	E/F	E/F	E/F	E/F
MIRAI SCORE	50.758	57.6465	-	-	-	57.3853	47.3057	51.6446	-	50.1553	55.6227	58.1513	57.942	-	-	46.2928	53.3489	55.9971	58.6286	55.9364	50.6494	58.7997	39.4549	50.0183	59.7324	52.3008
MIRAI CLASS	D	D	-	-	-	D	D	D	-	D	D	D	D	-	-	D	D	D	D	D	D	D	E	D	C	D

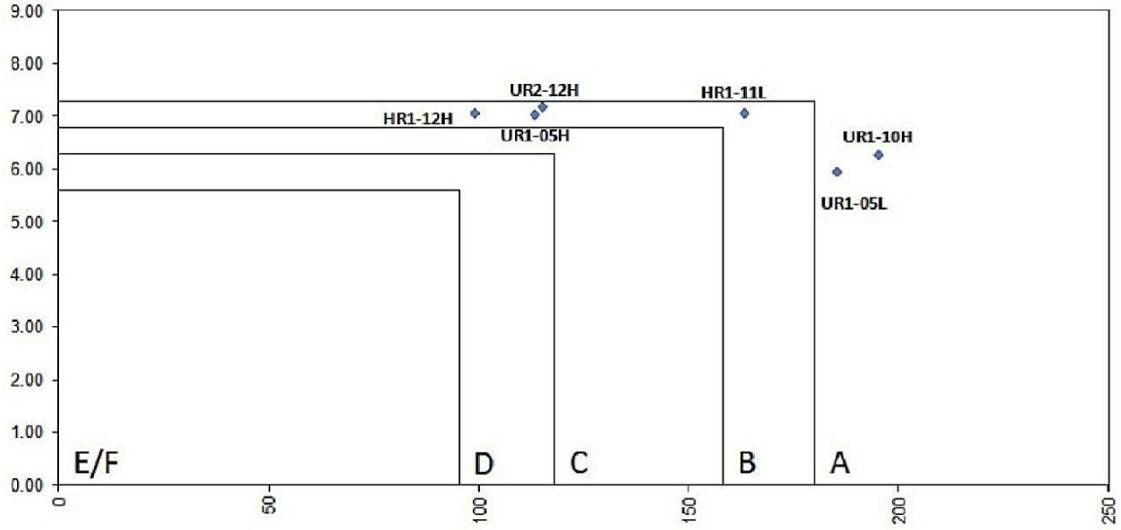


Figure 66: Historical and current average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (y axis) plotted relationships for the lower Umvoti (UR), Hlimbitwa (HR) and Nchaweni (NS) Rivers with integrity category bands from North Eastern Coastal Belt – Upper zone reference data, adopted from Dallas (2007)

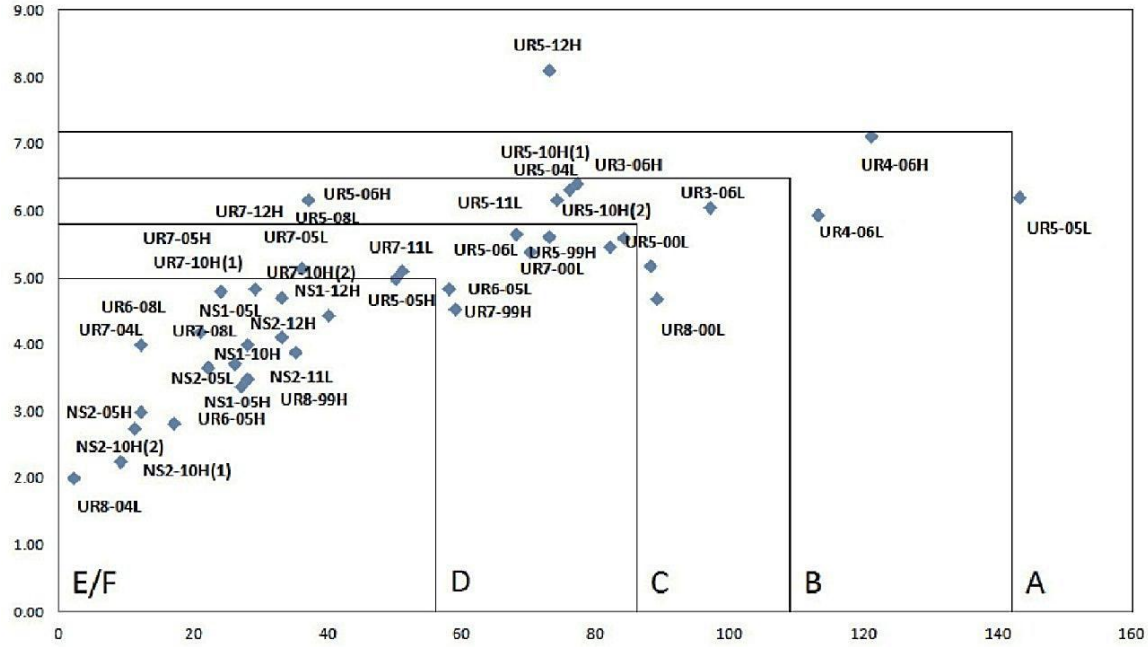


Figure 67: Historical and current average score per taxa (ASPT) (x axis) and South African Scoring System (SASS) score (y axis) plotted relationships for the lower Umvoti (UR), Hlimbitwa (HR) and Nchaweni (NS) Rivers with integrity category bands from North Eastern Coastal Belt – Lower zone reference data, adopted from Dallas (2007)

Trends of the SASS scores (Figure 68) indicate that the temporal SASS scores of the lower Umvoti, Hlimbitwa and Nchaweni Rivers fluctuate noticeably and that there is no clear evidence that the state of the macroinvertebrate communities generally decreases during low-flow periods and recovers in the high-flow periods. The trends further suggest that on the Umvoti River, site UR5 showed consistently better scores than site UR7. This is a result of the cumulative impacts that occur at the sites upstream on the Umvoti River as well as the Nchaweni River. The general trend of the Nchaweni River shows that site NS2 had lower or worse SASS scores than site NS1.

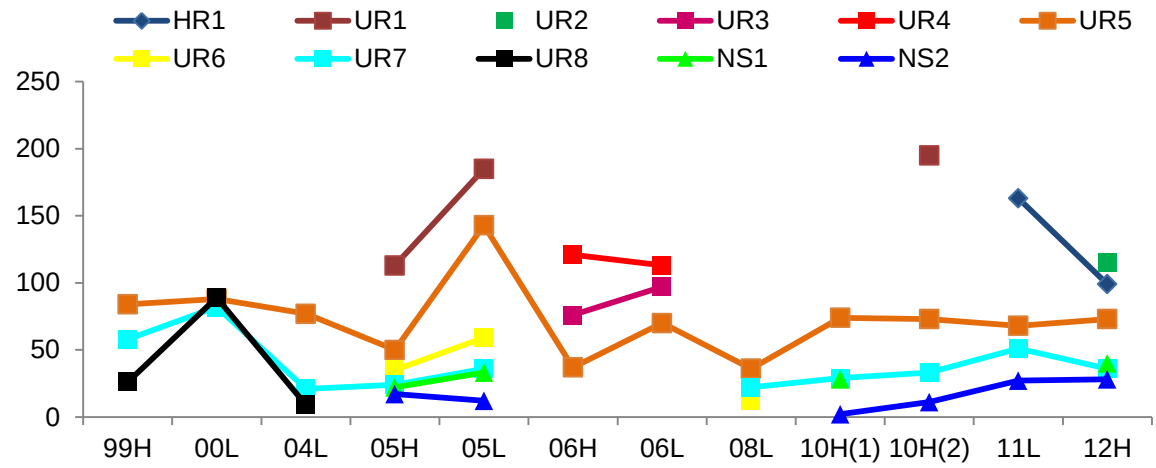


Figure 68: Trends of the South African Scoring System (SASS) scores (x axis) where available between 1999 (99) and 2012 (12) collected from the lower Umvoti (UR1 – UR8), Hlimbitwa (HR1) and Nchaweni (NS1 and NS2) Rivers during high (H) and low (L) flow sampling surveys (y axis)

Results regarding the MIRAI assessment indicated that sites on the upper reaches (HR1, UR1 and UR2) as well as the middle reaches (UR3 and UR4) of the Umvoti River ranged from a largely natural with a few modifications (Class B) to a moderately modified (Class C) state. The lower reaches (sites UR5 – UR8) of the Umvoti River were dominated by a largely modified (Class D) state. The Nchaweni River was also characterised to be in a Class D state with the exception of NS2 during the first high-flow survey in 2010 which was in a seriously modified (Class E) state and during 2011 in a Class C state. The general trends of the MIRAI scores (Figure 69) were similar to those of the SASS scores (Figure 68). Results regarding the MIRAI scores show that the trends also fluctuate noticeably. In general, the findings show that the MIRAI scores of the lower Umvoti, Hlimbitwa and Nchaweni Rivers were one class lower than the SASS scores obtained for the same area.

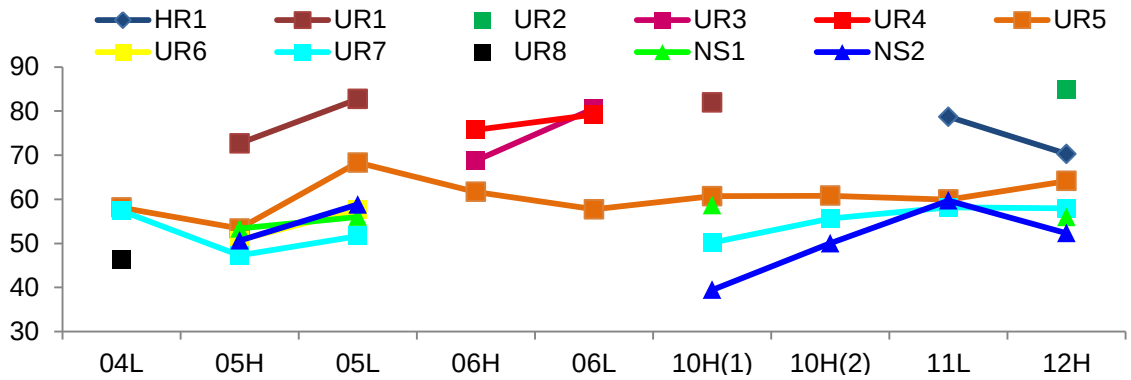


Figure 69: Trends of the Macroinvertebrate Response Assessment Index (MIRAI) scores (x axis) where available between 1999 (99) and 2012 (12) collected from the lower Umvoti (UR1 – UR8), Hlimbitwa (HR1) and Nchaweni (NS1 and NS2) Rivers during high (H) and low (L) flow sampling surveys (y axis)

3.3.2. Multivariate statistical analyses

The redundancy analysis (RDA) tri-plots of macroinvertebrates considered for the entire study area (Amatikulu, Thukela and Umvoti Rivers as well as associated tributaries which include the Nembe, eMandeni, Hlimbitwa and Nchaweni Rivers) were carried out and compared with the associated sites and driving environmental variables which include water quality, sediment and habitat. Results regarding the macroinvertebrates compared to high (H) and low (L) flows (Figure 70) (P = 0.001) show that flow had a significant influence on the community structures of the macroinvertebrates from the study area. Findings also indicate that a unique macroinvertebrate community structure closely related to the lower reaches of the Thukela (TR3 – TR6) and Umvoti (UR5 – UR7) Rivers were associated with the high-flow periods. Site UR2 is also related to the high flow; however, this might be influenced by the fact that this site was only sampled once during the high-flow period in 2012. A noticeably lower diversity of macroinvertebrates is related to the low flow and sites of the Amatikulu (AR2), eMandeni (ER1) and Umvoti (UR1, UR3 and UR4) Rivers. Results further reveal that a great diversity of macroinvertebrates is associated with community structures which are not affected by high and low flows. The Nembe and Hlimbitwa Rivers are closely associated with this macroinvertebrate community structure.

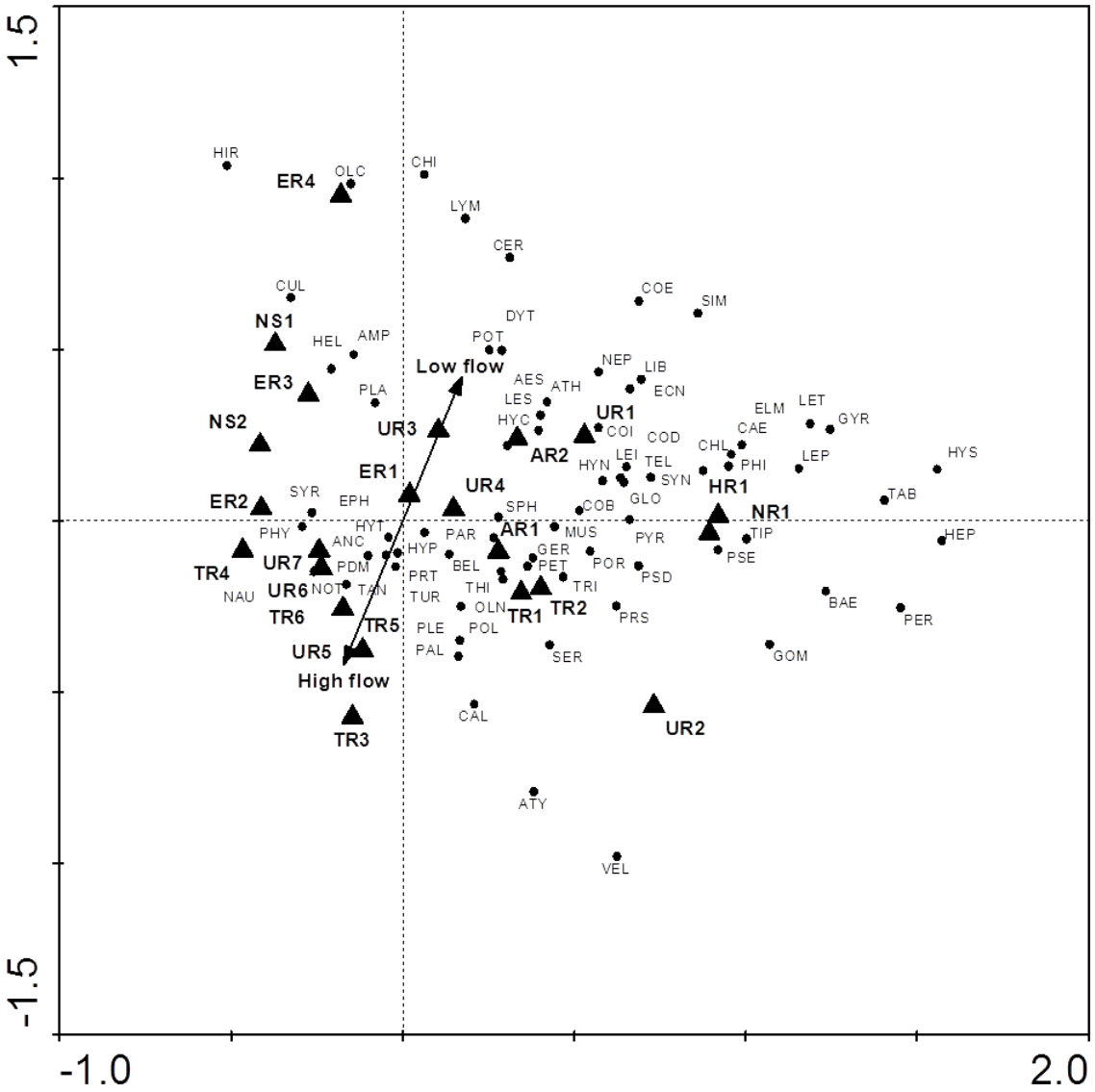


Figure 70: Redundancy analysis tri-plot of macroinvertebrates, sites and flow variables showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites and high (H) and low (L) flow survey variable ordination 48.2% of the variation within the data is presented, 32.8% on the 1st axis and an additional 15.4% on the 2nd axis.

