Determining the impact of a piggery on the Inhlavini and uMkhomazi Rivers, KwaZulu-Natal

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PREFACE AND ACKNOWLEDGMENTS

Firstly, I would like to thank the Most High God for the gift of life and of a sound mind, without Him I would not be able to do anything.

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ABSTRACT

This study was undertaken on the Inhlavini and uMkhomazi rivers, situated in the KwaZulu-Natal (KZN) province, South Africa (RSA). Its focus was on assessing the possible impact of a piggery (referred to as Piggery X, to keep its anonymity) on the condition of the rivers. Piggery X was directly discharging untreated effluent into the Inhlavini River, approximately 5 km upstream of its confluence with the uMkhomazi River. The activity was subsequently stopped by the National Department of Water and Sanitation (DWS); however, no rehabilitation was undertaken, to mitigate for any possible contamination that might have occurred.

Since there was no rehabilitation undertaken, the study aimed at assessing if natural recovery had taken place, and if so, how effective it has been. A total of five monitoring points (three on the Inhlavini and two on the uMkhomazi rivers) were selected. The three sites on the Inhlavini River were: 1) Inhlavini Upstream of Impact Monitoring Point (referred to as **IU**); 2) Inhlavini Impact Monitoring Point (**II**); 3) Inhlavini Downstream of Impact Monitoring Point (**ID**). The two on the uMkhomazi River were: 1) uMkhomazi Upstream Monitoring Point (upstream of confluence) (**UU**); and uMkhomazi Downstream Monitoring Point (below confluence) (**UD**).

Water quality variables (temperature, pH, electrical conductivity, total dissolved solids, potassium, copper, orthophosphate, suspended solids, chemical oxygen demand, nitrates and nitrites, *E. coli* and faecal coliforms) were mostly compliant to South African Water Quality Guidelines for Domestic Use and Agricultural Uses (Livestock and Irrigation); however, few variables (pH, copper and faecal coliforms) were slightly non-compliant to South African Water Quality Guidelines for Aquatic Ecosystem (DWAF, 1996). Macro-invertebrates were sampled at uMkhomazi River (UU and UD sites). Macro-invertebrates were not sampled at Inhlavini River as it was flooding in February 2020, and was dry in July and October 2020. Macro-invertebrates using SASS5 placed the uMkhomazi River within the ecological category A/B (EC A/B) at UU for both wet and dry season; whilst UD fell in EC A and EC B during wet and dry seasons, respectively, which indicates that the mentioned river was largely natural with few modifications.

Overall, site IU showed slight contamination, possibly due to anthropogenic influence from the nearby village, and Ixopo area. At site II, there was a slight increase in analysed variables, but still within limits. However, there was a decrease/improvement in all analysed variables at site ID – possibly due to the natural recovery process, because of extensive good condition riverine-associated wetlands within that reach. It can thus be concluded that the system was not significantly impacted or was able to recover naturally; and therefore, there would not be a need for any manual rehabilitation of the system.

Keywords: Bio-monitoring; Water quality; SASS5; Piggery; Pollution; Macro-invertebrates

ABBREVIATIONS AND ACRONYMS

ASPT	Average Score per Taxa
BHN	Basic Human Need
BOD	Biochemical Oxygen Demand
CMA	Catchment Management Agency
CME	Compliance, Monitoring and Enforcement
Cu	Copper
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
E. coli	*Escherichia coli*
EC	Ecological Category
ELU	Existing Lawful Use
GA	General Authorisation
GSM	Gravel, Sand and Mud
ID	Inhlavini Downstream of Impact Monitoring Point
II	Inhlavini Impact Monitoring Point
IU	Inhlavini Upstream of Impact Monitoring Point
IWRM	Integrated Water Resources Management
KZN	KwaZulu-Natal Province
MAP	Mean Annual Precipitation
mamsl	metres above mean sea level
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NEMWA	National Environmental Management: Waste Act (Act No. 59 of 2008)

NWA	National Water Act, 1998 (Act No. 36 of 1998)
P	Phosphorus
PES	Present Ecological Status
RSA	Republic of South Africa
RQO's	Resource Quality Objectives
S	Stones
SASS5	South African Scoring System version 5
S	Sulphur
SIC	Stones In Current
SOOC	Stones Out Of Current
SS	Suspended Solids
UD	uMkhomazi Downstream Monitoring Point (below confluence)
UU	uMkhomazi Upstream Monitoring Point (upstream of confluence)
Veg	Vegetation
WUL	Water Use Licence
WULA	Water Use Licence Authorisation
WWD	[International] World Water Day
WWTW	Wastewater Treatment Works

UNITS OF MEASUREMENTS

A	annum
ASPT	Average Score per Taxa
cm	centimetre
cm	kilometre
km^2	square kilometre
l	litre
m	metre
m^2	square metre
m^3	cubic metre
mamsl	metre above mean sea level
mg/L	milligram per litre
mgK/L	milligram per litre as Potassium
mgN/L	milligram per litre as Nitrogen
mgO_2/L	milligram per litre as Oxygen
mgP/L	milligram per litre as Phosphorus
ml	millilitre
mm	millimetre
mm/a	millimetre per annum
MPN/100ml	Most Probable Number per 100 milligrams
mS/m	milli Siemens per metre
NTU	Nephelometric Turbidity Unit
S	Seconds
µgCu/l	Microgram of copper per litre
µS/cm	Micro Siemens per centimetre

KEY DEFINITIONS

Population growth	Increase in the number of individuals in a population
Monitoring	Sampling and analysis of water constituents in a water resource
Water Pollution	Contamination of water resources by human activities
Water quality	The physical, chemical and biological properties of water that determine its fitness for use as and for aquatic protection
Watercourse	Refers to a river or a spring, wetland, and drainage
Water Resource	The watercourse, surface water, estuary and aquifer

