RE-EVALUATING VEGETATION COMMUNITY DYNAMICS AND WELL-BEING OF THE LOWER UTHUKELA AND UMVOTI RIVERS IN KWAZULU-NATAL, SOUTH AFRICA.

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ABSTRACT

Aquatic ecosystems are deteriorating due to the numerous anthropogenic stressors affecting them. Riparian vegetation and macrophytes can all be established as ecological indicators of the well-being of rivers and contribute to the sustainable management of water resources. In this study riparian vegetation and macrophyte communities were assessed to determine their condition and structures at the lower uThukela and uMvoti Rivers using historical data from 2013 and data collected from the same study sites in 2023.To determine the ecological state of the macrophytes and riparian vegetation communities, data was collected to represent the vegetation communities of the riparian ecosystem and macrophytes ecosystem using phytosociological methods. For this study, cross-sections for the sampled rivers, river discharge data (m^3/s), water quality variables, substrate types, water levels (m) and vegetation communities data were determined. The plant community data was superimposed into cross-sections of the rivers and used to provide information pertaining to the relative elevation and hydraulic niche requirements of each individual plant species. Substrate at each site associated with plant communities were estimated and categorized into either silt, mud, sand, gravel, cobble, boulders and bedrock following the grain-size analysis and sieving technique. The biological community structures and their associated abiotic variables were assessed using multivariate statistical techniques in the form of Canonical Correspondence Analysis (CCA) and Redundancy Analysis (RDA) multivariate approaches to determine the well-being of uThukela and uMvoti Rivers across the sampled sites. The significant threshold selected for this study was restricted to $p = 0.05$ where $p< 0.05$ is significant and $p> 0.05$ is regarded as not significant.

Change detection results indicated a decline in both the macrophytes (4914 Ha to 4002 Ha) and riparian vegetation (23292 Ha to 19055 Ha) communities of the uThukela River in the 10-year period (2013-2023).

Most of the plant communities were categorized under sub-adult and adult age groups except for few juveniles. The multivariate analysis indicated that water quality is a significant driver to the observed vegetation communities of the lower uThukela River.

Macrophytes and riparian vegetation communities data from the sampled sites of the lower uMvoti River were also evaluated using similar multivariate analysis methods. Change detection method indicated an increase in the riparian vegetation communities and a decrease in macrophytes communities. The riparian vegetation communities of uMvoti River increased from 8620 Ha to 10952 Ha between 2013 and 2023, respectively. A decline in macrophytes communities was observed in the period between 2013 and 2023 with 4488 Ha and 2106 Ha, respectively. Most of the sampled plant communities in the lower uMvoti River were observed as adults. The population structure of the river's vegetation communities is concerning as it is lacking juvenile individuals. The multivariate analysis indicated that water quality and substrates are not significant drivers of the observed plant communities in the lower uMvoti River. The plant communities superimposed to the cross sections for both uMvoti and uThukela Rivers did not show any clear association with elevation and water requirements.

Key words: drivers of change, riparian vegetation, macrophytes, change detection

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DECLARATION

I, Daphney Thobela, declare that this dissertation, entitled "Re-evaluating vegetation community dynamics and well-being of the lower uThukela and uMvoti Rivers in KwaZulu-Natal, South Africa," is my own work. I have not submitted it for any other degree or qualification at any other university. This work is solely the result of my intellectual endeavors, except where otherwise acknowledged.

I understand that the unauthorized use of another person's work, without due acknowledgement, is plagiarism. I have read and adhered to the guidelines and regulations on plagiarism set out in the University of Mpumalanga code of academic integrity.

I have cited all sources of information in this thesis accurately and have included complete references to all publications and other scholarly works in the text. I acknowledge that failure to do so constitutes plagiarism and may lead to rejecting this thesis or other appropriate action.

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Signature: ____________________

Date: 25 November 2025

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LIST OF ABBREVIATIONS AND ACRYONYMS

CCA- Canonical correspondence analysis.

COD- Chemical oxygen demand.

DWAF- Department of water affairs.

DO- Dissolved oxygen

E. COLI- Escherichia coli.

HA- Hectares.

IWRM-Integrated water resources management.

NDVI- Normalized difference vegetation index.

RHP- River health program.

RDA- Redundancy analysis.

SANS- South African National standards.

TDS- Total dissolved solids.

USGS- United states geographical survey.

VEGRAI- Vegetation response assessment index.

WHO- World health organization.

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CHAPTER 1: INTRODUCTION

1.1 Background of study

South Africa is a developing country with a large rural population that relies on natural resources for various purposes, such as building, craftwork, foods, cosmetics, and medicine (Corrigan *et al*., 2011). People rely on aquatic resources as one of their main sources of the necessities for living (Thomas, 2021). Due to numerous benefits they offer to both humans and animals, macrophytes and riparian vegetation are important parts of aquatic ecosystems. These benefits include increasing habitat heterogeneity (Thomas, 2021; Peternel *et al*., 2022), offering protection from predators, regulating flow, purifying water, and serving as a source of food and building materials (Wade, 2019; Riis *et al*., 2020; Thomas, 2021).

Plant communities can undergo changes, due to either natural or anthropogenic stressors (Coppin *et al*., 2004). The most common causes of changes in vegetation communities are anthropogenic causes (Li *et al*., 2012). The stressors contribute to the decline of the ecosystem services (Vörösmarty *et al*., 2010). According to Vörösmarty *et al*. (2010), altered flows, alien invasion, land-use change, overuse, sand mining, and industrialization are common stressors of vegetation communities. These stressors affect different vegetation species in different ways due to their varying tolerances to stress (Lenihan *et al.,* 2018; Fouchy *et al.,* 2019).

Since a substantial portion of the uThukela and uMvoti River passes in the rural KwaZulu-Natal, human-influenced changes have a significant impact on the vegetation communities of these rivers. For ecosystem services like firewood, building materials and traditional medicinal herbs, rural people mostly get them from the river, resulting in the over-utilization of the vegetation by harvesting at a faster rate than the regenerating rate (Gorvender, 2000).

Land-use change is among the activities that drives the loss of vegetation communities in the uThukela and uMvoti River, such as clearing natural vegetation for sugarcane plantations (Jewitt *et al*., 2015). The river's water quality is tempered with and macrophytes are impacted by the constant application of fertilizers to optimize agricultural production (Jewitt *et al.,* 2015). The uThukela River is surrounded by industries that have an impact on its macrophytes and riparian vegetation. For example, the Sappi Tugela pulp and paper mill draws a lot of water from the river and releases wastewater into the river, which degrades the water quality (Stryftombolas, 2010).

One of the most frequent activities in the uThukela River is illegal sand mining, which can drive vegetation communities by causing bank instability and sediment movement (Rentier & Cammeraat, 2022). Due to their competitive nature, alien invasion which includes silk oak *(Grevillea robusta)* and Umzimbeet *(Millettia grandis),* influence macrophytes and riparian vegetation in the uThukela River due to its dominance and fast re-production rate (Canavan *et al*., 2018).

The uMvoti River is also one of the rivers that suffers from degradation, resulting in it being named “the working river “(Ouma & Shane, 2022). The commercial agricultural sector and industries encircle a significant portion of the river, resulting in significant water abstraction for industrial and irrigation purposes (Malherbe, 2006). The abstraction of water results in low flows and the rapid flow increase during flooding has serious consequences to the riparian vegetation and macrophytes by supporting only plant species that have rapid growth rates and short life cycles (Mbanjwa, 2017).

The uMvoti River has semi-deciduous savanna woodlands, dominated by species of Euphorbia and Aloe (Whitaker, 2018). The riparian vegetation comprises of *Phragmites australis* and sedges in the marginal zone and the lower zone consists of alluvial floodplain vegetation, mainly grasses, *Syzigium cordatum* and *Ficus sur* (Whitaker, 2018). The upper zone is normally characterized by a dense riverine forest (Whitaker, 2018). The uMvoti River is in the vicinity of stanger which exposes it to overuse (Wade *et al*., 2022). The uMvoti River supports a large-scale of agricultural irrigation schemes and various other domestic uses to surrounding informal settlements (Wade *et al*., 2022). Agriculture as one of the dominating activities in the uMvoti River, contributes to the distribution, shaping, and well-being of macrophytes and riparian vegetation, since the clearing of natural vegetation is a necessary part of agriculture, exposing the river to the growth of invasive alien plant species (Sukdeo *et al*., 2014).

Plant species, such as gum trees (*Eucalyptus globulus),* pine trees *(Pinus pinaster),* and black wattle *(Acacia mearnsii),* are planted for timber (Lebek *et al.,* 2019). They hinder the re-establishment of native vegetation through allelopathy (chemical competition) and competition for resources such as space and sunlight (Lebek *et al*., 2019). A high volume of water abstraction to meet the demands of agriculture and industrialisation result in altered flows that causes high sedimentation loads (Malherbe *et al*., 2008). The movement of sediments is associated with sorting of grain sizes, that is not preferred by biodiversity, resulting in minimal habitat that is in good condition (Cooper, 1994). This degradation of natural habitat increases chances of alien invasion and prevents natural indigenous vegetation from returning, owing to alien plants' competitive nature (Malherbe *et al.,* 2008).

Macrophytes and riparian vegetation can be used to determine the ecological state of water resources and provide a better understanding of the effects of the multiple stressors acting upon them (Roni *et al.,* 2018). Their ability to respond to disturbances in aquatic environments allows them to be used as biological indicators of ecological conditions (Manning *et al.,* 2020). This is due to their sessile nature that allows the study of historic and present occurrences to be detected and monitored, such as flow patterns, water quality, and sedimentation (Cowley *et al.,* 2006). Riparian and macrophytes vegetation can provide a cost-effective way of monitoring water resources because information from them can be easily and quickly recorded in the field (Huylenbroeck *et al.,* 2020). In addition, their distribution and variation over time can be traced from aerial photographs using geographical information systems (Rivas-Fandino *et al.,* 2023).

1.2 Problem statement

Due to contributing factors such as overuse, altered water quality, sand mining, alien invasion, industrialisation, and changes in land-use, the uThukela and uMvoti Rivers are deteriorating. The condition of water resources is deteriorating, which is worrisome since these pressures impact both the quality and quantity of plant communities in the rivers. The loss of vegetation communities can lead to devastating consequences, as they play a huge role in the functioning of water resources. Absence of vegetation can result in loss of diversity, as they provide a crucial habitat for both aquatic and terrestrial organisms such as fish, small mammals and insects (Keddy, 2010). An absence of vegetation can lead to the decline in biodiversity through lack of feeding, breeding and sheltering for various organisms that depend on them (Keddy, 2010).

Additionally, macrophytes play a huge role in water purification and nutrient cycling, by absorbing toxins and excess nutrients, and stabilizing sediments (Chambers *et al*., 2014). Their absence can lead to a decline in water quality due to the presence of excess nutrients and high turbidity (Naiman *et al*., 2005). Vegetation also plays an important role in erosion management as it stabilises riverbanks and regulates water flow by reducing its velocity (Naiman *et al*., 2005). Its absence can lead to a high erosion rate, increased sediment transportation and changes in the river's hydrological regime.

The absence of macrophytes and riparian vegetation in rivers can open a gap for the establishment of alien invasive plants through the creation of ecological niches that they thrive in (Mack *et al*., 2000). The establishment of alien invasive plants is a major concern, as once they establish themselves, they can prevent the re-establishment of indigenous vegetation due to their fast reproductive rates and dominance (Mack *et al*., 2000).

1.3 Research aim and objectives

1.3.1 Main aim

The study aims to re-assess the vegetation communities within the lower uThukela and uMvoti Rivers and identify the primary drivers influencing their transformation, to determine the changes that have occurred between 2013 and 2023.

1.3.2 Specific objectives

- To assess vegetation condition of the lower uThukela and uMvoti Rivers.
- To determine potential drivers of change in the vegetation communities of lower uThukela and uMvoti Rivers.

1.4 Research questions

- What is the condition of the vegetation communities of the lower uThukela and uMvoti Rivers between 2013 and 2023?
- What are the significant drivers of the vegetation communities of the lower uThukela and uMvoti Rivers?

1.5 Justification of the study

The study is referred to as a re-evaluation because it revisits previously assessed macrophytes and riparian vegetation communities in the year 2013 along the uThukela and uMvoti River. A re-evaluation is necessary, because ecological conditions change significantly over time due to factors such as invasive species, climate change, natural disasters such as floods and droughts, land use change or river management practices.

Sustainable development and conservation of the environment greatly depend on the assessment and management of water resources (MEA, 2005). The study of macrophytes and riparian vegetation communities is a crucial component of this evaluation, since they are essential to preserving ecological balance, water quality, and the overall wellness of rivers (Sonneman, 2015). To ensure accurate understanding and efficient management, these components must be periodically re-evaluated due to the constantly changing nature of rivers (Chambers *et al*., 2014). Re-evaluating vegetation communities of uThukela and uMvoti River can serve as a vital component of environmental monitoring efforts (Hawkins *et al*., 2010). Changes observed in the vegetation can be used to indicate shifts in the water quality state, the condition of the habitat and the overall ecosystem health of the rivers in general (Hawkins *et al*., 2010).

The quality of water resources is continuously changing because of human and natural activities (Falkenmark & Rockstrom, 2004). The composition and health of riparian vegetation communities and macrophytes can be impacted by factors like land-use change and climate change; therefore, it is imperative to re-evaluate how these changes impact the water resources (Moss, 2010).

The re-evaluation of vegetation communities in the uMvoti and uThukela River can allow the assessment of time related changes that took place over the years, such as species composition, diversity and distribution (Davis *et al*., 2018). Understanding long term trends on how the vegetation communities has evolved over time can provide valuable insights into ecosystem changes and responses to environmental factors (Davis *et al*., 2018).

By filtering contaminants, stabilizing sediments, and controlling nutrient cycles, macrophytes and riparian vegetation play a critical role in preserving the quality of rivers (Chambers, 2014). Modifications to the land usage, water flow, or pollutant intake may have an impact on the health and well-being of these vegetation communities (Gregory *et al*., 2003). To understand their current contributions to water quantity and quality, it is essential to re-evaluate their state (Gregory *et al*., 2003). Furthermore, macrophytes and riparian vegetation communities support the general well-being and efficiency of aquatic ecosystems (Cardinale *et al*., 2012). A re-evaluation enables the formulation of conservation plans, the identification of possible risks, and the assessment of changes in biodiversity (Brooks *et al*., 2006). This is crucial, given the importance of assessing the continuous loss of biodiversity and the requirement for focused conservation initiatives.

The comparison of historic and present data through a re-evaluation, can also assist in gauging the resilience of vegetation communities to disturbances, such as land use change and climate change (Hobbs *et al*., 2009). Results from the study can assist in predicting future ecosystem trajectories and coming with effective conservation strategies (Hobbs *et al*., 2009). Additionally, re-evaluating vegetation communities of uThukela and uMvoti Rivers will enable validation of previous findings and ensure accuracy and reliability of the data by analysing persistence of plant species and improve the quality of ecological assessments (Dornelas *et al*., 2013).

Furthermore, new tools for researching macrophytes and riparian vegetation communities are available through technological advancements like remote sensing and GIS (Geographic Information System) (Pettorelli *et al*., 2014). The enhanced precision and in-depth information offered by these instruments facilitates a more comprehensive understanding of the structures and relationships within water resources (Pettorelli *et al*., 2014). The study takes advantage of these technical developments to improve vegetation assessment accuracy.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Biomonitoring of aquatic ecosystems has emerged and become recognised as a tool that can be used for monitoring and assessing the condition of water resources (Mangadze *et al*., 2018). Biomonitoring refers to the use of biological responses of aquatic communities, such as fish, macroinvertebrates, macrophytes and riparian vegetation, in assessing the condition of rivers (Mangadze *et al*., 2018; Duley *et al.,* 2022). Various biomonitoring programs have been adopted all over the world, such as the Rapid Bioassessment protocol in the United States, which is used in streams and rivers (Duley *et al*., 2022). This concept led to the Department of Water Affairs and Forestry (DWAF) developing the South African River Health Programme (RHP) in 1994 (Ndlovu *et al*., 2019; Wade *et al.,* 2022). The main purpose of the RHP was to produce information regarding the overall ecological status of river ecosystems in South Africa (Davies *et al*., 2010).

Few years after the RHP was initiated, the South African National Water Act (NWA) came into effect (WRC, 2006). The act acknowledges the vital role that aquatic ecosystems play and the importance of protecting them, hence there was a need for the establishment of an aquatic ecosystem health monitoring system (Agboola, 2017). Presently, the implementation of the RHP is driven by provincial environmental departments, conservation agencies, municipalities and universities (Brierley & Fryirs, 2015). It is essential to balance the use of rivers and protect them from overexploitation (Wade, 2019). The National Water Act 36 of 1998 facilitates the sustainable management of a country's water resource by addressing its use, protection, development, control, conservation, and management (Wade, 2019). The South African Water Law and Policy Framework of the 1996 constitution, section 27 paragraph B, mandates that the right of access to sufficient water should continually be progressively realised (The constitution of South Africa, 1996). Additionally, it implies that the right to water should not be constrained by water resource limitations or allocation of water for economic development (Gowlland-Gualtieri, 2007). The law is also designed to address the water challenges faced by South Africa (Colvin *et al*., 2019). Based on the Integrated Water Resources Management (IWRM), this law is widely recognized as one of the most progressive and is committed to addressing water issues by using a whole river approach to ensure water security, empower poor communities, provide water and sanitation for all. Furthermore, it ensures effective governance based on shared power with local communities (Colvin *et al*., 2019). The efforts made by these laws are not adequate as there is still a lack of balance between the use and protection of rivers, which is concerning as rivers play a vital role in the survival of humans and animals (Cosgrove & Loucks, 2015).

Water may be everywhere, but its use has always been constrained due to availability, quantity, and quality (Molobela & Sinha, 2011). Contemporary trends indicate that water scarcity will continue to become more complex and interfere with other development sectors, such as the energy, agriculture, mining and transportation sectors (Molobela & Sinha, 2011). South Africa is a semi-arid region, with an annual rainfall of less than 405 mm, while the world average is 860 mm (Wade *et al*., 2022). Recent studies demonstrated that most water resources in South Africa are degraded due to climate change, land-use change, over exploitation and alien invasive infestations (Du Preez & Van Huyssteen, 2020).

2.2 Importance of rivers

Since the dawn of time, aquatic resources have existed (Karr & Chu, 2000). Rivers have given humans food, water and places to live for as long as they have existed on the planet (Mauch & Zeller, 2008). Aquatic ecosystems have long been essential to humans and other creatures for waste treatment, flood control, shelter provision, and recreation (Teclaff, 1967; Mauch & Zeller, 2008). According to studies, river water is used to irrigate 62% of all irrigated land (Molle, 2003). Rivers directly support around a quarter of the world's food production, as irrigated land accounts for 40% of global food production (Lowder *et al*., 2016). Rivers provide irrigation water in places where rainfall is scarce (Molle, 2003). Additionally, alluvium deposited by the river during flooding results in fertile soil that is exploited for agriculture (Mohamed, 2016). Such occurrences are observed in the Nile valley and its delta in Egypt, and in Kiwira River in Tanzania (Mohamed, 2016).

2.3 Importance of vegetation (macrophytes and riparian vegetation)

2.3.1 Regulation services

Regulating services incorporate services that both directly and indirectly sustain environmental quality (Fu *et al*., 2013). For river ecosystems to function properly, macrophytes and riparian vegetation should be present (Abubakr, 2010). Riparian vegetation refers to the intricate terrestrial assemblages of plants next to the water resource and are influenced by the fluvial processes of the river, while macrophytes refer to aquatic plants that are large enough to be seen with the unaided eye (Zhu *et al*., 2023). In the aquatic carbon cycle, macrophytes and riparian plants play a significant role in carbon storage in aquatic environments (Reitsema *et al*., 2018; Zhu *et al.,* 2023). According to Sutfin *et al*. (2015), the distribution of carbon within riparian vegetation controls how much of carbon gets into the ocean and overall atmosphere. According to Reitsema *et al*. (2018), the sources of organic carbon in rivers come from the leaves, stems, and wood of riparian vegetation. Carbon cycle happens when riparian vegetation deposit plant detritus into streams as coarse particle organic matter that aquatic invertebrates in the river channel breakdown into fine particulate organic matter (Smith & Kaushal, 2015).

A significant amount of carbon in streams is not transferred to the seas, supporting the assumption that carbon is stored in the riparian zones (Ledesma *et al*., 2015). Considering the role that carbon plays in the health, efficiency and quality of aquatic resources, riparian vegetation is a crucial component that should be safeguarded and conserved (Groffman *et al*., 2002). A study by Groffman *et al*. (2002) also shows that carbon produced through riparian plants and soils plays a significant role in improving water quality as well as nitrate and nitrite concentrations (Groffman *et al*., 2002). Macrophytes and riparian vegetation can also help mitigate climate change through carbon storage in their biomass and substrates (Ma *et al*., 2019).

According to Sangeeta (2007), macrophytes are important for controlling nutrient enrichment and sediment in rivers. They accomplish this by absorbing and storing excess nutrients such as nitrogen and phosphorus from the water, reducing the severity of eutrophication (Chambers & Lacoul, 2011). Riparian vegetation also acts as a buffer zone by filtering excess nitrogen originating from run-off and preventing it from entering rivers (Lowrance *et al*., 2015). The control of nutrients is beneficial to rivers, because it prevents the development of harmful algal blooms, which disrupt aquatic ecosystems (Chambers & Lacoul, 2011). Riparian vegetation also plays a vital role in nitrogen cycling and fixation, transformation, including nitrification and denitrification (Vidon *et al.,* 2010). The transformation is crucial as it converts the nitrogen to a form that can be used by all plants.

Riparian vegetation also helps regulate temperature by providing shade, which can be useful to temperature sensitive aquatic organisms (Ma *et al*., 2019). According to Janauer *et al*. (2010), macrophytes and riparian plants also help control river flow as stems, complex root system and leaves create resistance to water flow (Nepf, 2012). This is important because slow flowing rivers play an important role in nutrient cycling by allowing settling of organic matter, assisting the decomposition process and ensuring nutrient availability for macrophytes (Fagan *et al*., 2016).

2.3.2 Provision services

According to Riis *et al*.(2020), provision services refer to tangible goods that are directly derived from riparian vegetation and macrophytes. As they offer innovative treatments for numerous ailments, plants whether aquatic or terrestrial, are regarded as a major source of medicine worldwide (Van Wyk & Prinsloo, 2018). Van Wyk & Prinsloo (2018) estimated that 25% of the world's clinical medications are derived from plants.

An estimation of 30,000 different plant species may be found in South Africa, and at least 10% of those species have the potential to be used medicinally (Van Wyk & Prinsloo, 2018). They are collected by traditional healers and herbalists by harvesting the whole plant or parts of the plant, such as barks, roots, leaves, flowers and bulbs (Van Wyk & Prinsloo, 2018). Traditional healers and herbalists are essential in many African nations, including South Africa (Thring & Weitz, 2006), for providing primary care, including taking care of patients with a variety of illnesses such meningitis, pneumonia, endocarditis, and diabetes mellitus. According to estimates, there are 27 million users of these indigenous medicines and 200,000 indigenous healers reportedly using about 3000 types of plants for medicine in South Africa (Moeng & Potgleter, 2011). It is known that a sizable portion of these plants can be found in riverine habitats (Grierson & Afolayan, 1999).

In South Africa, herbal medicine continues to be the primary method for treating HIV/AIDS-related illnesses for people living in rural areas, particularly those with poor access to medical care (Moeng & Potgleter, 2011). Local people have a rich history of using different medicinal plants, classifying plant parts according to their perceptions and experiences to treat various ailments (Omuruyi *et al*., 2012). Traditional healers and rural residents of the Eastern Cape region frequently mentioned plant species of the Asphodelaceae, Apocynaceae, Asteraceae, Mesembryanthemaceae, and Hypoxidaceae families as the most used plants (Grierson & Afolayan, 1999; Erasto *et al*., 2005).

According to Pert *et al*. (2010), the riparian vegetation also provides biomass for firewood. Some plants are utilised as building materials. For example, the stems of giant reeds (*Arundo donax*) and common reeds (*Phragmites australis*), are used to thatch houses (Riis et al., 2020). The riparian vegetation provides sustenance for some communities in developing nations, such as wild fruit like water berries (Riis *et al*., 2020; Singh *et al*., 2021). By offering seeds, spores, and harvestable genes, they may be harvested for breeding products that are disease-resistant, that will also function as seed banks (Pert *et al*., 2010). Seed banks are important for the conservation of genetic diversity through the process of preserving a variety of plant species and their unique genetics (Hoban *et al*., 2014). They are also useful in ecosystem rehabilitation by re-introducing them after disturbances, to restore the ecosystem (Hoban *et al*., 2014). Seed banks can also be used as a climate-adaptation strategy, by preserving seeds of plant species with traits that are valuable under changing environmental conditions (Jarvis *et al*., 2008).

2.3.3 Cultural services

Cultural services of riparian vegetation and macrophytes include direct interaction, such as walking along a river for aesthetics, which assist in destressing and providing mental health benefits (Riis *et al*., 2020; Roviello *et al.,* 2022). Some people gain environmental, intellectual and spiritual benefits from ecotourism, relaxation, and refreshment (Riis *et al*., 2020; Roviello *et al*., 2022). They also allow for leisure activities like bird viewing and bushwalking (Vollmer *et al*., 2015).

2.3.4 Supporting services

Supporting services have no direct benefits for people and include all biophysical structures and processes that keep ecosystems healthy and enable them to provide ecosystem services (Mcnally *et al*., 2016). Macrophytes and riparian vegetation provide diverse habitats and niches for various aquatic organisms such as invertebrates, fisheries and amphibians (Steinman *et al*., 2010). The availability of vegetation, both macrophyte and riparian, provide supporting services to fish and invertebrates such as suitable breeding grounds (Steinman *et al*., 2010). In so doing, they support the occurrence and well-being of these aquatic communities and ensure a biodiversity-rich ecosystems (Tiwari *et al.,* 2023).

2.4 Stressors of vegetation (macrophytes and riparian vegetation)

2.4.1 Metals and nutrients enrichment

The health of rivers and its various components, including macrophytes and riparian vegetation, are at risk from a variety of stressors (Fu *et al*., 2013). One of the frequent stressors influencing macrophytes and riparian plants in rivers is metal contamination (Xing & Liu, 2011). According to studies, iron solution exposure for extended periods causes root flaccidity, leaf mottling, increased shoot-die back, plant necrosis, and reduced root branching in macrophytes and riparian vegetation (Xing & Liu, 2011). Chlorophyll production, protein synthesis, and glucose uptake are frequently inhibited when macrophytes and riparian plants are exposed to high iron concentrations (Lapaz *et al*., 2021).

Macrophytes and riparian vegetation exposed to high chlorine concentrations often suffer from damaged plant tissues and necrosis, especially leaves, due to its oxidizing nature (McMahon *et al*., 2013). High concentrations of chlorine can disrupt crucial processes such as photosynthesis, by reducing the plant's ability to produce energy and sustain growth (Richardson *et al*., 2007).