Macroinvertebrates from the study area compared with years (Figure 71) indicated that the temporal changes in the macroinvertebrate community structure were not significant (P = 0.194). Results of this assessment revealed that higher diversities of macroinvertebrates were closely associated with surveys done in 2004, 2005, 2006 and 2010 where lower diversities were related to surveys carried out in 2011 and 2012. Again the community structure related to 2012 is also associated with site UR2.

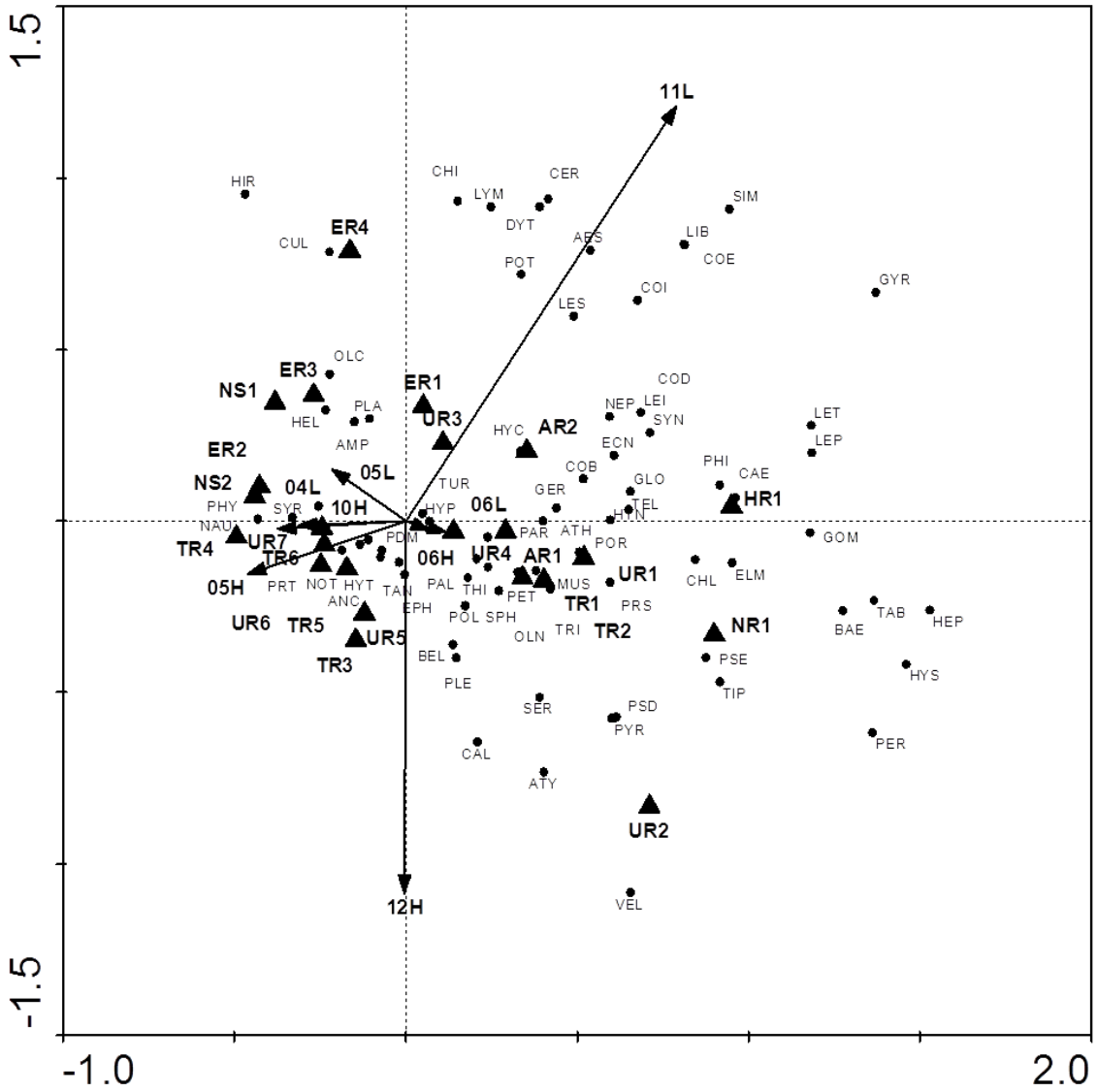


Figure 71: Redundancy analyses tri-plot of macroinvertebrates, sites and years variable showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites and years variable ordination 43% of the variation within the data is presented, 28.2% on the 1st axis and an additional 14.8% on the 2nd axis.

Findings of the statistical comparison between macroinvertebrates and water quality (Figure 72) from the study area were not significant (P = 0.281). Although the complete statistical analyses were not significant, several individual water-quality variables were significant. These variables include oxygen (P = 0.001), nitrite (P = 0.012), temperature (P = 0.001), electrical conductivity (P = 0.012) and pH (P = 0.018). Results show that a diverse macroinvertebrate community structure is associated with relatively high oxygen (mg/l and % saturation) levels and lower pH levels. Sites AR1 and AR2 on the Amatikulu River reflect a diverse macroinvertebrate community structure as do sites on the upper portions of the Thukela (TR1 and TR2), Nembe (NR1), eMandeni (ER1), Umvoti (UR1 and UR2) and Hlimbitwa (HR1) Rivers. A slightly different and less diverse macroinvertebrate community structure was related to elevated temperature levels, electrical conductivity levels, sulphate and ammonia loads which are associated with sites located in the middle and lower reaches of the Thukela (TR3 – TR6), eMandeni (ER2), Umvoti (UR5 – UR7) and Nchaweni (NS2) Rivers. Elevated chloride loads were recorded for sites ER3 and NS1 on the eMandeni and Nchaweni Rivers while elevated nitrate and nitrite levels were recorded for site ER4 on the eMandeni River.

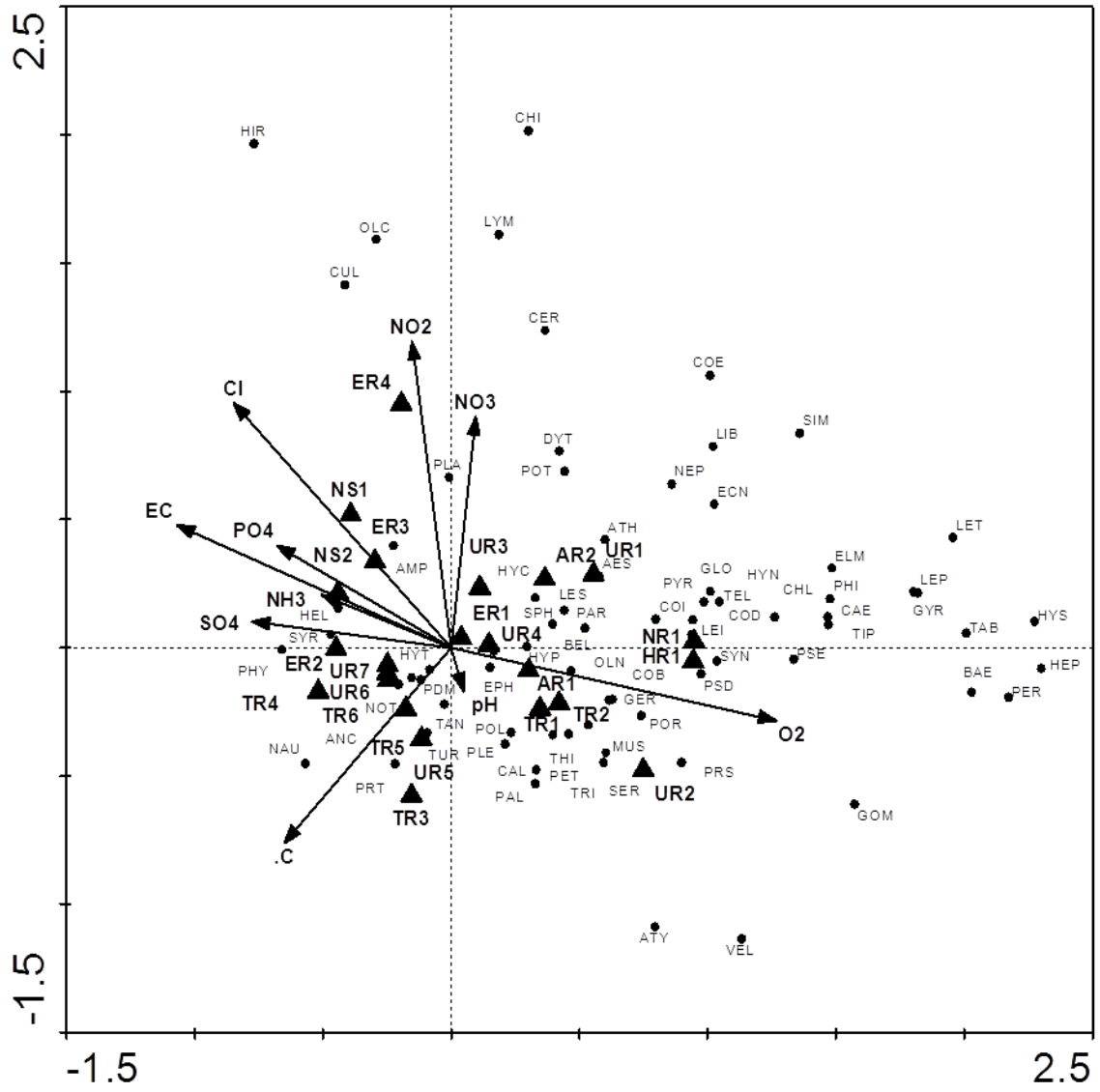


Figure 72: Redundancy analysis tri-plot of macroinvertebrates, sites and water quality variables showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites and water quality variable ordination 64.4% of the variation within the data is presented, 36.6% on the 1st axis and an additional 27.8% on the 2nd axis.

Macroinvertebrates from the study area compared to the sediment grain-size distribution (Figure 73) were statistically not significant (P = 0.117). Findings reveal that the Amatikulu (AR2), Nembe (NR1), Umvoti (UR1 and UR2) and Hlimbitwa (HR1) Rivers were all characterised by a macroinvertebrate community structure which is associated with gravel and very coarse sand.

Sites situated on the Amatikulu River as well as the middle and lower portions of the Thukela and Umvoti Rivers were categorised by a macroinvertebrate community structure which is associated with coarse sand, medium sand and very fine sand. A macroinvertebrate community structure with a low diversity of macroinvertebrates was closely associated with mud which commonly occurred at site ER3 on the eMandeni River as well as the Nchaweni River.