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is the most widely distributed substance on our planet which is available almost everywhere and supply both the needs of humans and the environment (Shiklomanov, 1991). According to Shiklomanov (1991), human impact on water resources had been practically insignificant for hundreds of years and water cycles could achieve successful self-purification. This understanding contributed to careless decisions regarding the use and management of water resources. This then resulted in an illusion of immutability and inexhaustibility of water resources, considered as a gift of the natural environment (Shiklomanov, 1991). A tradition of poor management of water and water resources was born because of this attitude. This tradition was also an outcome of the understanding that water was not seen as a resource that requires exceptional care; instead water was seen as never ending gift. It has been noted that clean (treated) water has been used for every use, including those uses that may not necessarily need such water quality. An example is using treated water for gardening, sanitation purposes, etc., whilst grey water could be used for such. As a result, no water use had a specified water quality. During the recent decades, the need for proper use and management of water resources has increased due to the impact imposed by human activities to water resources (Mwangi, 2014). According to Rahaman (2012), water is seen as the most important resource and requires to be properly managed in the 21st century. It has been noted that there has been a change of mind-set from different countries as a result of visible pollution to water resources, due to overuse and/or abuse (Loucks, 2017). The way water resources have been managed is in contradiction with the fact that freshwater is a scarce resource which is 2.5% of total volume of water on earth (Okello *et al*., 2015). This percentage is an indication of how little freshwater the entire earth contains. According to Okello *et al*. (2015), the largest percentage of freshwater is located underground which is unseen and not easy to access. Facts listed above about freshwater give more reasons for proper management of water resources and the need for strategies to minimize the impact and the threat to them.

The statement made by the Vice-President of the World Bank, Ismail Serageldin, that the war of the next century will be a war about water diverting from the current wars which are about oil (Wolf, 1999; Morrissette & Borer, 2004), is mostly remembered when observing the challenges faced by the world regarding water. It is assumed that the statement came because of the revelation of the challenges of water availability and water pollution diverting from it seen as readily available resource. The statement aimed at changing the mind-set from understanding water resources being able to treat itself. The statement further indicated challenges that are faced by the world regarding the availability of clean water to supply the demand. It was also a wisdom statement clearly indicating the importance of water (Butts, 1997) which reveals that Africa and Asia are having the highest population growth rate that poses a risk to water resources. Asia is much better as it has more water available compared to Africa which has the least water available compared to all other continents (Shiklomanov, 1991). Population growth, water pollution and economic growth are regarded as the main factors threatening freshwater (Okello *et al.,* 2015). The world population keeps on increasing which further increases pressure on this limited resource (Okoh *et al*., 2007; Gerland *et al*., 2014). It is basically impossible to distinguish these factors as they are interlinked. Population growth pushes the need for water use and as a result freshwater gets depleted and increases in its pollution; all these factors then affect the availability of clean freshwater. The increase in population is further seen as a threat to freshwater which may result in water borne diseases that affect human life (Sowers *et al*., 2011), the threat is also posed to aquatic ecosystems. The industries, mines, agricultural activities, etc. (land based activities) are built to sustain the economy of every country. Unfortunately, these land based activities discharge polluted water into the land and surface water resources and as a result ground water gets impacted. To indicate the importance of water and its preservation, the United Nations General Assembly approved the International World Water Day (WWD), which is celebrated on 22nd March annually (Hatami, 2013). The approval of the WWD was aimed at raising awareness regarding water challenges and the way every human being is expected to use water. Freshwater is important and requires to be preserved for its benefit to life. South Africa has also joined the world in celebrating WWD by having what is known as National Water Week, which is celebrated in March every year extending from the WWD (UN, 1992).

Water pollution is defined as the change of water quality from a pristine state to a compromised state (Juma *et al*., 2014). The world is trying to strike the balance between using freshwater and preventing pollution of waters at all cost. The laws and regulations passed in the water sector are aimed at ensuring the continuous availability of water fit for every use, including aquatic life, domestic use, etc. (as these seem to require water of a certain quality). According to Moss (2012), rivers are impacted by catchment activities, mostly due to human impacts. Moss *et al*., (2012), further describes the relationship between the catchment and receiving water as the house and its waste bins. The activities that are undertaken in the house are clearly indicated in the bin and its surrounding. This statement is regarded as a clear explanation of the manner in which catchment activities manifest on water resources. Groundwater and surface water must be managed together as they interact with each other. Should there be pollution in one of the two compartments (groundwater and surface water), the interaction between them may then result in both resources being polluted. It is therefore expected that where surface water is polluted and interact with groundwater, groundwater will also be polluted, and vice versa (Sangodoyin & Agbawhe, 1992). It is therefore clear that measures undertaken to properly manage water resources should not separate groundwater and surface water.

The concept and understanding of the use of water resources in the Republic of South Africa (RSA) is no different from the global approach. The previous Water Act of South Africa (Act No. 54 of 1956) was criticised for failing to recognise equal distribution to all South Africans by granting riparian landowners high volumes of water (referred to as riparian rights) (van Koppen *et al*., 2002). The onset of democracy in 1994 assisted in the change in the way water is managed (Kidd, 2009). As water is regarded as the most precious natural resource in RSA and the entire world, its proper management became important and the new legislation, called the National Water Act, 1998 (Act No. 36 of 1998) (or simply referred to as NWA) was promulgated. The NWA ensures that there is no ownership of water resources, and that the Minister of Water is the custodian of water resources of the country. Better ways of implementing the NWA are detailed in the National Water Resource Strategy (NWRS2). The Department of Water and Sanitation (DWS), through Catchment Management Agencies (CMA's), is required to ensure that land based activities that impact receiving water resources are authorised for better management (Gildenhuys, 1998).

Pollution of water resources is regarded as a challenge that is faced by most countries in the world. Population growth requires that more crops should be planted and livestock farming to meet the demand. Of all the agricultural activities, piggeries are considered as the highest water user which also produces the highest amount of wastewater (Velho *et al*., 2012). This requires wastewater to be properly discharged to limit the impact to both surface water and groundwater resources. The DWS through CMA's is required to ensure that land based activities that have an impact on receiving water resources are effectively managed through Water Use Authorisations. Water Use Authorisations are divided into four categories which are as follows:

- **Schedule 1**

  Schedule 1 is described as water that is required for domestic use and livestock watering for households (Gildenhuys, 1998). This volume is regarded as low and with a low impact. The NWA states that this water use requires no authorisation and is an entitlement to all South Africans.