Sulphate can also affect vegetation (macrophytes and riparian) by interfering with nutrient uptake. The nutrient starvation caused by sulphate often leads to reduced growth rates (Stiles *et al*., 2015). Elevated sulphate content can also be a driver of the vegetation communities by allowing only sulphate-tolerant species to dominate, while displacing sulphate-sensitive species (Richardson *et al*., 2007). High sulphate concentration can also lead to nutrient imbalance (Stiles *et al*., 2015). Additionally, it may lead to morphology damage of the root system (Wang *et al*., 2010). These changes can affect nutrient uptake and overall plant stability (Wang *et al*., 2010). They can also affect macrophytes and riparian vegetation communities through interference with reproductive process such as seed germination and viability (Khan *et al*., 2009; McMahon, *et al*., 2013)

Vegetation exposed to high concentration of copper metal can also be affected (Ghaderian & Ravandi, 2012; Slonecker, 2018). Common effects involve leaf discoloration due to breakdown of chlorophyll and disruption of leaf production (He & Dijkstra, 2014). Some vegetation species also suffer from necrosis, resulting in tissues turning dry, and brown to black (He & Dijkstra, 2014).

2.4.2 Altered flows

Altered flow regime is one of the factors affecting the macrophytes and riparian vegetation in rivers (Soko, 2019). According to Lytle and Poff (2004), the abrupt shifts in the flow regime result in bank erosion, undercut banks and exposed vegetation roots, all of which have serious effects on macrophytes and riparian vegetation. Effects of exposed roots include susceptibility to mechanical damage, which can compromise their health (Dodds *et al*., 2017). The impacts can come in the form of habitat degradation and habitat loss that the macrophytes and riparian vegetation are well adapted to (Nilsson & Svedmark, 2002).

Additionally, many macrophytes species depend on predictable flow patterns, therefore altered flows can cause macrophytes to dislodge, flagellate irregularly, and modify their substrates (Lytle & Poff, 2004; Asaeda & Rashid, 2017). According to Asaeda & Rashid (2017), sudden turbulent flow might interfere with cellular and molecular functions of macrophytes, such as inducing oxidative stress. Increased flow can also encourage the spread of invasive plant species at the expense of native macrophytes and riparian vegetation, by sweeping them downstream (Lytle & Poff, 2004).

Research by Allan, (2004), indicated that rivers exposed to altered flow regimes often suffer from increased erosion and sedimentation. The sediment-increase can affect the water quality parameters, consequently affecting the growth of the macrophytes, by limiting the growth of species sensitive to altered water quality (Bunn & Arthington, 2002). Riparian vegetation communities can be affected by altered flow regimes, experiencing stress due to inundation or water shortage for prolonged and unpredictable periods (Dohrenbusch & Bork, 2010). Changes brought by altered flow regimes influence the germination and establishment of seeds, as some vegetation species depend on specific hydrological cues for successful germination (Tonkin *et al*., 2018). Altered flow regime can also influence vegetation communities by changing the water availability to plant roots (Osterkamp & Hupp, 2010). These changes can affect the soil moisture content, the growth and development of juvenile species (Tal & Pola, 2010). These changes can lead to imbalanced vegetation communities dominated by adults. The limited establishment and growth of sensitive vegetation communities can lead to shifts in the species and community composition, resulting in more adapted communities only, which affect the biodiversity of the vegetation in the river (Arthington *et al*., 2006; Merritt *et al*., 2010).

2.4.3 Alien invasion

Numerous water resources in South Africa are progressively showing the effects of the extensive alien plant invasions (Chamier *et al*., 2012). Western Cape has the highest alien invasion water usage, of about a third of the estimated total water use, followed by KwaZulu-Natal with a total of 17% (Maitre, *et al.,* 2000). By altering the chemical composition and nutrient content of the soil, alien invasive plants have an impact on native plants (Tasker *et al*., 2022). For instance, Black wattle (*Acacia mearnsii*) is known to increase soil nitrogen levels, that influences plant species that are acclimated to low nitrogen soils (Pattison, 2016). Gum trees (*Eucalyptus*) are known to poison the soil by an allelopathic process that kills native species nearby (Tererai *et al*., 2013). The occurrence of these species has been observed to affect vegetation occurring in the riparian zones, as they commonly invade the riparian zone. Some alien invasive macrophyte plant species, like water lettuce (*Pistia stratiotes*) and coarse oxygen weed (*Lagarosiphon major*) develop dense monotypic stands in river columns (Gaertner *et al*., 2014). According to Gaertner *et al*. (2014), dense canopies are known to decrease air exchange with water, which lowers the overall quantity of dissolved oxygen in the water.

Due to their competitive nature and capacity to persevere under pressure and outnumber native macrophytes species, alien invasive plant species get most of the resources that are essential for survival such as sunlight and space (Vila`& Weiner, 2004). According to Versfeld *et al*. (1998), 15 alien invasive plant species were recognized as the common and dominating species in the KwaZulu- Natal province together with their total invaded areas (Table 2.1)

Table 2.1: Common invasive plant species occurring at KwaZulu-Natal in 1998.

Scientific names	**Common names**	**Habitat** **Riparian = R** **Aquatic = A** **Landscape = L**	**Area invaded in HA**
Solanum mauritianum	Night shade	R	404999
Chromolaena odorata	Siam weed	R	326139
Acacia mixed species	Acacia	R. L	116584
Acacia dealbata	Silver wattle	R. L	136004
Opuntia imbricata	Cane cholla	R. L	133344
Opuntia species	Opuntia	R	132701
Acacia mearnsii	Black wattle	R	190542
Melia azedarach	Syringa	R	202764

Robus species	Brambles	R	163475
Lantana camara	Tick berry	R	235849
Caesalpinia decapetala	Mysore thorn	R	161982
Psidium guajava	Guava tree	R	104250
Pinus species	Pine species	R. L	49810
Eucalyptus species	Gum trees	R	153103
Eucalyptus grandis	Rose gum	R. L	108391

2.4.4 Eutrophication

Eutrophication is among the frequent stressors impacting macrophytes in rivers (Van Ginkel, 2011). It is caused by increased fertiliser usage in agriculture, wastewater treatment plant outflow, and improper farming practices such planting crops along riverbanks (Van Ginkel, 2011). According to Van Ginkel (2011), eutrophication-affected water resources exhibit an overabundance of opportunistic macrophytes, that lead to a reduction in the biodiversity of native macrophyte populations. The competition for resources like sunlight and space, as well as the invasion of foreign plants, are the main causes of the decline in native biodiversity (Van Ginkel, 2011).

2.4.5 Water quality

One of the common stressors of water resources are the alteration or contamination of water quality. Water quality is often altered by effluents from waste treatment areas, industries and agricultural activities and the discharge of heavy metals (Parida & Das, 2005). The effluent from industries such as Sappi, changes the water chemistry, making it unfavourable for plant growth. Changes in water pH due to contamination have been observed to have significant impact on water quality, as increased pH is associated with converting ammonium ($NH4$) to ammonia ($NH3$) which is toxic to macrophytes and other aquatic organisms (Tenza, 2018). Thermal effluents discharged from industries can cause an increase in water temperature, which may also lead to prolonged and more intense anoxia phases that may stimulate microbial processes and even lead to a decrease in species richness (Bornette & Puijalon, 2011).

Increased water temperature can affect macrophytes, as they have specific temperature requirements, therefore fluctuations in temperature can affect their distribution and growth (Riis & Sand-Jensen, 2001). Discharge of heavy metals such as zinc, lead, and copper can alter water quality and specialized treatment methods are required to remove them (Wang & Zhang, 2019).

Vegetation exposed to enriched cadmium normally suffer from reduced nutrients and water uptake (Parnian, 2016). This may result in death of some plants. Vegetation exposed to aluminium suffer from inhibited root elongation, stunted growth and reduced chlorophyll production (Parnian *et al*., 2016). This can affect the vegetation communities, as reduced chlorophyll results in leaf discoloration and eventually, death of the plants.

Nutrient enrichment is considered one of the common factors that can alter water quality in rivers (Smith, 2003). These nutrients normally originate from agricultural activities and sewage contamination, such as nitrogen, phosphorus and pesticides (Smith, 2003). The enrichment of these nutrients leads to eutrophication, promote the growth of algae and causes shifts in macrophyte communities (Hilt *et al*., 2017). These shifts come in a form of space and sunlight competition (Bakker *et al*., 2016). Nutrient enrichment can also promote the growth of weeds and alien species. It can also reduce the biodiversity of native species with low nutrient tolerance (Daws *et al*., 2021). For example, vegetation exposed to increased nutrients such as NPK fertiliser showed an increase in the growth of weeds, while the survival of the targeted proteaceous shrubs decreased due to their sensitivity to phosphorus in a study conducted at the Cape floristic region (Daws *et al*., 2021).

2.4.6 Sand mining

Sand mining is one of the factors affecting macrophytes and riparian vegetation in rivers (Padmalal *et al*., 2008). The constant disturbance of sand removal can lead to the alteration of aquatic habitats due to lack of suitable habitat, which ends up affecting their growth and distribution (Gupta, 2007).

Sand mining can result in sedimentation and increased turbidity, with the potential to affect water quality (Gupta, 2007). Increased turbidity can limit light penetration to the water, affecting photosynthetic capabilities of macrophytes in the river (Cao *et al*., 2017; Hilt *et al*., 2018). Macrophytes communities with less tolerance to increased turbidity can be eliminated, resulting in species composition shifts (Jeppesen *et al*., 2019). Macrophytes and riparian vegetation communities can be affected by sand mining due to the removal of species located in the targeted areas (Padmalal *et al*., 2008). This can lead to habitat fragmentation and biodiversity loss in both macrophytes and riparian vegetation communities (Padmalal *et al.,* 2008).

2.4.7 Overgrazing

Overgrazing is regarded as one of the additional stressors affecting riparian vegetation in many rivers (Bear *et al*., 2012). The continuous grazing of livestock can decrease vegetation cover due to being grazed continuously, preventing them from reaching reproductive and maturity stages (Hobbs & Harris, 2001). Additionally, overgrazing can cause species composition shift by favouring the growth of less palatable and more resilient species over the palatable and less resilient ones (Samuelson & Rood, 2011).

The continuous grazing of riparian vegetation can cause decline in biodiversity by continuously removing new growth and flowers (Bear *et al*., 2012). The removal of new growth and flowers affects seed production and dispersal, further limiting the germination of new plants (Dauwalter *et al.,* 2018). According to research by Tumba (2018), overgrazing can promote the establishment and spread of invasive plants, as the disturbance caused by grazing may provide suitable conditions for establishment of non-native species. Additionally, the plant biomass is reduced by overgrazing as the animals consume it at a higher rate than the natural replenishing rate (Tumba, 2018; Cubley *et al*., 2021). This results in the decline of overall productivity of the plant communities. Overgrazing can also contribute to a decline in slow growing plants species (Cubley *et* *al.,* 2021). It can also degrade the habitat, making it unsuitable for plants, and in turn impacting overall health and functioning of ecosystems (Sakai *et al*., 2022).

2.4.8 Land- use change

Land-use change such as agricultural activities can contribute to stressors of macrophytes and riparian vegetation (Mortl *et al*., 2018). The application of fertilizers in agricultural activities alter water quality in a form of nutrient enrichment and sedimentation, resulting in the compromising of macrophytes and riparian vegetation's health (Zhao *et al*., 2018). The transformation of natural land to urbanisation can also affect vegetation by modifying water flow patterns and flood regimes through storm water channelling, resulting in hydropeaking (Nilsson *et al*., 2019). This then affects the macrophytes that require stable flow and riparian vegetation through inundation (Jansson *et al*., 2017). Land-use change can also provide suitable environment for establishment and spread of invasive plant species, which may outcompete native macrophytes and riparian vegetation (Stohlgren *et al*., 2018). This is concerning, as once invasive species establish themselves, chances of reversal are slim due to their fast-reproducing rate, high tolerance to stress and lack of natural enemies (Pyšek *et al*., 2020).

2.5 Vegetation as indicators of stress (macrophytes and riparian vegetation)

Riparian vegetation and macrophytes are excellent indicators of stress in rivers due to having unique tolerances and environmental requirements (Hough-Snee *et al*., 2015). Additionally, they have predictable responses to physical, chemical, and biological factors (Camporeale *et al*., 2013). One of the instruments used to track riparian vegetation condition is called Riparian Vegetation Response Assessment Index (VEGRAI). The ecological state of riparian vegetation is described and rated using metrics in this semi-qualitative technique (Agboola *et al*., 2020). According to Agboola *et al*. (2020), the tool evaluates the degree and scope of vegetation modification, invasive alien plant infestation, and other important factors, such as agricultural species, as well as changes in the functional groupings and distribution of the vegetation.

The VEGRAI tool was developed after an observation that previous tools were partly based on those developed for rapid reserve determination and ecological reserve determination (Kleynhans & Louw, 2007). Some of the existing tools were subjective, with few explicit and consistent rules to be followed, therefore different results would be obtained when the studies need to be repeated by a different team of experts (Kleynhans & Louw, 2007). The VEGRAI tool aims to provide a single but integrated index value that indicates the ecological state of rivers in a simple but ecologically relevant way (Kleynhans & Louw, 2007). The VEGRAI tool provides information that is accurate, consistent and repeatable, and it is currently used in South Africa to monitor a water resource's condition.

A study by Philips *et al*. (2015) on wetland macrophytes as indicators of heavy metal contamination, found that the monitoring of heavy metals in the water column directly can be problematic, since spatial and temporal patterns of contamination need to be defined before the observed metal concentration can be meaningfully interpreted (Phillips *et al*., 2015). Macrophytes such as water fern (*Azolla africana)* have been used to remove heavy metals such as mercury and nickel from water resources (Parida & Das, 2005). Therefore, macrophytes as bio-indicators can provide a meaningful quantitative assessment of heavy metal contamination as they accumulate them in their tissues (Phillips *et al*., 2015). The stationary positions of macrophytes and riparian vegetation make them useful for monitoring changes that occurred over time, making them an ideal option to be used as bioindicators, and provide a cost-effective long-term approach for monitoring pollution (Phillips *et al*., 2015).

For macrophytes and riparian vegetation, long-time iron accumulation and iron toxicity could change their physiology and ecology, such as morphology, anatomy, life-history traits, species composition and community dynamics (Parida, & Das, 2005). Previous studies indicated that an iron concentration from 1 mg L-1 inhibits the growth of common reeds (Phragmites australis) (Xing & Liu, 2011). Duckweed (*Lemna minor*) and water lettuce (*Pistia stratiotes*) can be used to remove excessive nutrients from polluted water, although they are invasive in South Africa (Parida, & Das, 2005). These findings make macrophytes and riparian vegetation appropriate for use as indicators of iron pollution in rivers (Parida, & Das, 2005).

Studies indicated that macrophytes respond differently to laminar flow than to turbulent flow (Vettori, & Rice, 2019). Laminar flow favours the growth of submerged plants by thinning their boundary layer thickness and acting as a tensile shear stress on the body of the plant, while turbulent flow flagellates it in an irregular way (Asaeda & Rashid, 2017). Turbulent flow also affects plant cells by impacting the integrity of the cell wall, leading to changes in cell shape and structure (Vettori, & Rice, 2019).

2.6 Expected species in the uThukela and uMvoti River

According to a study conducted by McKenzie (2017), an estimation of 68 plant species was recorded at uThukela and uMvoti Rivers in the year 2017 (Table 2.2).

Table 2.2: Expected vegetation species in the sampled areas of uThukela and uMvoti Rivers.

Scientific name	Common name	Scientific name	Common name
Abildgaardia ovata	Flat spike sedge	*Apodytes dimidiate*	White pear
Achyranthes aspera	Devil's horsewhip	*Arundo donax*	Giant reeds
Aeschynomene indica	Curly indigo	*Brachylaena elliptica*	Bitter leaf
Ageratum houstoninum	Floss flower	*bridelia micrantha*	Coastal golden leaf
Antidesma venosum	Tassel berry	*Buddleja salviifolia*	*S*age wood
Caesalpinia decapetala	Mysore thorn	*Caesalpinia decapetala*	Common culpurnea
Cardiospermum grandiflorum	Baloon vine	*Cestrum laevigatum*	Ink berry
Chlorophytum fasciculatum	Spider plant	*Chromolaena odorata*	Siam weed

Commelina erecta	Day flower	*Cyclosorus interruptus*	Swamp shield fern
Cynodon dactylon	Bermuda grass	*Cyperus albostriatus*	Star sedge
Cyperus articulatis	Jointed flat sedge	*Cyperus brevis*	*Sweet Cyperus*
Cyperus congestus	Dense flat sedge	*Cyperus dives*	Ikhwane
Cyperus natalensis	Giant dune sage	*Cyperus papyrus*	Paper reed
Dactyloctenium australe	Durban grass	*Dichrostachys cinerea*	Sickle bush
Diospyros natalensis	Lebombo jackal berry	*Dracaena aletrisformis*	Dragon tree
Eragrostis curvula	Weeping love grass	*Eucalyptus cladocalyx*	Sugar gum
Angustifolia	Wild sweet-pea	*Ficus burkei*	Common wild fig
Ficus capreifolia	River sandpaper	*Ficus sur*	Broom cluster fig
Ficus sycomorus subsp	Fig mulberry	*Fimbristylis ferruginea*	Rusty sedge
Gomphostigma virgatum	River stars	*Grewia occidentalis var*	Button wood
Euclea natalensis subsp	Guarri	*Gymnosporia buxifolia*	Spike thorn
Hemarthria altissima	Halt grass	*Ilex mitis var. mitis*	African holly
Ipomoea carnea	Morning glory	*schaemum fasciculatum*	Loosely tufted grass
Juncus kraussii	Jointed rush	*Kraussia floribunda*	Rhino coffee
Kyllinga erecta var. erecta	Navua sedge	*Lantana camara*	Tick berry
Ludwigia octovalvis	Primerose willow	*Melia azedarach*	Syringa
Mimusops obovate	Red milkwood	*Morus alba*	Mulberries
Panicum maximum	Guinea grass	*Paspalum distichum*	Knot grass

Paspalum scrobiculatum	Rice grass	*Persicaria lapathifolia*	Pale smartweed
Phragmites australis	Common reeds	*Pittosporum viridiflorum*	Cape cheese wood
Pluchea bojeri	Camphor weed	*Polypogon monspeliensis*	Beard grass
Pycreus polystachyos	Bunchy sedge	*Rhoicissus tomentosa*	Cape grape
Ricinus communis	Castor oil plant	*Salix mucronata*	Cape silver willow
Sansevieria Hyacinthoides	Snake plant	*Scadoxus puniceus*	Paint brush lily

2.7 Stressors specific to uThukela and uMvoti Rivers

The uThukela and uMvoti Rivers are affected by multiple stressors that act together in a synergically, antagonistic and additive form (Liess *et al*., 2016). The uThukela River is impacted by faecal eutrophication because of the presence of residential areas near to the river, such as the settlements created by SAPPI mill in 1940, the Mandeni and Sundumbili (Figure 2.3) (Ashforth, 2012; Nengomasha, 2018). Due to the Sundumbill treatment works' presence and the discharge of waste into the lower uThukela River, the river is additionally impacted by *Escherichia coli* (E. coli) from human waste (Ashforth, 2012; Nengomasha, 2018).

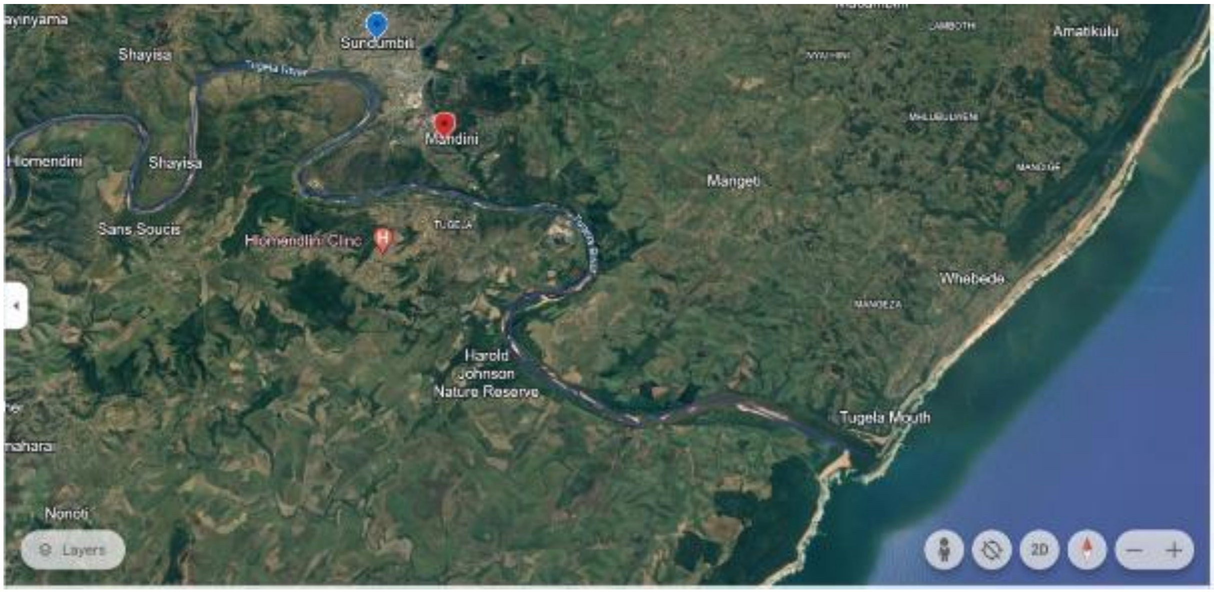


Figure 2.1: Mandini and Sundumbili settlements close to the sampled sites within the uThukela River. Red circle indicates Mandini settlement and blue circle indicates Sundumbili settlements.

Additionally, effluent stress from industries like SAPPI mill and denim factory has an impact on the uThukela and uMvoti Rivers (Ashforth, 2012; Scheren *et al*., 2016). The water's chemistry is altered by the effluent discharged, making it unsuitable for plant development. Eutrophication is frequently brought on by the nutrients in wastewater (Antil, 2012). Algal blooms and eutrophication are linked, and cyanotoxins are produced as a result (Van Ginkel, 2011). Due to the toxins' severe negative effects on macrophytes' ability to survive, water resources exposed to cyanotoxins also exhibit a loss in their biodiversity. Rivers that are invaded by cyanotoxins, it is typical to notice an increase in biological oxygen demand, anoxia, and the demise of aquatic life (Van Ginkel, 2011; Manning & Nobles, 2017).

Due to the large amount of water withdrawn at the abstraction point for the Mhlathuze transfer scheme, altered flows are another stressor affecting the uThukela River (Stryftombolas, 2010). The uMvoti River is also affected by multiple abstraction to supply agricultural activities and industries. The abstraction of water resulting in low flows and the rapid increase during flooding in the rivers have serious consequences to the riparian vegetation and macrophytes by supporting plant species with rapid growth and short life cycles (Mbanjwa, 2017). Such conditions lead to the establishment and dominance of plant communities dominated by annual weeds with less economically advantageous features, such as *Tagetes minuta* (Tall Khaki Weed), *Argemone subfusiformis* (Mexican Poppy), *Datura stramonium* (Stinkblaar), and *Xanthium strumarium* (Large Cockle Bur) (Mbanjwa, 2017). In addition to the current stressors related to land-use that influence the lower uMvoti River's health, from 2014 to 2017, the area experienced one of the worst droughts in contemporary memory, with the river's flows completely halting (Wade *et al*., 2022). Anthropogenic stressors combined with the natural stressors acting together in the uMvoti River may cause irreversibly effects (Wade *et al*., 2022).

Numerous sugar plantations also receive irrigation support from the uThukela and uMvoti Rivers (Nengomasha, 2018). The application of fertilizers and pesticides to maximize production have an effect in the macrophytes by altering the natural water chemistry of the rivers that the macrophytes have adapted to (Kremser & Schunug, 2002.). Some of the riparian vegetation on the banks of the uMvoti and uThukela River has been eliminated because of intensive cultivation related to commercial sugarcane farming (Wade *et al*., 2022).

Another stressor affecting the uThukela and uMvoti Rivers is sand mining (Zolghadr *et al*., 2021). The nearby towns take part in illegal sand mining. Macrophytes and riparian plants are removed when pits are made during the sand mining operation (Zolghadr *et al*., 2021). As a result, existing vegetation is lost, which decreases their biodiversity (Zolghadr *et al*., 2021). Increased turbidity in water may be a side effect of the sand mining process (Edwards, 1969). The excessive turbidity of the water can function as a sun blocker, slow down photosynthesis, and further contribute to the reduction of biodiversity (Edwards, 1969).

The lower uMvoti River's substrate is primarily made of sand, sand mining is one of the contributing factors (Sukdeo, 2010). The lower uMvoti River's habitat integrity has been decreased (Wade *et al*., 2022). The ecosystem of the uMvoti River has been completely altered, with a nearly complete loss of natural habitat, an obvious decline in biodiversity, as well as the elimination of numerous fundamental ecological processes (Sukdeo, 2010).

Alien species have also invaded the uThukela and uMvoti Rivers (McConnachie, 2012). According to studies, 8.89% of the uThukela River was colonized by alien plant species in the year 1998 (Versfeld *et al*., 1998; Richardson *et al.,* 2007; Nelufule *et al*., 2023). In KwaZulu-Natal, it is estimated that alien invasive plant species use approximately 576 million m^3 of water annually, which is more than the natural vegetation they have invaded or replaced (Versfeld *et al*., 1998; Marais & Wannenburgh, 2008). Historically, the most abundant and dominant alien invasive plants at the uMvoti and uThukela Rivers included *Solanum mauritianum*, the *Acacia* species, particularly *A. dealbata* and *A. mearnsii*, *Eucalyptus* species, *Opuntia* species, and *Jacaranda mimosifolia* (Versfeld *et al*., 1998). The rivers also suffer from overgrazing by livestock such as cattle (Mahlobo, 2016). The continuous grazing of vegetation often results to decrease cover by preventing them from reaching reproductive and maturity stage (Hobbs & Harris, 2001). The constant grazing of the vegetation also prohibits new growth due to removal of flowers, further affecting seed production and new generation of new species (Carminati, 2008).

CHAPTER 3: METHODOLOGY

3.1 Description of the study area

3.1.1 uThukela River

3.1.1.1 Location

With a catchment area of over 28 000 square kilometres, the uThukela River is the second-largest rivers in South Africa (Department of Water and Forestry, 2003). The known tributaries of the uThukela River from the south include the Little Thukela River, Bloukrans River, Bushman River, and Mooi River; while notable tributaries from the north include the Klip River, Sundays River, and Buffalo River (De Lecea & Cooper, 2016). Approximately 95 kilometres from Durban, near Thukela Mouth, the uThukela River discharges into the Indian Ocean after flowing east from Drakensburg (Department of Water and Forestry, 2003; Mutema *et al*., 2015).

Figure 3.1: uThukela River at KwaZulu-Natal in South Africa.