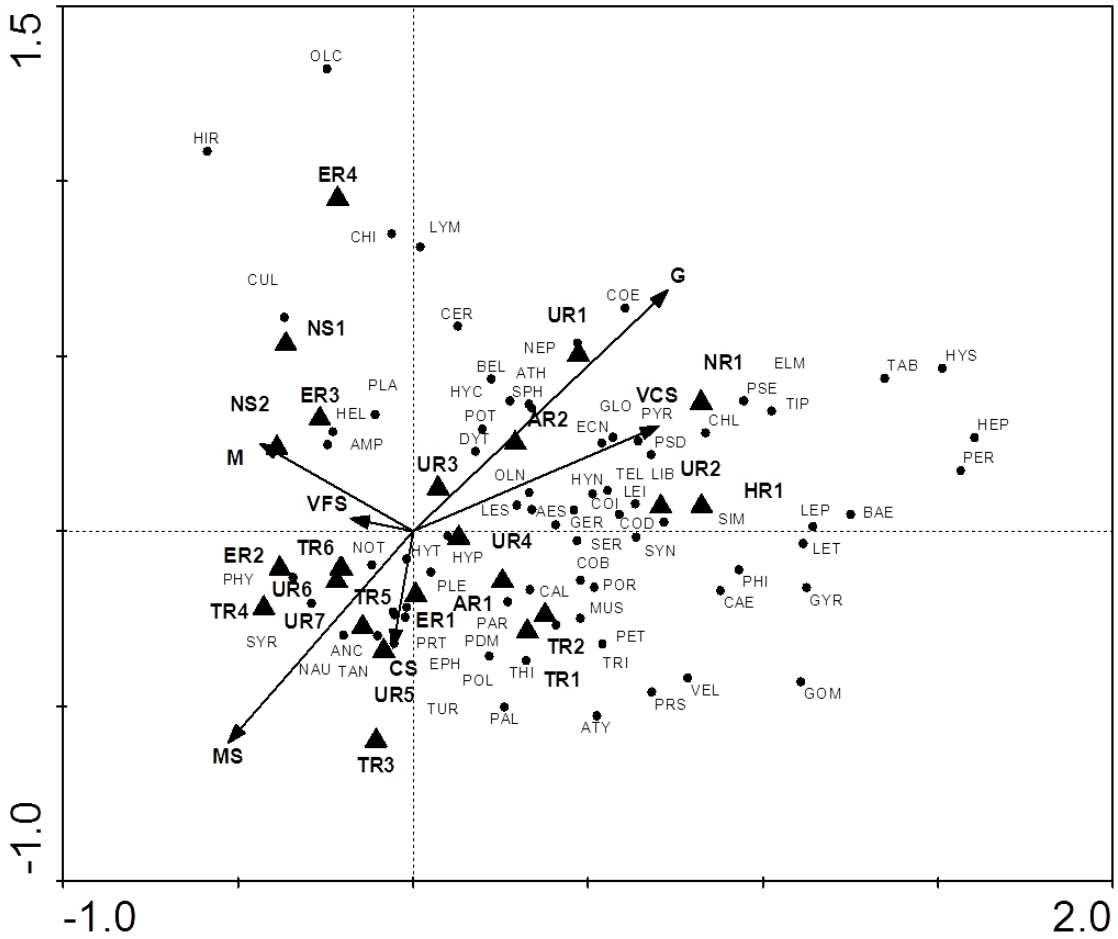


Figure 73: Redundancy analysis tri-plot of macroinvertebrates, sites and sediment grain-size variables showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites and sediment grain-size variable ordination 65.3% of the variation within the data is presented, 48.2% on the 1st axis and an additional 17.1% on the 2nd axis.

Results of the statistical comparison between macroinvertebrates and the Invertebrate Habitat Assessment System (IHAS) scores (Figure 74) were significant (P = 0.001). The findings suggest that the majority of the sites in the study area were not closely related to high IHAS scores except for site UR1 on the Umvoti River. This shows that habitat availability and diversity of the lower Amatikulu, Thukela and Umvoti Rivers are low.

A unique macroinvertebrate community structure with a noticeably lower diversity was recorded for site ER3 on the eMandeni River and for both sites on the Nchaweni River.

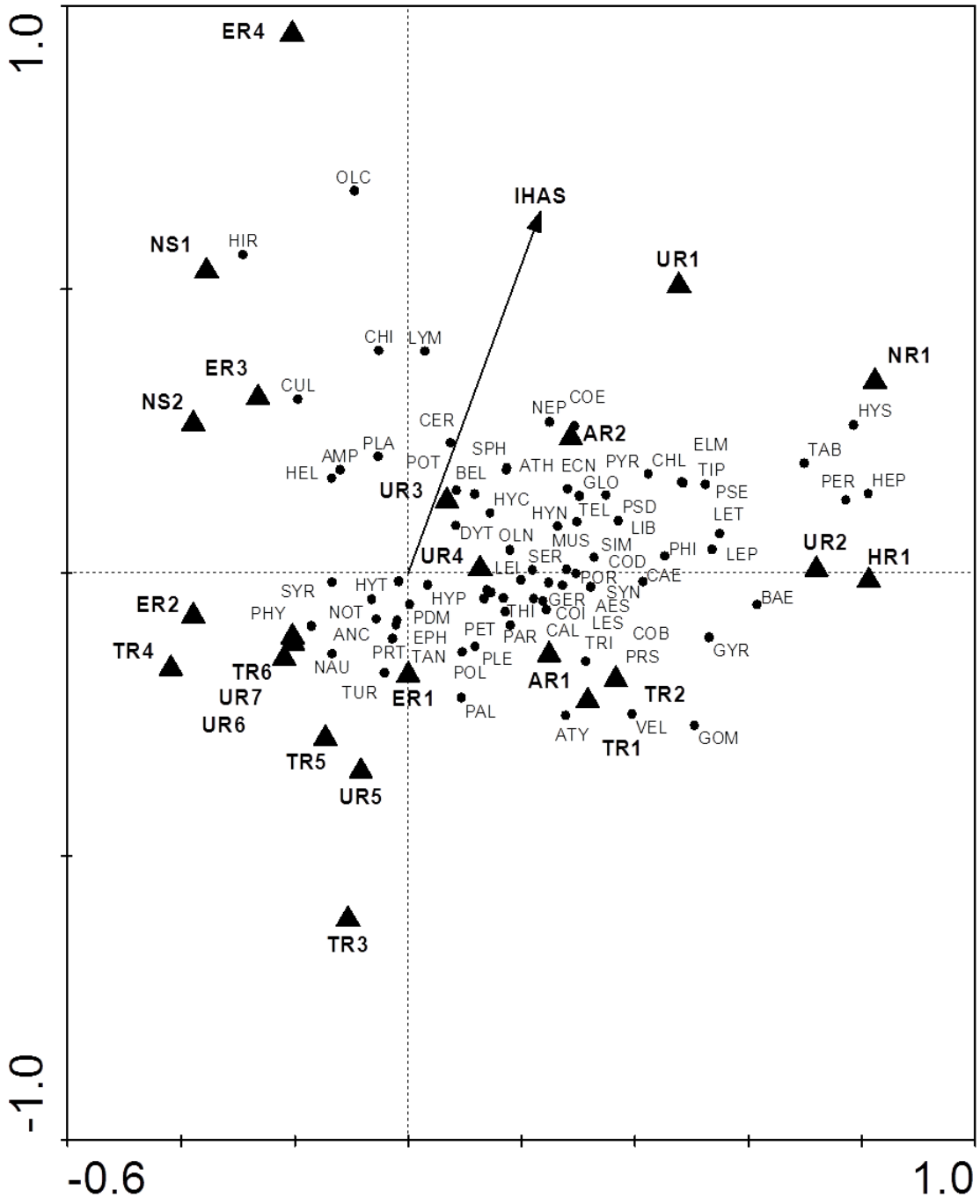


Figure 74: Redundancy analysis tri-plot of macroinvertebrates, sites and habitat variables showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites and IHAS variable ordination 23.8% of the variation within the data is presented, 2.5% on the 1st axis and an additional 21.3% on the 2nd axis.

Findings regarding macroinvertebrates compared to the South African Scoring System (SASS) and Macroinvertebrate Response Assessment Index (MIRAI) scores (Figure 75) were not significant (P = 0.181). The statistical comparison revealed that the majority of the sites had low SASS and MIRAI scores with the exception of the Nembe River sites that had higher MIRAI scores.

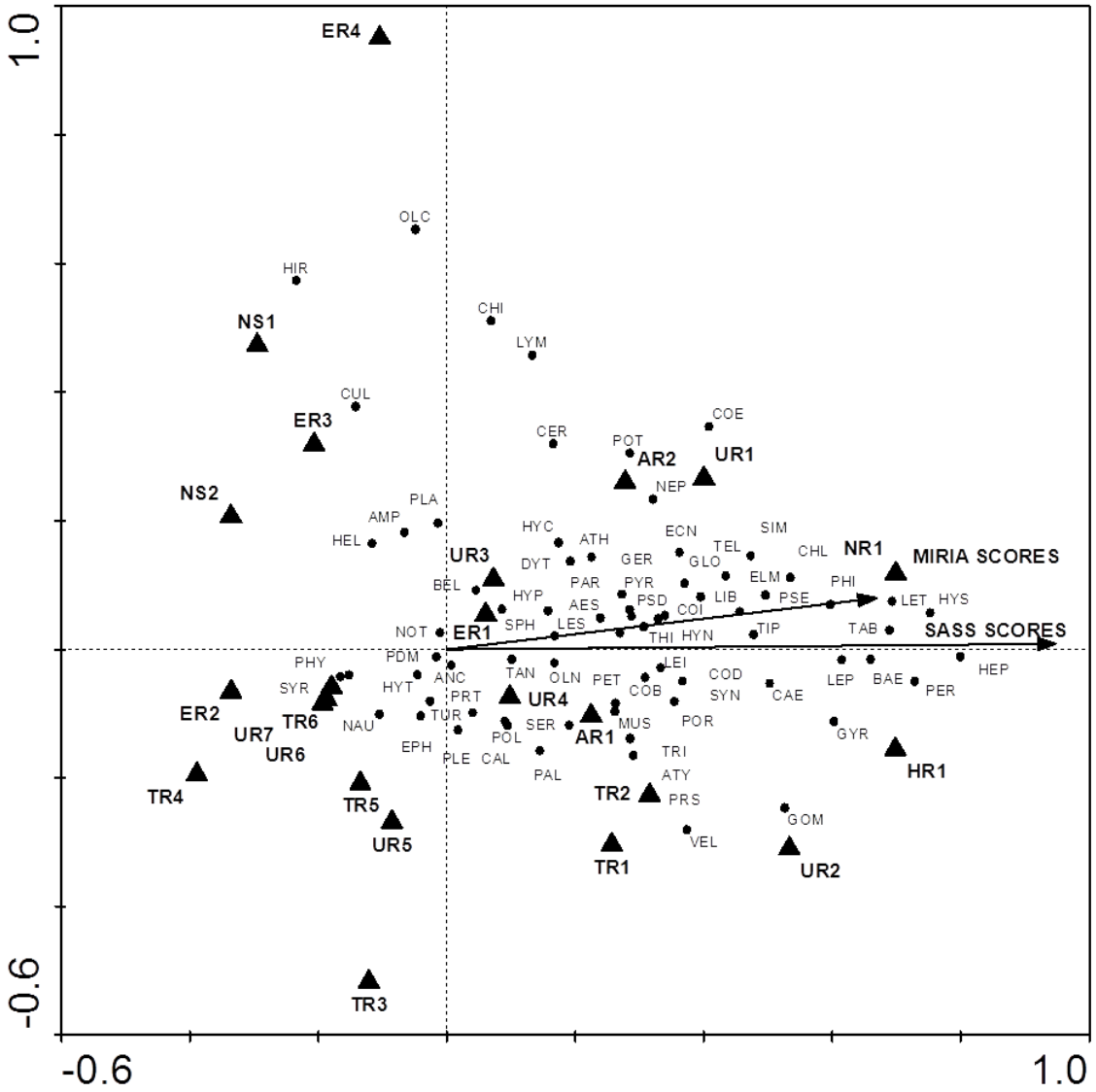


Figure 75: Redundancy analysis tri-plot of macroinvertebrates, sites, SASS and MIRAI variables showing dissimilarity among sites assessed in this study, represented as triangles. The macroinvertebrates (displayed as spots) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the taxa, sites, SASS and MIRAI variable ordination 50.1% of the variation within the data is presented, 35.7% on the 1st axis and an additional 14.4% on the 2nd axis.

3.4. Conclusion

Macroinvertebrates from the lower Amatikulu, Thukela and Umvoti Rivers responded to the quality and state of the environmental driver variables considered in the study. The integrity classes of MIRAI were generally one class lower than the integrity classes of SASS for each site. This is an indication of how the additional metrics considered in MIRAI affect the structure and/or state of macroinvertebrate communities. Throughout the multivariate statistical analyses the general distribution of the macroinvertebrate community structures related to the different sites showed noticeable similarities. The multivariate statistical comparisons between macroinvertebrates and the environmental driver components revealed that macroinvertebrate community structures of the Amatikulu River were generally similar to those in the upper portions of sites located on the Thukela, Umvoti, Nembe and Hlimbitwa Rivers. In addition, sites located on the middle reaches of the Thukela and Umvoti Rivers were generally closely related. The lowest site on the eMandeni River, site ER4, was an outlier and not associated to any of the different macroinvertebrate community structures and related sites in all the statistical analyses. This is a result of poor water quality, well-sorted sediment grain sizes and impaired habitat availability and diversity occurring at the site which negatively affects the macroinvertebrate community structure.

Outcomes discussed in this chapter clearly indicate that the structure and integrity of macroinvertebrate communities (responder) are affected by the quality, state and/or health of environmental driving variables which in this study included water quality, sediment and habitat.

CHAPTER 4: Assessment of the present ecological integrity and community structures of fish assemblages of the lower Amatikulu, Thukela and Umvoti Rivers, KwaZulu-Natal

4.1. Introduction

Fish assemblages are commonly used as key indicators to describe the ecological state of aquatic ecosystems (Maceda-Veiga and De Sostoa, 2011). Fish assemblages are good ecological indicators as they are long-lived, occupy a variety of habitats as they are mobile, are comprised of different species from different trophic levels and can indicate the health condition of the food chain situated below them (DWAF, 1999; Todd and Roux, 2000; Whitfield and Elliott, 2002; Van der Oost *et al.,* 2003; Harrison and Whitfield, 2004; Maceda-Veiga and De Sostoa, 2011; Cabral *et al.,* 2012; Gamito *et al.,* 2012). However, there are some limitations and challenges when using fish as ecological indicators as each river has a different fish community structure which can be affected in several ways by environmental changes (Whitfield and Elliott, 2002; Harrison and Whitfield, 2004; Cabral *et al.,* 2012; Gamito *et al.,* 2012).

The Fish Response Assessment Index (FRAI) as well as multivariate statistical analyses are used to address specific information requirements regarding the response of fish assemblages to changes in ecosystem variables. These ecosystem variables usually include water quality and habitat integrity which are referred to as ecological driver components (Dickens and Graham, 2002; Thirion, 2007). In South Africa FRAI is commonly used to determine the state of ecological integrity of fish assemblages in aquatic ecosystems and is implemented by the National River Health Programme (RHP) (Kleynhans, 2007).

The aim of this chapter is to evaluate the current ecological integrity of fish assemblages in the lower Amatikulu, Thukela and Umvoti Rivers and compare current findings with historical data where available between 1999 and 2012.