- **General Authorisation (GA)**

  The General Notice sets the limits and conditions which are permissible under the General Authorisation Government Gazette No. 42576 (GA). This category replaces the need for applying for a water use licence (WUL) since the impact is low.

- **Existing Lawful Use (ELU)**

  The Existing Lawful Use (ELU) is regarded as the water use that was permitted during the previous Water Act, (Act No. 54 of 1956) before the promulgation of the new National Water Act, 1998 (Act No. 36 of 1998). Those water uses that were permitted under the previous Water Act, (Act No. 54 of 1956) are therefore referred to as the ELU (Gildenhuys, 1998).

- **Water Use Licence (WUL)**

  This category is referred to as those water uses that fall outside schedule 1, GA, and ELU; and have high impact on water resources. This category requires that specialist studies be undertaken and be included as part of the Water Use License Application (WULA). Under this authorisation (WUL issued), conditions are attached and required to be adhered to. Section 21 of the NWA describes different water uses that are triggered by land based activities (**Table 1-1**) and requires authorisation (Gildenhuys, 1998).

Table 1- 1: Water Uses as per Section 21 of the NWA**.**

S21(a)	taking water from a water resource;
S21(b)	storing water;
S21(c)	impeding or diverting the flow of water in a watercourse;
S21(d)	engaging in a stream flow reduction activity (currently only commercial afforestation);
S21(e)	engaging in a controlled activity – activities which impact detrimentally on a water resource (activities identified in s37(1) or declared as such under s38(1)) namely: ➢ irrigation of any land with waste or water containing waste which is generated through an industrial activity or a waterwork; ➢ an activity aimed at the modification of atmospheric precipitation; ➢ a power generation activity which alters the flow regime of a water resource; or ➢ intentional recharge of an aquifer with any waste or water containing waste
S21(f)	discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
S21(g)	disposing of waste or water containing waste in a manner which may detrimentally impact on a water resource;
S21(h)	disposing in any manner of water which contains waste from, or has been heated in, any industrial or power generation process;
S21(i)	altering the bed, banks, course or characteristics of a watercourse;
S21(j)	removing, discharging or disposing of water found underground if it is necessary for the efficient continuation if an activity or for the safety of people; and
S21(k)	using water for recreational purposes

Domestic Use

Domestic Water Use, referred to in the NWA as Schedule 1, is described as water that is used for drinking, washing, hygiene purposes and home gardening. This water use is referred to in the NWA as Basic Human Need (BHN). The need for effective management of the Inhlavini and uMkhomazi rivers is crucial to maintain the ecological category (EC), which is EC B (Province, 2017). Ingestion of faecal polluted water by humans who depend on the Inhlavini and uMkhomazi rivers may cause a disease known as diarrhoea (DWAF, 2002), as local rural communities are using these waters without any treatment prior to use.

Agricultural Use

Agricultural Use refer to the water that is used to irrigate land to grow crops. In other cases, grass is being irrigated to grow and be used as feed for livestock. When it comes to agriculture, water uses that are generally triggered in terms of the NWA are Sections 21 (a), (b), (e), (f), and (g) of the NWA, as per **Table 1- 1**, above. The Inhlavini and uMkhomazi rivers are dominated by agricultural water use; and pesticides and fertilisers used in agricultural activities may increase salt levels into water resources (Agrawal, 1999). Apart from chemistry of the rivers, agriculture encourages soil erosion resulting in increased turbidity and sediment load into rivers (Asselman *et al*., 2003). In some cases, over-abstraction may also result in the river being dry, which then would affect both the ecology and local communities.

The mentioned water uses are the contributing factors on the water resources. Agriculture is the major water user in the entire river system (Fernandes & Adams, 2016). The current ecological category B (EC B) is also recommended for future considering the proposed uMkhomazi-Mngeni Transfer Scheme, also known as the uMkhomazi Water Project. Most countries, including RSA, require increasing the economy and ensuring provision of pork to supply the growing population demand (Fernandes & Adams, 2016). Hence piggeries are also found in the KwaZulu-Natal Province of RSA. The impact of piggery effluent is as a result of the use of manure in agricultural fields, which result in the leaching of contaminants into groundwater. The parameters that are associated with piggery effluent in different parts of the world are similar and are chemical oxygen demand (COD), nitrates and nitrites (N), ammonium nitrogen (NH4-N), orthophosphate (PO_4^{3-}), suspend solids (SS), biochemical oxygen demand (BOD), faecal coliforms and total coliforms (TC) (Sezerino *et al*., 2003). The content of piggery effluent defines the impact associated with piggery activities on the water resources. Runoff from the fields as a result of precipitation events enters groundwater through infiltration and also impact surface water through base flow. Common water pollution from piggeries is as a result of wastewater ponds leaching and polluting groundwater and wastewater overflows and/or discharges into surface water. These challenges are also found in KwaZulu-Natal Province and through the entire RSA.

1.2 Problem Statement

Piggery X was discharging untreated piggery effluent into the Inhlavini River, which is a tributary of the uMkhomazi River. The discharge took place without a water use authorisation and the content of effluent discharged into the water resource was unknown as there was no water quality sampling undertaken by the Piggery X owner. In terms of the NWA, undertaking water use without an authorisation is regarded as unlawful and transgressors are guilty of an offence and liable to a fine or imprisonment in terms of Section 151 of the NWA (NWA, 1998). Piggery X was operating unlawfully since there was no water use authorisation in place. In principle, Piggery X requires to be authorised for the following water uses of the NWA, 1998:

- Section 21 (a) – Taking water from the water resource;
- Section 21 (b) – Storing water;
- Section 21 (e) – Irrigating with water containing waste;
- Section 21 (g) – Disposing in a manner which may detrimentally impact on a water resource; and
- Section 21 (f) – Discharging water containing waste through a pipe into a water resource.

The first two water uses, Sections 21(a) & (b) impact mostly on the quantity of the water resource, whilst the last three, Section 21 (e), (g), and (f) relate to the quality caused by Piggery X on the water resource.