3.1.1.2 Sampled sites

The study was designed as a driver-respondent setup, where flow, water quality and substrates are selected as drivers and the vegetation (riparian and macrophytes) is the respondent. The driver component data was collected in the lower reach of the uThukela River. Site V5THUK-CONTROL is the most upstream site on the uThukela River. It is located adjacent to Mdlebeni town. It is characterized by sandbanks and rifles. Site V5THUK-EWR-18 is on the uThukela River, approximately 1 km downstream of SAPPI mill discharge point. The site is characterized by alluvial sands and sandbars. Site V5THUK-EWR19 is on the uThukela River, approximately 50 m downstream of the N2 bridge. The site is dominated by alluvial sands and numerous sandbars. For the respondent data, the whole of uThukela River was selected from source to mouth using satellite images from Landsat 8 United States Geological Survey (USGS) and a change detection method (NDVI) technique was used.

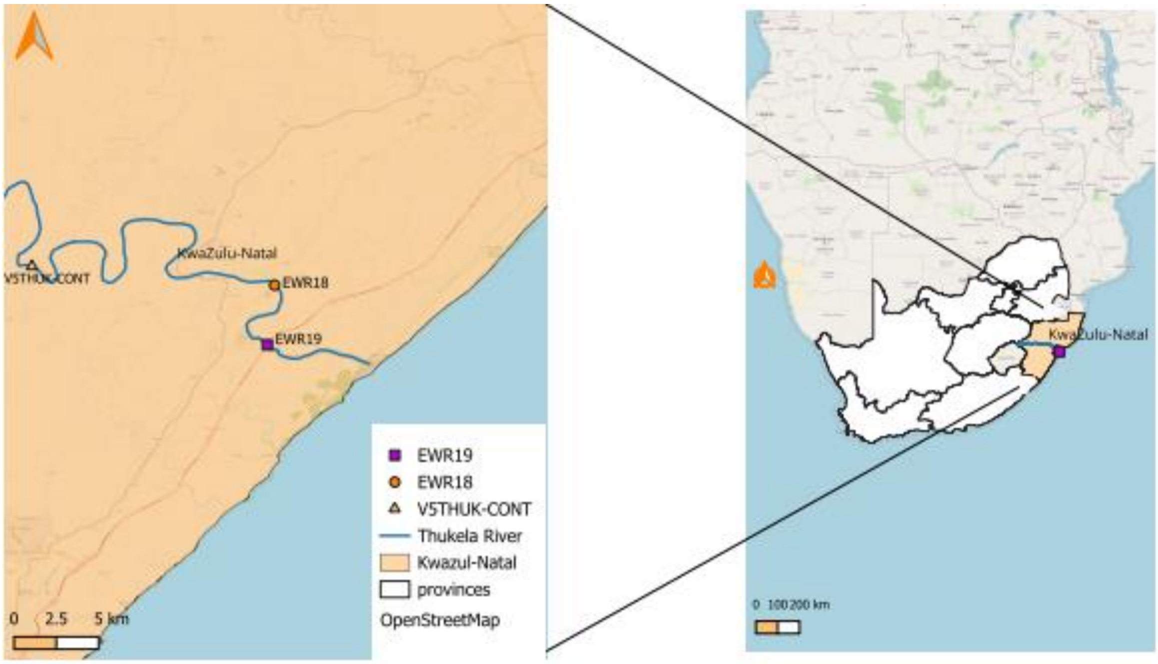


Figure 1.2: uThukela River in South Africa, KwaZulu-Natal and the sites sampled during the 2013 and 2023 survey.

3.1.1.3 Climate

uThukela River has extreme variability in flow during the different seasons, with a mean annual runoff of 3 799 million m3 and a mean annual precipitation of less than 500 mm (Wade, 2019). According to Andersson *et al.* (2011), it has dry, cool winters and warm summers with heavy precipitation and a mean annual evapotranspiration between 1600 mm and 2000 mm. In the summer, when the current's flow rises, muddy water walls up to 1.5 meters high can be seen streaming downstream (Andersson *et al*., 2011; Wade, 2019). Due to the increased silt loads, the riverbeds may shift as a result. Macrophytes are affected by the high turbulent flow and increased siltation causing them to be uprooted and buried under the silts. The unstable banks brought on by the turbulent flow have also been documented to lead to the loss of riparian vegetation through erosion (Dehsorkhi *et al*., 2010). Rapid changes in water level cause banks and beds to be exposed and submerged repeatedly, affecting the river habitats. The riparian vegetation and macrophytes in the river are further reduced because of this alteration and unstable flow patterns (Andersson *et al*., 2011).

3.1.1.4 Geology

During natural flow, the length of the river mouth is approximately 350 m, with a width of 50 m however the width can increase to over 1 km during floods (Wade, 2019; Bezuidenhout, 2023). During flooding, an unstable 700 m high sandbar without vegetation forms across the mouth and moves to form an offshore sandbar directing floodwater southward (Wade, 2019; Bezuidenhout, 2023).

The uThukela River lies in the formation of the Karoo System. The lower part of the river area is situated on the formations of the primitive system near the coast and on the Table Mountain series of the Cape System (Wade, 2019). According to Tanganedzen *et al.* (2018), the upper uThukela River rises from the Drakensberg's basaltic and rhyolitic lavas. Due to fewer erodible soils from the underlying basaltic lavas, Stormberg beds, and upper Beaufort layers, the water from the upper stretch of the watershed includes little dissolved and suspended solids (Ntanganedzen *et al*., 2018).

Beaufort beds and Natal Ecca beds make up most of the middle range of the uThukela River, which causes high concentrations of dissolved material containing significant levels of calcium and magnesium bicarbonates in the river (Bosmana *et al*., 2007). Due to the sparse vegetation cover and the steep valley side slopes, there is a substantial accumulation of silt in the river (Bosmana *et al.,* 2007).

Primitive granites, gneisses, Table Mountain sandstones, and the Natal coastal Ecca of the lower coastal part of the river are what make up the lower reach of the river (Bezuidenhout, 2023). Some areas in the river's lower reach have different chloride and sulphate concentration levels (Bezuidenhout, 2023). The geology of the river's lower reach has an influence on the flora that grows there (Green & Mackay, 2015). Elevated levels of chloride and sulphate damage various plant sections, which impacts plant yields (Geilfus, 2018). Furthermore, low chlorophyll content is a known result of these elevated levels (Zhang *et al.,* 2016). Plants exposed to high chloride concentrations also display yellow leaves that fall off (Simmons, 2012). According to Tuna *et al*. (2007) and Zhang *et al*. (2016), plants exposed to high sulphate content frequently exhibit low plant development and small leaves.

The occurrence, quality, and quantity of macrophytes and riparian vegetation are significantly influenced by the substrate texture in rivers (Kuhar *et al*., 2007). Common reeds (*Phragmites australis*), for example, appear to benefit from the presence of sandstone in the lower reach of uThukela River since they are adapted to sand substrates and are also tolerant to a variety of substrate textures (Jacobs, 2017). Sand, silt, and mud are just a few of the substrates that the *P. australis* is known to thrive in (Liu *et al*., 2021).

3.2.1 uMvoti River

3.2.2.1 Location

The uMvoti River is located in the KwaZulu-Natal province, originating from Drakensberg Mountain and draining into the Indian Ocean (Sukdeo *et al*., 2012). The Department of Water Affairs and Forestry classified the uMvoti River as a medium-sized river (DWAF, 2004). With the Mbozamo River, and Nchaweni River serving as its principal tributaries, it has a catchment area of approximately 2728 km2 and a total mean run-off of over 595 million m3/annum (Creemers, 2002; Sukdeo, 2010). According to Creemers (2002) and Sukdeo *et al*. (2012), the river's top, middle, and lower reaches take up 14400, 98000, and 31000 ha, respectively, of land.

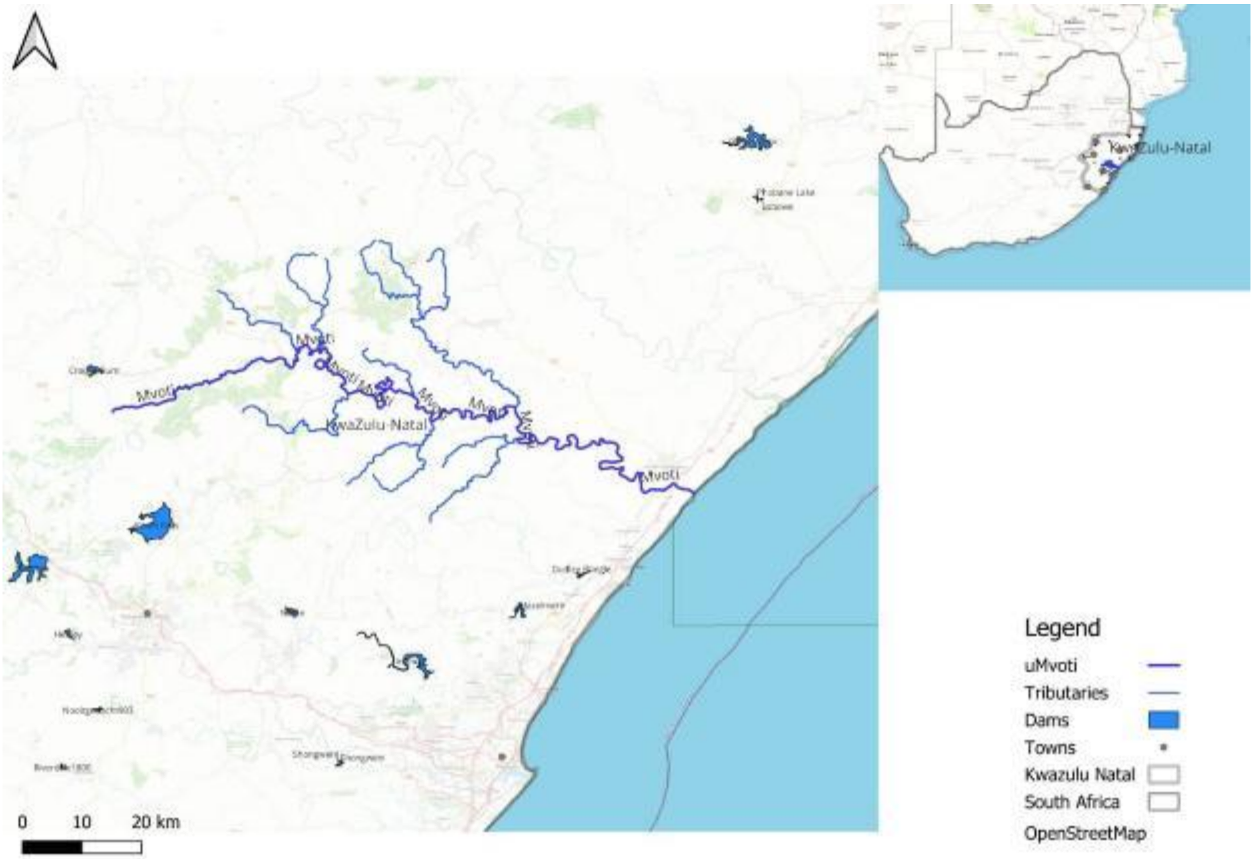


Figure.3.3: uMvoti River in South Africa, KwaZulu-Natal.

3.2.2.2 Sampled sites

For this study, three sampling areas were selected in the lower uMvoti River (U4MVOT-GLADH, HLIMBITWA and U4MVOT-N2BRG). The U4MMVOT-GLADH has modified stream banks, dominated by sand. The HLIMBITWA site is near SAPPI mill. Sugarcane plantations are a dominating activity in the area. The site is characterized by sandy substrates. Just few metres upstream of HLIMBITWA, there is an illegal sand mining activity taking place. The U4MVOT-N2BRG site is located few m upstream of the N2 bridge. The is a water abstraction point few metres upstream of the site.

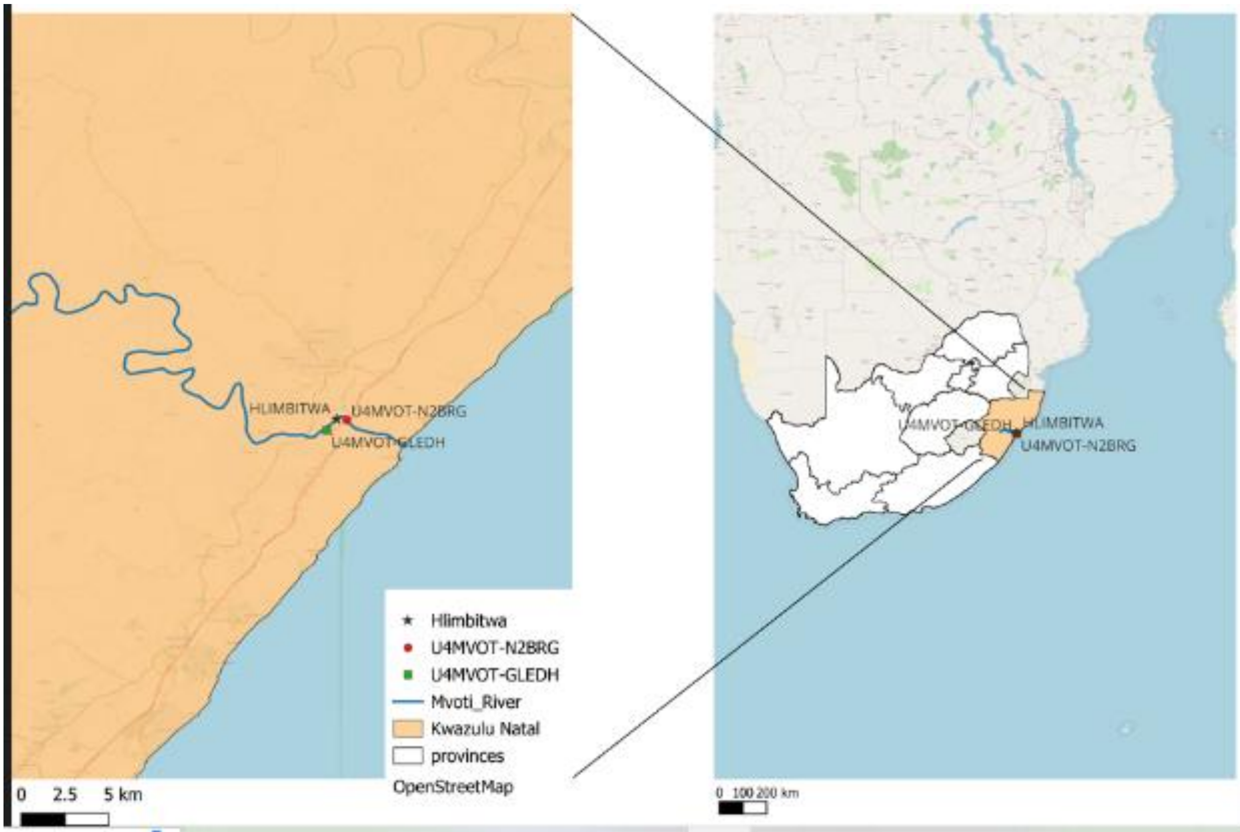


Figure 3.4: Map showing the lower uMvoti River, KwaZulu-Natal in South Africa and sampled sites during the 2013 and 2023 survey.

3.2.2.3 Climate

Warm and humid weather prevails in the uMvoti River (Malherbe, 2006). With an average annual rainfall of about 1000 mm, the river receives most of its precipitation in the summer season (Malherbe, 2006). Berg winds, which warm the air and raise the temperature in the region, frequently cause floods (Sukdeo, 2010). The flooding event in September 1987, which was ranked as one of the worst floods ever, had a significant impact on the uMvoti River and altered its structure (Sukdeo *et al*., 2014). The river's width is typically 35 m, but during the 1987 floods, it increased to 900 m, and a significant number of sediments were deposited in it (Sukdeo, 2010). The flooding incident was one of the sources of high sedimentation in the lower reaches of the river.

3.2.2.4 Geology

According to Sukdeo *et al*. (2012), the geology of the uMvoti River’s varies depending on the river's reaches and includes Ecca shales, Table Mountain sandstone, granite, gneiss, and dwyka. The river's middle and lower reaches are characterized by sedimentary rocks, while the upper reach is dominated by igneous rocks (Sukdeo, 2010). The uMvoti River's geology allows for a huge amount of erosion, which produces significant amounts of sand and silt, particularly in the river's lower reaches (Andrew & Cooper, 1994). Grey to yellowish hues can be found in the sand (Andrew & Cooper, 1994). The lower uMvoti River's geology impacts the type and quantity of flora that grows there.

The lower reach of the uMvoti River's heavy silt and sand content causes considerable turbidity, preventing sunlight from passing through (Pillay *et al*., 2017). By restricting photosynthesis and favouring only floating macrophytes, the limited amount of light in the water column has a significant negative impact on the submerged macrophytes (Hestir & Schoellhamer, 2016). As a result, certain species, including *Potamogeton* species, *Lagarosiphon* species, and *Aponogeton* species, have rather sparse communities (Fernandes & Adams, 2016). According to research, because of the different geology, these species only start to become prevalent in the upper reach of the uThukela and uMvoti Rivers only in the late autumn and early winter, when the water is less murky, flow rates have decreased, and the concentration of nutrients has risen (Venter, 2013).

The quantity and quality of the riparian plants have been demonstrated to be impacted by the sand soil that predominates in the lower reach of the uMvoti River (Venter, 2013). It is challenging for the large trees along the riparian zone to adequately anchor their roots because of the large particles in the sandy soil (Hestir *et al*., 2016). Some of the large trees are swept during the rainy season, which consequently weakens their communities.

3.3 Study survey design

The 2013 and 2023 vegetation communities' data were used to document the degree of vegetation changes, and its drivers of change between 2013 and 2023. Rectified Satellite images from Landsat 8 (USGS) were used to quantify the spatio-temporal changes of macrophytes and riparian vegetation communities between 2013 and 2023. Data relating to water quality, water flow and substrate types was used as possible drivers of change in vegetation communities and to determine the well-being of the lower uThukela and uMvoti Rivers.

3.4 Vegetation changes overtime (2013 and 2023)

The change detection method was applied using the Normalized Difference Vegetation Index technique (NDVI). The NDVI is a method developed for estimating vegetation cover using reflective bands of satellite data (Rouse *et al*., 1973). It is a widely used method for detecting and tracking changes in vegetation health, land cover and land-use change over time (Tucker, 1979; Bid, 2016). It was also developed for identifying the vegetation's health and well-being (vigor) (Hayes & Sader, 2001). For this study, the method was carried out following the steps below:

1) Selected satellite images from Landsat 8 (USGS) for 2013 and 2023 were used to assess changes in vegetation communities for the 10-year period (2013-2023).

2) Atmospheric correcting was performed to the downloaded images. Classes in the study area were added and evaluated to determine which surfaces were present. Six classes were added that are: Instream vegetation (macrophytes), Riparian vegetation, Water, Cultivated, Bare land and Development.

3) Training samples of spectrally pure pixels were created to indicate the different surfaces in the raster using the draw polygon function and then digitized for each of the six classes.

4) Signature files were created using the Maximum Likelihood method (class definition file) for the uThukela clipped raster (2013 and 2023) and used to complete the

classification. Accuracy assessments were performed to measure the quality standards of the images.

5) Reference points/accuracy points were created to determine which class they represent.

6) The accuracy and the Kappa Index of Agreement (KHAT) assessment was used to check the quality of the classification.

7) Change was detected using categorial change from classified 2013 raster to 2023 classified raster.

8) Classes were configured to filter change for all the classes used in the classification and the results were saved as a raster data set.

3.5 2023 vegetation data

The 2023 Vegetation data was sorted by compiling a vegetation species list for both macrophytes and riparian vegetation using phytosociological methods. The species were identified using a plant identification book containing species that were previously identified at the uThukela and uMvoti Rivers. Species that could not be confidently identified were sent to qualified and experienced personnel for verification.

3.6 River flow variability

Cross-sections were conducted with the use of a Leica TCR403 Power total station and apparatus. Permanent benchmarks were installed at each of the sites to allow for future replication. The benchmarks were installed by drilling markers into prominent bedrock or boulders. Additionally, steel pegs were inserted into the bases of large trees that would not be at risk of removal during large flooding events. As an added measure, two benchmarks were installed. One cross section was selected to be sufficient for each of the selected sites. The total station was positioned perpendicular to the river flow. The spacing between the points was determined by the change in topography such as at an elevation or lowland. The locations of the cross sections were selected strategically to ensure the entire area in question and its hydraulic interactions with the landscape were represented.

Discharge data were collected using either an OTT MF Pro handheld velocity-depth meter or a SonTek M9 Hydro Surveyor. The handheld device was used when the rivers were wadable while the Hydro Surveyor was used when the rivers were deep. The Hydro Surveyor recorded both the channel shape and total discharge. The Pythagorean theorem was applied to calculate the chainage (distance) between the points. Cross-sections provided coordinate data which enabled the viewer to observe the shape of the river profile. Biological data that were collected included individual plants and the substrates they were associated with. This information was superimposed into the cross-section coordinate data to provide information pertaining to the relative elevation and their hydraulic requirements. Selected indicator species varied across sites based on the observed impacts and biological responses.

Data surveyed and related to the cross section included cross section shape, water levels along the cross sections, slope points and plant points (plants within and associated with the cross section). Elevation values were adjusted according to the lowest point along the cross-sections, commonly referred to as relative elevation/height. Left and right banks were observed when facing downstream (DWAF, 2005).

3.7 Substrates

Substrate distribution of the sampled sites was estimated into percentages and categorized into either silt, mud, sand, gravel, cobble, boulders and bedrock, using the grain-size analysis technique (Folk & Ward, 1957). Substrates data were collected at every point where a vegetation species was recorded.

Table 1.1: Substrate classification showing class, size and description.

Substrate class	**Grain size (mm)**	**Practical description**
Silt and clay	< 0.06	Powdery, with no visible grains
Sand	0.06-2.00	Visible grains

Gravel	2.00-64.00	From the size of a thumb to the size of an adult's fist
Cobbles	64.00-256.00	From a size of a fist but < than an adult's head
Boulder	>256.00	Larger than an adult's head
Bedrock	N/A	Too big to be moved

3.8 Water quality variables

Water samples were collected in duplicate using acid-washed 1 litre plastic bottles for further analysis in the laboratory. The 1 litre bottles were kept in a cooler box away from direct sunlight until it was refrigerated. The chloride, nitrite, nitrate, sulphate, phosphate, fluoride, alkalinity and COD variables were measured from the 1 litre sample bottles at a laboratory. In situ testing of water quality variables also took place in all the study sites. Parameters measured included pH, temperature (°C), oxygen saturation (%), dissolved oxygen (mg/L), electrical conductivity (mS/m) and total dissolved solids (TDS) measured in (ppm). The measurements were taken using EUTECH DO610 and HANNA HI98198 instruments. The water quality results were interpreted following the South African National Standard (SANS) and World Health Organization (WHO) for total dissolved solids guidelines (DWAF, 1996).

3.9 Statistical analysis

Statistical analysis for this study was conducted with the use of Canoco version 5 for windows. The biological community structures and their associated abiotic variables were assessed using multivariate statistical techniques in the form of Canonical Correspondence Analysis (CCA) and Redundancy Analysis (RDA) multivariate approaches. The significant threshold selected for this study was restricted to $p = 0.05$ where $p < 0.05$ is significant and $p > 0.05$ is regarded as not significant.

The RDA and CCA multivariate analysis were used to interpret the degree of similarities and dissimilarities between the plant communities and different abiotic variables. The arrows represent a variable, pointing in the direction that represent the steepest increase of value relative to the corresponding variable depicted in the bi-plot. The angles between the arrows provide an understanding of the relationships between the variables, if two arrows are close to each other, it suggests a positive correlation between the corresponding variables. Conversely, if the arrows are far apart, it indicates a negative correlation (Ter Braak & Smilauer, 2012).

Additionally, the size of the arrows varies in length. The long arrows represent a strong association while short arrows represent a less strong association with less influence on the variable (Ter Braak & Smilauer, 2012). The color of the arrows also differs, the red arrows indicate a positive correlation with the environmental variables, suggesting that the species are associated with higher values of the environmental gradient (Ter Braak & Smilauer, 2012). Blue arrows represent the direction of decreasing values of the environmental variables in the biplot, indicating a negative correlation with the environmental variables, suggesting an association with lower values of the environmental gradient (Ter Braak & Smilauer, 2012).

CHAPTER 4: RESULTS

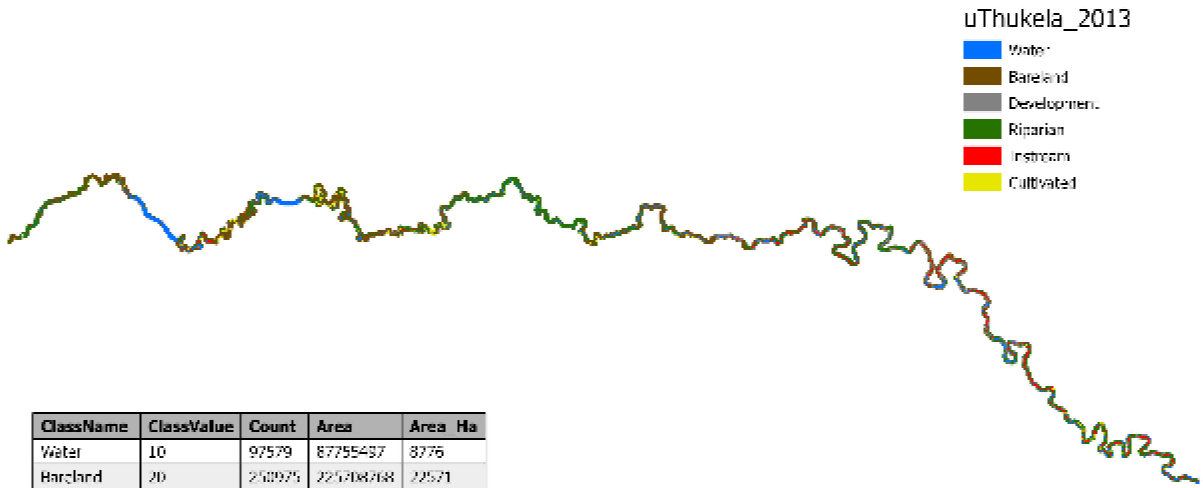
4.1. uThukela River

4.1.1 Vegetation changes between 2013-2023

There was a decline in the riparian vegetation of uThukela River in the 10-year period (2013-2023). It covered an area of 23292 hectares (Ha) in 2013 (Figure 4.1 and 4.2) and it declined to 19055 Ha in 2023 (Figure 4.3, figure 4.4 and figure 4.5). A total of 16% of riparian vegetation was converted to a cultivated land (Figure 4.6) in the 10-year period.

In the year 2023, the was less exposed water compared to 2013 with 8776 ha and 7466 ha in 2013 and 2023 respectively. The amount of bare land increased from 22571 ha to 27629 ha between 2013 and 2023 (Figure 4.1, Figure 4.3 and Figure 4.5). Development also showed an increase from 5502 ha to 6304 ha between 2013 and 2023. There was a significant amount of change in riparian vegetation quantities, with a decline of 4241 ha in 2023. There was also a decline in instream vegetation, with a reduction of 913 ha in 2023. The amount of cultivated land also showed an increase of 672 ha in 2023 when compared to 2013 (Figure 4.1, Figure 4.3 and Figure 4.5).