4.2. Materials and methods

4.2.1. Field sampling

Fish were sampled from the sites situated on the Amatikulu, Thukela and Umvoti Rivers (see Chapter 2 for sites) during the low flow (2011) and high flow (2012) surveys using netting techniques and electro-narcosis or commonly termed electro-fishing (Meador *et al.,* 1993; Barbour *et al.*, 1999). Netting techniques included the use of a 'small' seine net (12 mm mesh, 5 m long) seine net. This small seine net was hauled through all shallow (less than 1 m depth) habitats onto sand banks at all sites dominated by sandy bottoms. Additionally, a 'medium' sized seine net (22 mm mesh, 30 m long, fitted with a bag) was hauled through deep (greater than 1 m) open water habitats at all of the sandy bottomed sites. The habitats that were sampled include slow (<0.3 m/s) deep (> 1m), slow shallow (< 1m), fast (>0.3 m/s) deep and fast shallow as well as areas with marginal and overhanging vegetation.

4.2.2. Fish Response Assessment Index (FRAI)

Fish data collected from the seine netting and electro-fishing techniques were used to determine the ecological integrity of the fish communities by implementing the Fish Response Assessment Index (FRAI) (Kleynhans, 2007). The purpose of FRAI is to provide a habitat-based, cause-and-effect underpinning in order to interpret the deviation of the fish assemblage from a pre-selected reference condition (Kleynhans, 2007). The Reference Frequency of Occurrence of fish species (FROC), developed by Kleynhans *et al*. (2007), was used to determine the reference list of fish species in order to determine FRAI for the lower Amatikulu, Thukela and Umvoti Rivers. The FRAI index is based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent species of the assemblage to certain environmental conditions or drivers. The intolerance and preferences are categorised into several metric groups. These metric groups include (Kleynhans, 2007):

- The available habitats or velocity and depth.
- A cover metric which considers the preferences of overhanging vegetation, aquatic vegetation, water column, substrate as well as undercut banks and root wads.
- Flow modifications in terms of volume, timing and the duration of flows.
- Migration.
- Introduced species.

Any changes in the environmental conditions are related to fish stress and form the basis of ecological response interpretation. Figure 76 indicates the relationship between the environmental conditions (drivers) and the fish metric groups.

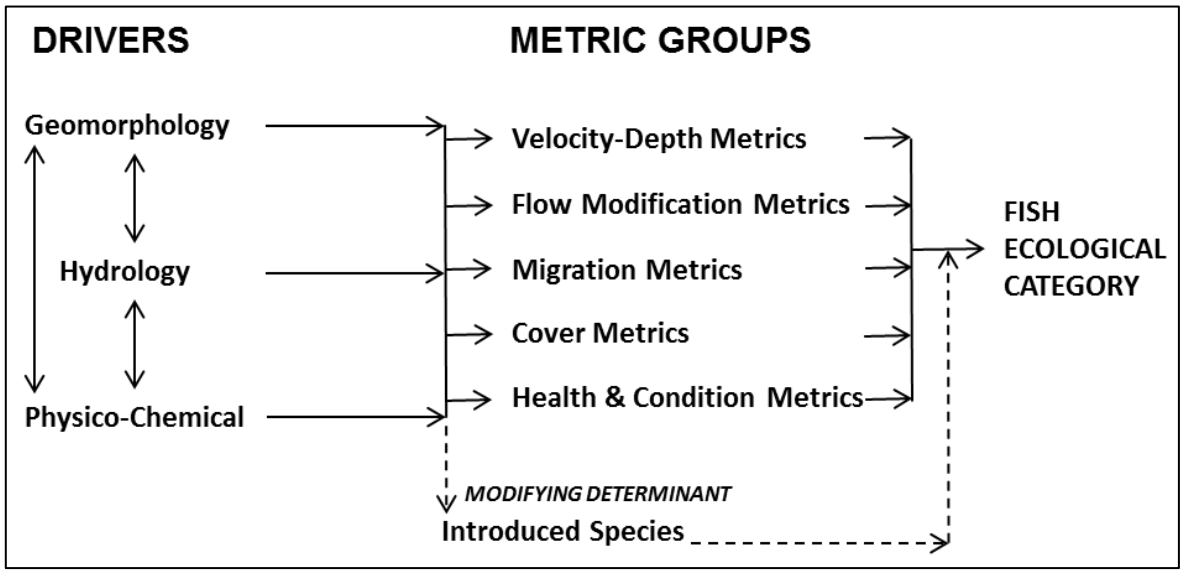


Figure 76: The relationship and interaction between the driver metric groups and the ecological integrity status or category of fish community structures (Kleynhans, 2007)

The FRAI assessment presents the ecological integrity state of the fish assemblages that were sampled. The different ecological integrity state categories as well as a description of each category are presented in Table 27.

Table 27: The FRAI ecological integrity state categories as well as a description of each category, adopted from Kleynhans (1999)

Ecological category	Description of category	Acceptable / Unacceptable	FRAI score
A	Unmodified, natural state. Fish communities compare with reference assemblages	Acceptable	90 - 100
B	Largely natural with few modifications. A small change in the natural habitats and fish communities have taken place but the ecosystem functions are essentially unchanged.	Acceptable	80 - 89
C	Moderately modified. Loss and change of natural habitats and moderate change in fish community structures, ecosystem functions are still predominantly unchanged.	Acceptable	60 - 79
D	Largely modified. A large loss of natural habitat and large change in fish community structures. Ecosystem functions are impaired.	Unacceptable	40 - 59
E	Seriously modified. Extensive loss in natural habitats and change to fish community structures. Ecosystem function disruptions are extensive.	Unacceptable	20 - 39
F	Critically or extremely modified. Modifications have reached a critical level resulting in almost complete loss of natural habitat and fish species. In worst cases basic ecosystem functions have been completely removed and changes may be irreversible.	Unacceptable	0 - 19

4.2.3. Multivariate statistical analyses

Multivariate statistical analyses techniques have been widely utilised to assess biological community structures and patterns in various ecosystems (Ter Braak, 1994; Van den Brink *et al*., 2003; O'Brien *et al*., 2009). The same approach and methodologies used to perform multivariate statistical analyses of macroinvertebrate communities (discussed in Chapter 3) were used in this chapter in order to evaluate the response of fish assemblages to driving environmental variables which include water quality, sediment and habitat.

4.3. Results and Discussion

4.3.1. Fish Response Assessment Index (FRAI)

4.3.1.1. Amatikulu River

Diversity and abundance data of the fish species identified in the lower Amatikulu River between 2006 and 2012 are presented below (Table 28).

Table 28: Diversity and abundance of fish species collected from the lower Amatikulu River (AR) during 2006 (06), 2011 (11) and 2012 (12) for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score

Fish Species	Common Name	ABR	AR1-06H	AR1-06L	AR1-11L	AR1-12H	AR2-06H	AR2-06L	AR2-11L	AR2-12H
Acanthopagrus berda (Forsskål, 1775)	Riverbream	ABER	-	-	-	-	2	-	-	17
Awaous sp			-	-	-	30	-	-	-	16
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	-	-	1	-	-	-	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	-	48	-	-	-	9
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	4	-	3	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	3	-	-	-	1	-	-	2
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	1	4	-	-	1	5	-	-
Glossogabius sp			-	-	-	-	-	-	-	4
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	-	2	-	-	1	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	1	-	-	-
Mullet fry			-	-	-	120	-	-	-	50
Micropterus salmoides (Lacepède, 1802)	Largemouth bass	MSAL	-	-	-	1	-	-	-	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	-	2	4	14	9	-	-	35
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	1	-	-	4	6	1	-	-
Total abundance			5	8	9	217	24	6	0	133
Diversity			3	3	3	6	8	2	0	7
Automated FRAI score			25.8	33.1	30.1	45.5	39.9	25.8	20	44.6
Automated FRAI Integrity class			E	E	E	D	D/E	E	E/F	D
Adjusted FRAI score			81.8	81.7	76.8	83.1	86.5	70.6	54.6	82.2
Adjusted FRAI Integrity class			B/C	B/C	C	B	B	C	D	B

From the eight surveys carried out on the lower Amatikulu River, 14 fish species were found (Table 28). The diversity of fish species ranged from 0 (AR2 during 2011 low flow) to 8 (AR2 in 2006 high flow). The ecological integrity of the fish assemblages determined using the automated FRAI (Table 28) analyses ranged between a largely modified (Class D) and seriously modified (Class E). The FRAI ecological integrity state of the adjusted FRAI scores ranged between largely natural with few modifications (Class B) to largely modified (Class D). The general trend of the automated FRAI scores (Figure 77) for site AR1 suggests an increasing trend between 2006 and 2012, whereas a decreasing trend between 2006 and 2011 was identified for site AR2 whereafter it increased towards 2012.

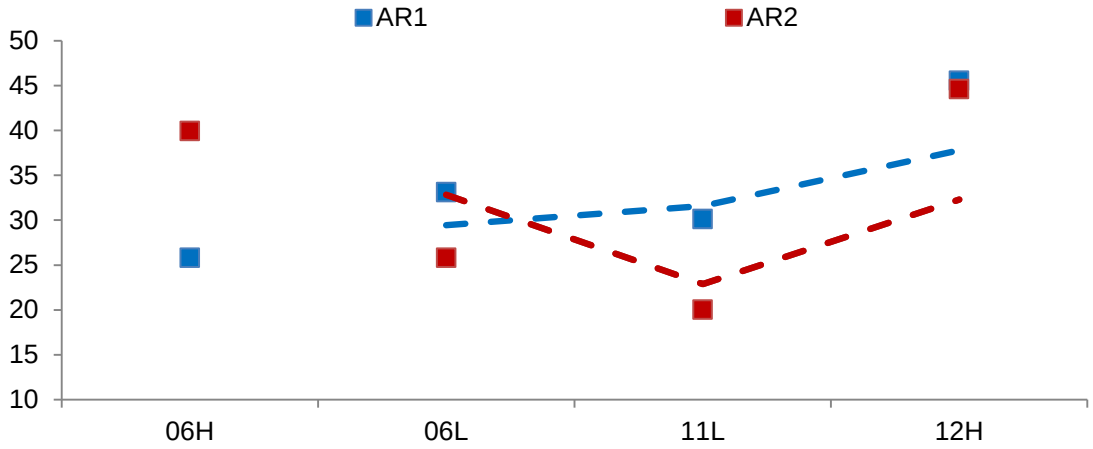


Figure 77: Trends of the automated Fish Response Assessment Index (FRAI) scores (x axis) during 2006 (06), 2011 (11) and 2012 (12) collected from the lower Amatikulu River (AR1 and AR2) during high (H) and low (L) flow sampling surveys (y axis)

The adjusted FRAI trend (Figure 78) at site AR1 on the lower Amatikulu River was stable throughout 2006 towards 2012. Site AR2 revealed a similar adjusted FRAI trend as the automated FRAI trend and the integrity classes of fish assemblages declined from 2006 towards 2011 and increased again in 2012. The noticeably higher adjusted FRAI scores in comparison to the automated FRAI scores of both sites AR1 and AR2 are due to fact that the metric groups considered in FRAI which affect the ecological integrity state of fish assemblages are ranked according to the effect of each metric group on the fish community structures.

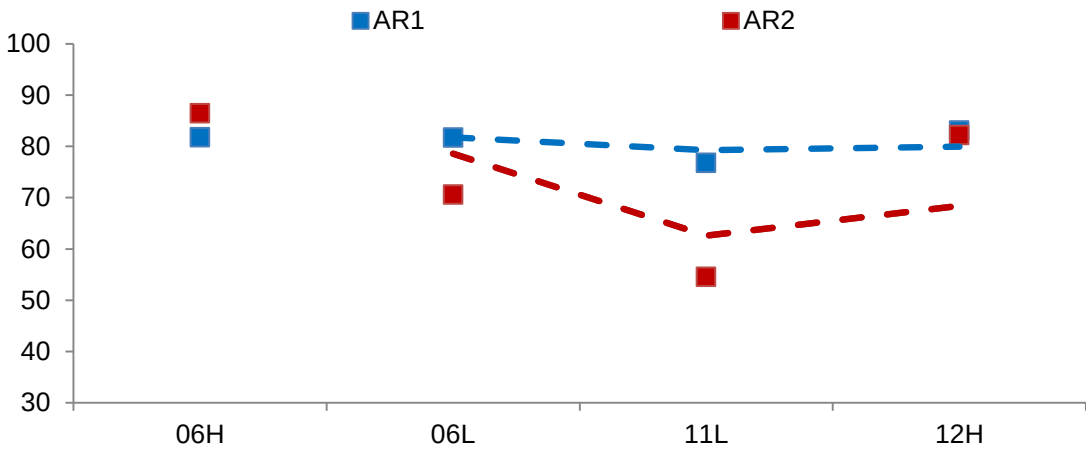


Figure 78: Trends of the adjusted Fish Response Assessment Index (FRAI) scores (x axis) during 2006 (06), 2011 (11) and 2012 (12) collected from the lower Amatikulu River (AR1 and AR2) during high (H) and low (L) flow sampling surveys (y axis)

4.3.1.2. Thukela River

Diversity and abundance data of the fish species identified in the lower Thukela, Nembe and eMandeni Rivers between 2005 and 2012 are presented below (Table 29-Table 31).