Currently, there is no study that was previously conducted assessing possible impacts caused by Piggery X on the Inhlavini and uMkhomazi rivers. Furthermore, no rehabilitation was undertaken. The outcomes of the study will therefore indicate the impact, and extent, caused by Piggery X on both Inhlavini and uMkhomazi rivers. Therefore, should there be no noticeable impacts, it could either be that the impact of Piggery X on the receiving system was not severe or that the system managed to recover.

1.3 Research Aim, Objectives, and Question

The main aim of this study is to determine the extent of the piggery effluent impact (if any) on the Inhlavini and uMkhomazi rivers using *in situ* water quality parameters, laboratory water quality analysis and bio-monitoring using macro-invertebrates. The objectives of the study are to:

- To determine the effects of Piggery X on the *in situ* and water quality of the Inhlavini and uMkhomazi rivers;
- To assess macro-invertebrate community composition using South African Scoring System Version 5 (SASS5), as described by Dickens and Graham (2002);
- To compare monitoring points upstream and downstream of point of impact; and
- To finally assess if there is any impact of the Piggery on the Inhlavini River and the uMkhomazi River.

1.4 Structure and Outline of the Dissertation

The outline of this dissertation is as follows:

- Chapter 1. Introduction
    - Background
    - Problem Statement
    - Research Aim, Objectives, and Question
    - Structure and Outline
- Chapter 2. Methodology
    - Introduction
    - Description of uMkhomazi River
    - Description of Inhlavini River
    - Site Description and Research Design
        - Description of monitoring points
        - Research design
    - Data Collection
        - Water quality
        - Macro-invertebrates
    - Statistical Analysis
    - Ethical Considerations
    - Methodological Limitations
    - Chapter Summary
- Chapter 3. Literature Review
    - Introduction
    - Global Perspective on Piggeries
    - South Africa
    - Water Quality Variables Related to Piggery Effluent
    - Macro-invertebrates
    - Legislation
    - Chapter Summary/Conclusion on Literature
- Chapter 4. Results and Discussion
    - Introduction
    - Water Quality
    - Macro-invertebrates
    - Statistical Analysis
    - Chapter Summary
- Chapter 5. Conclusion and Recommendations
    - Conclusions
    - Recommendation and Areas of Future Research

CHAPTER 2: METHODOLOGY

2.1 Introduction

The study area is located in Inhlavini area which falls under the Ubuhlebezwe Local Municipality within the Harry Gwala District Municipality (formerly known as Sisonke District Municipality) (**Figure 2- 1**).

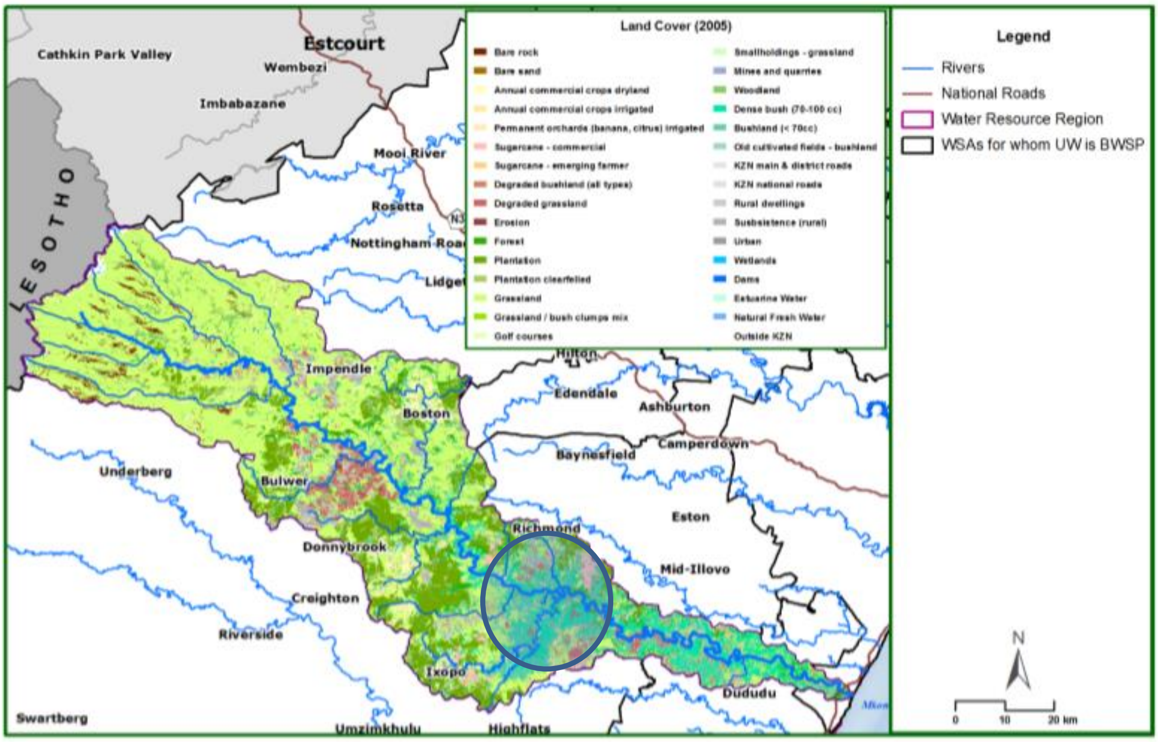

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Figure 2- 1. Map of the uMkhomazi catchment, showing the location of the study area – circled area. (Umgeni Water, 2019).

The uMkhomazi River system has its source in Drakensberg Mountains, at an elevation of approximately 3 300 metres above mean sea level (mamsl) (Chelin *et al.*, 2004; Flügel & Märker, 2003). According to Louw *et al.* (2017), the uMkhomazi region encompasses the entire U10 tertiary catchment. The river flows in a south-easterly direction and enters the Indian Ocean near the town of Umkomaas, approximately 50 kilometres (km) south of Durban (Brown & Clark, 2017; Flügel & Märker, 2003). Several large tributaries, including the Loteni, Nzinga, Mkomazane, Elands, Inhlavini, and Xobho rivers flow into the uMkhomazi River (Umgeni Water, 2017).