The quantity of instream vegetation (macrophytes) has decreased from 4914 Ha to 4002 Ha between 2013 to 2023 respectively (figure 4.1 and 4.3). A total amount of 20% of instream vegetation has been lost due to development (Figure 4.6). An additional 16% of instream vegetation has been lost and converted to bare land (Figure 4.6). The primary conversion is mostly development as a total of 20% of land that was once covered by instream vegetation has been developed (Figure 4.6).



ClassName	ClassValue	Count	Area	Area Ha
Water	10	97579	87755437	8776
Bareland	20	250975	225708768	22571
Development	30	61182	55022687	5502
Riparian	40	258997	232923175	23292
Instream	50	21638	19137467	1914
Cultivated	60	29414	26452825	2645

ClassName	Water	Bareland	Development	Riparian	Instream	Cultivated	Total	U_Accuracy	Kappa
Water	8	0	0	1	1	0	10	0,8	0
Bareland	0	8	1	0	1	0	10	0,8	0
Development	0	1	8	0	0	1	10	0,8	0
Riparian	0	2	0	8	0	0	10	0,8	0
Instream	0	0	1	1	7	1	10	0,7	0
Cultivated	0	0	0	2	0	8	10	0,8	0
Total	8	11	10	12	9	10	60	0	0
P_Accuracy	1	0,727273	0,8	0,666667	0.777778	0,8	0	0,783333	0
Kappa	0	0	0	0	0	0	0	0	0,74

Figure 4.1: Land-use and cover classification in 2013 at uThukela River representing changes in the amount of vegetation and land-use activities.

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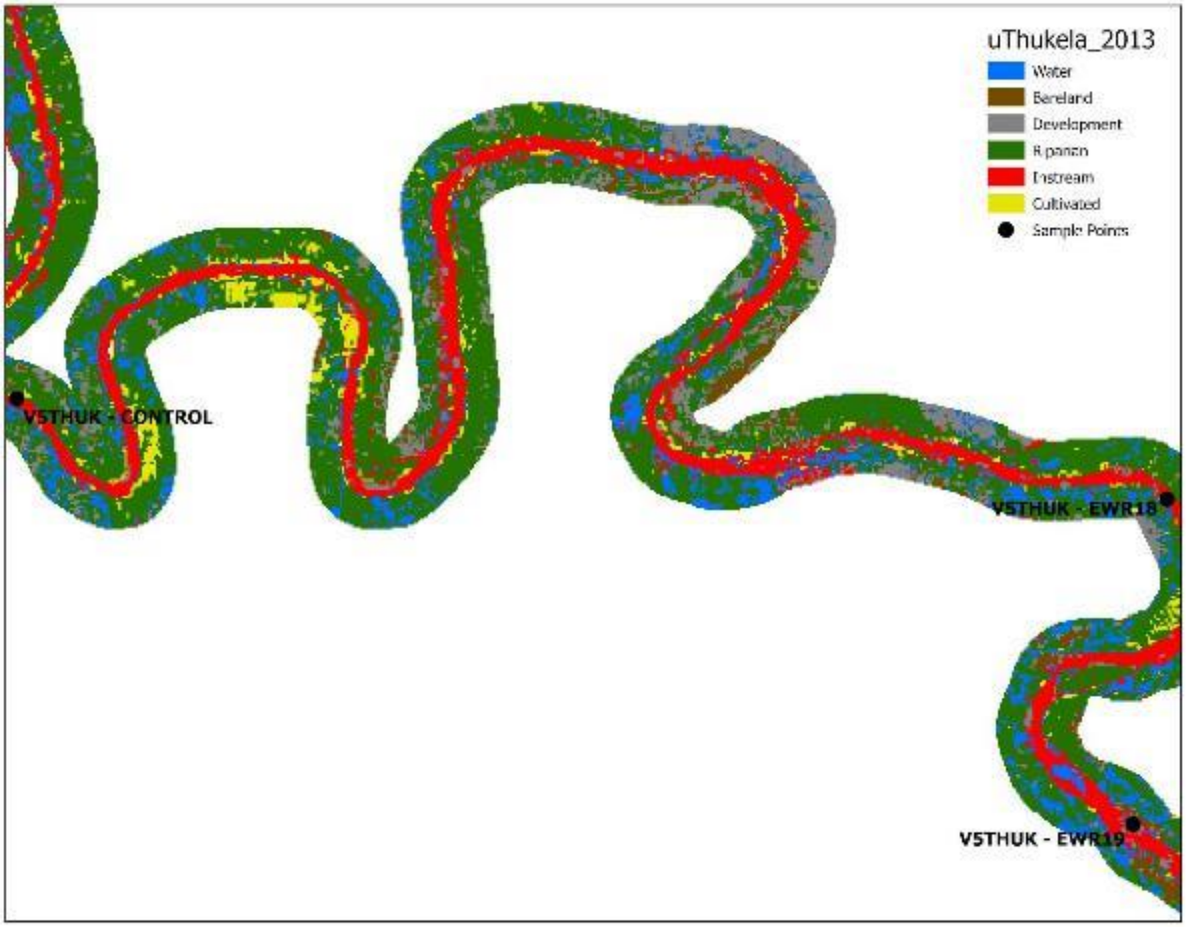
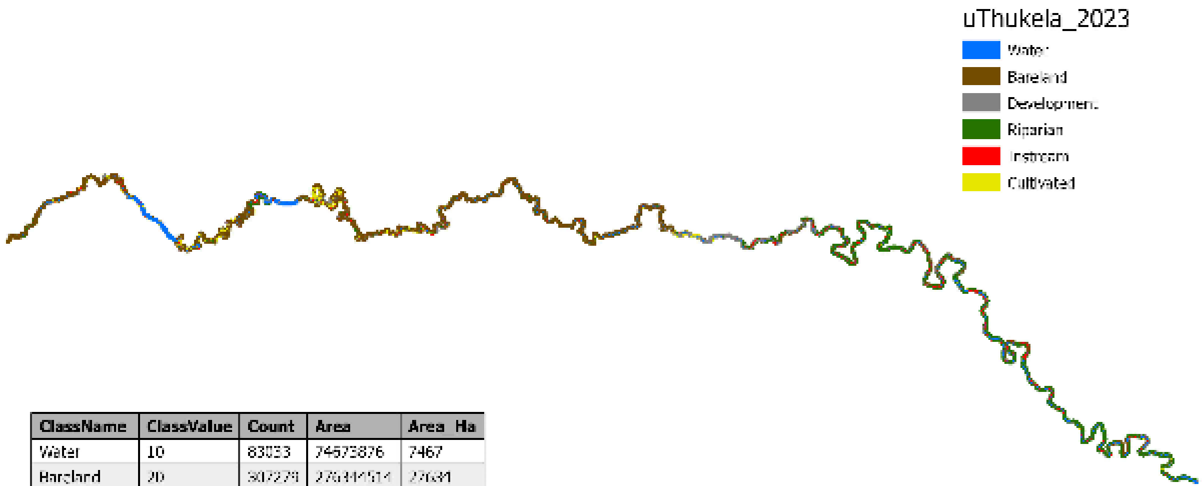


Figure 4.2: Land-use cover classification in 2013 at uThukela River showing the sampled sites namely V5THUK-CONTROL, V5THUK-EWR18 and V5THUK-EWR19.



ClassName	ClassValue	Count	Area	Area_Ha
Water	10	83033	74673876	7467
Bareland	20	307279	276444514	27644
Development	30	70076	63021287	6302
Riparian	40	211880	190549552	19055
Instream	50	44504	40023680	4002
Cultivated	60	36893	33178897	3318

ClassName	Water	Bareland	Development	Riparian	Instream	Cultivated	Total	U_Accuracy	Kappa
Water	8	1	0	0	1	0	10	0,8	0
Bareland	0	8	1	1	0	0	10	0,8	0
Development	0	2	7	1	0	0	10	0,7	0
Riparian	1	1	0	8	0	0	10	0,8	0
Instream	0	0	0	1	8	1	10	0,8	0
Cultivated	1	0	1	1	0	7	10	0,7	0
Total	10	12	9	12	9	8	60	0	0
P_Accuracy	0,8	0,666667	0,777778	0,666667	0,888889	0,875	0	0,766667	0
Kappa	0	0	0	0	0	0	0	0	0,72

Figure 4.3: Land-use and cover classification in 2023 at u Thukela River representing changes in the amount of vegetation and land-use activities.

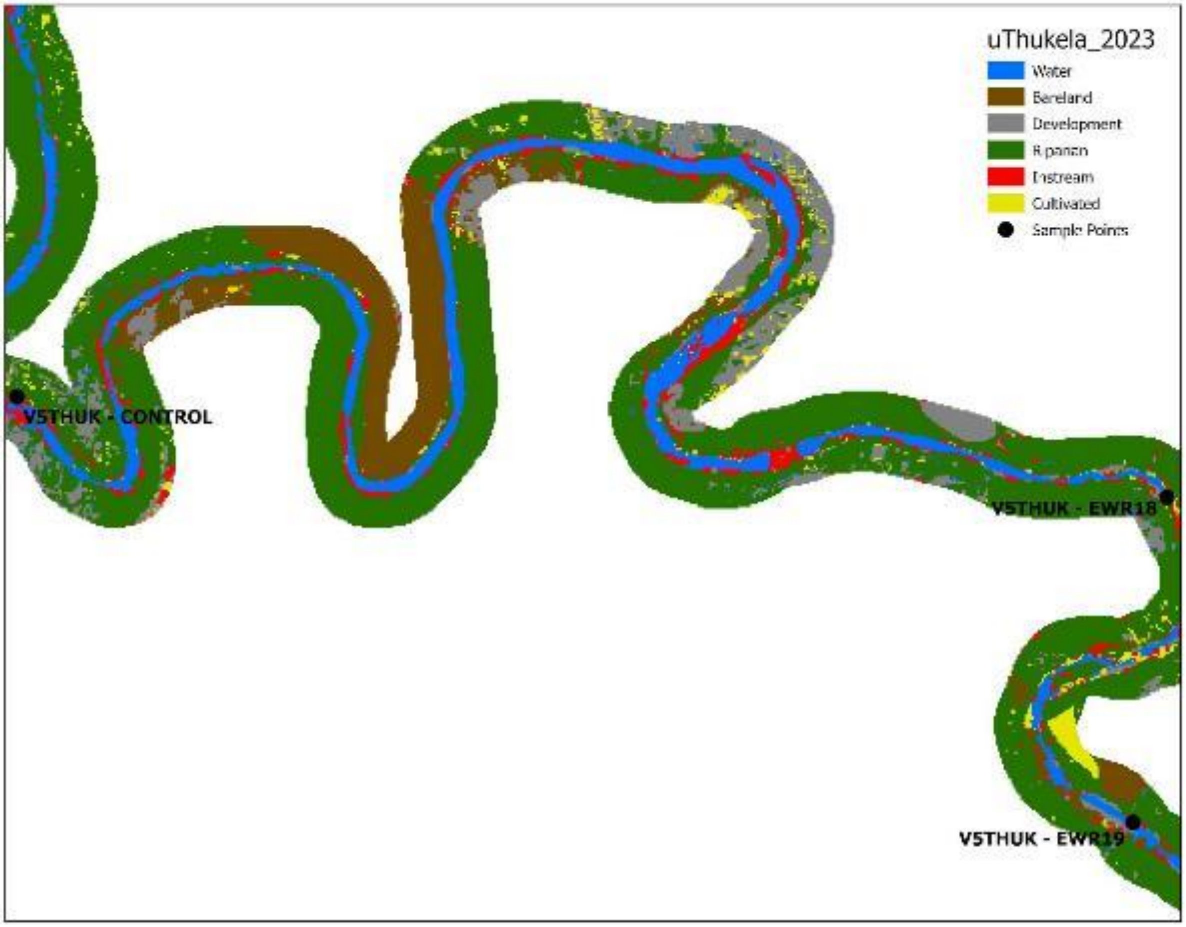


Figure 4.4: Land-use and cover classification in 2023 at uThukela River showing the sampled sites namely V5THUK-CONTROL, V5THUK-EWR18 and V5THUK-EWR19.

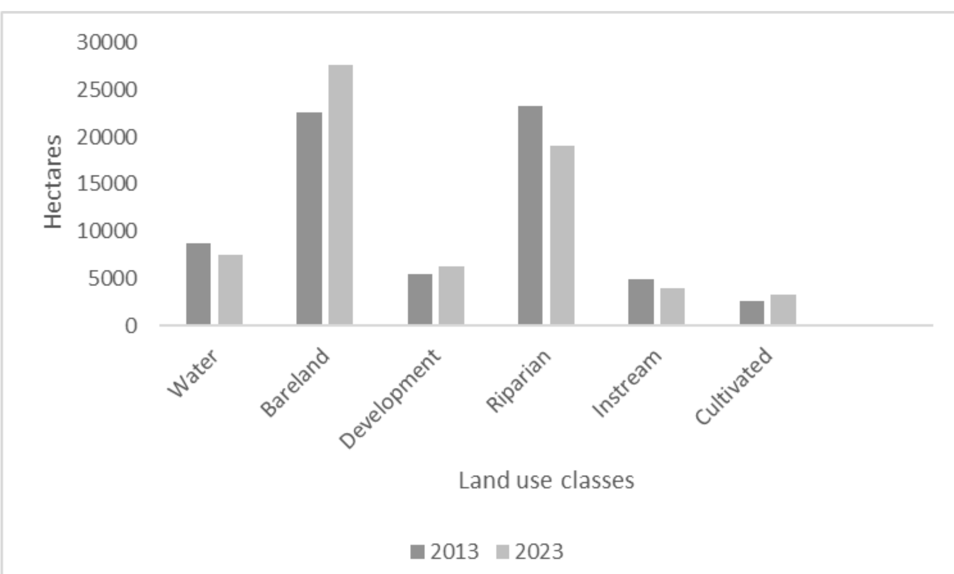


Figure 4.5: Changes in land-use classes between 2013 and 2023 at the uThukela River, KwaZulu-Natal in South Africa.

Figure 4.6: Land-use class change at the uThukela River in a 10-year period, between 2013 and 2023.

4.1.2 Vegetation community structures

A total of 50 plant species from 25 families were recorded in all the sampled sites V5THUK-CONTROL, V5THUK-EWR18 and V5THUK-EWR19 within uThukela River (Table 4.1). A total of 37 plant communities were superimposed into the cross sections of the sampled sites within the lower uThukela River. Elevation, distance from the left bank, abundance and associated substrate types were recorded (Table 4.2).

Table 4.1: Plant communities recorded in the lower uThukela River during the April 2023 survey.

Scientific name	Common name	Abbreviation
Xanthium strumarium	Rough cocklebur	*Xant strm*
Phragmites australis	Common reeds	*Prg aust*
Ricinus communis	Castor oil bean	*Ricn comm*
Melia azedarach	syringa	*Meli azed*
Cyperus articulatis	sedges	*Cyperus artic*
Panicum maximum		*Panc maxm*
Achyranthes aspera	Devils horsewhip	*Achr aspr*
Solanum sisymbriifolium	Sticky nightshade	*Soln sism*
Senna alexandrina	Egyptian senna	*Senna alex*
Calpurnia aurea	Common calpurnia	*Calp aure*
Dichrostachys cinerea	Sickle bush	*Dichr cinera*
Diospyros mespiliformis	Jackalberry	*Diospyros mes*
Morus alba	Mulberries	*Mors alba*
Bidens pilosa	Blackjack	*Bidn pils*
Brachiaria mutica	Bread grass	*Brach mutica*
Parthenium hysterophorus	Santa Maria feverfew	*Parthen hyste*
Malvastrum coromandelianum	Threelobe false mallow	*Malv corm*
Ficus sycomorus	Fig mulberry	*Fics sycm*
Ficus sur	Broom cluster fig	*Ficus sur*
Ageratum houstonianum	Blue mink	*Ager hous*
Colocasia	Elephant ear	*Colocasia*
Cyperus brevis	Flat sedges	*Cyperus brev*
Paspalum distichum	Knot grass	*Paspalum dist*
Psidium guajava	Guava	*Psid guaj*
Arudo donax	Giant reeds	*Arun donx*
Aloidendron barberae	Tree aloe	*Aloiden barbe*

Scientific name	**Common name**	**Abbreviation**
Mimosa pudica	Humble plant	*Mimosa pud*
Solanum sisymbriifolium	Sticky nightshade	*Soln sism*
Sonchus oleraceus	Common sowthistle	*Sonchus oler*
Syzygium cordatum	water berries	*Syzg cordtm*
Musaceae	Banana	*Musa*
Ipomoea carnea	Morning glory	*Ipom carnea*
Cereus jamacaru	Queen of the night	*Cereus jamc*
Senegalia catechu	Black catechu	*Sen catch*
Datura stramonium	Devil's trumpet	*Datura stram*
Terminalia sericea	Silver cluster leaf	*Termn serce*
Cyperus papyrus	Paper reed	*Cyp papy*
Acacia senegal	Gum acacia	*Acac sen*
Trichilia emetica	Natalia mahogany	*Trich emet*
Vachellia nilotica	Egypian gum	*Vach nilt*
Urochloa mosambicensis	White buffalo grass	*Uroch mosmb*
Opuntia	Prickly pear	*Opuntia*
Paspalum scrobiculatum	Rise grass	*Paspalum scrob*
Pergularia daemia	Trellis vine	*Pergu daem*
Commelina erecta	Day flower	*Comm erecta*
solanum incanum	Bitter apple	*Soln incan*
Ziziphus mucronata	Buffalo thorn	*Zizphu mucron*
Vangueria infausta	Wild medlar	*Vangu infausta*
Cucurbita moschata	Butternut vine	*Cucbta moscht*
Pyrostria hystrix	Porcupine bush	*Pyrost hystrix*

The V5THUK- EWR18 site was dominated by juvenile species associated with fine sand substrates. The *C. aura* and *R. communis* were dominating. In site V5THUK-EWR19, fine sand was the dominating substrate and a minor contribution of silt. The *P. australis* and *A. donax* had higher abundance compared to other species.

The vegetation communities were mostly sub-adults and adults with a combination of silt, fine sand and sand as their substrate types (Table 4.2). In site V5THUK-CONTROL, plant species positioned at point 31 had higher abundance of approximately 10 species (*R. communis*, *F. sycomorus* and *S. puniceus* (Table 4.2). There was no clear relationship between the elevation and distance from the left bank and substrate types.

In site V5THUK-EWR18, all the plant communities that were linked to the cross section were juveniles (table 4.2). Site V5THUK-EWR18 had no macrophytes present in the stream. Site V5THUK-EWR19 was mostly dominated by plant communities categorized as sub-adults and adults with few juvenile species. Site V5THUK-CONTROL site was dominated by sub-adults and adults, with few juvenile communities (table 4.2). The *fabaceae* and *poaceae* families emerged as the dominating families in the sampled sites within the uThukela River (Table 4.2.).

Table 4.2: Plant communities superimposed into the cross section of the sampled sites within uThukela River, showing their substrate types, abundance and position in the river.

Site name	Scientific name	Common name	Point number	Evelation (m)	Distance from left bank (m)	Silt	Sand fine	Sand	Boulder	Abundance	Notes
V5THUK-EWR18	*Calpurnea aurea*	common calpurnea	13	4.125	27.765		100			1	juvenile
V5THUK-EWR18	*Ricinus communis*	castor oil plant	14	3.219	33.904		100			2	juvenile
V5THUK-EWR18	*Ricinus communis*	castor oil plant	15	3.202	33.896		100			>10	juvenile
V5THUK-EWR18	*Calpurnea aurea*	common calpurnea	17	4.027	27.287		100			>10	juvenile
V5THUK-EWR18	*Solanum sisymbriifolium*	Sticky nighshade	18	3.742	38.740		100			>10	juvenile
V5THUK-EWR18	*Persicaria senegalensis*	Snake root	18	3.742	38.740	70	30			1	juvenile
V5THUK-EWR19	*Ficus sycomorus*	Fig mulberry	1	3.647	252.612	90	10			2	adult
V5THUK-EWR19	*Parthenium hysterophorus*	Santa Maria	1	3.647	252.612	100				1	
V5THUK-EWR19	*persicaria lapathifolia*	Pale smartweed	1	3.647	252.612	100				1	
V5THUK-EWR19	*Phragmites australis*	Common reeds	1	3.647	252.612	95	5			>70	adults
V5THUK-EWR19	*pergularia daemia*	Trellis vine	1	3.647	252.612		100			1	
V5THUK-EWR19	*Calpurnea aurea*	common calpurnea	2	2.954	250.714		100			2	sub-adults
V5THUK-EWR19	*Diospyros mespiliformis*	Jackal berry	2	2.954	250.714		100			1	adult
V5THUK-EWR19	*melia azedarach*	Syringa	3	3.317	250.245	90	10			1	adult
V5THUK-EWR19	*Ipomoea carnea*	Moring glory	3	3.317	250.245	90	10			2	sub-adults
V5THUK-EWR19	*Ficus sur*	Cluster fig	4	3.435	248.358		100			1	Adult
V5THUK-EWR19	*Arudo donax*	Giant reed	5	3.543	246.006		100			>30	Adult
V5THUK-EWR19	*Solanum sisymbriifolium*	Sticky nighshade	5	3.543	246.006		100			1	juvenile
V5THUK-EWR19	*Calpurnea aurea*	Calpurnea aurea	6	3.540	222.667		100			1	
V5THUK-COTROL	*Dichrostachys cinerea*	Sickle bush	1	5.685	131.742		100			1	Adult
V5THUK-COTROL	*Calpurnea aurea*	Calpurnea aurea	3	5.597	155.728		100			1	Adult
V5THUK-COTROL	*Acacia senegal*	Gum acacia	13	5.572	133.940		100			1	sub-adults
V5THUK-COTROL	*Terminalia sericea*	Silver cluster	13	5.572	133.940		100			1	adult
V5THUK-COTROL	*Solanum sisymbriifolium*	Sticky nighshade	14	5.463	128.692		100			>10	sub-adults
V5THUK-COTROL	*Datura stramonium*	Devil's trumpets	30	3.834	25.468		100			2	adults
V5THUK-COTROL	*Parthenium hysterophorus*	Santa Maria	30	3.834	25.468		100			4	
V5THUK-COTROL	*commelina erecta*	Day flower	30	3.834	25.468		100			5	
V5THUK-COTROL	*Ricinus communis*	common reeds	31	3.834	25.468		90	10		1	
V5THUK-COTROL	*Ficus sycomorus*	Fig mulberry	31	3.834	25.468		90	10		1	adult
V5THUK-COTROL	*scadoxus puniceus*	Paint brush lily	31	3.834	25.468		90	10		1	juvenile
V5THUK-COTROL	*Panicum maximum*		32	6.538	46.885		50		50	14	
V5THUK-COTROL	*Ficus sycomorus*	Fig mulberry	32	6.538	46.885		50		50	1	adult
V5THUK-COTROL	*Ricinus communis*	castor oil plant	32	6.538	46.885		100			5	
V5THUK-COTROL	*Parthenium hysterophorus*	Santa Maria	33	6.361	50.128		100			1	juvenile
V5THUK-COTROL	*vangueria infausta*	African medlar	33	6.361	50.128		100			1	sub-adults
V5THUK-COTROL	*Solanum sisymbriifolium*	Sticky nighshade	34	5.989	57.861		100			3	sub-adults
V5THUK-COTROL	*Diospyros mespiliformis*	Jackal berry	34	5.989	57.861		100			1	Adult

The water level at the site V5THUK-EWR18 had an elevation of 47.186 m from the left edge and an elevation of 5.668 m from the right bank, with a discharge of 46.052 m^3/s (figure 4.7). Green dots represent the plant communities linked to the cross section. 13) *S. sisymbriifolium* 14 *R. communis* 15) *R. communis, C. aurea* 17) *P. senegalensis* 18) *C. aurea.*

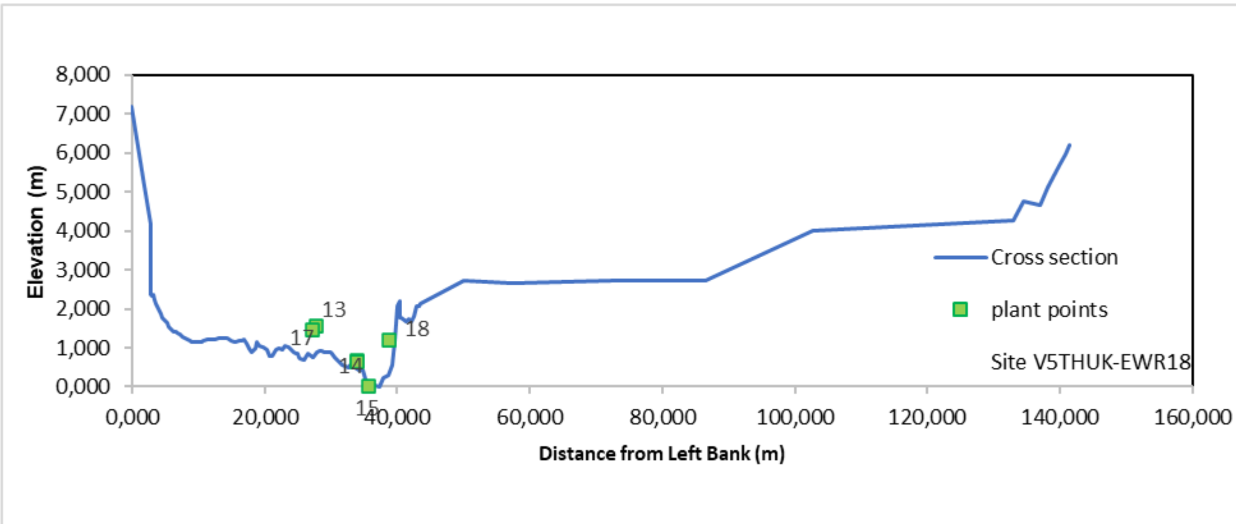


Figure 4.7: Cross section with a superimposed plant points at V5THUK-EWR18 site within uThukela River.

The cross section had an elevation of 4.921 m for the left bank and an elevation of 5.267 m from the right bank, with a discharge of 29, 444 m^3/s (figure 4.8). Green dots represent the plant communities linked to the cross section. *1) F. sycomorus, P. hysterophorus, P. lapathifolia, P. australis, P. daemia 2 C. aurea, D. mespiliformis, P. senegalensis, M. coromandelianum 3) I. carnea, M. azedarach 4) F.sur 5) A. donax, P. hysterophorus 6) C. aurea.*

Figure 4.8: Cross section with superimposed plant points at V5THUK-EWR19 site within uThukela River.