Table 29: Diversity and abundance of fish species where available between 2005 (05) and 2012 (12) from the lower Thukela River (TR1 – TR3) for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score

Fish Species	Common Name	ABR	TR1-05L	TR2-05L	TR2-06L	TR2-08L	TR2-10H(1)	TR2-10H(2)	TR2-11L	TR2-12H	TR3-11L	TR3-12H
Ambassis natalensis (Gilchrist & Thompson, 1908)	Slender glassy	ANAT	-	-	-	-	-	-	-	-	-	-
Ambassis sp			-	-	-	-	-	-	-	-	-	1
Anguilla marmorata (Quoy & Gaimard, 1824)	Giant mottled eel	AMAR	-	-	-	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	2	5	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	-	-	-	-	51	-	-	-	-
Awaous sp.			-	-	-	-	-	-	3	-	50	11
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	-	-	-	-	-	-	-	-	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	-	-	-	11	-	-	-	-
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	1	3	4	-	-	1	-	5	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	3	-	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	8	-	-	3	-	2	-	50	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	2	-	20	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	1	-	3	-	2	62	1	-	-	-
Labeo rubromaculatus (Gilchrist & Thompson, 1913)	Tugela labeo	LRUB	-	17	2	-	-	25	2	2	-	-
Liza dumerilii (Steindachner, 1870)	Groovy mullet	LDUM	-	-	-	-	-	-	-	-	-	-
Microphis sp			-	-	-	-	-	-	-	-	-	15
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	-	-	-	-	-	-	-	-	-
Mullet fry			-	-	-	-	-	39	-	30	50	-
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	-	-	-	-	-	-	-	-	1	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	-	-	-	-	-	-	-	3	7	13
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	-	-	-	-	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	-	-	-	-	-	-	-	-	-	-
Rhabdosargus holubi (Steindachner, 1881)	Cape stumpnose	RHOL	-	-	-	-	-	-	-	-	-	-
Rhabdosargus sarba (Forsskål, 1775)	Tropical stumpnose	RSAR	-	-	-	-	-	-	-	-	-	-
Tilapia rendalli (Boulenger, 1896)	Redbreast tilapia	TREN	-	-	-	-	-	-	-	-	-	-
Total abundance			2	28	9	0	8	138	7	40	128	28
Diversity			2	3	3	0	3	5	4	4	5	2
Automated FRAI score			25.6	27.6	26.6	20	27.3	50.2	28.4	29.3	34.6	25.7
Automated FRAI Integrity class			E	E	E	E/F	E	D	E	E	E	E
Adjusted FRAI score			76.7	78.4	78.2	51.5	80.6	89.4	80.7	81.5	66.4	60.2
Adjusted FRAI Integrity class			C	B/C	B/C	D	B/C	A/B	B/C	B/C	C	C/D

Table 30: Diversity and abundance of fish species where available between 2005 (05) and 2012 (12) from the lower Thukela River (TR4 – TR6) for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score

Fish Species	Common Name	ABR	TR4-05L	TR4-06L	TR4-08L	TR4-10H(1)	TR4-10H(2)	TR5-05L	TR5-08L	TR5-10H(1)	TR5-10H(2)	TR5-11L	TR5-12H	TR6-05L
Ambassis natalensis (Gilchrist & Thompson, 1908)	Slender glassy	ANAT	-	-	-	-	2	-	-	-	-	-	-	-
Ambassis sp			-	-	-	-	-	-	-	-	-	-	-	-
Anguilla marmorata (Quoy & Gaimard, 1824)	Giant mottled eel	AMAR	-	-	-	-	-	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	-	-	-	4	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	-	-	-	11	-	-	-	7	-	-	-
Awaous sp.			-	-	-	-	-	-	-	-	-	-	36	-
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	-	-	-	-	-	-	-	-	-	-	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	-	-	4	-	-	-	-	-	6	-
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	1	-	-	-	-	-	-	-	1	-	7	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	2	3	1	-	-	1	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	3	-	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	5	9	2	-	2	29	-	-	2
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	2	-	-	-	1	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-	6	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	-	-	2	-	2	-	-	-	-	-	1	-
Labeo rubromaculatus (Gilchrist & Thompson, 1913)	Tugela labeo	LRUB	1	-	-	-	-	-	-	-	-	-	-	-
Liza dumerilii (Steindachner, 1870)	Groovy mullet	LDUM	-	-	-	-	-	-	-	-	-	-	-	-
Microphis sp			-	-	-	-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	1	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	-	-	-	-	-	-	-	-	-	-	-
Mullet fry			-	-	-	-	345	-	-	-	65	350	60	-
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	-	-	-	-	3	1	-	-	1	-	-	2
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	66	4	-	7	165	1	-	2	15	3	23	16
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	-	-	4	-	-	-	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdosargus holubi (Steindachner, 1881)	Cape stumpnose	RHOL	-	-	-	-	4	-	-	-	-	-	-	2
Rhabdosargus sarba (Forsskål, 1775)	Tropical stumpnose	RSAR	-	-	-	-	15	-	-	-	-	-	-	-
Tilapia rendalli (Boulenger, 1896)	Redbreast tilapia	TREN	-	-	-	-	-	-	-	-	-	-	-	-
Total abundance			68	4	2	16	558	5	0	5	112	353	103	22
Diversity			3	1	1	4	12	4	0	3	6	2	6	4
Automated FRAI score			27.7	22.1	23.9	23.4	44.1	24.9	20	23.4	35.3	30.8	37.8	25.3
Automated FRAI Integrity class			E	E	E	E	D	E	E/F	E	E	E	D/E	E
Adjusted FRAI score			59.6	54.6	56.1	59.3	71.1	61.2	43.3	61.2	67.5	57.1	71.2	61.2
Adjusted FRAI Integrity class			C/D	D	D	C/D	C	C/D	D	C/D	C	D	C	C/D

Table 31: Diversity and abundance of fish species where available between 2006 (06), 2011 (11) and 2012 (12) from the lower Nembe (NR1) and eMandeni (ER1 –ER4) Rivers for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score

Fish Species	Common Name	ABR	NR1-11L	NR1-12H	ER1-11L	ER1-12H	ER2-06L	ER3-11L	ER3-12H	ER4-11L	ER4-12H
Ambassis natalensis (Gilchrist & Thompson, 1908)	Slender glassy	ANAT	-	-	-	-	-	-	-	-	-
Ambassis sp			-	-	-	-	-	-	-	-	-
Anguilla marmorata (Quoy & Gaimard, 1824)	Giant mottled eel	AMAR	-	-	-	-	-	-	-	-	1
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	-	-	-	2
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	-	-	-	-	-	-	-	-
Awaous sp.			-	4	-	-	-	-	-	-	-
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	5	-	-	-	-	-	-	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	9	-	-	-	-	-	-	-	-
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	15	-	-	-	-	-	1	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	1	-	-	-	-	-	3	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	-	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	-	-	115	-	21
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	-	-	-	-	-	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	1	3	-	-	-	-	-	-	-
Labeo rubromaculatus (Gilchrist & Thompson, 1913)	Tugela labeo	LRUB	9	12	-	-	-	-	-	-	6
Liza dumerilii (Steindachner, 1870)	Groovy mullet	LDUM	-	-	-	-	-	-	-	-	-
Microphis sp			-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	-	-	-	-	-	-	-	-
Mullet fry			-	-	-	-	-	-	-	-	-
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	-	-	-	-	-	-	-	-	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	-	3	-	50	-	-	23	-	5
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	-	-	4	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	17	30	8	28	-	-	3	-	-
Rhabdosargus holubi (Steindachner, 1881)	Cape stumpnose	RHOL	-	-	-	-	-	-	-	-	-
Rhabdosargus sarba (Forsskål, 1775)	Tropical stumpnose	RSAR	-	-	-	-	-	-	-	-	-
Tilapia rendalli (Boulenger, 1896)	Redbreast tilapia	TREN	-	-	1	6	-	-	-	-	-
Total abundance			42	63	9	84	4	0	144	1	32
Diversity			6	5	2	3	1	0	4	1	3
Automated FRAI score			33.6	33	24.0	30.3	20.0	20.0	24.5	22.3	29.0
Automated FRAI Integrity class			E	E	E	E	E/F	E/F	E	E	E
Adjusted FRAI score			90.5	88.3	59.0	61.8	45.8	43.4	61.1	52.7	61.3
Adjusted FRAI Integrity class			A/B	A/B	C/D	C/D	D	D	C/D	D	C/D

A total of 26 fish species over 31 surveys between 2005 and 2012 were found in the lower Thukela River as well as associated tributaries which include the Nembe and eMandeni Rivers. The automated FRAI integrity classes of the Thukela, Nembe and eMandeni Rivers (Table 29-Table 31) ranged between largely modified (Class D) and seriously modified (Class E) from 2005 to 2012. Adjusted FRAI (Table 29-Table 31) integrity classes from 2005 to 2012 of the lower Thukela, Nembe and eMandeni Rivers ranged between an unmodified natural (Class A) state and largely modified (Class D) state. General trends of the automated FRAI scores (Figure 79) from the lower Thukela River (TR1-TR6) showed an upward trend from 2005 to 2012. The integrity of fish species in the Nembe River (NR1) was very stable throughout 2011 and 2012. All the sites on the eMandeni River, except for site ER2, showed noticeably increasing trends from 2011 to 2012.

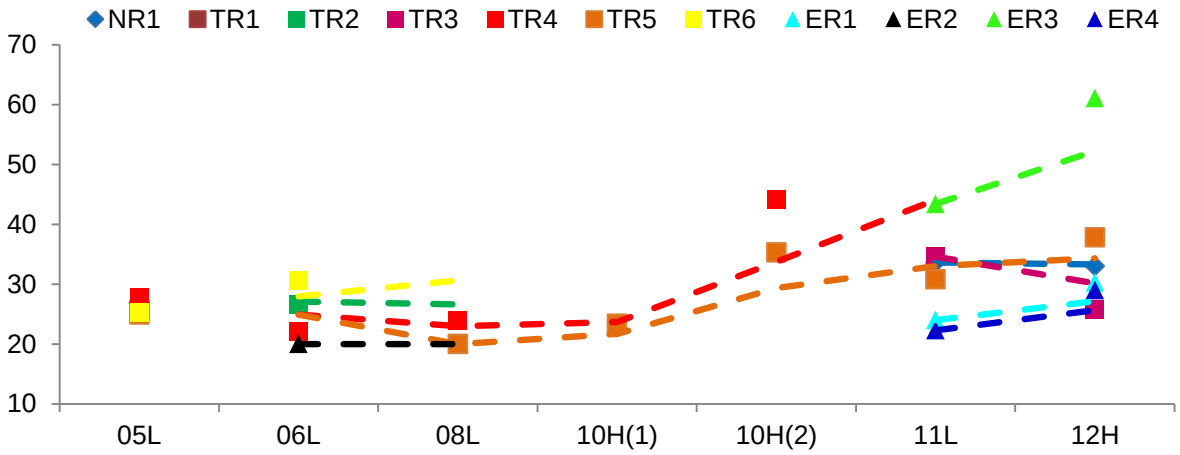


Figure 79: Trends of the automated Fish Response Assessment Index (FRAI) scores (x axis) where available between 2005 (05) and 2012 (12) collected from the lower Thukela (TR1 – TR6), Nembe (NR1) and eMandeni (ER1 – ER4) Rivers during high (H) and low (L) flow sampling surveys (y axis)

Trends identified using the adjusted FRAI scores (Figure 80) of the lower Thukela, Nembe and eMandeni Rivers were similar to those of the automated FRAI scores. The only difference between the automated and adjusted FRAI scores being the fact that the adjusted FRAI scores are noticeably higher resulting in better ecological integrity classes. This is because of the fact that the effects of each metric group considered in FRAI are better represented in the adjusted FRAI than in the automated FRAI.

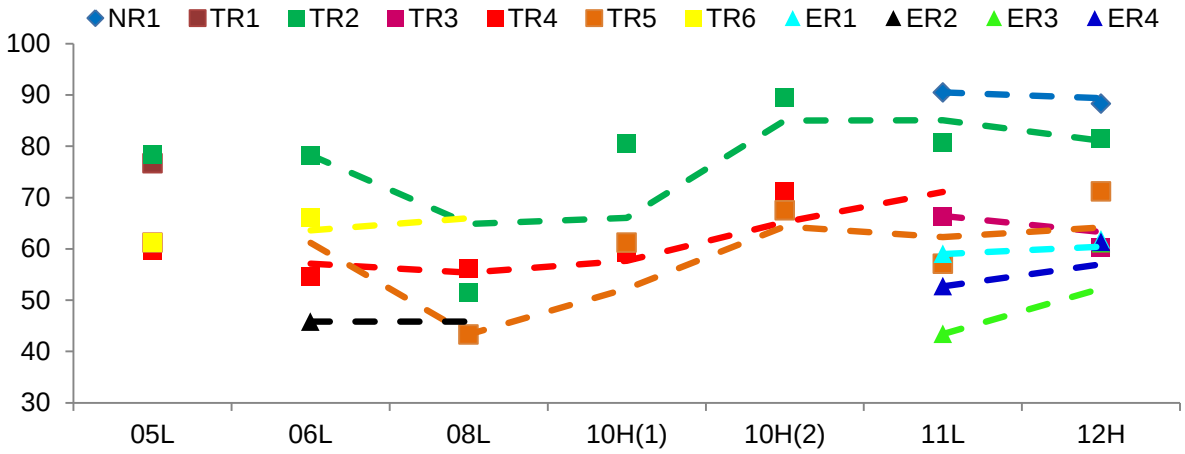


Figure 80: Trends of the adjusted Fish Response Assessment Index (FRAI) scores (x axis) where available between 2005 (05) and 2012 (12) collected from the lower Thukela (TR1 – TR6), Nembe (NR1) and eMandeni (ER1 – ER4) Rivers during high (H) and low (L) flow sampling surveys (y axis)

4.3.1.3. Umvoti River

Diversity and abundance data of the fish species identified in the lower Umvoti, Hlimbitwa and Nchaweni Rivers between 1999 and 2012 are presented below (Table 32-Table 35).

Table 32: Diversity and abundance of fish species where available between 1999 (99) and 2012 (12) from the lower Umvoti (UR1 – UR4) and Hlimbitwa (HR1) Rivers for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score. The 'x' indicates presence of fish species where abundance data were not available.