2.2 Description of uMkhomazi River

The upstream area of the uMkhomazi River is bounded by small towns, farming areas and scattered rural residential areas (Umgeni Water, 2017). Due to relatively small extent of the above-mentioned activities, the uMkhomazi River remains mainly in good category (EC B) (Brown & Clark, 2017). The entire study area includes the small towns of Bulwer, Impendle, and Ixopo, which have low water requirements (Umgeni, 2017). The major water user located on the banks of the uMkhomazi River is Sappi Southern Africa. It abstracts water for its operations around lower reaches of the river, and discharges its effluent into the sea (Scott, 1999). Sappi Saiccor Southern Africa, Umkomaas and Craigieburn are located downstream of the study area hence their impact does not affect this study.

The uMkhomazi River is regarded as the second largest river in the KwaZulu-Natal Province of RSA (Du Bois, 2015). The estuarine report produced by Anchor Environmental Consultants in 2017 states that the uMkhomazi Estuary is one of two permanently open estuaries in the KwaZulu-Natal Province (Fernandes & Adams, 2016). The uMkhomazi catchment covers 4387 km^2 area (**Table 2- 1**) (DWS, 2013; Province, 2017). The uMkhomazi Estuary is rated as category C (EC C) compared to natural conditions in the upper reaches, whilst the rest of uMkhomazi River remains category B (EC B) in the upper reaches (Brown & Clark, 2017). According to the WRC (2002), geomorphic units that are found in the study area are the highlands, floodplains, swamps, and marshes. The Mean Annual Rainfall (MAR) for the study area for the past 48 years (i.e., from 1970 – 2017) is 947.8 mm/a (DWS, 2013; Ndlovu & Demlie, 2020) (**Table 2- 2**).

Table 2- 1. Quaternary catchments of uMkhomazi and its hydrological characteristics (DWA, 2013). (MAP – Mean Annual Precipitation; MAR – Mean Annual Runoff; MAE – Mean Annual Evapotranspiration)

Quaternary Catchment	Incremental Area (km^2)	MAP (mm)	MAE (mm)	Incremental Natural MAR		
				(Million m^3/annum)	(mm/annum)	(% MAP)
U10A	418	1287	1,300	209.52	501	39
U10B	392	1176	1,300	164.49	420	36
U10C	267	1091	1,300	96.70	362	33
U10D	337	999	1,300	98.22	291	29
U10E	327	1034	1,300	100.92	309	30
U10F	379	963	1,300	67.08	177	18
U10G	353	981	1,250	70.12	199	20
U10H	458	924	1,200	82.66	180	20
U10J	505	878	1,200	77.99	154	18
U10K	364	793	1,200	40.42	111	14
U10L	307	758	1,200	29.56	96	13
U10M	280	858	1,200	40.06	143	17
Total	**4387**	**981**	**1,252**	**1077.74**	**246**	**25**

Table 2- 2. List of KZN weather stations, including Richmond Weather Station located near the study site (Ndlovu & Demlie, 2020).

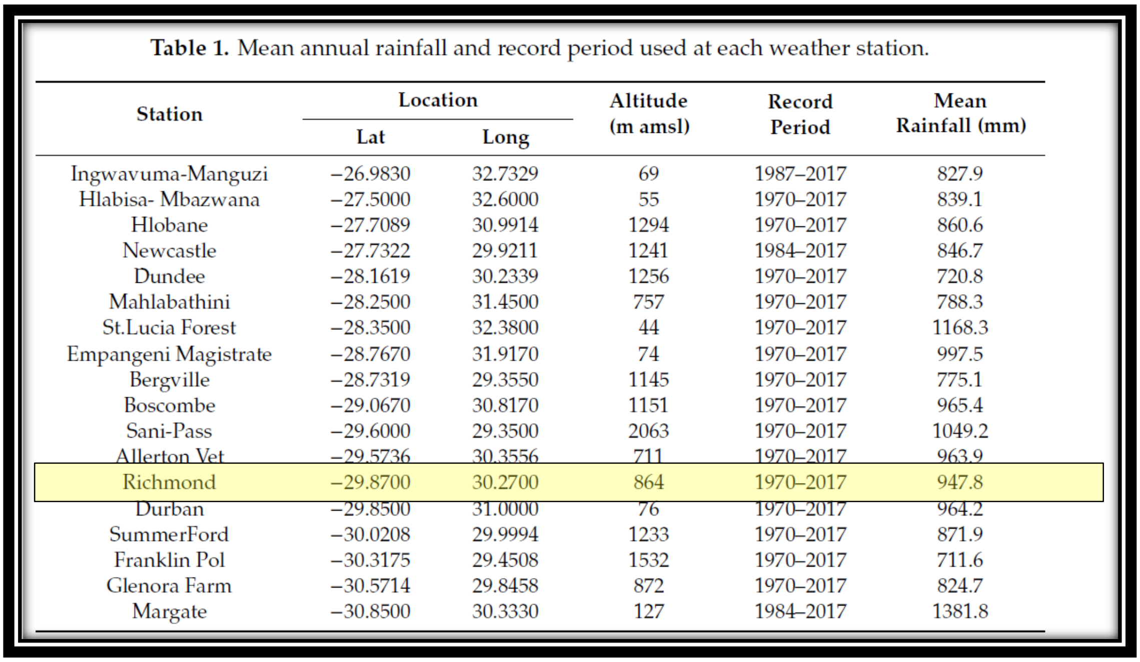

Table 1. Mean annual rainfall and record period used at each weather station.