The cross section had an elevation of 3.978 m at the left edge and an elevation of 4.623 m at the right edge, with a discharge of 14.228 m^3/s (figure 4.9). *1) D. cinera 3) C. aurea 13) A. senegal, T. sericea 14) S. sisymbriifolium 30) D. stramonium, P. hysterophorus, Commelina erecta 31) R. communis, F. sycomorus, Scadoxus puniceus 32) P. maximum, F. sycomorus, R. communis 33) P. hysterophorus, V. infausta 34) S. sisymbriifolium, D. mespiliformis*

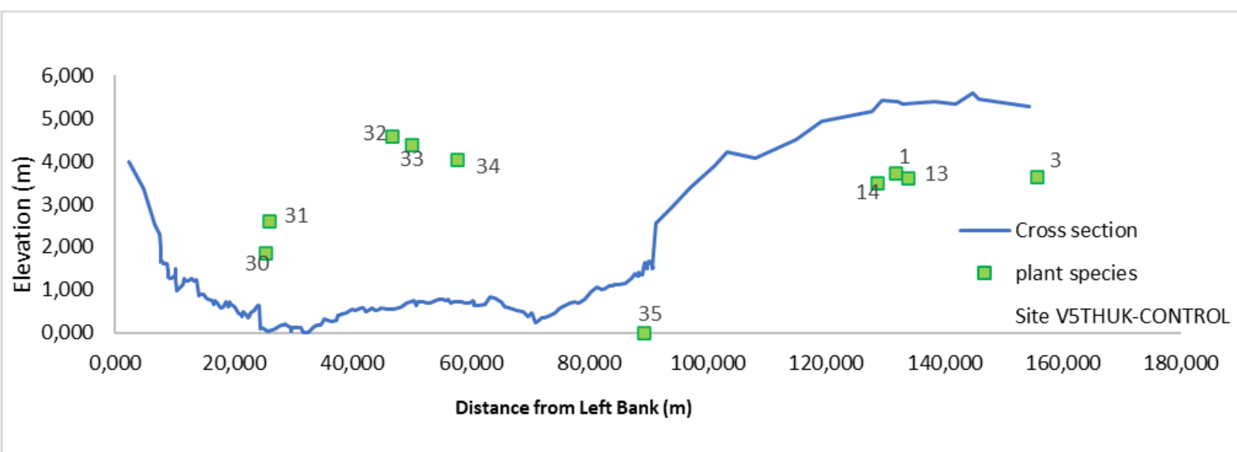


Figure 4.9: Cross section with superimposed plant points at site V5THUK-COTROL within uThukela River.

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During this study, site V5THUK-EWR18 was dominated by juvenile plant communities in the portion of the stream that is temporarily dry due to flow fluctuations. There was an observation of stream flow reduction by almost 50% due to fluctuating water level (Figure 4.10). This gives the buried seeds in the sand an opportunity to establish themselves when the area of land that was once covered with flowing water during high flows becomes a temporary dry area.

Figure 4.10: Stream reduction due to flow fluctuations at the V5THUK-EWR18 site within uThukela River.

Most of the plant communities in site V5THUK-EWR19 were categorized as adults and sub-adults. The moderate flow rate of the water might have influenced this, giving the plant communities a chance to establish themselves and reach sub-adult and adult stage. The few communities that were still in the juvenile stage were also establishing themselves in a temporary dry portion of the river, with a possibility of getting washed away in the occurrence of high flows before they could establish themselves (Figure 4.11).

The plant communities sampled in V5THUK-CONTROL site were dominated by sub-adults and adults, with few juvenile communities. Land-use activities in the area might be the driving factor, such as livestock grazing, as was among common land-use activities observed during the sampling period (Figure 4.12). This then resulted in few juvenile plant communities being on site, as they were being overgrazed.

Figure 4.11: Juvenile plants established in the temporary dry area of the V5THUK-CONTROL site within uThukela River.

Figure 4.12: Livestock grazing at site V5THUK-CONTROL, within uThukela River.

4.1.3: Flow/ cross sections

Cross-section profiles were surveyed across the sampled sites V5THUK-CONTROL, V5THUK-EWR18 and V5THUK-EWR19 within the lower uThukela River. The water levels were recorded on the left and right edges of the channel.

The discharge values of the sampled sites were 46.052 m^3/s at site V5THUK-EWR18, 29.45 m^3/s at site V5THUK-EWR19 and 14.23 m^3/s at site V5THUK-CONTROL (Figure 4.13; Figure 4.14 and Figure 4.15). Site V5THUK-EWR18 had an elevated discharge which was approximately three times higher than that of V5THUK-CONTROL. The V5THUK-EWR18 site also had higher elevation edges, with elevations of 7.19 m from the left bank and 5.66 m from the right bank. The V5THUK-EWR18 site also had higher elevation edges, with a value of 7.186 m from the left bank and 5.668 m from the right bank.

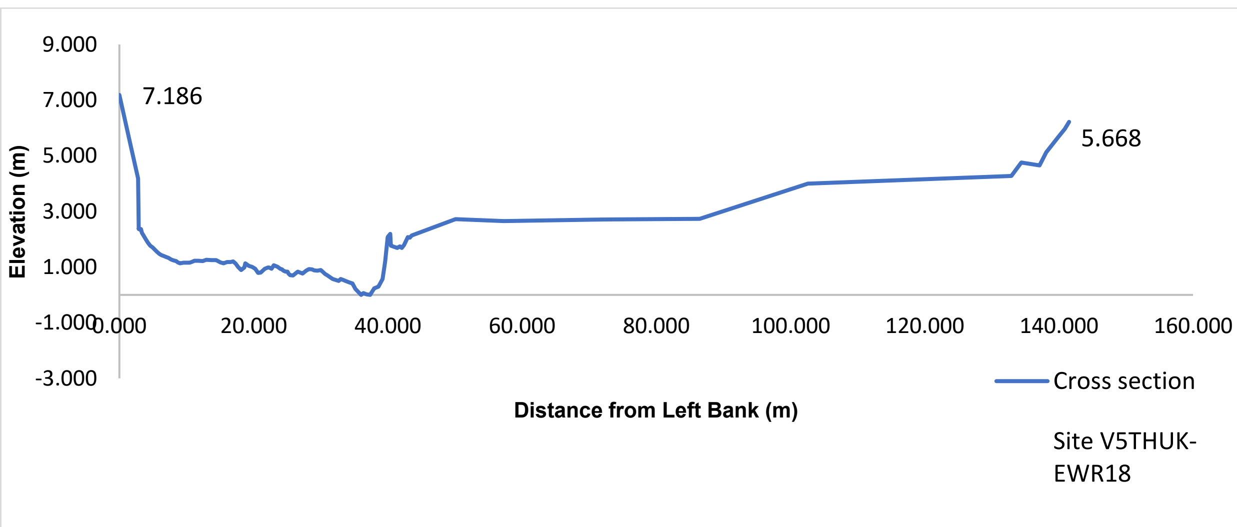

Figure 4.13: Cross section showing elevation points at site V5THUK-EWR18.

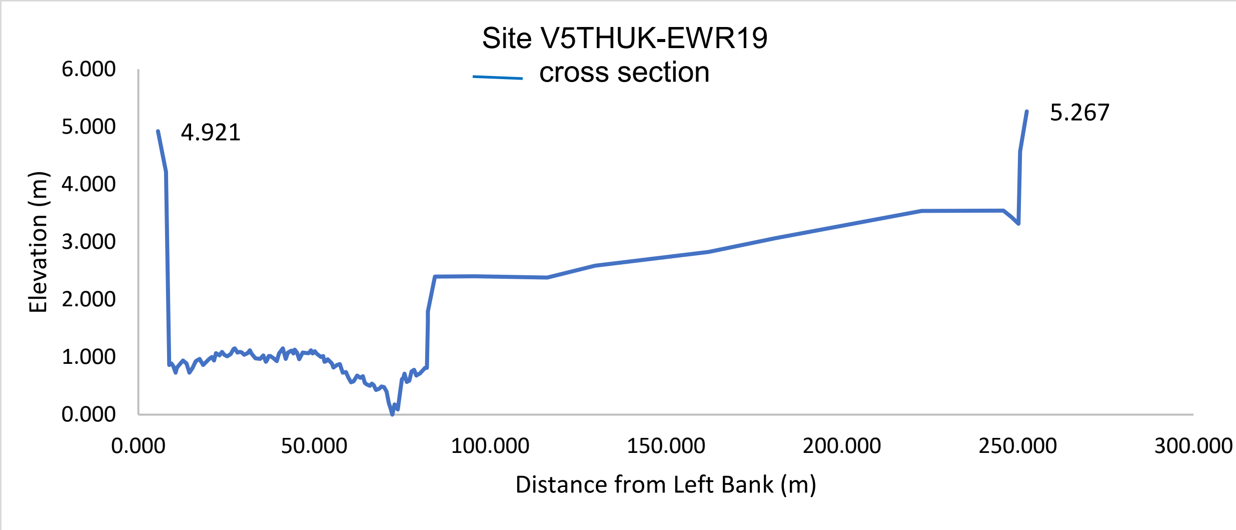

Figure 4.14: Cross section showing elevation points at site V5THUK-EWR19.
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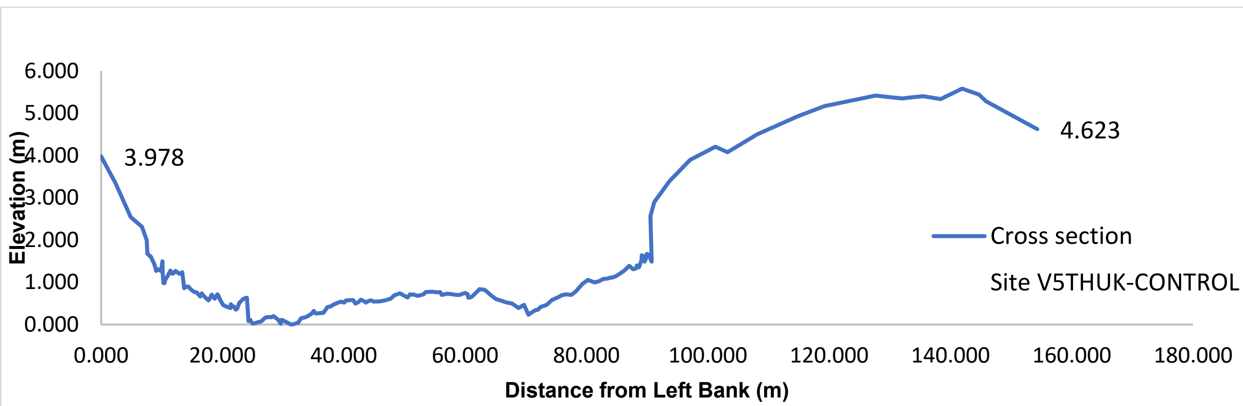


Figure 4.15: Cross section showing elevation points at site V5THUK-CONTROL.

The associations between plant communities and discharge were assessed using RDA multivariate analysis. The analysis displayed a non-significant association of plant communities and discharge (P= 0,169; F = 1,7) (Figure 4.16). The *Dich cinr* community displayed a close association with the 14.228 m/s and 46.052 m/s. The *Fics sycm* community displayed a close association with a discharge of 29.444 m/s.

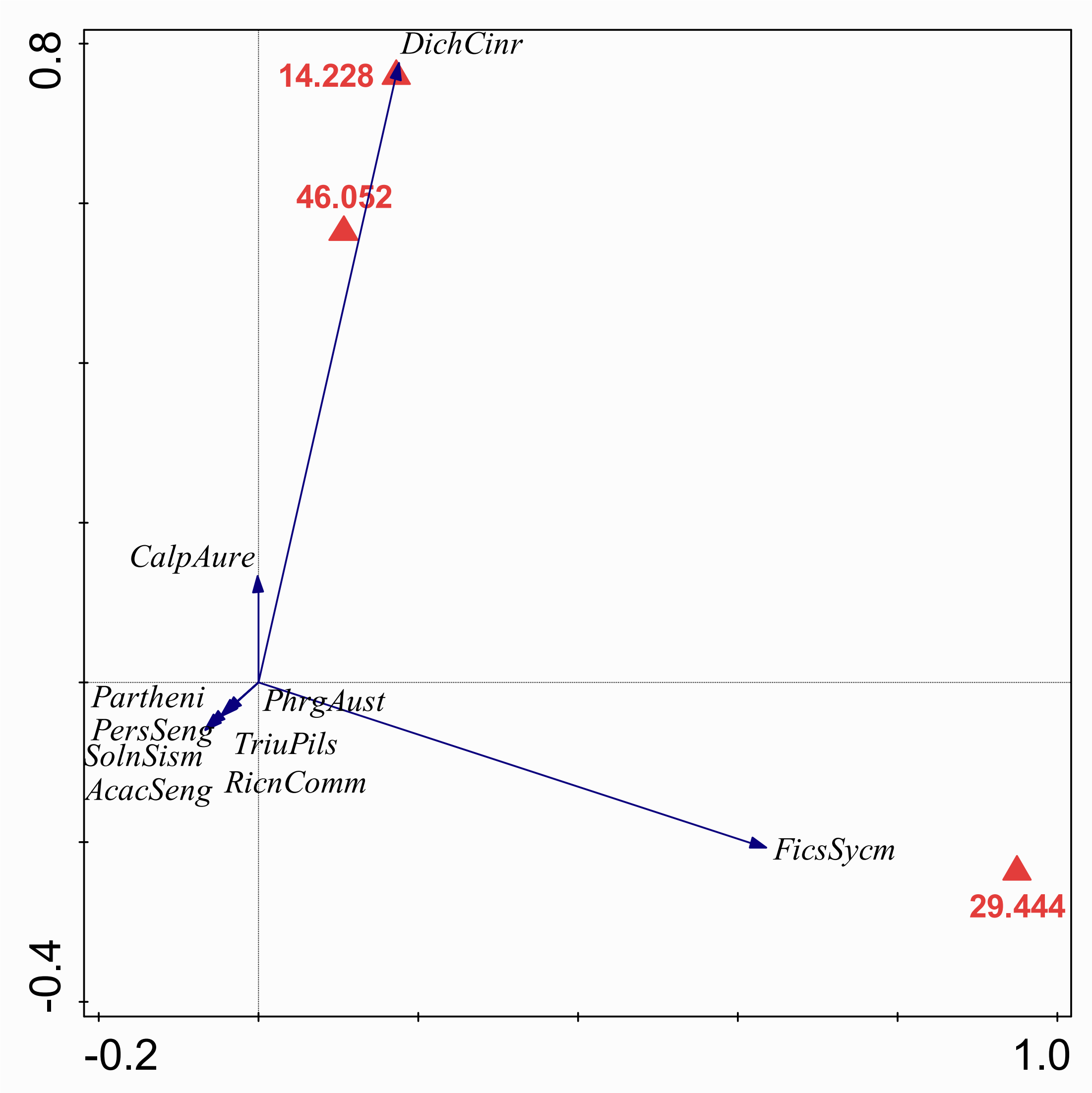


Figure 4.16: RDA analysis showing associations between plant communities and discharge at uThukela River.

The bi-plot describes 28.7% of the total variation. Of the fitted variation, 86.03% is described in the first axis (x) and 6% is described in the second axis (y).

4.1.4 Substrates

The relationships or associations between substrate types and plant communities were identified using RDA multivariate analysis. The RDA multivariate analyses combining the plant communities collected at V5THUK-CONTROL V5THUK-EWR18 and V5THUK-

EWR19 within the lower uThukela River indicated no significance difference/ associations with substrate types (p= 0.98; F= 0.3) (Figure 4.17).

Panc maxm communities displayed a close association with the boulder substrate, while the *Fics syc sycm* showed a close association with the sand substrates. The *Vang infa* and *Pers seng* communities displayed a close association with the silt substrate and *Dio mesp* with a less close association with the silt substrate. The *Scad punc* and *Vach nilt* also displayed a close association with the fine sand substrate with *Calp aure, Datr strm, Dich cinr, Ricn comm, Acac seng, Triu Pils* displaying a less strong association with fine sand substrate.

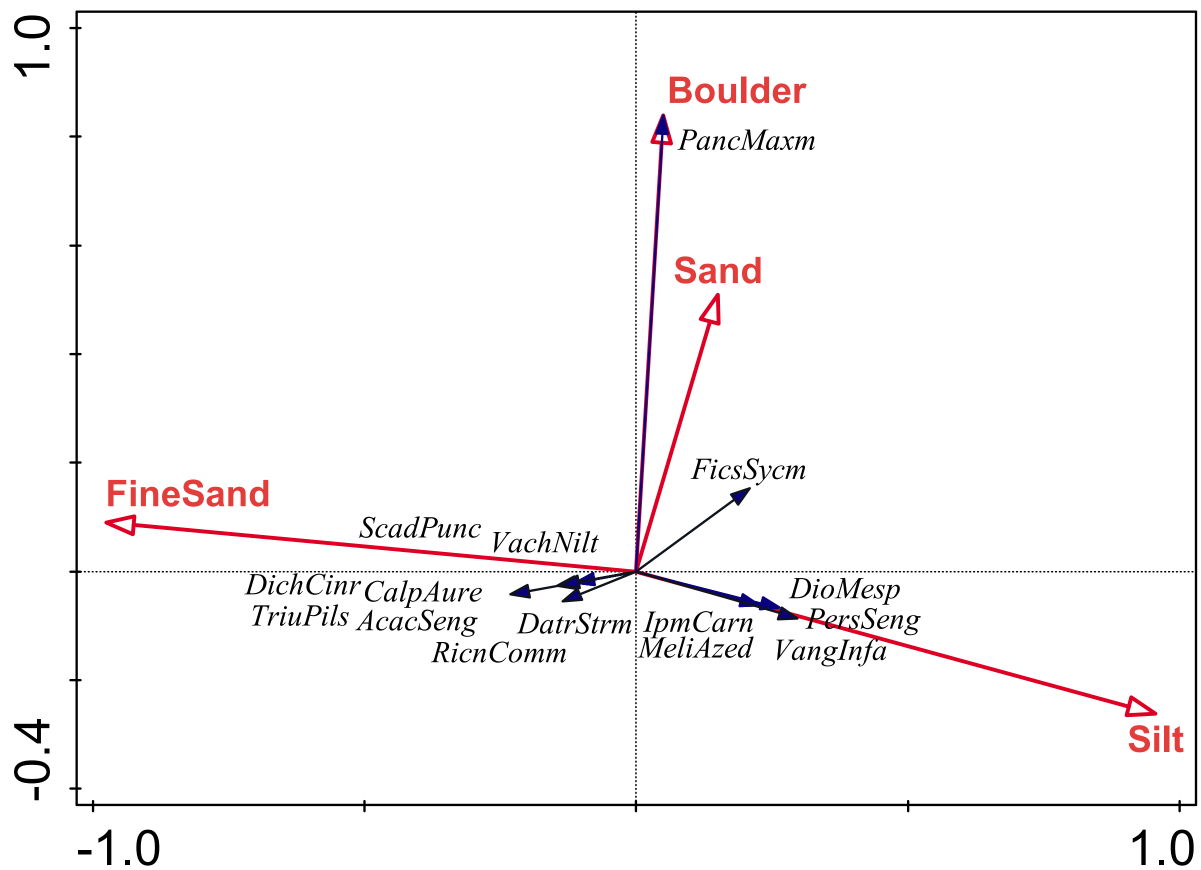


Figure 4.17: Redundancy analysis (RDA) bi-plot showing the association of plant species and substrate types at the lower uThukela River.

The biplot explains 2.1% of the variation. Of the fitted variation, 63.30% is explained in the first axis and 22.39% is explained in the second axis.

4.1.5: Water quality

The *In-situ* water quality analysis was conducted during the April 2023 sampling period in the three selected study areas in the lower uThukela River, namely V5THUK-CONTROL, V5THUK-EWR18 and V5THUK-EWR19. The results indicated that site V5THUK-CONTROL had higher DO (mg/l), pH and total dissolved solids compared to the V5THUK-EWR18 and V5THUK-EWR19 sites. The conductivity levels were slightly elevated beyond the acceptable ranges (Table 4.3).

Table 4.3: Water quality results sampled from V5THUK-EWR18, V5THUK-CONTROL and V5THUK-EWR19 within uThukela River.

Variables	V5THUK-CONTROL	V5THUK-EWR18	V5THUK-EWR19
DO (mg/L)	8.39	7.94	7.32
DO (%)	97	97.9	90.8
Temperature	18.3	23.3	26.1
pH	7.76	7.75	7.49
Conductivity	339.2	328.5	339.4
TDS	339.2	164.9	166.6
Chloride	18	22	16
Nitrate	0.8	0.9	0.6
Nitrite	0.012	0.016	0.014
Sulphate	23	27	16
Phosphate	0.04	0.04	0.05
Fluoride	0.17	0.11	0.1
Alkalinity	109.836	91.53	85.428
COD	60.5	54.3	56.6

Water quality results for the laboratory analyzed parameters indicated that chloride, nitrite, nitrate and sulphate were high in the V5THUK-EWR18 site compared to the other sampled sites (table 4.3). The fluorite, alkalinity and chemical oxygen demand (COD) levels were high in the V5THUK- CONTROL site.

The associations between plant communities and water quality variables were assessed using CCA multivariate analyses. The analysis indicated a significant association of plant communities with water quality (P = 0.04; F =1.3) (Figure 4.18). The COD (p = 0.02, f = 1.6) alkalinity (p = 0.01, f = 1.6) fluoride (p = 0.01, f = 1.6) and total dissolved solids (p = 0.02, f = 1.6) were significantly different and accounted for most of the variation observed in the vegetation communities.

The *Ricn comm* displayed a close association with the chloride variable, while *Soln sism* displayed a less close association with chloride and sulphate variables. The *Arun donx* and *Panc maxm* communities represented a slight association with temperature. The pH, DO (%) and sulphate variables indicated a close association with each other (figure 4.18).

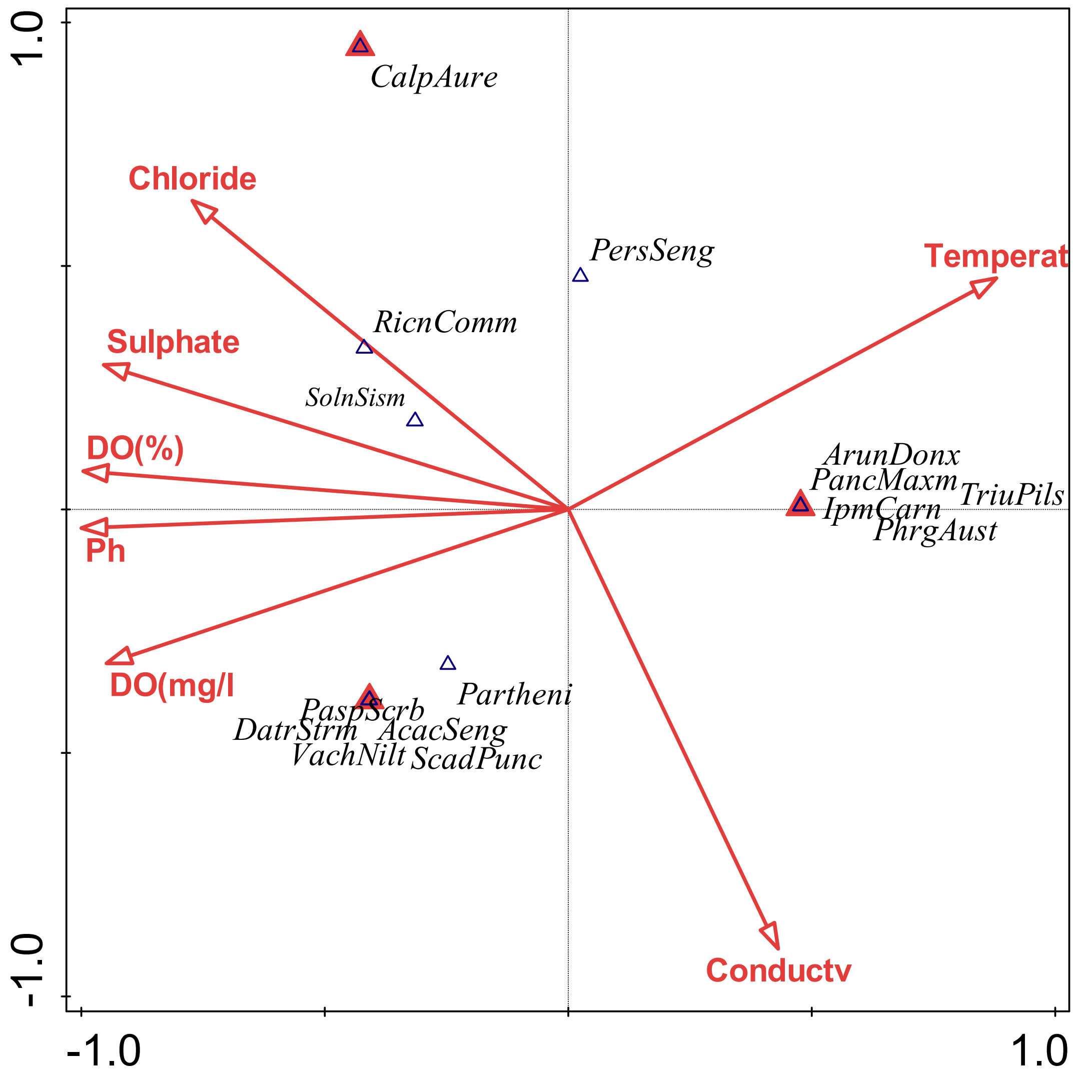


Figure 4.18: Canonical correspondence analysis multivariate analysis bi-plot showing associations between plant communities and water quality variables at uThukela River.

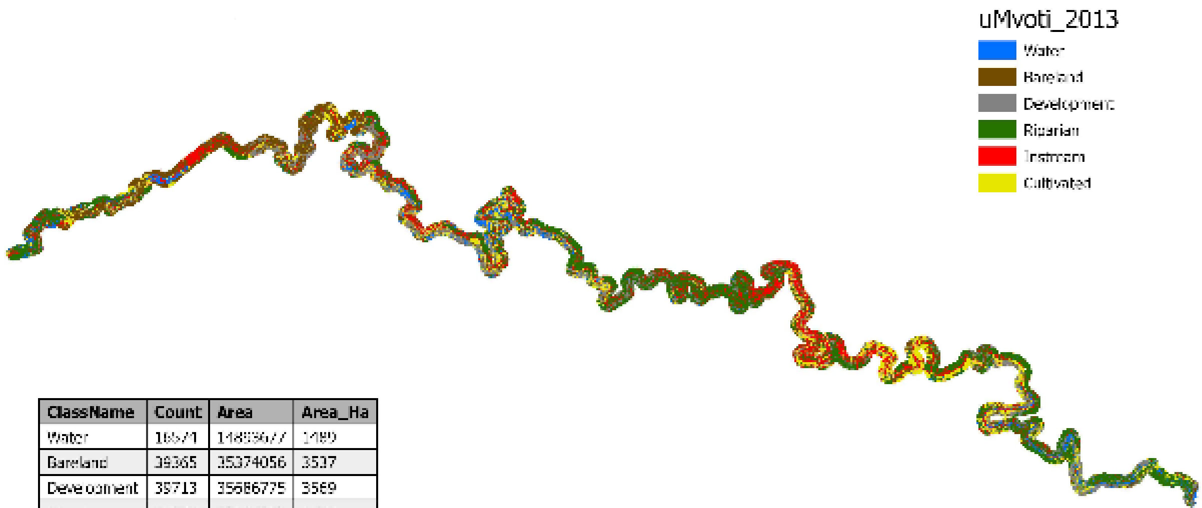
The biplot displays 6.4% of the total variation. Of the fitted variation, 61.71% is described in the first axis and 38.29% is described in the second axis.