Fish Species	Common Name	ABR	HR1-11L	HR1-12H	UR1-04L	UR1-05H	UR1-05L	UR1-10H	UR2-12H	UR3-06H	UR3-06L	UR4-06H	UR4-06L
Acanthopagrus berda (Forsskål, 1775)	Riverbream	ABER	-	-	-	-	-	-	-	-	-	-	-
Ambassis ambassis (Lacepède, 1802)	Commerson's glassy	AAMB	-	-	-	-	-	-	-	-	-	-	-
Ambassis producta (Guichenot, 1866)	Longspine glassy	APRO	-	-	-	-	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	2	-	-	-	-	-
Anguilla sp			1	-	1	-	-	-	-	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	-	-	-	-	-	-	-	-	-	-
Awaous sp			-	-	-	-	-	-	-	-	-	-	-
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	-	-	3	1	-	-	-	-	-	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	4	201	18	4	41	-	54	-	65	32	93
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	4	21	-	-	14	-	-	7	-	-	16
Caranx sp			-	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	-	-	4	2	2	-	23	1	-	-	-
Diplodus sargus capensis (Smith, 1844)	Blacktail	DCAP	-	-	-	-	-	-	-	-	-	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	-	-	-	-	-	-	-
Gambusia sp			-	-	-	-	-	-	-	-	-	-	-
Gilchristella aesturia (Gilchrist, 1913)	Estuarine round-herring	GAES	-	-	-	-	-	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	-	-	-	-	-	-	-	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	-	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	-	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	27	80	21	3	3	32	21	7	5	-	7
Liza tricuspidens (Smith, 1935)	Striped mullet	LTRI	-	-	-	-	-	-	-	-	-	-	-
Megalops cyprinoides (Broussonet, 1782)	Oxeye tarpon	MCYP	-	-	-	-	-	-	-	-	-	-	-
Microphis brachyurus (Bleeker, 1853)	Short-tail pipefish	MBRA	-	-	-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	-	-	-	-	-	-	-	-	-	-
Mullet fry			-	-	-	-	-	-	-	-	-	-	-
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	-	-	-	-	-	-	-	-	-	-	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	2	5	16	-	43	1	32	23	29	1	17
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	-	-	-	-	-	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	1	-	1	2	-	-	-	-	-	1	3
Terapon jarbua (Forsskål, 1775)	Thornfish	TJAR	-	-	-	-	-	-	-	-	-	-	-
Valamugil cunnesius (Valenciennes, 1836)	Longarm mullet	VCUN	-	-	-	-	-	-	-	-	-	-	-
Total abundance			39	307	64	12	103	35	130	38	99	34	136
Diversity			6	4	7	5	5	3	4	4	3	3	5
Automated FRAI score			46.5	77.8	71.1	46.1	59.2	56.7	66.3	47.5	45.9	30.4	58.9
Automated FRAI Integrity class			D	B/C	C	D	C/D	D	C	D	D	E	C/D
Adjusted FRAI score			90.4	88.3	92.2	82.2	83.7	82.1	83.3	82.9	74.6	72.8	80.2
Adjusted FRAI Integrity class			A/B	A/B	A	B	B	B	B	B	C	C	B/C

Table 33: Diversity and abundance of fish species where available between 1999 (99) and 2012 (12) from the lower Umvoti River (UR5) for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score. The 'x' indicates presence of fish species where abundance data were not available.

Fish Species	Common Name	ABR	UR5-99H	UR5-00L	UR5-04L	UR5-05H	UR5-05L	UR5-06H	UR5-06L	UR5-08L	UR5-10H(1)	UR5-10H(2)	UR5-11L	UR5-12H
Acanthopagrus berda (Forsskål, 1775)	Riverbream	ABER	-	-	-	-	-	-	-	-	-	-	-	-
Ambassis ambassis (Lacepède, 1802)	Commerson's glassy	AAMB	-	-	-	-	-	-	-	-	-	8	-	-
Ambassis producta (Guichenot, 1866)	Longspine glassy	APRO	-	-	9	-	-	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	-	-	-	-	-	-	-
Anguilla sp			-	-	1	-	-	-	-	1	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	x	3	-	-	-	-	-	-	-	-	-
Awaous sp			-	-	-	-	-	-	-	-	-	-	-	6
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	x	-	2	-	2	-	-	30	-	2	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	18	1	3	-	2	56	29	3	-	44
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	-	-	-	-	-	-	-	-	-	11
Caranx sp			-	-	-	-	-	-	-	-	1	3	-	1
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	-	x	1	1	1	-	4	-	-	-	-	-
Diplodus sargus capensis (Smith, 1844)	Blacktail	DCAP	-	-	-	-	-	-	-	-	-	2	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	-	-	-	-	-	-	-	-
Gambusia sp			-	-	-	-	-	-	-	-	-	-	-	-
Gilchristella aesturia (Gilchrist, 1913)	Estuarine round-herring	GAES	-	-	4	-	1	-	-	1	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	-	-	-	-	-	-	-	-	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	-	-	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	-	-	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	-	-	1	-	1	-	-	-	-	-	-	-
Liza tricuspidens (Smith, 1935)	Striped mullet	LTRI	-	-	-	-	63	-	-	-	-	-	-	-
Megalops cyprinoides (Broussonet, 1782)	Oxeye tarpon	MCYP	-	-	-	1	1	-	-	-	-	-	-	-
Microphis brachyurus (Bleeker, 1853)	Short-tail pipefish	MBRA	-	-	-	1	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	x	-	-	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	-	-	-	4	1	4	4	1	-	-	-
Mullet fry			-	-	-	3	-	-	-	-	-	-	-	25
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	-	-	81	-	-	-	-	20	6	-	-	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	x	x	14	2	18	10	31	12	49	80	1	30
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	-	-	-	-	-	-	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	-	x	8	3	2	4	-	2	13	29	-	-
Terapon jarbua (Forsskål, 1775)	Thornfish	TJAR	-	-	-	-	-	-	-	-	-	-	-	-
Valamugil cunnesius (Valenciennes, 1836)	Longarm mullet	VCUN	-	-	-	-	-	-	-	26	-	-	-	-
Total abundance			-	-	142	12	96	15	41	152	99	127	1	117
Diversity			3	4	11	7	10	3	4	9	6	7	1	6
Automated FRAI score			-	-	55.1	33.9	45	26.5	30.4	55.5	39.8	35.7	23.2	51.6
Automated FRAI Integrity class			-	-	D	E	D	E	E	D	D/E	E	E	D
Adjusted FRAI score			-	-	81.7	65.3	75.8	64.4	65.1	78	69.8	67.5	60.3	69.4
Adjusted FRAI Integrity class			-	-	B/C	C	C	C	C	B/C	C	C	C/D	C

Table 34: Diversity and abundance of fish species where available between 1999 (99) and 2012 (12) from the lower Umvoti River (UR6 and UR7) for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score. The 'x' indicates presence of fish species where abundance data were not available.

Fish Species	Common Name	ABR	UR6-04L	UR6-05H	UR7-99H	UR7-00L	UR7-04L	UR7-05H	UR7-05L	UR7-08L	UR7-10H(1)	UR7-10H(2)	UR7-11L	UR7-12H
Acanthopagrus berda (Forsskål, 1775)	Riverbream	ABER	-	-	-	-	-	-	-	-	-	-	-	1
Ambassis ambassis (Lacepède, 1802)	Commerson's glassy	AAMB	-	-	-	-	-	-	-	-	-	-	-	-
Ambassis producta (Guichenot, 1866)	Longspine glassy	APRO	-	2	-	-	9	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	-	2	-	-	-	-	-
Anguilla sp			-	-	-	x	1	-	1	-	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	1	x	x	3	-	-	-	-	-	-	-
Awaous sp			-	-	-	-	-	-	-	-	-	-	-	3
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	1	-	x	-	2	7	2	-	-	13	-	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	-	-	18	11	2	6	-	4	1	200
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	-	-	-	-	-	-	5	-	-	-
Caranx sp			-	3	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	-	-	x	x	1	-	-	4	1	-	-	8
Diplodus sargus capensis (Smith, 1844)	Blacktail	DCAP	-	-	-	-	-	-	-	-	-	-	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	-	-	-	-	1	-	-	-
Gambusia sp			-	-	-	-	-	-	-	-	-	-	-	-
Gilchristella aesturia (Gilchrist, 1913)	Estuarine round-herring	GAES	-	-	-	-	4	-	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	x	-	-	-	-	-	-	-	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	3	-	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-	-	3
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	-	-	-	-	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	-	-	-	-	1	-	-	-	-	-	-	-
Liza tricuspidens (Smith, 1935)	Striped mullet	LTRI	-	-	-	-	-	-	-	-	-	-	-	-
Megalops cyprinoides (Broussonet, 1782)	Oxeye tarpon	MCYP	-	-	-	-	-	-	-	1	-	-	-	-
Microphis brachyurus (Bleeker, 1853)	Short-tail pipefish	MBRA	-	-	-	-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	-	1	x	x	-	1	-	-	1	-	-	-
Mullet fry			-	27	x	x	-	-	3	-	3	-	-	5
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	2	-	x	x	81	-	-	9	3	-	1	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	21	24	x	x	14	46	28	6	36	6	2	100
Poecilia reticulata (Peters, 1859)	Guppy	PRET	-	-	x	x	-	-	7	-	-	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	-	-	x	x	8	-	-	5	8	-	-	5
Terapon jarbua (Forsskål, 1775)	Thornfish	TJAR	-	-	x	-	-	-	-	-	-	-	-	-
Valamugil cunnesius (Valenciennes, 1836)	Longarm mullet	VCUN	-	-	-	-	-	-	-	-	-	-	-	-
Total abundance			24	58	-	-	142	65	48	31	58	23	4	325
Diversity			3	6	10	10	11	4	8	6	8	3	3	8
Automated FRAI score			31.7	38.7	-	-	56.4	34.3	38.5	34	37.8	29.5	28.6	50.8
Automated FRAI Integrity class			E	D/E	-	-	D	E	D/E	E	D/E	E	E	D
Adjusted FRAI score			64.7	67.5	-	-	82.9	69.1	73.2	69.8	70.6	61.3	60.1	71
Adjusted FRAI Integrity class			C	C	-	-	B	C	C	C	C	C/D	C/D	C

Table 35: Diversity and abundance of fish species where available between 1999 (99) and 2012 (12) from the lower Umvoti (UR8) and Nchaweni (NS1 and NS2) Rivers for high (H) and low (L) flow surveys with automated and adjusted FRAI scores as well as the integrity classes for each FRAI score. The 'x' indicates presence of fish species where abundance data were not available.

Fish Species	Common Name	ABR	UR8-99H	UR8-00L	NS1-05H	NS1-10H	NS1-12H	NS2-05H	NS2-05L	NS2-10H	NS2-11L	NS2-12H
Acanthopagrus berda (Forsskål, 1775)	Riverbream	ABER	-	-	-	-	-	-	-	-	-	-
Ambassis ambassis (Lacepède, 1802)	Commerson's glassy	AAMB	-	-	-	-	-	-	-	-	-	-
Ambassis producta (Guichenot, 1866)	Longspine glassy	APRO	-	-	-	-	-	-	-	-	-	-
Anguilla mossambica (Peters, 1852	Longfin eel	AMOS	-	-	-	-	-	-	-	-	-	-
Anguilla sp			-	-	-	-	1	-	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	Freshwater goby	AAEN	-	x	-	-	-	-	-	-	-	-
Awaous sp			-	-	-	-	-	-	-	-	-	-
Barbus paludinosus (Peters, 1852)	Straightfin barb	BPAU	-	-	-	33	-	-	-	-	10	-
Barbus trimaculatus (Peters, 1852)	Threespot barb	BTRI	-	-	-	3	43	-	-	-	5	102
Barbus viviparus (Weber, 1897)	Bowstripe barb	BVIV	-	-	-	5	-	-	-	-	-	10
Caranx sp			-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	CGAR	-	x	-	6	10	6	8	15	6	9
Diplodus sargus capensis (Smith, 1844)	Blacktail	DCAP	-	-	-	-	-	-	-	-	-	-
Eleotris fusca (Schneider, 1801)	Dusky sleeper	EFUS	-	-	-	-	-	-	-	-	-	-
Gambusia sp			-	-	-	-	5	-	-	-	-	-
Gilchristella aesturia (Gilchrist, 1913)	Estuarine round-herring	GAES	-	-	-	-	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	River goby	GCAL	-	-	-	-	-	-	-	-	-	-
Glossogobius giuris (Hamilton-Buchanan, 1822)	Tank goby	GGIU	-	-	-	-	-	-	-	-	-	-
Glossogobius sp			-	-	-	-	-	-	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	Mosquitofish	GAFF	-	-	27	39	-	-	-	-	-	-
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal yellowfish	LNAT	-	-	-	-	-	-	-	-	-	-
Liza tricuspidens (Smith, 1935)	Striped mullet	LTRI	-	x	-	-	-	-	-	-	-	-
Megalops cyprinoides (Broussonet, 1782)	Oxeye tarpon	MCYP	-	-	-	-	-	-	-	-	-	-
Microphis brachyurus (Bleeker, 1853)	Short-tail pipefish	MBRA	-	-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)	Natal moony	MARG	-	-	-	-	-	-	-	-	-	-
Mugil cephalus (Linnaeus, 1758)	Flathead mullet	MCEP	x	x	-	-	-	-	-	-	-	-
Mullet fry			x	x	-	-	-	-	-	-	35	205
Myxus capensis (Valenciennes, 1836)	Freshwater mullet	MCAP	x	x	-	-	-	-	-	-	-	-
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	OMOS	x	x	17	15	90	5	22	5	9	207
Poecilia reticulata (Peters, 1859)	Guppy	PRET	x	x	-	-	-	-	3	-	-	-
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder	PPHI	-	-	-	3	1	-	-	-	3	-
Terapon jarbua (Forsskål, 1775)	Thornfish	TJAR	-	-	-	-	-	-	-	-	-	-
Valamugil cunnesius (Valenciennes, 1836)	Longarm mullet	VCUN	-	-	-	-	-	-	-	-	-	-
Total abundance			-	-	44	104	150	11	33	20	68	533
Diversity			5	8	2	7	6	2	3	2	6	5
Automated FRAI score			-	-	23.5	37.7	39.3	26.5	26.5	27	43	49.8
Automated FRAI Integrity class			-	-	E	D/E	D/E	E	E	E	D	D
Adjusted FRAI score			-	-	55.4	70.3	66.8	58.9	58.9	58.9	73	71.8
Adjusted FRAI Integrity class			-	-	D	C	C	C/D	C/D	C/D	C	C

A total of 29 fish species over 45 surveys between 1999 and 2012 were found in the lower Umvoti River as well as associated tributaries which include the Hlimbitwa and Nchaweni Rivers. The automated FRAI integrity classes of the lower Umvoti, Hlimbitwa and Nchaweni Rivers ranged from a largely natural (Class B) state to a seriously modified (Class E) state. Trends regarding the automated FRAI scores (Figure 81) of the Umvoti River (UR1 – UR7) fluctuated slightly between 2004 and 2012 with UR1 and UR7 being the most stable. Both the Nchaweni River (NS1 and NS2) sites experienced a slight increase from 2004 towards 2010 whereafter NS2 noticeably increased towards 2012. Automated FRAI scores of the Hlimbitwa River (HR1) noticeably increased between 2011 and 2012.