Station	Location		Altitude (m amsl)	Record Period	Mean Rainfall (mm)
	Lat	Long			
Ingwavuma-Manguzi	−26.9830	32.7329	69	1987–2017	827.9
Hlabisa- Mbazwana	−27.5000	32.6000	55	1970–2017	839.1
Hlobane	−27.7089	30.9914	1294	1970–2017	860.6
Newcastle	−27.7322	29.9211	1241	1984–2017	846.7
Dundee	−28.1619	30.2339	1256	1970–2017	720.8
Mahlabathini	−28.2500	31.4500	757	1970–2017	788.3
St.Lucia Forest	−28.3500	32.3800	44	1970–2017	1168.3
Empangeni Magistrate	−28.7670	31.9170	74	1970–2017	997.5
Bergville	−28.7319	29.3550	1145	1970–2017	775.1
Boscombe	−29.0670	30.8170	1151	1970–2017	965.4
Sani-Pass	−29.6000	29.3500	2063	1970–2017	1049.2
Allerton Vet	−29.5736	30.3556	711	1970–2017	963.9
Richmond	−29.8700	30.2700	864	1970–2017	947.8
Durban	−29.8500	31.0000	76	1970–2017	964.2
SummerFord	−30.0208	29.9994	1233	1970–2017	871.9
Franklin Pol	−30.3175	29.4508	1532	1970–2017	711.6
Glenora Farm	−30.5714	29.8458	872	1970–2017	824.7
Margate	−30.8500	30.3330	127	1984–2017	1381.8

The Mean Annual Precipitation (MAP) for uMkhomazi catchment is 981 mm/a, which is almost double that of RSA (467 mm/a) (Nel, 2009). The study area's MAP also exceeds the world's MAP which is 786mm/a (Ndlovu & Demlie, 2020). The uMkhomazi River meanders for approximately 298 kilometres and has no existing in-stream dam (Google Earth, 2020). However, there are few proposed dams aimed at relieving droughts (**Table 2- 3**).

Table 2- 3. Proposed dams on the uMkhomazi System.

Impoundment Name	**River**	**Capacity (million m^3/year)**
Smithfield Dam	uMkhomazi	138
Impendle Dam	uMkhomazi	270
Ngwadini Dam	uMkhomazi (off channel)	10
Temple Dam	uMkhomazi (off channel)	6.7
Bulwer Dam	Luhane River	9.8

Smithfield, Impendle and Bulwer dams will be located upstream of the confluence of the Inhlavini and uMkhomazi rivers. The mentioned dams will therefore not be impacted by the activities undertaken in the study area, but dams may have an impact on the study area. The dilution factor during this study on the uMkhomazi River may change in the future when the three proposed upstream dams are built because water will be captured before reaching the study area. The Ngwadini and Temple dams will be located below the confluence of the Inhlavini and uMkhomazi rivers. It is therefore understood that should Piggery X continue to discharge effluent into the Inhlavini River and the proposed dams (the Ngwadini and Temple dams) are constructed; these dams may be affected due to them being located downstream of the study area.

In comparison to Inhlavini catchment, the uMkhomazi catchment received over 150% more rain between 01st February 2020 and 31st March 2020 (**Figure 2- 2**).

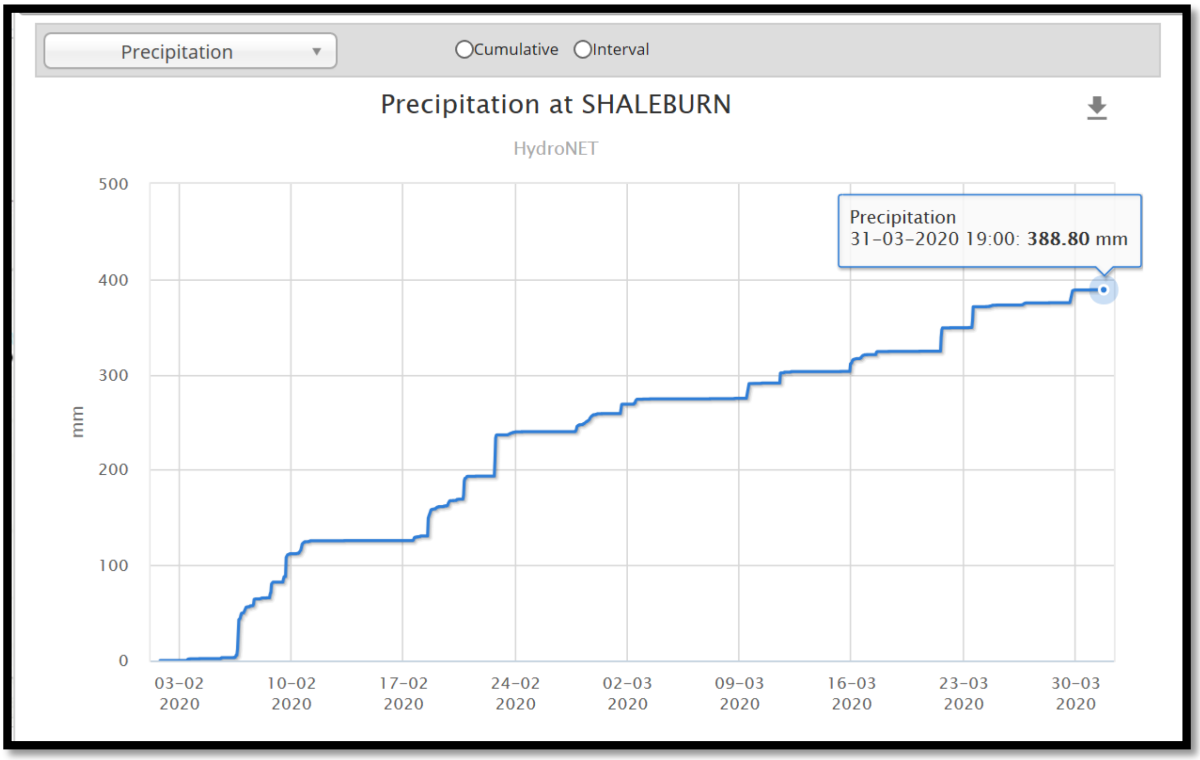

Figure 2- 2. Precipitation in uMkhomazi catchment for 1st February 2020 to 31st March 2020.

The Upstream Monitoring Point of the uMkhomazi River (UU) is located at approximately 4000 metres upstream of the confluence of the Inhlavini and uMkhomazi rivers (Google Earth, 2020). The Impact of the upstream-proposed dams (Smithfield, Impendle and Bulwer) will be detected in the UU. The downstream proposed dams will not impact this monitoring point as it is located upstream of the proposed dams.