4.2 uMvoti River

4.2.1 Vegetation changes between 2013-2023.

The riparian vegetation of uMvoti River indicated an increase in quantity, from a quantity of 8620 Ha in 2013 (Figure 4.19, Figure 4.20 and Figure 4.23) to 10952 Ha in 2023 (Figure 4.21, Figure 4.22 and Figure 4.23). The riparian vegetation showed an increase of 2332 ha in 2023 when compared to the year 2013 Ha (Figure 4.19 and Figure 4.21). A decline in terms of instream vegetation (macrophytes) quantity has been observed in the period between 2013 and 2023 with 4488 Ha in 2013 (Figure 4.19, Figure 4.20 and Figure 4.23) and 2106 Ha in 2023 (Figure 4.21 and Figure 4.22). There was an increase in the amount of bare land between 2013 and 2023, with 3537 Ha in 2013 and 4508 Ha in 2023 (Figure 4.20 and 4.21). The amount of land covered by development also showed an increase from 3569 Ha to 4454 Ha between 2013 and 2023 (Figure 4.19 and 4.21).

There was a decrease in the amount of exposed water in 2023 when compared to 2013, with a reduction of 544 ha (Figure 4.19, Figure 4.21, figure 4.23). The amount of bare land also increased with 971 ha in 2023 when compared to the year 2013 (figure 4.19 and figure 4.21). There was also an increase in the amount of development that took place in 2023 with 885 ha. A total of 19% of land that was once cultivated was converted to riparian vegetation (Figure 4.24). A total of 21% of land that was once bare land has converted to riparian vegetation (Figure 4.24).



ClassName	Count	Area	Area_Ha
Water	16571	14889677	1489
Bareland	39365	35374056	3537
Development	39713	35686775	3569
Riparian	95922	86197135	8620
Instream	49942	44876726	4488
Cultivated	43679	39250690	3925

ClassName	Water	Bareland	Development	Riparian	Instream	Cultivated	Total	U_Accuracy	Kappa
Water	7	0	0	2	0	1	10	0.7	0
Bareland	0	10	0	0	0	0	10	1	0
Development	1	2	6	1	0	0	10	0.6	0
Riparian	1	0	0	7	1	1	10	0.7	0
Instream	1	0	0	1	7	1	10	0.7	0
Cultivated	0	0	1	0	2	7	10	0.7	0
Total	10	12	7	11	10	10	60	0	0
P_Accuracy	0.7	0.833333	0.857143	0.636364	0.7	0.7	0	0.733333	0
Kappa	0	0	0	0	0	0	0	0	0.68

Figure 4.19: Land-use and cover classification in 2013 at uMvoti River.

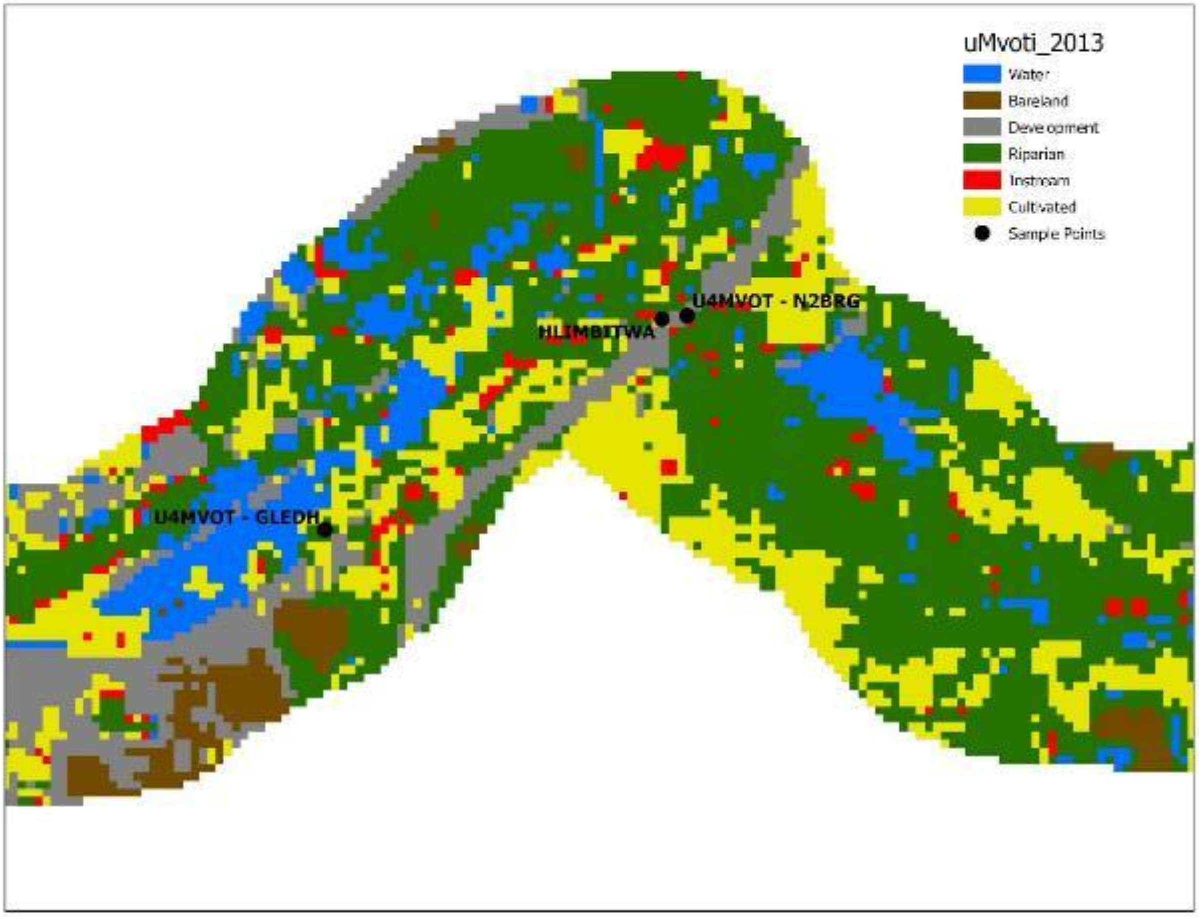
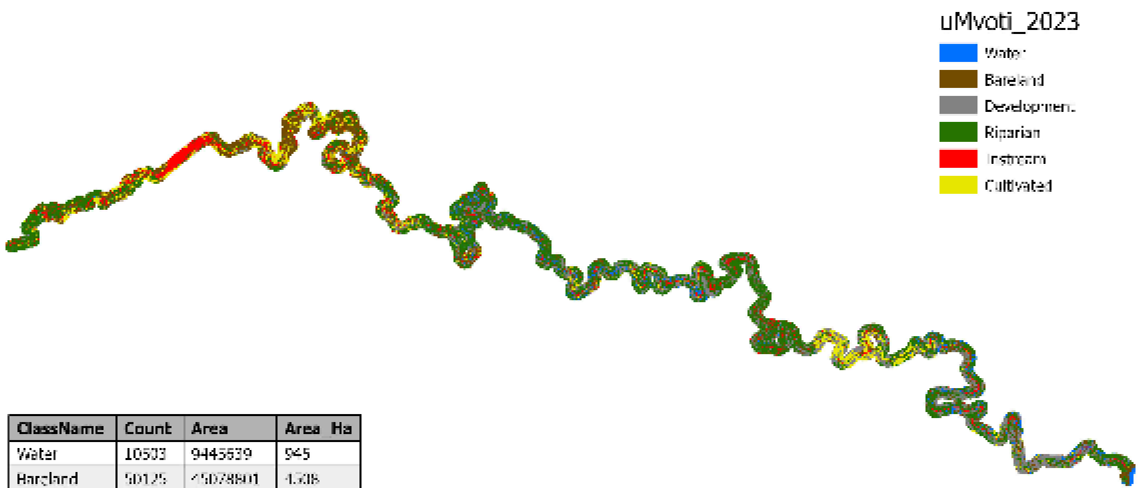


Figure 4.20: Land-use cover classification in 2013 at uMvoti River in KwaZulu-Natal representing the sampled sites.



ClassName	Count	Area	Area_Ha
Water	10503	9445639	945
Bareland	50125	45078801	4508
Development	49529	44542801	4454
Riparian	121776	109516525	10952
Instream	23413	21055939	2106
Cultivated	30476	27407911	2741

ClassName	Water	Bareland	Development	Riparian	Instream	Cultivated	Total	U_Accuracy	Kappa
Water	6	1	1	1	0	1	10	0,6	0
Bareland	1	5	1	1	0	1	10	0,6	0
Development	2	1	6	1	0	0	10	0,6	0
Riparian	0	0	0	7	1	2	10	0,7	0
Instream	0	1	0	1	7	1	10	0,7	0
Cultivated	1	3	0	0	0	6	10	0,6	0
Total	10	12	8	11	8	11	60	0	0
P_Accuracy	0.6	0,5	0,75	0,636364	0.875	0,545455	0	0,633333	0
Kappa	0	0	0	0	0	0	0	0	0,56

Figure 4.21: Land-use and cover classification in 2023 at uMvoti River.

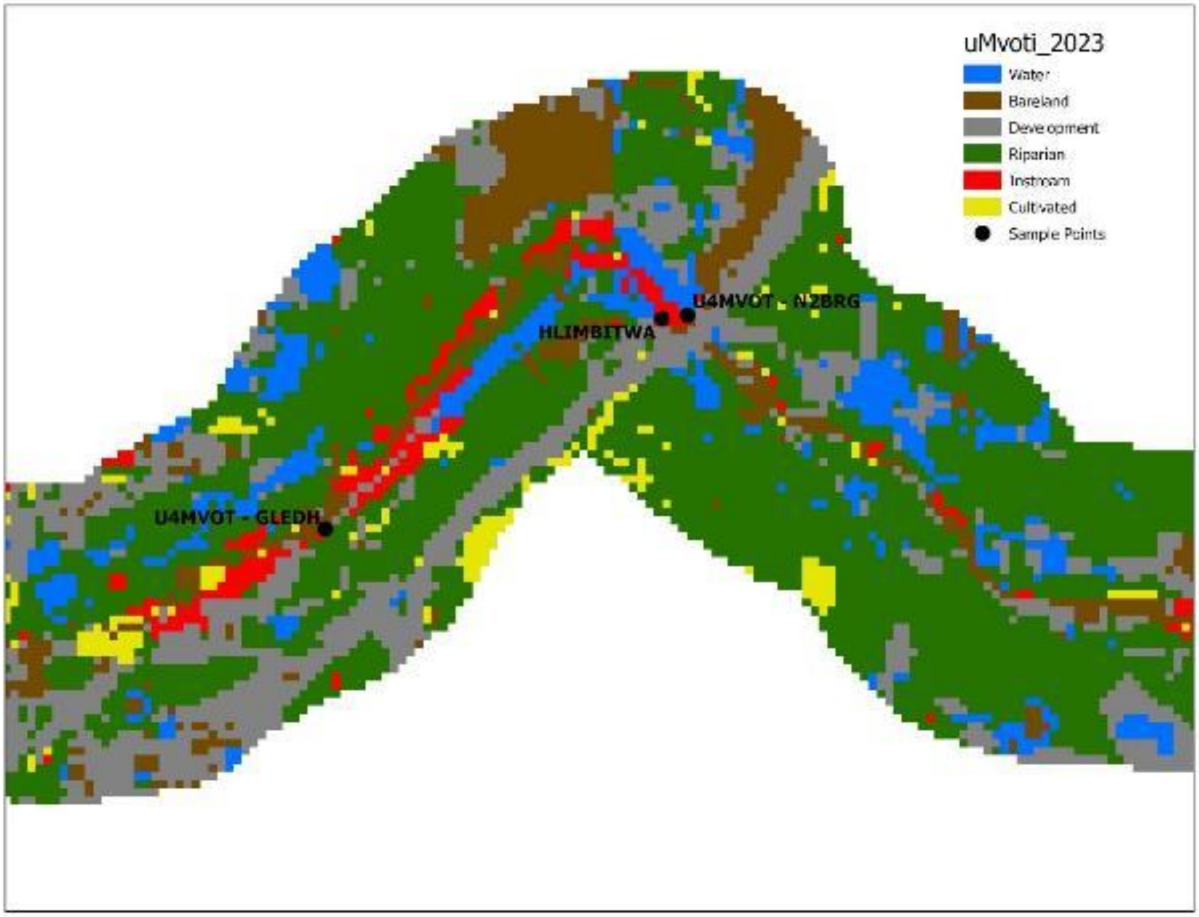


Figure 4.22: Land-use and cover classification in 2023 at uMvoti River in KwaZulu-Natal representing the sampled sites.

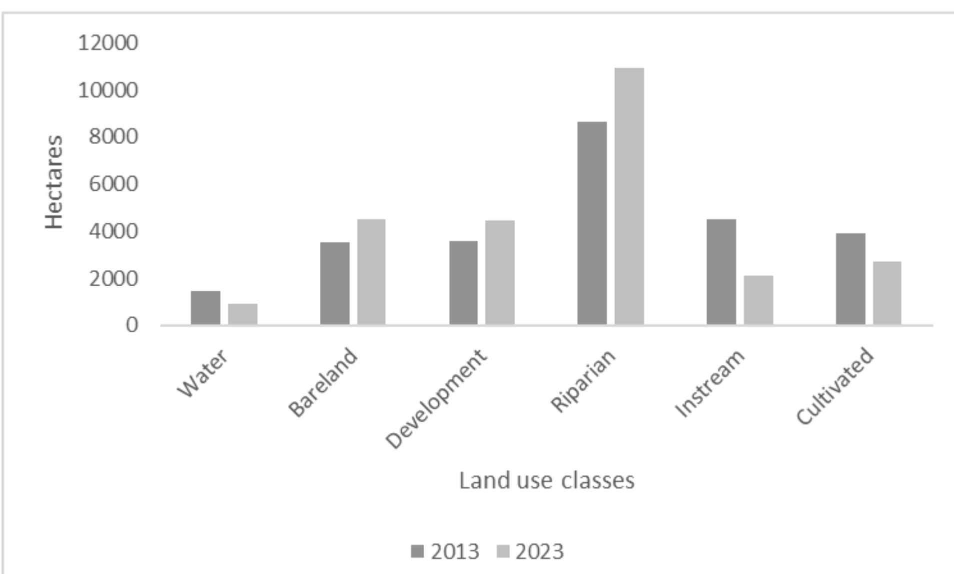


Figure 4.23: Comparison of area changes between land-use classes and cover changes between 2013 and 2023 at uMvoti River.

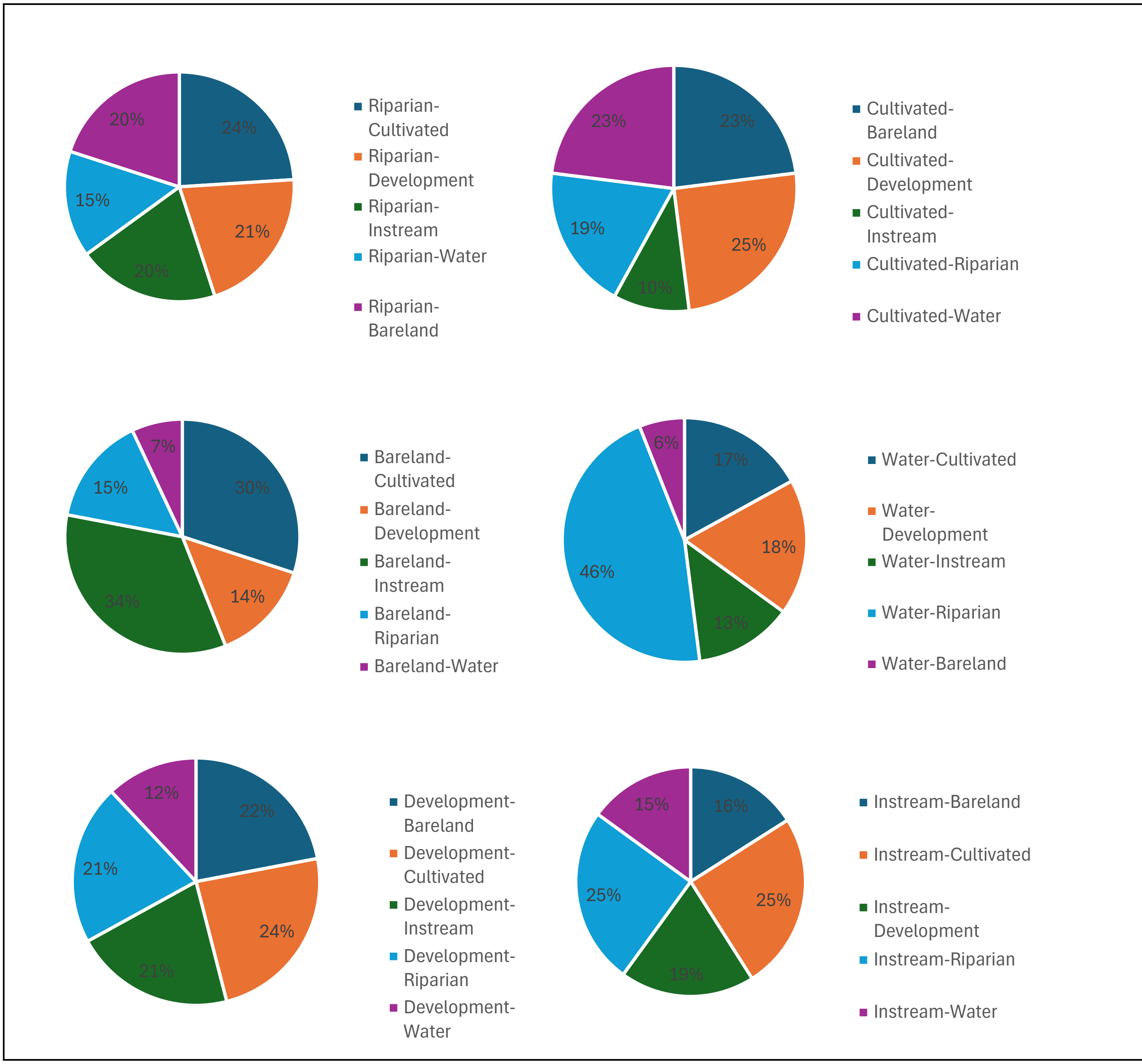


Figure 4.24: Land-use class change in percentages at the uMvoti River in a 10-year period, between 2013 and 2023.

A total of 16% of land that was once occupied by instream vegetation (macrophytes) was converted to bare land, which might be due to channel modification and flow reduction (figure 4.24). An additional 15% of land that was once used by macrophytes has been converted to water. This might be due to removal of floods and sand mining (figure 4.24). Furthermore, land accounting to 25% that was once covered by instream vegetation (macrophytes) was converted to riparian vegetation (Figure 4.24). This might be due to stream reduction caused by reduced flow and channel modification.

4.2.2 Vegetation community structures

A total of 44 plant species from 23 families were recorded in all the sampled sites (U4MVOT-N2BRG, U4MVOT-GLADH and HLIMBITWA) within the lower uMvoti River (Table 4.4). A total of 29 plant communities were superimposed into the cross sections of the sampled sites within the lower uMvoti River. Elevation, distance from the left bank, abundance and associated substrate types were recorded (Table 4.5).

Table 4.4: Plant communities recorded in the lower uMvoti River during the April 2023 survey.

Scientific name	Common name	Abbreviation
Calpurnia aurea	Common calpurnia	*Cal aure*
Phragmites australis	Common reeds	*Prg aust*
Melia azedarach	Syringa	*Meli azed*
Morus alba	Mulberries	*Mors alba*
Arudo donax	Giant reeds	*Arun donx*
Xanthium strumarium	Rough cocklebur	*Xant strm*
Ageratum houstonianum	Blue mink	*Ager hous*
Achyranthes aspera	Devils horsewhip	*Achr aspr*
Panicum maximum		*Panc maxm*
Solanum sisymbriifolium	Sticky nightshade	*Soln sism*
Malvastrum coromandelianum	Threelobe false mallow	*Malv com*
Ipomoea carnea	Morning glory	*Ipom carnea*
Schinus terebinthifolius	Brazilian pepper tree	*Schinus*
Sonchus oleraceus	Sowthistle	*Sonchus oler*
Ambrosia acanthicarpa	Common ragweed	*Ambrosia acan*
Lavandula angustifolia	English lavender	*Lavandula angu*
Commelina erecta	Day flower	*Comm erecta*
Persicaria lapathifolia	Pale smartweed	*Pers*
Solanum incanum	Bitter apple	*Soln*
Ricinus communis	Castor oil bean	*Ricn comm*

Trichilia emetica	Natalia mahogany	*Trichilia*
Dichrostachys cinerea	Sickle bush	*Dichros cinera*
Tagetes Minuta	Southern cone marigold	*Tagetes min*
Abildgaardia ovata	Flat spike sedge	*Abild ovata*
Amaranthus	Livid Amaranth	*Amarant*
Rivina humilis	Blood berries	*Rivina hum*
Pittosporum viridiflorum	Cheese wood	*Pittos viridiflor*
Juncus patens	Spreading rush	*Juncus patn*
Bridelia micrantha	Coastal golden leaf	*Bridel micranta*
Dactyloctenium australe	Durban grass	*Dactyl australe*
Cyperus dives	Ikwane	*Cyperus div*
Chloris virgata	Finger grass	*Chloris vir*
Cyperus brevis	Nut sedge	*Cyperus brev*
Paspalum distichum	Knot grass	*Paspalum dist*
Rumex spinosus	Devil's thorn	*Rumex spin*
Cyperus albostriatus	Paper reed	*Cyperus albo*
Hydrocotyle	Water pennywort	*Hydrocotyle*
Juncus kraussii	Salt marsh rush	*Juncus krau*
Crotalaria juncea	Brown hemp	*Crotalaria jun*
Lantana camara	Tick berry	*Lantana cam*
Ambrosia acanthicarpa	Hookers' bur	*Ambrosia acan*
Spermacoce alata	Button weed	*Sperm alata*
Senna occidentalis	Stick weed	*Senna occid*

The common substrate at site U4MVOT-GLADH was silt, contributing high percentages followed by fine sand, sand, sand course and some few percentages of cobbles and boulders (Table 4.5). The site was dominated by *P. maximum, P. australis and P. lapathifolia*. The U4MVOT-N2BRG site's substrate type is mostly composed of silt and fine sand (Table 4.5). The site is dominated mostly by alien plants, with *S. sisymbriifolium and A. donax* having higher abundances. The common substrate types included silt and fine sand in site U4MVOT-N2BRG. The HLIMBITWA site was mostly sandy and dominated by alien plants as well (Table 4.3). The vegetation communities had higher abundances except for *S. terebinthifolius* and *M. alba*. The was no clear link between substrate and position (distance from the left bank and elevation) and vegetation communities across the sampled sites namely U4MVOT-GLADH, HLIMBITWA and U4MVOT-N2BRG.

Table 4.5: Plant communities superimposed in the cross section of the sampled sites within the lower uMvoti River, showing their association with substrate types, abundance and position in the river.

Site name	Scientific name	common name	Point number	Evelation (	Distance from left bank (m)	Silt	Sand fine	Sand	Sand course	Gravel	Gravel, course	Couble large	Boulder	Abundance	Notes
U4MVOT-GLADH	*Panicum maximum*		3	69.065	4.013		15				80	5		<10	adult
U4MVOT-GLADH	*Phragmites australis*	Common reeds	3	69.065	4.013	45		50		5				>10	adult
U4MVOT-GLADH	*Panicum maximum*		10	37.245	0.792	30	30		5			20	5	2	adult
U4MVOT-GLADH	*Echinochloa*	Barnyard grass	10	37.245	0.792	100								1	adult
U4MVOT-GLADH	*Panicum maximum*		10	37.245	0.792	10	90							1	dead
U4MVOT-GLADH	*Persicaria lapathifolia*	Pale smartweed	12	46.060	0.425	100								10	adult
U4MVOT-GLADH	*Echinochloa*	Barnyard grass	12	46.060	0.425	100								1	adult
U4MVOT-GLADH	*Pergularia daemia*	Trellis vine	18	57.302	0.280	10		10	80					>10	adult
U4MVOT-GLADH	*Phragmites australis*	Common reeds	18	57.302	0.280	10	90							7	adult
U4MVOT-GLADH	*Persicaria lapathifolia*	Pale smartweed	18	57.302	0.280	10	90								adult
U4MVOT-GLADH	*Persicaria lapathifolia*	Pale smartweed	19	30.722	1.617	5		95						3	adult
U4MVOT-GLADH	*Phragmites australis*	Common reeds	19	30.722	1.617	10		90						>80	adult
U4MVOT-GLADH	*Echinochloa*	Barnyard grass	19	30.722	1.617	100								1	adult
U4MVOT-N2BRG	*Solanum sisymbriifolium*	Sticky nighshade	1	20.397	3.645		100							>10	sub-adult
U4MVOT-N2BRG	*Ricinus communis*	Castor oil bean	1	20.397	3.645	100								4	adult
U4MVOT-N2BRG	*Panicum maximum*		1	20.397	3.645		100							5	adult
U4MVOT-N2BRG	*Bindens pilosa*	Black jack	1	20.397	3.645	70	30							3	adult
U4MVOT-N2BRG	*Xanthium strumarium*	Rough cocklebur	3	3.938	3.188	100								3	sub-adult
U4MVOT-N2BRG	*Malvastrum coromandelianum*	Threelobe false mallow	3	3.938	3.188		100							1	adult
U4MVOT-N2BRG	*Calpurnia aurea*	Common calpurnea	4	1.969	2.986	100								1	adult
U4MVOT-N2BRG	*Persicaria senegalensis*	Snake root	5	6.302	1.005	100								4	adult
U4MVOT-N2BRG	*Phragmites australis*	Common reeds	5	6.302	1.005		100							5	adult
U4MVOT-N2BRG	*Arudo donax*	Giant reeds	5	6.302	1.005		100							>60	adult
U4MVOT-N2BRG	*Commelina erecta*	Day flower	5	6.302	1.005		100							1	adult
HLIMBITWA	*Phragmites australis*	Common reeds	3	3.972	2.656			100						>50	adult
HLIMBITWA	*Arudo donax*	Giant reeds	3	3.972	2.656			100						>15	adult
HLIMBITWA	*Morus alba*	Mulberrries	12	32.094	2.095			100						1	adult
HLIMBITWA	*Achyranthes aspera*	Devil's horsewhip	12	32.094	2.095			100						>10	adult
HLIMBITWA	*Schinus terebinthifolia*	Brazilian pepper tree	16	50.271	0.363			100						1	adult

The cross section had an elevation of 3.127 m from the left bank and an elevation of 0.752 m from the right bank. The site had a discharge of 3.609 m^3/s (figure 4.25).