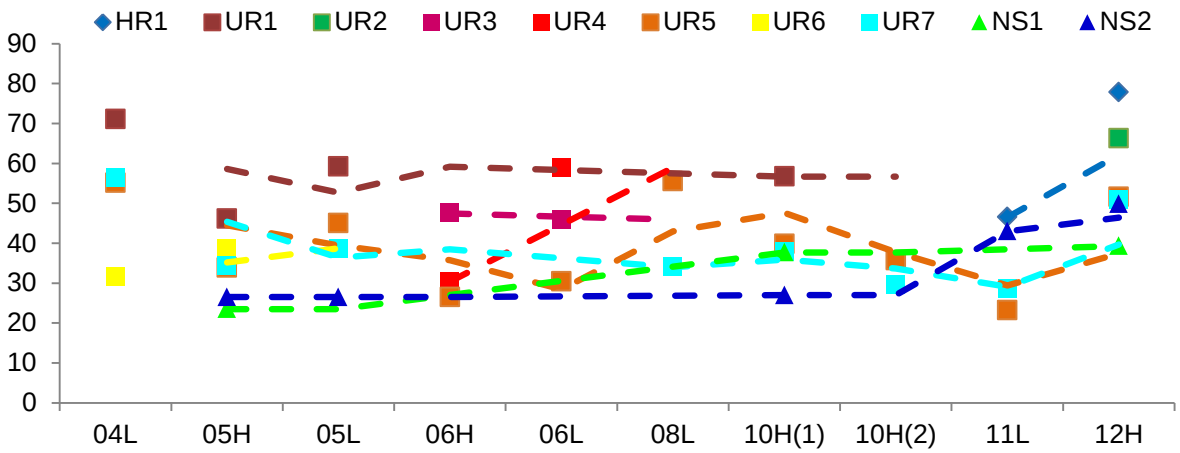


Figure 81: Trends of the automated Fish Response Assessment Index (FRAI) scores (x axis) where available since 1999 (99) and 2012 (12) collected from the lower Umvoti (UR1 – UR8), Hlimbitwa (HR1) and Nchaweni (NS1 and NS2) Rivers during high (H) and low (L) flow sampling surveys (y axis)

Adjusted FRAI (Figure 82) scores of the lower Umvoti and Nchaweni Rivers showed similar trends in comparison to the automated FRAI score trends. However, the Hlimbitwa River showed a slightly decreasing trend. Although the automated and adjusted FRAI score trends are similar, the adjusted FRAI scores are noticeably higher and result in better ecological integrity classes, due to the fact that the effects of each metric group considered in FRAI are better represented in the adjusted FRAI than in the automated FRAI.

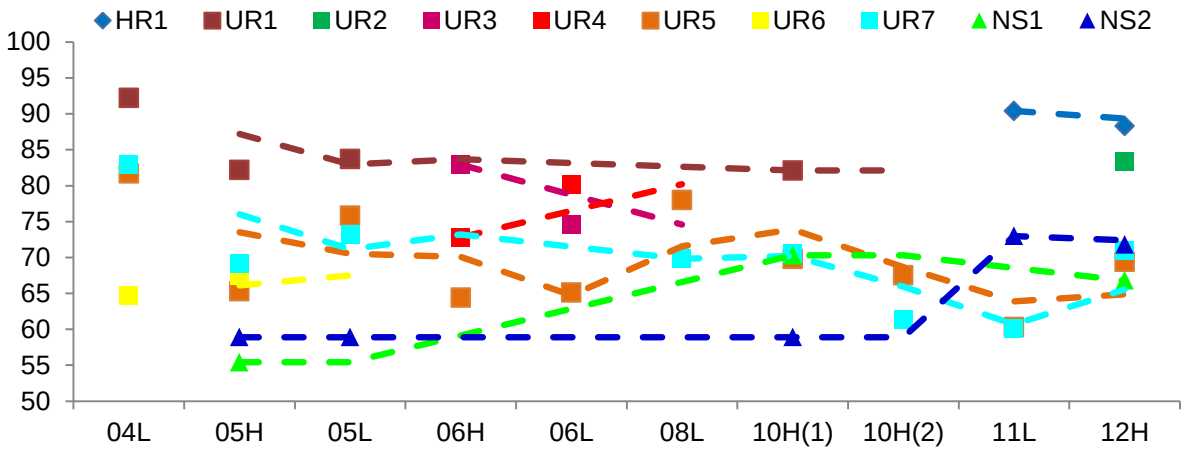


Figure 82: Trends of the adjusted Fish Response Assessment Index (FRAI) scores (x axis) where available between 1999 (99) and 2012 (12) collected from the lower Umvoti (UR1 – UR8), Hlimbitwa (HR1) and Nchaweni (NS1 and NS2) Rivers during high (H) and low (L) flow sampling surveys (y axis)

4.3.2. Multivariate statistical analyses

The redundancy analysis (RDA) tri-plots of fish species considered for the entire study area (Amatikulu, Thukela and Umvoti Rivers as well as associated tributaries which include the Nembe, eMandeni, Hlimbitwa and Nchaweni Rivers) were performed and compared with the associated sites and driving environmental variables which include water quality, quantity, sediment and habitat.

Results regarding the fish community structures comparing high (H) and low (L) flows (Figure 83) show that flow had a significant (P = 0.02) influence on the fish assemblages of the study area. Findings reveal that a fish community structure with great diversity was more closely related to high flows than to low flows. Upper portions of the Thukela River (sites TR1 and TR2) as well as sites ER2 and ER4 on the eMandeni River were associated with low-flow periods. *Labeo rubromaculatus* (LRUB) was closely related with low-flow periods and *Oreochromis mossambicus* (OMOS) with high-flow periods.

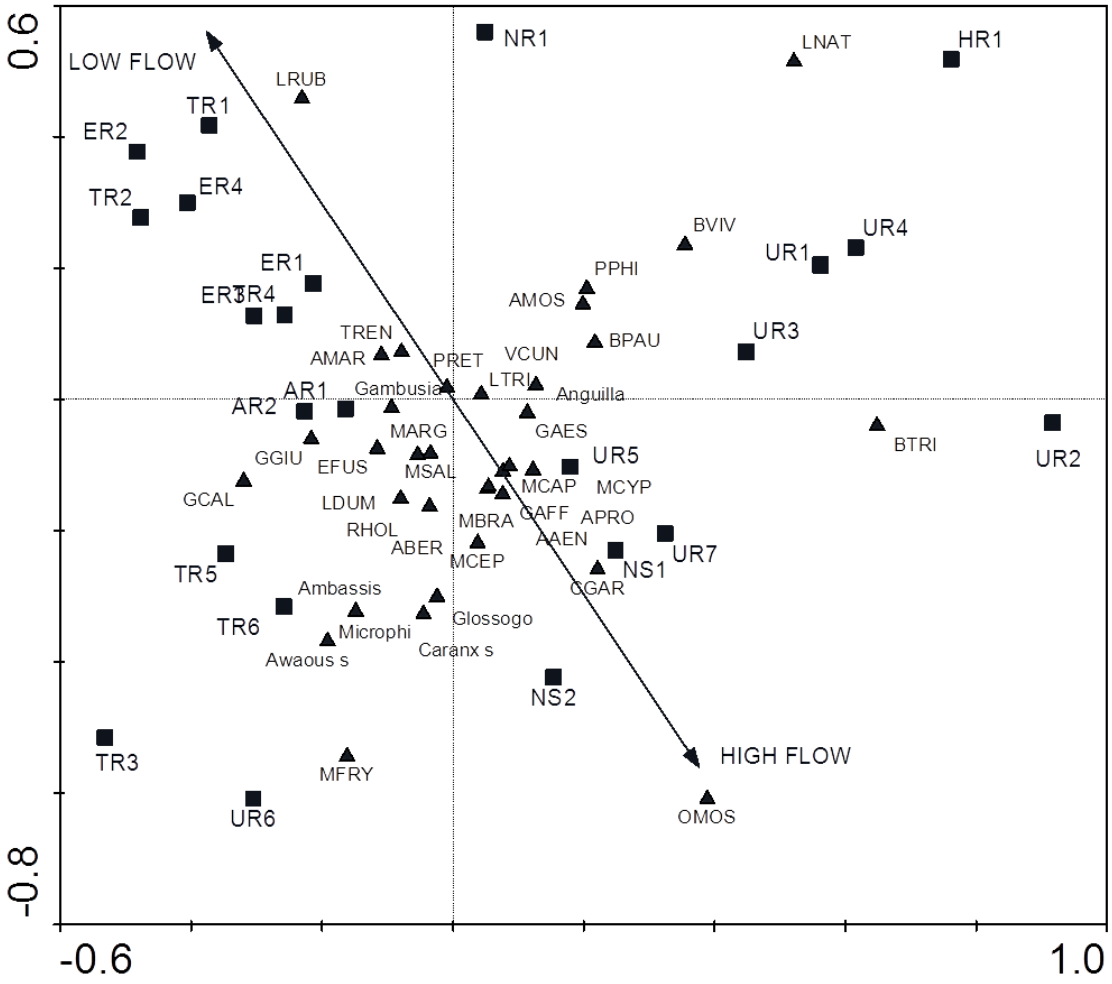


Figure 83: Redundancy analysis tri-plot of fish species, sites and flow variables showing dissimilarity among sites assessed in this study, represented as squares. The fish species (displayed as triangles) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the species, sites and flows variable ordination 49.4% of the variation within the data is presented, 30% on the 1st axis and an additional 19.4% on the 2nd axis.

Fish species from the study area compared with years (Figure 84) indicated that the temporal changes in the fish community structure were significant (P = 0.02). A unique fish community structure is associated with studies done during 2004 on the Umvoti River at sites UR1 and UR4. Results further show that studies done in 2005, 2006 and 2008 were all associated with the same fish community structure.

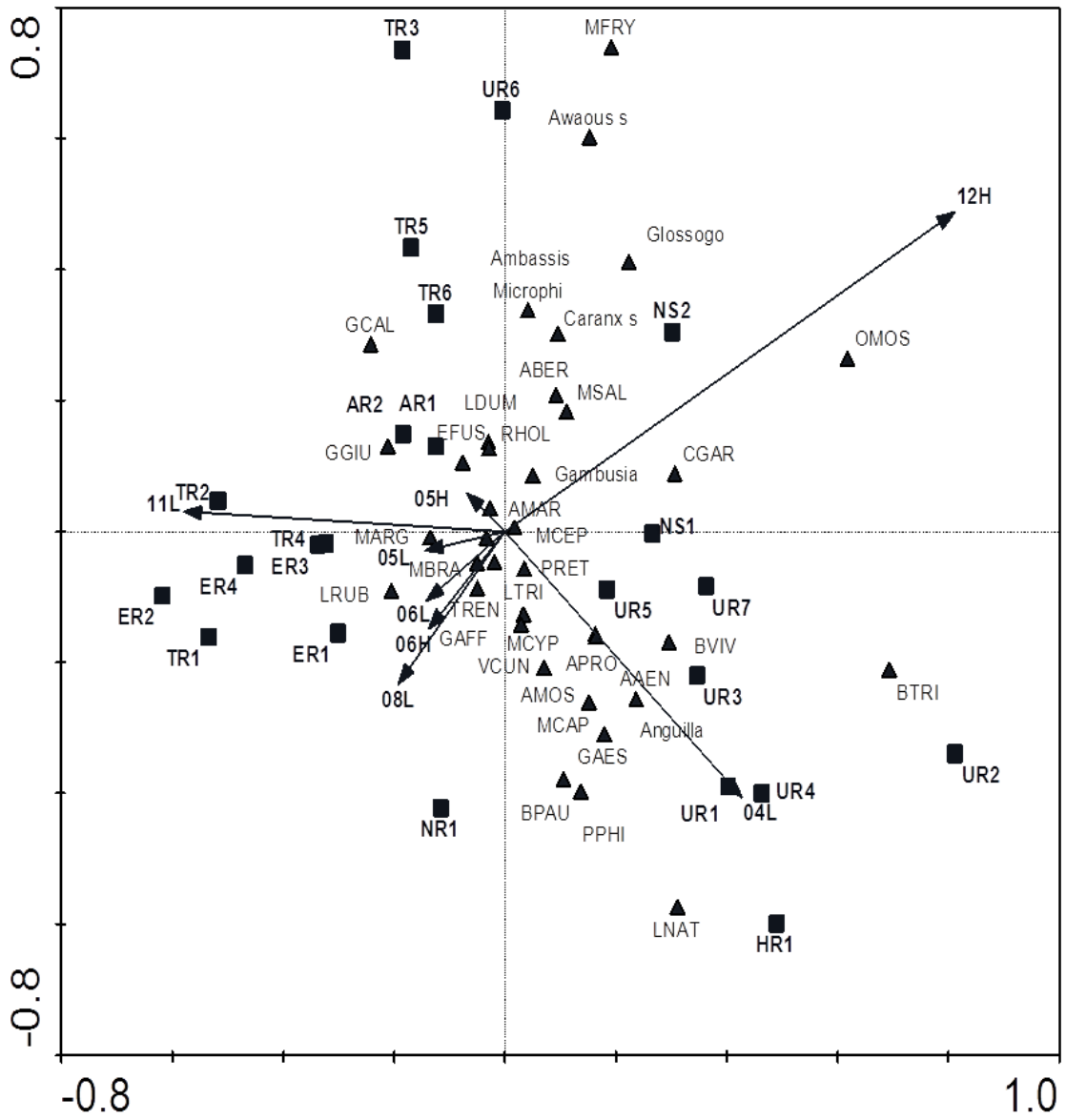


Figure 84: Redundancy analysis tri-plot of fish species, sites and years variable showing dissimilarity among sites assessed in this study, represented as squares. The fish species (displayed as triangles) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the species, sites and years variable ordination 49.4% of the variation within the data is presented, 30% on the 1st axis and an additional 19.4% on the 2nd axis.