2.3 Description of Inhlavini River

The Inhlavini River originates approximately 10 km east of Ixopo Town within the Ubuhlebezwe Local Municipality, Harry Gwala District Municipality in KwaZulu-Natal (Google Earth, 2020). According to DWA (2015), the Inhlavini River is approximately 26 km long and in a Category B, which indicates that the river is largely natural with few modifications (**Table 2- 5**). There are several streams which join the Inhlavini River before it discharges into the maistem uMkhomazi River (Google Earth, 2020). These tributaries include Ixobho, Kwanokwena and Mzinhlanga. The Ixobho River is impacted by agricultural activities and sewage that leaks from ageing sewerage infrastructure (Design, 2013).

The Inhlavini area, where the Piggery X is located, is 500 m.a.m.s.l. (Google Earth, 2020). Rainfall recorded in Ixopo indicated that the area received approximately 194.00 mm over a period of two months – i.e., 01st February and 31st March 2020 (**Figure 2- 3**). Rainfall data records abstracted from Hydronet (a programme used by DWS for storing weather-related information) indicated that the rainfall received by Inhlavini River catchment was 50% less than that of the rainfall recorded for the uMkhomazi River catchment for the same period. The average rainfall of the Inhlavini River catchment is 793 mm/a (Nel, 2009). This average annual rainfall for the Inhlavini area is above the average rainfall of the country (RSA), which is 467 mm/a, and is slightly above the global average rainfall of 786mm/a (Nel, 2009). With an MAP which ranges between 1000 mm/a and 2000 mm/a, the KwaZulu-Natal region receives more than the country's average MAP (Nel, 2009). According to Kruger and Nxumalo (2017), there has been an increase of rainfall in the southern interior of RSA and a decrease in far northern and north eastern of the country for the period of 1921-2015.

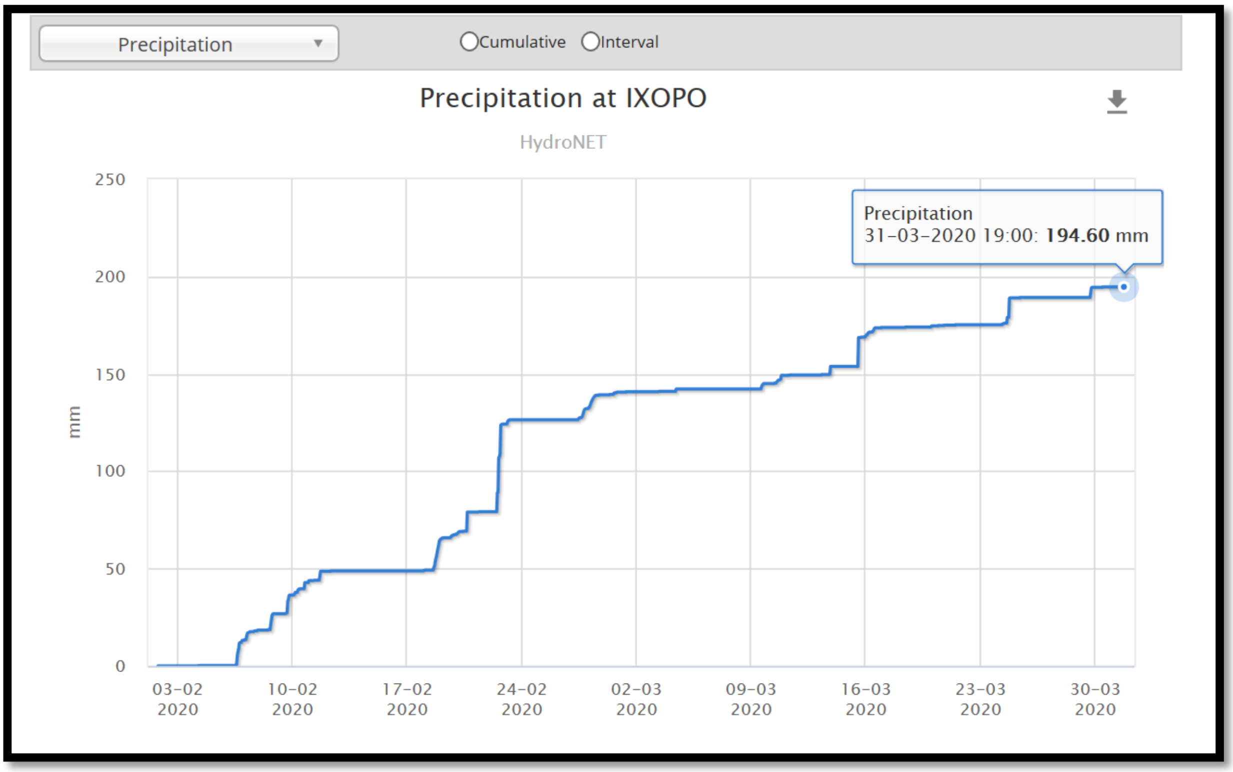

Figure 2- 3. Rainfall recorded in Ixopo for 01st February 2020 to 31st March 2020.

The property on which Piggery X is located, also has a chicken farm (these are approximately 500 m apart); however, the chicken farm does not drain into the same point as Piggery X, rather it drains into the upper reaches of the Inhlavini River (control point). Therefore, the impact of the chicken farm, if any, should be detected at the control point (Inhlavini Upstream Monitoring Point =IU). Piggery X started discharging untreated piggery effluent in 2016 and allegedly stopped discharging in October 2019. The discharging of untreated piggery effluent into the Inhlavini River had been going on for almost three years. The discharge into the Inhlavini River was done through a pipeline.

2.4 Site Description and Research Design

2.4.1 Description of monitoring points

The study area is located on a remote area of Inhlavini and uMkhomazi rivers near Ixopo and part of Richmond (**Figure 2-4**).