The green dots indicate the position (distance from the left bank and elevation) of the plant communities. 1=*Solanum sisymbriifolium, Ricinus communis, Panicum maximum, Bidens pilosa* 3=*Xanthium strumarium, Malvastrum coromandelianum* 4=*Calpurnea aurea* 5=*Persicaria senegalensis, Phragmites australis, Arudo donax, Commelina erecta.*

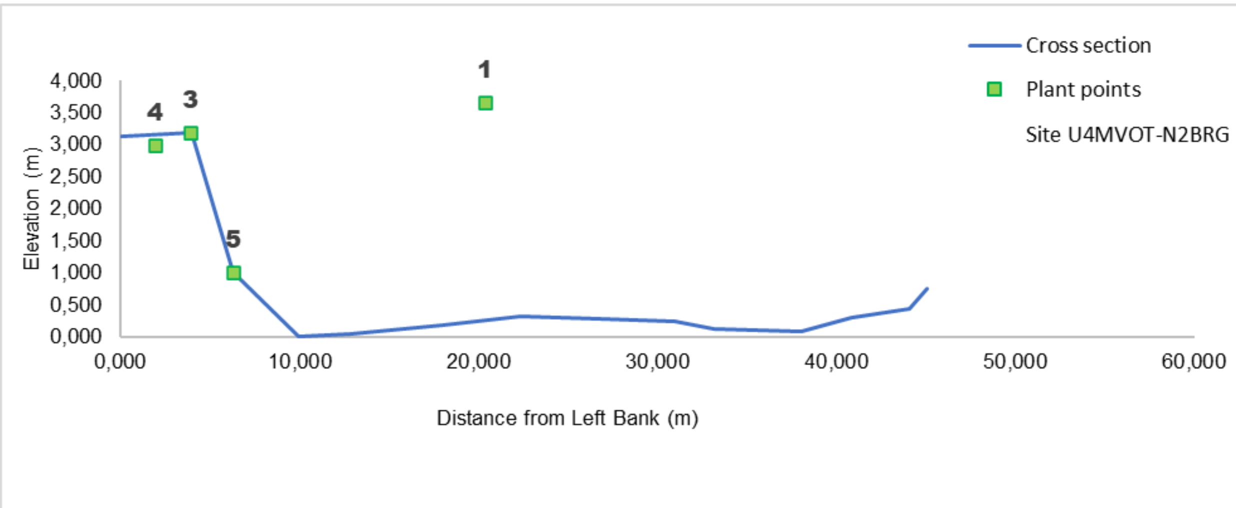


Figure 4.25: Cross section with superimposed plant communities at U4MVOT-N2BRG within the lower uMvoti River.

The cross section had an elevation of 3.179 m^3/s from the left bank and an elevation of 2.449 m^3/s from the right bank, with a discharge value of 5.351 m^3/s (figure 4.26). The green dots indicate the position (distance from the left bank and elevation) of the plant communities. 3) *Phragmites australis, Arudo donax, 12) Morus alba, achyranthes aspera 16) Schinus terebinthifolia*

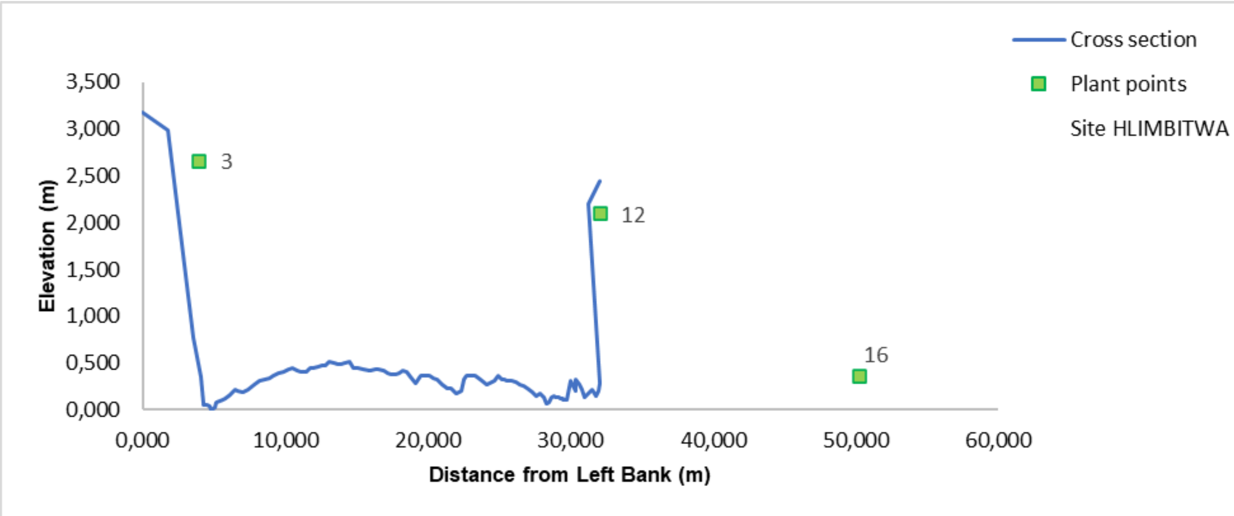


Figure 4.26: Cross section with superimposed plant communities at HLIMBITWA site, within the lower uMvoti River.

The cross section had an elevation of 3.152 m^3/s from the left bank and an elevation of 4.369 m^3/s from the right bank (figure 4.27). The site had a discharge value of 6.256 m^3/s. The green points with numbers represent the sampled plant communities and their position (distance from the left bank and elevation). *3=P. maximum, P. australis 10 =P. maximum, Echinochloa 12=P. senegalansis, Echinochloa 18=Hydrocotyle, P. australis, P. senegalansis 19=P. senegalansis, P. australis, Echinochloa*

Most of the plant communities sampled at the lower uMvoti River were categorized to be in the Asteraceae family. The vegetation communities were diverse, representing 23 families. Plant communities that were superimposed to the cross section were mostly adults and were mostly associated with sandy substrates (Silt, fine sand, sand and coarse sand) (table 4.5).

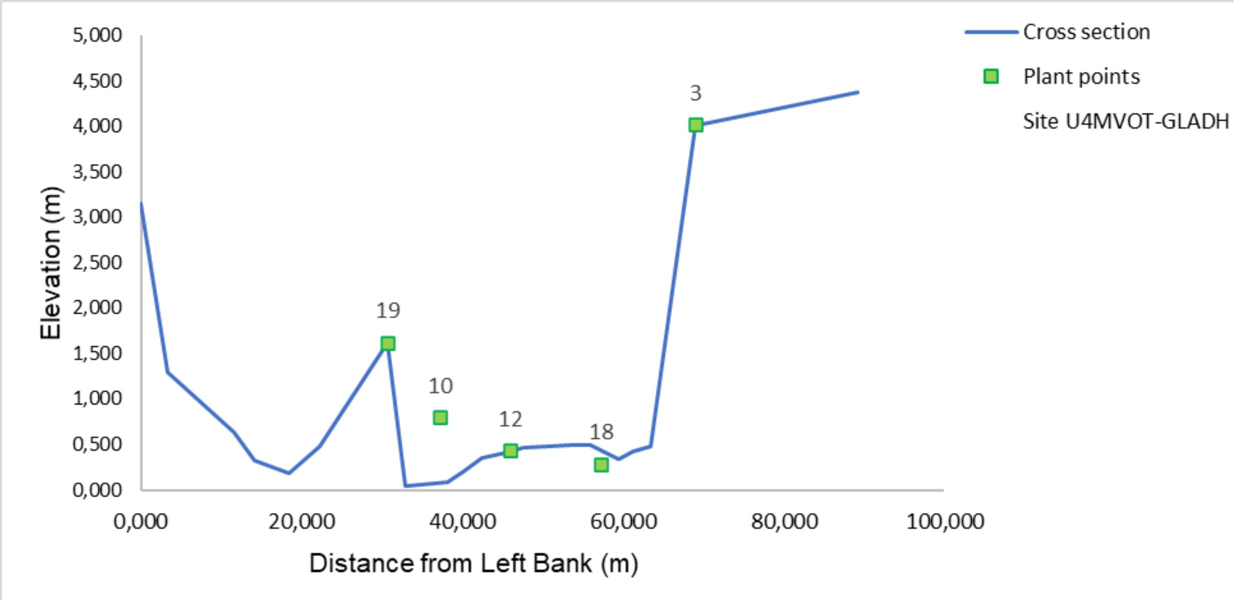


Figure 4.27: Cross section with superimposed plant communities at U4MVOT-GLADH site within the lower uMvoti River.

4.2.3 Flow

Cross section profiles were surveyed across the sampled sites namely, (U4MVOT-GLADH, and HLIMBITWA and U4MVOT-N2BRG) within the lower uMvoti River. Water levels were recorded on the left and right edges of the channel and their discharge values. The U4MVOT-GLADH site had an elevation of 3.152 m from the left bank and 4.369 m from the right bank (figure 4.28). It had a discharge of 6.256 m^3/s. Site HLIMBITWA had elevations of 3.179 m and 2.449 m from the left to the right bank (figure 4.29). The site also had a discharge of 5.351 m^3/s. The U4MVOT-N2BRG side had a low discharge of 3.609 m^3/s and elevations of 3.127m and 0.752 m from left to right (figure 4.30).

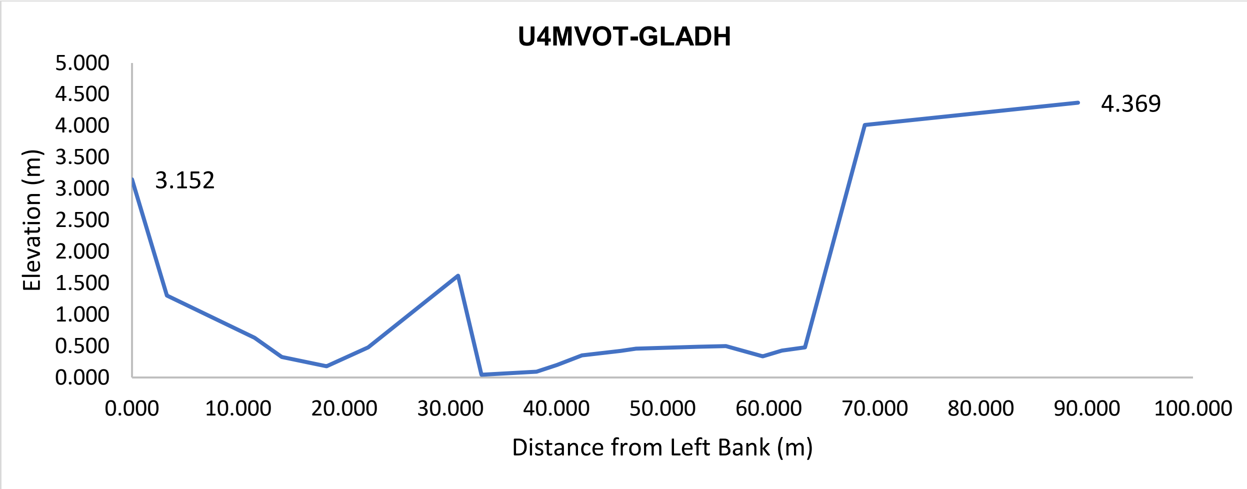


Figure 4.28: Cross section of site U4MVOT-GLADH.

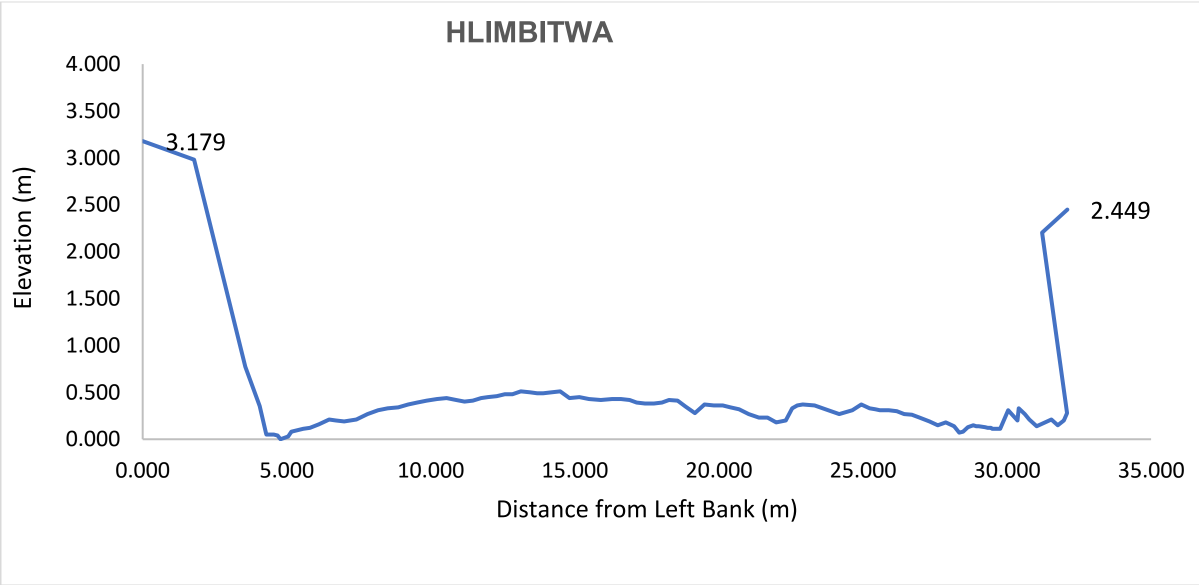


Figure 4.29: Cross section of site HLIMBITWA.

Site HLIMBITWA had elevation points of 3.179 m and 2.449 m from left to right (figure 4.29).

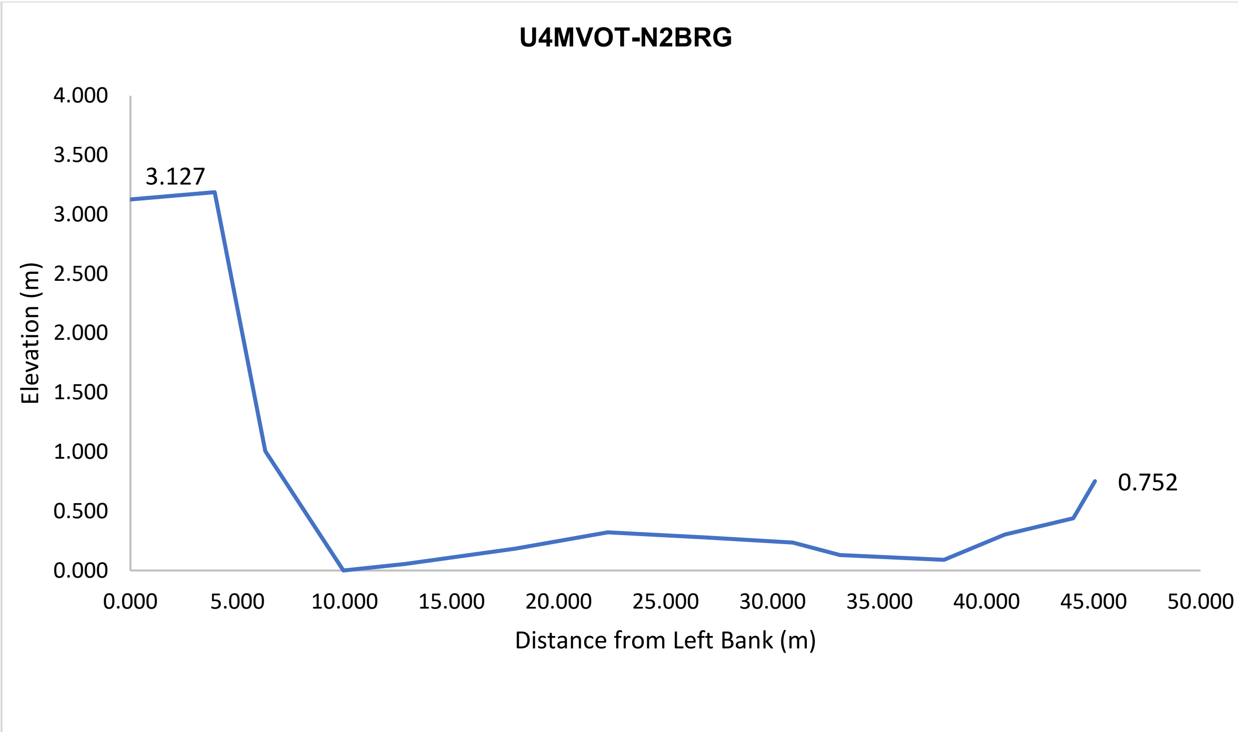


Figure 4.30: Cross section of site MVOT-N2BRG.

Site MVOT-N2BRG had elevation points of 3.127 m from the left bank and 0.752 m from the right bank (figure 4.30).

Associations between plant communities and discharge were identified using RDA multivariate analysis. The RDA multivariate analysis combining the plant communities collected at (U4MVOT-GLADH, HLIMBITWA and U4MVOT-N2BRG) within the lower uMvoti River indicated a significance association with discharge values (P = 0,01; F = 2,4) (Figure 4.31). The 3.609 m/s discharge contributed to the significance of the test (explains 7.6% of variation, p = 0.04). The *Soln sism* communities displayed a close strong association with the 3.609 m/s discharge. The *Arun donx*, *Echn gras* displayed a close but less strong association with the 5.351 m/s discharge (figure 4.31).

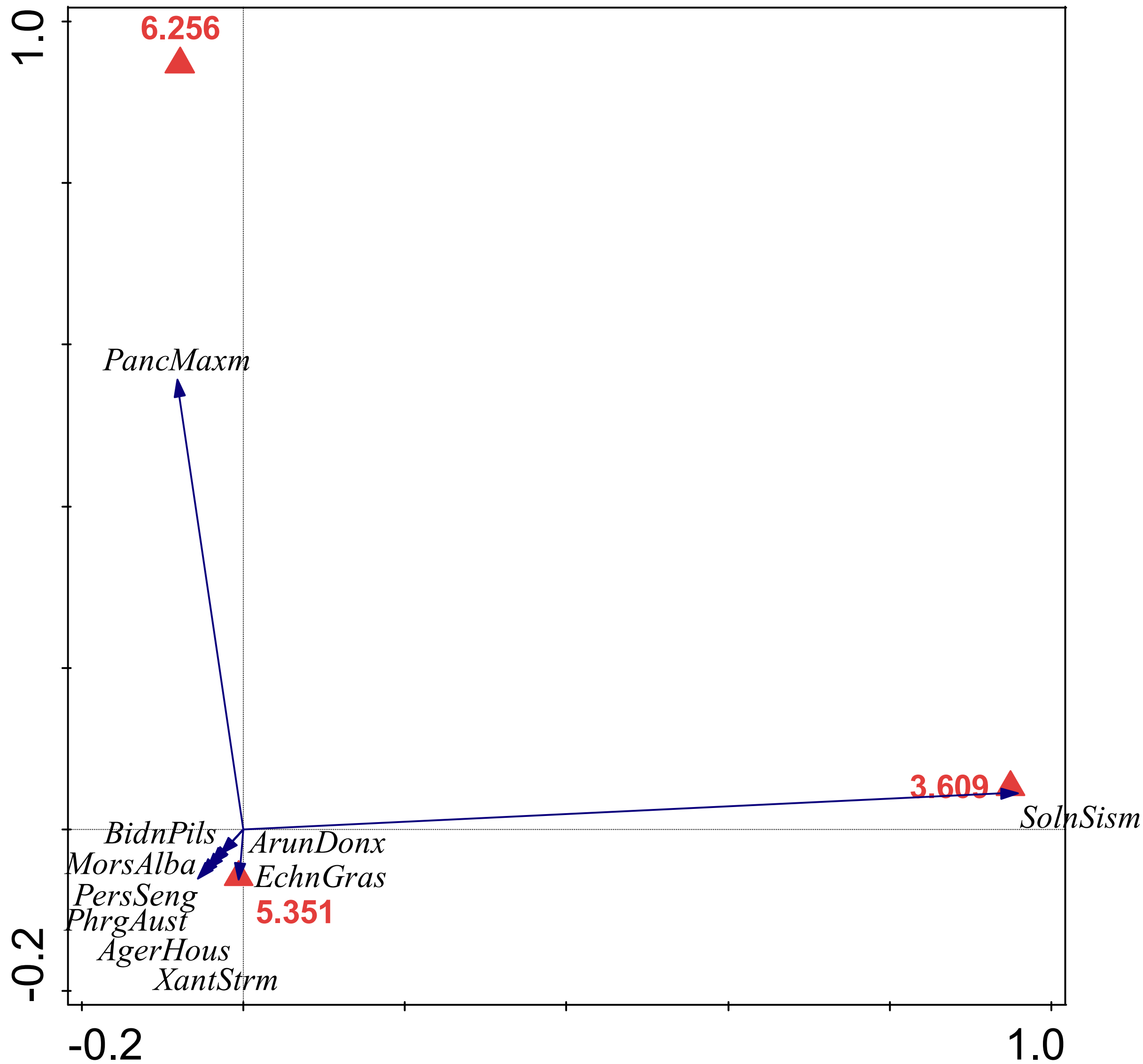


Figure 4.31: Redundancy analysis (RDA) bi-plot showing the association of plant communities and discharge at the lower uMvoti River.

The bi-plot describes 52.5% of the total variation. Of the fitted variation, 45.20% is described in the first axis and 15.71% is described in the second axis.

There is a presence of multiple sources of factors that affect flow in the lower uMvoti River. One of the sources of flow alteration involves the presence of a water abstraction point/ pump station near the sampled sites of the lower uMvoti River (Figure 4.32).

Figure 4.32: Water pump/abstraction point at the lower uMvoti River next to the sampled uMvoti River sites.

4.2.4: Substrates

Associations between substrate types and plant communities were identified using a CCA multivariate analysis. The CCA multivariate analyses combining the plant communities collected along the three sampled sites in the lower uMvoti River, indicated no significance difference/ associations (p= 0.91; F=0.7) (Figure 4.33). The *A. donax* and *X. strumanium* displayed a close association with course gravel.

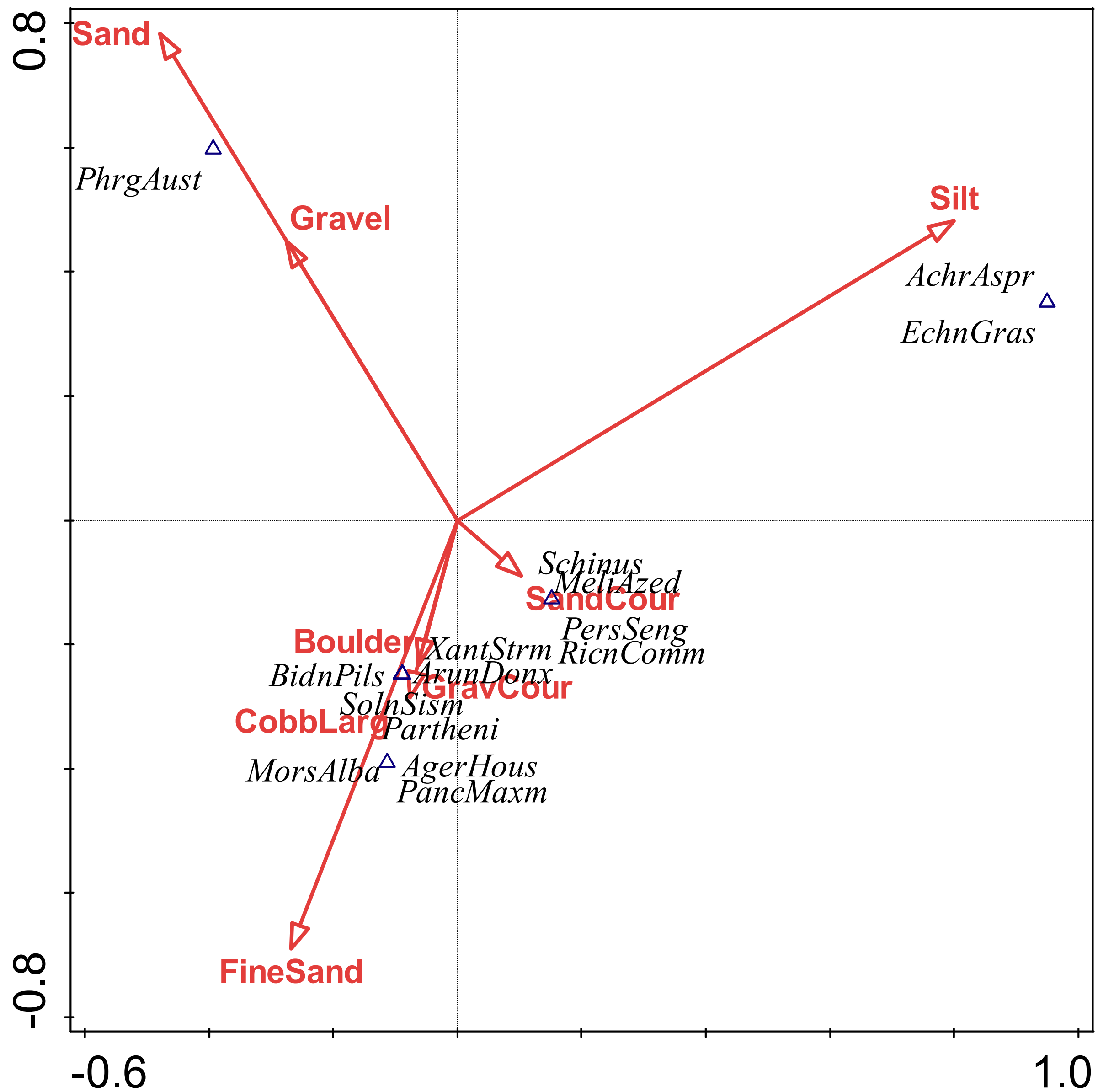


Figure 4.33: Canonical correspondence analysis (CCA) multivariate analysis indicating associations between plant communities and substrate types.

The biplot describes 14.6% of the variation. Of the fitted variation, 32.69 % is explained in the first axis, 30.53% is explained in the second axis.

Based on associations in the CCA multivariate analysis and visual analysis, the sandy soil was the dominating substrate type across the lower uMvoti River's sampled sites (Figure 4.33 and 4.34). Sand mining was also among the common activities at the lower uMvoti River, it is likely a possible explanation why the site is dominated by sandy soil. The sand mining activity also results in unstable riverbanks at the lower reach of the river (Figure 4.35).

Figure 4.34: Sandy soil as the dominating substrate type across the lower uMvoti River.

Figure 4.35: Unstable riverbanks at a sand mining site at the lower uMvoti River.

4.2.5 Water quality

Water quality sampling was conducted once due to time restriction, during the April 2023 sampling period in the three selected study areas in the lower uMvoti River, namely U4MVOT-N2BRG, U4MVOT-GLEDH and HLIMBITWA. The water quality variables were within the good and acceptable ranges (Table 4.6). The results indicated that site U4MVOT-GLEDH had high DO (mg/L), DO (%) values compared to the other sites. The HLIMBITWA site had higher conductivity and TDS values compared to all the sampled sites (Table 4.6).

Results indicated that the chloride, nitrate, nitrite, sulphate, phosphate, fluoride and alkalinity content variables were high at U4MVOT-GLEDH site compared to the other sampled sites, while U4MVOT-N2BRG had higher COD level compared to the other sampled sites (Table 4.6).

Table 46: Water quality results sampled from U4MVOT-N2BRG, U4MVOT-GLADH and HLIMBITWA within uMvoti River.