Findings of the statistical comparison between fish assemblages and water quality (Figure 85) were significant (P = 0.042). Several individual water-quality variables were also significant which include temperature (P = 0.004), oxygen (P = 0.004) and ortho-phosphate (P = 0.0046). The results show that sites TR1, TR2 and TR4 of the Thukela River as well as the eMandei River sites (ER1-ER4) were all associated with elevated salt loads and nutrient levels.

Both sites of the Amatikulu River were closely related to each other which indicates that the water quality at these two sites were very similar. A unique and diverse fish community structure is related to sites UR3, UR5 and UR7 of the Umvoti River and site NS1 of the Nchaweni River. The upper reaches of the Umvoti River (UR2) and the Hlimbitwa River (HR1) is associated with freshwater fish species such as *Barbus trimaculatus* and *Labeobarbus natalensis*. The Nembe River (NR1), which is situated in the upper reaches of the Thukela River, is closely related to high levels of dissolved oxygen.

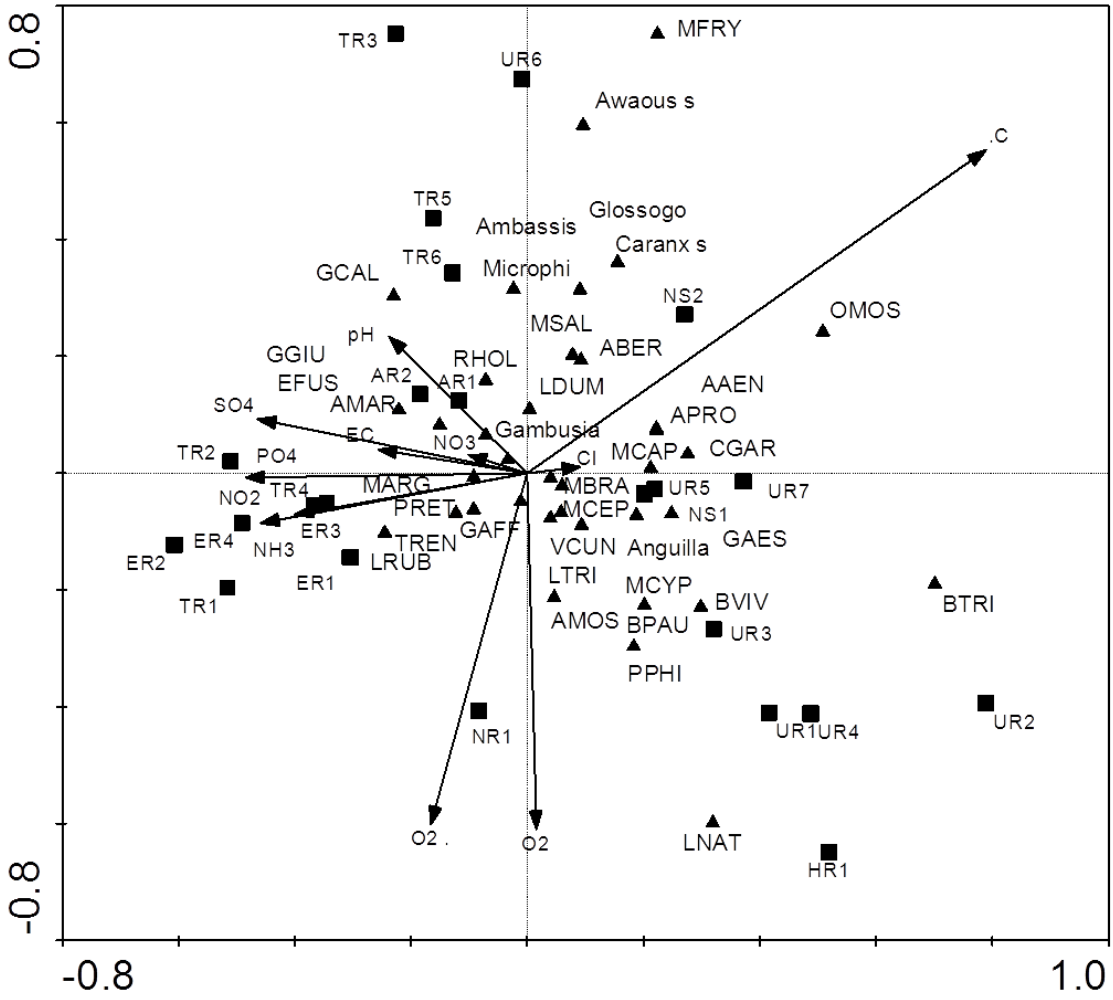


Figure 85: Redundancy analysis tri-plot of fish species, sites and water quality variables showing dissimilarity among sites assessed in this study, represented as squares. The fish species (displayed as triangles) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the species, sites and water quality variable ordination 47.2% of the variation within the data is presented, 28.3% on the 1st axis and an additional 18.9% on the 2nd axis.

Findings of the statistical comparison between fish assemblages and the sediment grain-size distribution (Figure 86) were not significant (P = 0.065). Both sites on the Amatikulu River (AR1 and AR2) as well as those on the lower reaches of the Thukela River (TR5 and TR6) were closely associated with muddy sediment types. The majority of the sites on the Thukela and eMandeni Rivers were composed of very fine sand (VFS) and medium sand (MS), while the Nembe River site (NR1) was composed of gravel (G). Findings also show that the great diversity of fish species sampled in the lower Amatikulu, Thukela and Umvoti Rivers were associated with poorly sorted sediment grain sizes and not one particularly well-sorted sediment type in which the grains are all about the same size.

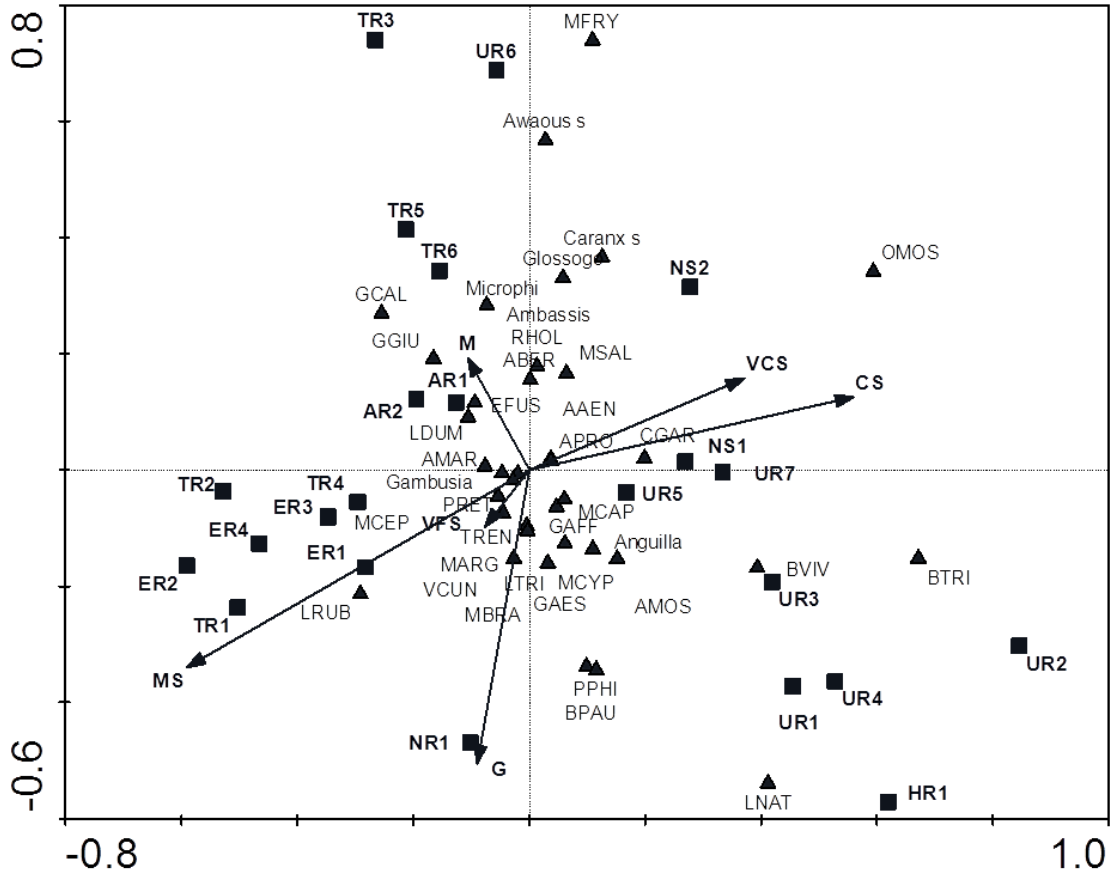


Figure 86: Redundancy analysis tri-plot of fish species, sites and sediment grain-size variables showing dissimilarity among sites assessed in this study, represented as squares. The fish species (displayed as triangles) and environmental data collected during these surveys (arrows) have been overlaid onto the RDA to present possible driving variables. In the species, sites and sediment grain-size variable ordination 49.7% of the variation within the data is presented, 28.4% on the 1st axis and an additional 21.3% on the 2nd axis.

4.4. Conclusion

Fish assemblages in the lower Amatikulu, Thukela and Umvoti Rivers responded to the quality and state of the environmental driver variables considered in the study. The integrity classes of FRAI showed noticeable differences between automated and adjusted FRAI scores with adjusted FRAI scores consistently being higher, leading to better integrity classes. This is an indication that the effects of each metric group considered in FRAI are better represented in the adjusted FRAI than in the automated FRAI.

Multivariate statistical analyses of fish communities and driving variables revealed that the Hlimbitwa River (HR1) as well as site UR2 of the Umvoti River were outliers and not associated with any of the different fish community structures and related sites in all the statistical analyses. This shows that these two sites are not related to a specific type of environmental driver variable. Throughout the multivariate statistical analyses *Labeobarbus natalensis* was associated with the Hlimbitwa River (HR1) and *Barbus trimaculatus* with site UR2 on the Umvoti River. This shows that the environmental conditions at these two sites favour these two fish species. Multivariate statistical analyses showed that the structure of fish assemblages is affected by the state or health of environmental driver variables.

Outcomes discussed in this chapter clearly indicate that the structure and integrity of fish assemblages (responder) are affected by the quality, state and/or health of environmental driving variables which in this study included water quality, sediment and habitat. It is also clear that the integrity of fish communities in the lower Amatikulu, Thukela and Umvoti Rivers as well as associated tributaries recovered rather than deteriorated towards 2012.

CHAPTER 5: Revisiting hypotheses and recommendations

This study evaluates the current ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers as well as establishing trends of current and historical data. The ecological integrity was determined by driver and responder lines of evidence. The driver lines of evidence included water quality, sediment analyses and habitat assessments. The responder lines of evidence included macroinvertebrates and fish assemblages. Two main hypotheses were tested during the course of this study. In this concluding chapter these hypotheses are revised and either accepted or rejected. Recommendations for future studies are also presented.

5.1. Hypotheses

Hypothesis 1: The ecological integrity of the lower Amatikulu River is better than that of the lower Thukela River and Umvoti River.

This hypothesis is accepted, because the results from this study clearly indicated that the ecological integrity of the lower Amatikulu River is currently in a largely natural, with few modifications (Class B) state. The Thukela River was found to be in a moderately modified (Class C) state while the Umvoti River was found to be in a largely modified (Class D) state.

Hypothesis 2: The ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers experienced a downward trend between current and historical periods.

This hypothesis is rejected as the trends in ecological integrity of the selected driver components which include water quality, sediment and habitat availability fluctuated noticeably. The general trend in water quality of the lower Amatikulu, Thukela and Umvoti Rivers as well as the associated tributaries which include the Nembe, eMandeni, Hlimbitwa and Nchaweni Rivers slightly recovered towards 2012. Sediment analyses revealed that the sediment grain-size distribution as well as the moisture and organic contents generally remained stable. There was a decline in the general state of habitat integrity towards 2012. As a result of the decline in the habitat ecological integrity the ecological integrity of macroinvertebrates also slightly declined towards 2012. However, a noticeable improvement in the ecological integrity of fish assemblages was observed towards 2012.

To conclude, the ecological integrity of water quality and fish assemblages improved towards 2012, while habitat and macroinvertebrates deteriorated and sediment stayed the same. The general and overall state of ecological integrity of the lower Amatikulu, Thukela and Umvoti Rivers did not deteriorate nor did it improve, but rather stayed the same over the period analysed.

5.2. Recommendations

The following reaserch and specifically long-term monitoring is presented:

- Long-term environmental monitoring programs which include water quality, sediment analyses, habitat assessments as well as macroinvertebrates and fish assemblages should be implemented twice a year during the high and low-flow periods on the lower reaches of the Amatikulu, Thukela and Umvoti Rivers. This will ensure that sufficient data is available in order to establish long-term trends and identify changes within the selected components. Long-term environmental monitoring is essential to develop and implement sustainable and sound management plans which mitigate impacts on the surrounding environment.

- Water quality measurements at effluent discharge points must be taken on a monthly basis to monitor and to ensure that the associated industries and land use activities meet their requirements.

- Management plans considering water abstraction, rehabilitation of the riparian zone and improved soil management processes should be implemented in order to mitigate impacts that increase sedimentation and to encourage natural filtration of runoff from sugarcane plantations.

The data and findings of this study can be used to a great extent when considering management and conservation plans for the surrounding areas of the lower Amatikulu, Thukela and Umvoti Rivers. The long-term data and trends of the selected lines of evidence presented in this study, can help decision-makers to implement sufficient management plans in order to improve sustainable development and mitigate impacts on the aquatic ecosystems of the lower Amatikulu, Thukela and Umvoti Rivers, preventing excessive utilisation of the ecosystem services provided.

CHAPTER 6: References

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