Variables	U4MVOT-GLADH	HLIMBITWA	U4MVOT-N2BRG
DO (mg/L)	8.85	7.36	7.54
DO (%)	92	86	87.5
Temperature	19.1	21.3	22.3
pH	6.55	6.66	6.95
Conductivity	202.2	221.1	212.5
TDS	108.3 PPM	108.8 PPM	100.1 PPM
Chloride	29	24	21
Nitrate	1.3	1	0.6
Nitrite	0.013	0.013	0.011
Sulphate	4	-1	0
Phosphate	0.06	0.04	0.03
Fluoride	0.15	0.07	0.11
Alkalinity	61.02	54.918	48.812
COD	60.1	55.6	63.3

Associations between plant communities and water quality variables were assessed using the CCA multivariate analysis. The analysis displayed a non-significant association of plant communities with water quality variables ($P = 0,19$; $F = 1.1$) (Figure 4.36).

The pH and temperature variables displayed a positive correlation as they are close to each other (Figure 4.36). The *Soln sism and Arun donx* plant communities showed a close relationship with the temperature variable and a bit of overlap of *Soln sism* with temperature and ph. The *Bidn pils, Ricn comm* and *Malv corm* showed a close association with the pH variable (Figure 4.36).

There biplot displayed a close correlation between DO (%), DO (mg/l) and Sulphate variables (Figure 4.36). The *Pers seng* plant community displayed a close association with the DO (%), DO (mg/L) and sulphate variables. The *Echn gras* plant communities displayed a close association with DO (mg/L) and a less close association with sulphate variables. The *Phrg aust* community showed a close association with the chloride variable (Figure 4.36).

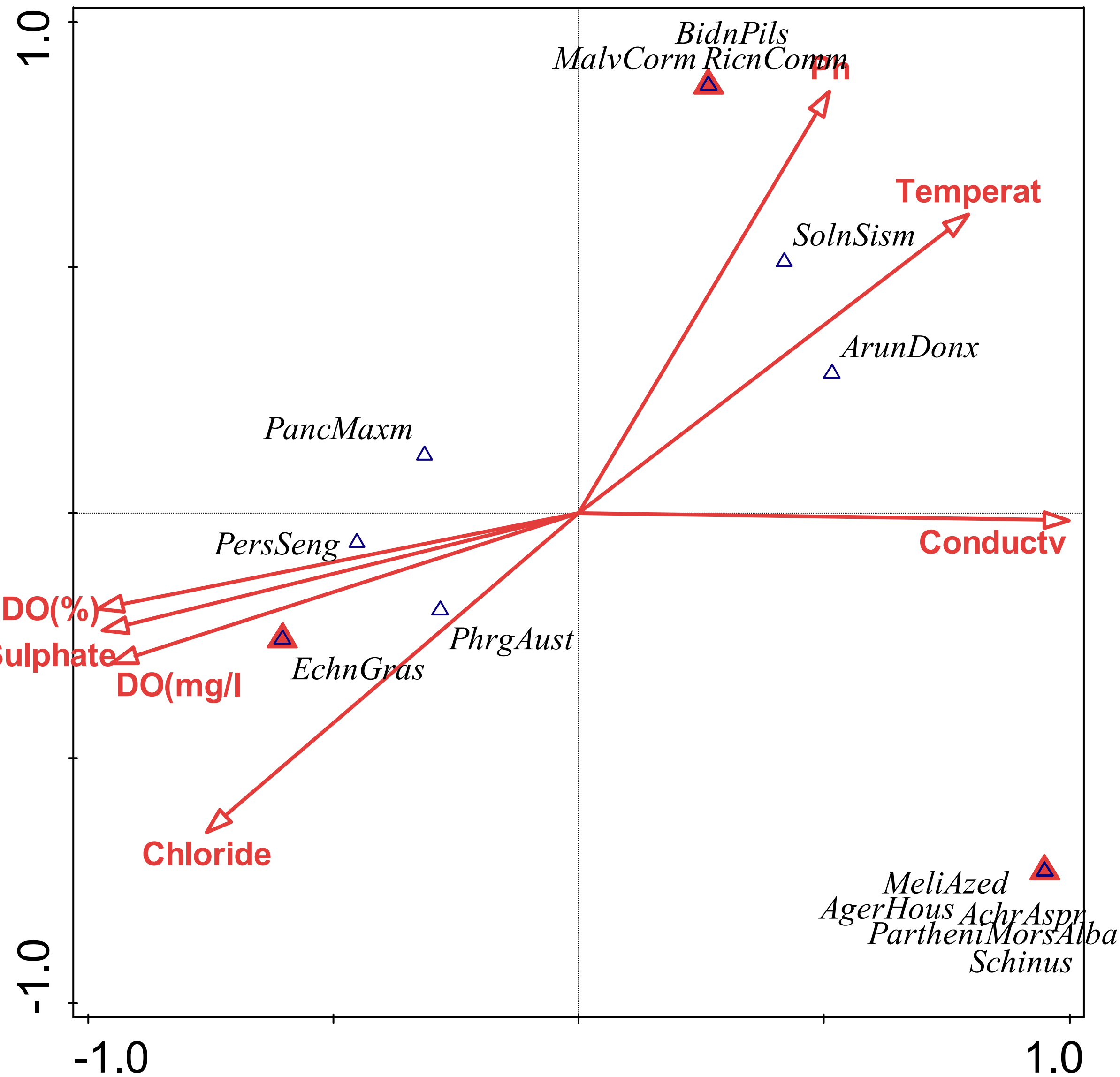


Figure 4.36: Canonical correspondence analysis multivariate analysis bi-plot showing associations between plant communities and water quality variables at uMvoti River.

The bi-plot describes 6.3% of the total variation. Of the fitted variation, 57.71% is described in the first axis (x) and 42.29% is described in the second axis (y).

CHAPTER 5: DISCUSSION

5.1 uThukela River

5.1.1 Vegetation changes between 2013-2023.

The results indicated a decline in the vegetation communities (macrophytes and riparian vegetation) between 2013 -2023 in uThukela River. These findings might have been influenced by land-use change, as there was an increase in land used for agricultural activities and development in close proximity to the uThukela River. Previous studies indicated that agricultural activities are some of the most dominating activities in the uThukela River and they often result in increased total dissolved solids in the water column (Suding *et al*., 2004; Schindler, 2006). This is concerning as they often lead to the dominance of few plant communities that are more tolerant of high dissolved solids, resulting in the decline of plant biodiversity (Stevens *et al*., 2004).

During the conversion of natural land to agricultural land, a sizeable portion of vegetation gets removed, the removal impacts the vegetation communities by reducing their quantity and quality (Jordan *et al*., 2003). The tillage process also influences vegetation communities, both macrophytes and riparian vegetation. The tillage process often results in total dissolved solids elevation in the river column (Zhang *et al*., 2019). The sudden increase of total dissolved solids results in high turbidity (Zhang *et al*., 2019).

Previous studies revealed that rivers exposed to high turbidity reduces sunlight penetration, consequently limiting photosynthesis and eventually death of macrophytes (Zhang *et al.,* 2019). The tillage process can be a driving factor in the composition and diversity of both riparian and macrophytes vegetation communities by favoring plant species that can tolerate disturbances (Sarr & Heilman, 2018).

5.1.2 Plant communities structures

During this study, site V5THUK-EWR18 was dominated by juvenile plant communities in the portion of the stream that is temporarily dry. The domination of the juveniles in the site is concerning as it indicates a disturbance. Findings from previous studies indicated that dominance of juveniles is often a succession of the plant communities that frequently gets disturbed (Islam *et al*., 2023). In addition, the dominance of plant juveniles also makes the river more prone to the establishment of opportunistic alien plants (Islam *et al*., 2023). Once a river is invaded by opportunistic alien plants, it is often difficult for it to regain its space due to its competitive nature and fast reproduction rate (Cousins *et al*., 2014), hence the lower uThukela River suffers from alien infestation.

Most of the plant communities in site V5THUK-CONTROL and V5THUK-EWR19 were categorized as adults and sub-adults and a few juveniles establishing themselves in the dry section of the river that temporarily gets inundated. These findings are raising concern as vegetation communities dominated by adults and sub-adults are often an indication of declining vegetation communities (Cousins *et al*., 2014). The portion of the river that temporarily gets inundated got inundated temporarily due to floods that occurred before this survey was carried out, that's what led to the establishment of the few juvenile species. This suggests that prior to the temporary inundation, the vegetation communities of site V5THUK-EWR19 and V5THUK-CONTROL consisted of only sub- adults and adults age groups. Findings from previous studies indicate that vegetation communities with little to no juveniles are in danger of collapsing due to less chances of recovery during disturbance such as fire and cutting (Yanban *et al*., 2010). The V5THUK-CONTROL site is also used as a grazing site for livestock.

The plant communities superimposed on the cross section did not display a clear relationship between plant communities with substrate types and position (elevation and distance from the left bank). Across the sampled sites within the lower uThukela River, there is an observation of alien plants infestation, and they are the ones with high abundance values.

5.1.3 Flow

Site V5THUK-EWR18 showed flow discharge elevation of 46.052 m^3/s. The discharge elevation at site V5THUK-EWR18 might be due to the presence of SAPPI mill discharge point approximately one kilometer upstream of the site. This is concerning, as previous studies indicated that effluent from SAPPI mill contributes to temperature increase and reduces dissolved oxygen content (Stryftombofolas, 2010). Rivers with increased water temperature are known to affect the survival and structure of macrophytes, by favoring the growth of high temperature tolerant plants only and eliminate sensitive plant species (Nagisetty *et al*., 2019).

The presence of a weir approximately 6 km upstream of site V5THUK-EWR18, might have contributed to the observed discharge elevation at the site. The presence of the weir could have influenced the discharge at the site, due to possibilities of opening the weir to ensure continuous water flow during the low flow season. Research by Dudgeon *et al*. (2006), indicated that dams/weir can have an impact on the flow of water in rivers by causing hydropeaking when the dam gates are open, causing sudden increase of flow, affecting ecosystems that have adapted to consistent water flow. Additionally, changes in river discharge have the potential to affect macrophytes and riparian vegetation, by favoring plant species that are adapted to constantly changing flow (Nilsson *et al.,* 2005).

SAPPI mill also has an abstraction point near site V5THUK-EWR18. The abstraction of water has an influence on the flow alteration of rivers. The SAPPI mill is considered the largest water user in the lower section of the uThukela River, with an estimation water requirement of 24 million m^3/a (DWAF, 2004). An additional estimation of 38 million m^3/a is transferred from the lower reach of the river to Mhlathuze Catchment to augment the water supply to Richards Bay (DWAF, 2004). Altered flows can affect vegetation communities by eliminating the communities that are less tolerant to unstable flows (Pander *et al*., 2021). For example, some *Cyperus* communities were absent in site V5THUK-EWR18 during the study conducted by Mackenzie, (2017) while they were present in previous years. During this study, only one species of *Cyperus* was found (*Cyperus brevis*). Cyperus species are known to respond to extreme altered flows which can negatively affect their survival (Amier & Gawad, 2017). This finding is concerning as the vegetation biodiversity of the uThukela River is affected by the altered flows.

5.1.4 Substrates

The multivariate analysis displayed a non-significant relationship between vegetation communities and substrate types. However, certain vegetation communities displayed close associations with certain substrate types. For example, *P. maximum* displayed a close association with the boulder substrate, while the *F. sycomorus* showed a close association with the sand substrate. *Scadoxus puniceus* and *Vachellia nilotica* also displayed an association with the fine sand substrate. The moisture storage capacity of different soil types depends on the depth and the quality of soil (Abutaha *et al*., 2020). Sandy substrate has been observed as the dominating substrate type across the sampled sites of lower uThukela River. Sandy soil normally displays poor water storage capacity, due to its unique physical and chemical properties, which might affect the growth of the vegetation growing in it (Abutaha *et al*., 2020).

Sandy soil is often nutrient poor and well drained, which can limit plant growth and favor only plants adapted to drier conditions (Nyakudya & Stroosnijder, 2010). Macrophytes communities can also be influenced by sandy substrates by favoring plant communities with specialized root system for anchoring in loose substrates (Nyakudya & Stroosnijder, 2010). Sandy soil is normally characterized by fluctuating temperatures, it heats up and cools down very quickly, these fluctuations can drive plant communities by allowing only those that have adapted to fluctuating temperatures to thrive (Harte *et al*., 1995).

5.1.5 Water quality

The obtained results indicated an elevation of conductivity levels across the sampled lower uThukela River sites. When comparing the 2023 conductivity data with the 2013 data, there was a huge increase in the electrical conductivity values. In most cases, rivers with elevated conductivity levels often suffer from increased dissolved solids which gives rise to electrical conductivity levels (DWA, 1996). Additionally, a rapid increase of electrical conductivity in a river serve as an indication of a disturbance that has the potential to decrease the relative condition of the water body and associated biota (Munns & Tester, 2008).

The multivariate analysis indicated a significant association of plant communities with water quality variables. This finding indicates that water quality might be a potential driver of the vegetation communities at the lower uThukela River. Studies by Güsewell and Koerselman, (2002), discovered that elevated water conductivity levels can lead to a decrease in plant species diversity in a river affected due to limitation of plant species that can tolerate the elevated salinity levels. Elevated electrical conductivity concentration in rivers also impact plant physiology due to stress caused by osmotic pressure, resulting in reduced water uptake and growth (Munns & Tester, 2008). Elevated electrical conductivity levels are also known to change plant community composition by favoring salt tolerant plant species over sensitive ones, leading to shifts in the composition of plant communities (Heschel *et al*., 2002). Furthermore, elevated electrical conductivity levels, especially from excess salts can disrupt the uptake of essential nutrients, resulting in nutrient imbalances (Marschner, 1995).

The V5THUK-EWR18 site had some elevated nitrite and nitrate values. These elevations can be caused by the activities taking place in the river such as nutrient contaminants from wastewater treatment works (Sundumbili wastewater treatment works and Isithebe treatment works) (Stryftombofolas, 2020). The application of fertilizers in the agricultural sector and high concentration of manure from livestock are identified as some of the main factors that can elevate nitrite and nitrate concentrations level, affecting the water quality of the uThukela river (DWS, 2021). The elevated nitrite levels are raising concerns, as vegetation exposed to high concentration of nitrite often exhibit symptoms of toxicity such as leaf discoloration and stunted growth (Lin *et al*., 2002).

Furthermore, effluent from manufacturing and industrial areas such as Sappi Mill and denim factory are believed to have an influence in chloride elevation in the lower uThukela River (DWS, 2021). The elevated chloride level is raising concerns, as vegetation exposed to high concentration of nitrite often exhibits symptoms of toxicity such as leaf discoloration and stunted growth (Lin *et al*., 2002). Additionally, plants exposed to elevated chloride levels suffer from the development of necrotic spots on leaves (Simmons, 2012).

5.2 uMvoti River

5.2.1 Vegetation changes between 2013 -2023

The results indicated some changes in vegetation communities between the period of 2013 and 2023 in both riparian vegetation and macrophytes. The riparian vegetation communities showed an increase of 2 332 Ha in 2023. The increase of riparian vegetation is believed to be caused by the expansion of sugar cane farms, as it is one of the dominating land-use activities around the uMvoti River that is constantly expanded to meet the demand (Matavire, 2015). The decline of macrophytes communities with 2 382 Ha between 2013 and 2023 might be due to the flood that took place early in the year 2023, which resulted in the uprooting of macrophytes in the river as observed in the sample sites. The statement is supported by similar findings from Chambers, (2010) revealing that strong flow currents due to floods can uproot macrophytes, resulting in loss of vegetation communities and biodiversity decline. Further studies indicated that floods could wash away essential nutrients and disrupt nutrient cycling in rivers, affecting the overall health and growth of macrophytes (Stanely & Doyle, 2003).

An additional possible explanation of macrophyte community reduction might be due to sand mining, as it was observed as one of the common activities at the lower uMvoti River during the 2023 sampling period. Sand mining can affect macrophytes communities through removal in the mining process (Ashley & Baker, 2010). The sand mining process also affects macrophytes communities by removing substrates that they have adapted to, allowing only the tolerant species to strive (Roy *et a*l., 2016).

5.2.2 Vegetation communities structures

The vegetation communities of the lower uMvoti River were diverse, representing 23 families. Plant communities that were superimposed to the cross section were mostly adults and were mostly associated with the sandy substrates (Silt, fine sand, sand and coarse sand).

Majority of the plant communities that were superimposed to the cross section were mostly in their adult stage. The flooding event that occurred early 2023 might have washed away the plant communities from juvenile stages due to their underdeveloped root system that are less resistant to turbulent flows. The population structure of the lower uMvoti river's vegetation communities is concerning as plant communities lacking juvenile individuals often suffer from reduced genetic diversity (young & Boyle, 2017). Reduced genetic diversity makes the population more vulnerable to environmental changes and diseases (young & Boyle, 2017). Additionally, plant communities with no juvenile individuals tend to be more vulnerable to disturbances such as fire, drought or habitat alteration (Turner *et al*., 2015). The loss or disturbance of the vegetation communities in the adult's category in a single event can lead to serious population decline, with less chances of recovery (Turner *et al*., 2015).

Plant communities superimposed to the cross section did not show any clear relationship and association between substrate type and position (distance from the left bank and elevation). Based on the results, the lower uMvoti River is invaded by alien species, with a possibility of taking over the river.

5.2.3 Flow

The U4MVOT-GLADH site had an elevated discharge among the other sampled sites. The discharge elevation might be due to the presence of a discharge point, located approximately 330 m from the U4MVOT-GLADH site. The U4MVOT-N2BRG site had a low discharge of 3.609 m^3/s when this study was conducted. The presence of a water pump station just upstream of U4MVOT-N2BRG might be a driver to the reduction of the flow in the site. This instability of flows in rivers can have an effect in vegetation communities due to their different morphological structures and stress tolerance level (He *et al*., 2016). Due to lack of historical discharge data for observation of trends, it cannot be stated with confidence that flow is a driver of vegetation communities at the lower uMvoti River.

Different vegetation communities are adapted to specific flow patterns, the sudden increase and decrease in flow can promote the establishment of plant communities that are less sensitive to altered flow patterns, automatically eliminating the sensitive ones (Rood *et al.,* 2018). This might be an explanation behind the dominating of *P. australis* communities in the U4MVOT-GLADH and U4MVOT-N2BRG sites, as *P. australis* are known to tolerate varying flow patterns due to their dense root system allowing them to anchor in the substrate, providing stability against the flowing water (Davis & Smith, 2001). Additionally, their hollow stems allow them to bend with flowing water, reducing the risk of breakage in an event of turbulent flow (Mendelssohn & Kuhn, 2003).

5.2.4 Substrate

Different substrate types are essential for the existence and well-being of plant communities (Gore & Shields, 2015). The CCA multivariate analysis displayed a non-significant association of plant communities with substrate types. However, most of the plant communities showed a close association with different sand types namely (sand, coarse sand, course gravel and fine sand). Based on associations in the CCA multivariate analysis and visual analysis, the sandy soil was the dominating substrate type across the lower uMvoti River sampled sites. Agricultural activities as a common activity at the lower uMvoti River, it is likely to contribute to the domination of sandy soil at the lower reaches of uMvoti River. According to Malherbe, (2006) & Water Affairs (2013), the lower uMvoti River is sandy dominated due to afforestation and agriculture in the upstream of the uMvoti River. These activities cause erosion and sediments get transported and accumulate in the lower reaches of the river, for approximately 40 km until it reaches the Indian Ocean.

Illegal sand mining as one of the common activities in the lower uMvoti River, is one of the contributing factors to dominating sandy substrates. Sand mining is also associated with sediment and nutrient load increase which can affect macrophytes by reducing light penetration (Lefebvre & Gazeau, 2016). Reduced light penetration will prohibit photosynthesis, resulting in death of the macrophytes. The sediment influx can also affect riparian vegetation communities by disrupting the nutrient balance, resulting in vegetation composition changes (Lefebvre & Gazeau, 2016).

Findings by Johnson *et al.* (2006), revealed that sandy soil encourages nutrients leaching due to its high permeability, resulting in poor nutrient conditions for the vegetation communities, limiting plant growth and biodiversity. Sandy soils often struggle with nutrient recycling and organic matter decomposition due to lower microbial activity, making it challenging for some vegetation communities to adapt and thrive (Carrera *et al*., 2007).

5.2.5 Water quality

The water quality results indicated no significant association of plant communities with water quality variables. Both the *in situ* and laboratory analyzed water samples were within the good and acceptable ranges. The *in-situ* results indicated that U4MVOT-GLEDH had high DO (mg/L) and DO (%) values compared to the other sampled sites within the lower uMvoti River. Additionally, the U4MVOT-GLEDH site had high DO (mg/L and %) readings when comparing the historic DO (mg/L and %) readings. Sites with high dissolved oxygen values are an indication of a healthy water resource as the amount of dissolved oxygen in the water serve as one of the most important parameters of water quality in water resources (Baxter *et al.,* 2019). Dissolved oxygen content of a water resource is crucial in assessing condition or state of the water resource, the higher the concentration of dissolved oxygen, suggests that the quality of the water resource is good (Baxter *et al*., 2019. The *P. senegalensis* showed a close association with DO (%) and DO (mg/L), this close association can be an indication that these plant communities are attracted to areas with high oxygen content. Presence of *P. senegalensis* can be used as an indicator of a health water resource.

The chloride, nitrate, nitrite, sulphate, phosphate, fluoride and alkalinity content for U4MVOT-GLEDH were high but within the acceptable range compared to all the other sampled sites within the lower uMvoti River. The slight elevation of alkalinity is normally an indication of industrial or chemical pollution (Stets *et al*., 2014). Industrialization might be the possible explanation for the slight increase of alkalinity content due to the presence of industries such as SAPPI Mill discharging directly to the U4MVOT-GLEDH. The SAPPI Stanger Mill and Ushukela sugar Mill discharges its effluent directly to the lower reach of uMvoti River (Ashforth, 2012). Although the water quality analysis showed a slight increase in some water quality variables, the observations are not concerning as the variables were still within the acceptable ranges, meaning the contributing activities such as the industries around the lower uMvoti River are not causing significant damage to the lower reach of uMvoti.

CHAPTER 6: GENERAL SYNTHESIS

The distribution and composition of vegetation communities of the lower uThukela and uMvoti Rivers are primarily driven by environmental and anthropogenic factors. The uThukela vegetation communities both macrophytes and riparian vegetation showed a decline between the year 2013 -2023, however the uMvoti River displayed an increase in riparian vegetation communities and a decline in the macrophytes communities between 2013 – 2023. When assessing the vegetation structure composition of the lower uThukela River, majority of the vegetation communities recorded were adults and sub-adults (site V5THUK-CONTROL and V5THUK-EWR19), apart from few juvenile individuals in site V5THUK-EWR18. When assessing the vegetation community structure composition of the lower uMvoti River, it was discovered that majority of the vegetation occurring there was under the adults category.

The vegetation communities diversity in both rivers showed distinct patterns with uThukela River showcasing higher species richness compared to uMvoti River. The differences in diversity among the rivers can be attributed to varying environmental factors such as water quality in the uThukela River and flow alteration in the uMvoti River among other factors, as they were identified as significant drivers of change in their vegetation communities.

The resilience of vegetation communities to disturbances between the lower uThukela and lower uMvoti Rivers varied greatly. The lower uMvoti River's vegetation displayed *P. australis* as dominating species. *P. australis* species are known to tolerate varying flow patterns due to their dense root system allowing them to anchor in the substrate, providing a stability against the flowing water. The increase in their population may be driven by altered flows due to a discharge point, located approximately 330 m from the U4MVOT-GLADH site and the presence of a water pump station just upstream of site U4MVOT-N2BRG. In the lower uThukela River, altered flow due to the presence of SAPPI mill's abstraction point near site V5THUK-EWR18 could have affected vegetation communities by eliminating the communities that are less tolerant to unstable flows. For example, the *Cyperus* communities used to be present in abundance but only one species was found during the 2023 survey, the *Cyperus brevis* species. *Cyperus* species are known to respond to extreme altered flows with can negatively affect their survival.

Sandy substrate was the dominating substrate type among the lower uThukela and uMvoti Rivers. Previous studies indicated that afforestation and agricultural activities are the driving factors behind the dominating sandy substrates in the lower uMvoti and uThukela River, with sand mining as an additional factor through observation.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Objective 1: Assess vegetation condition of the lower uThukela and uMvoti Rivers

uThukela River

There was a decline in the vegetation communities of the uThukela River for both macrophytes and riparian vegetation between 2013 and 2023. The vegetation condition of the lower uThukela is concerning as the sampled sites lack variation in terms of different age groups, because a healthy vegetation community should consist of different age groups consisting of juveniles, sub-adults and adults. site V5THUK-EWR18 was dominated by juvenile plant communities in the portion of the stream that was temporarily dry. The domination of juveniles only on the site is concerning as it indicates a disturbance. The domination of juveniles is often a sign of succession of the plant communities that frequently get disturbed.

Most of the plant communities in site V5THUK-CONTROL and V5THUK-EWR19 were categorized as adults and sub-adults and a few juveniles establishing themselves in the dry section of the river that temporarily gets inundated. The portion of the river that temporarily gets inundated got inundated due to floods that occurred before this survey was carried out, that's what led to the establishment of the few juvenile species that were recorded. The findings suggest that there was no juvenile vegetation before the temporary inundation occurred on the sampled site. These findings raise concern as vegetation communities that lack juveniles are an indication of a declining vegetation community.

uMvoti River

Results indicated an increase in the riparian vegetation of the uMvoti River and a decrease in macrophytes quantities between 2013 - 2023. The findings of this study indicated that majority of the plant communities in the sampled sites of the lower uMvoti River are skewed to the adult category. The population structure of the lower uMvoti River's vegetation communities is concerning as plant communities lacking juvenile individuals often suffer from reduced genetic diversity.

7.2 Objective 2: Determine potential drivers of change in the vegetation communities of lower uThukela and uMvoti Rivers.

uThukela River

The study revealed that water quality is a significant driver in the vegetation communities of the lower uThukela River. The multivariate analysis results indicated that flow and substrate types were not significant drivers of change in the vegetation communities of the lower uMvoti River.

uMvoti River

The analysis revealed flow as a significant driver of the vegetation communities in the uMvoti River. The multivariate analysis results indicated that water quality and substrate types were not significant drivers of change in the vegetation communities of the lower uMvoti River.

Recommendations

There is a need for a collaboration between water resources scientists, conservationists, land managers and local community members to participate in the restoration and rehabilitation of the declining vegetation communities, which can be in the form of controlling human activities, raise awareness on the importance of river health and re-introduction of native vegetation species. Establishment of long- term monitoring programs along the riverbanks of uThukela and uMvoti Rivers to track changes in the vegetation communities overtime can also be helpful.

Conservation efforts should be made with the aim of finding ways that can encourage recruitment in populations with limited or with no juvenile individuals. It can also be done by practicing sustainable land management techniques such as preventing overgrazing in the riparian zone and prohibiting the cutting of plants as well.

There is also a need for more studies to be conducted with the aim of finding improved ways of discharging waste in the rivers, especially in the lower uThukela River as it was identified as the significant driver of vegetation communities, to maintain healthy water quality chemistry. Additionally, strategies should be implemented to reduce flow alterations. Promoting practices that can improve water quality entering the river such as reducing run-offs from agricultural activities may improve the quality of vegetation communities.

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