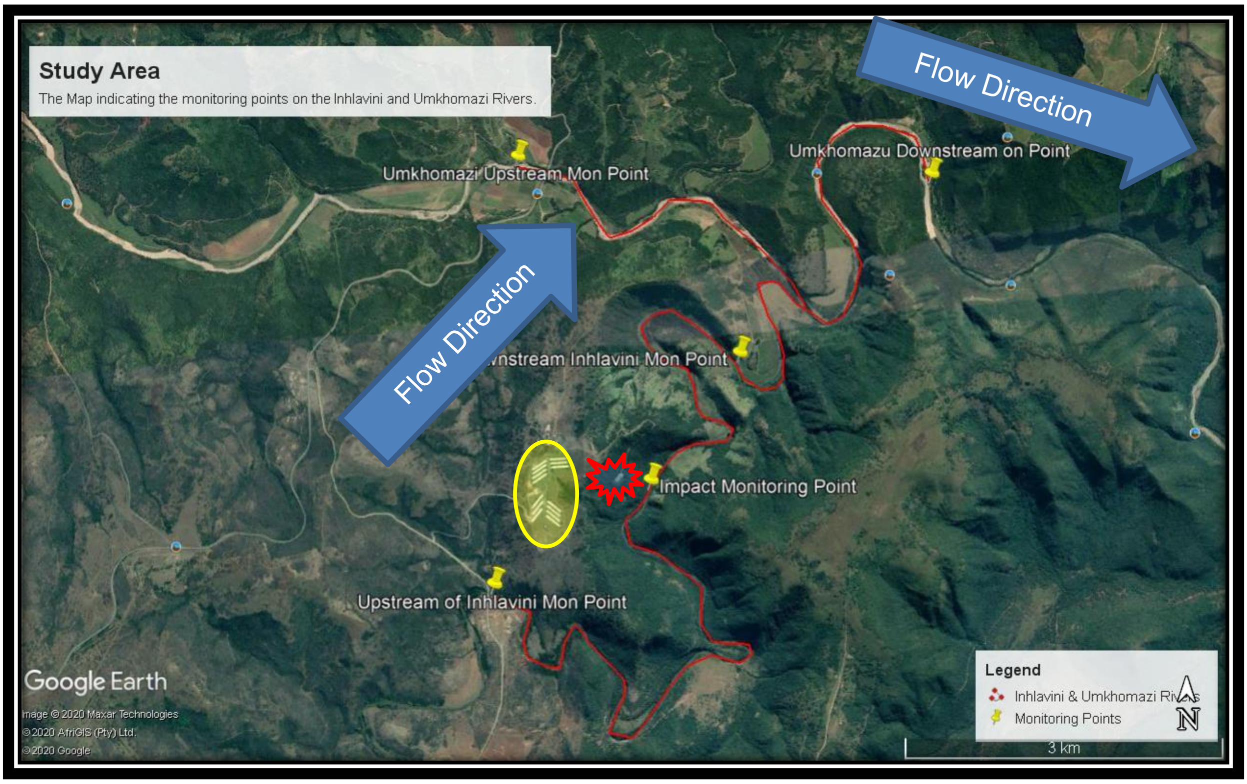

Figure 2- 4. Inhlavini and uMkhomazi rivers showing monitoring points, Piggery X (red star) and the chicken farm (yellow oval shape). (Google Earth, 09 October 2020).

A total of five monitoring points were selected for the study. Three of the monitoring points were on the Inhlavini River – i.e., upstream of the Impact Monitoring Point (IU), Impact Monitoring Point (II) and Downstream of the Impact Monitoring Point (ID) (**Table 2- 4**), for further description). The last two monitoring points were located on the uMkhomazi River to assess the impact of Piggery X on the uMkhomazi River. The first one is upstream of the Inhlavini and uMkhomazi rivers confluence, referred to as uMkhomazi Upstream Monitoring Point (UU), which acts as a control site and downstream of the confluence, referred to as uMkhomazi Downstream Monitoring Point (UD).

Table 2- 4. Inhlavini and uMkhomazi rivers monitoring sites description.

Site Name	Site Code	Description of the site	Co-ordinates
Inhlavini Upstream Monitoring Point	IU	Located 6 700m upstream of the Inhlavini Impact Monitoring Point – to act as a control monitoring point.	S30^{0}02’44.07” E30^{0}14’23.04”
Inhlavini Impact Monitoring Point	II	Located at the discharge point of untreated piggery effluent – to assess the extent of impact of effluent as it enters the Inhlavini River.	S30^{0}02’12.19” E30^{0}15’23.26”
Inhlavini Downstream Monitoring Point	ID	Located 3 720m downstream of the II to assess if the impact is reduced.	S30^{0}02’34.88” E30^{0}15’54.35”
uMkhomazi Upstream Monitoring Point	UU	Located 3 840m above the confluence of uMkhomazi and Inhlavini rivers.	S30^{0}00’28.91” E30^{0}14’30.46”
uMkhomazi Downstream Monitoring Point	UD	Located 3 774m downstream of uMkhomazi and Inhlavini rivers confluence.	S30^{0}00’33.60” E30^{0}17’03.07”

The co-ordinates and altitude of monitoring points were determined using the Garmin Geographic Positioning System (GPS). Google Earth was also used as a confirmation of the recorded co-ordinates on each monitoring point (**Table 2- 4**). The motive for taking co-ordinates was to ensure that the work is undertaken at the same spot for all monitoring schedules. In addition, should there be other interest emanating from the study by a different person, the co-ordinates will assist in identifying the monitoring points.

A. Description of Inhlavini Upstream Monitoring Point (IU)

This monitoring point is located within a rural residential area (**Figure 2- 5**). There was small-scale subsistence sand mining upstream of the monitoring point. Residents were observed taking water from the Inhlavini River for domestic use and also washing clothes within the Inhlavini River. Livestock were grazing in the area and near the Inhlavini River. Alien vegetation was also observed taking over indigenous vegetation along the monitoring point area. The reason for locating the monitoring point at that specific position was due to access – i.e., the only accessible site/point upstream of the discharge point for Piggery X. Engagement with the residents revealed that the entire village relies on the Inhlavini River as there is no potable water in the area.

Figure 2- 5. Google Earth imagery showing Inhlavini Upstream Monitoring Point (IU) (Google Earth, 09 October 2020).

B. Description of Inhlavini Impact Monitoring Point (II)

This monitoring point is located where effluent from Piggery X was discharged into the Inhlavini River, through a pipeline (**Figure 2- 6**). The reasoning behind selecting this point, as the impact point, was due to the visibility (through naked eyes) of the change in the water observed in October 2019, when the discharge was discovered. The change in the colour and the smell from the discharge point towards downstream was distinct from upstream waters. This observation was pointing to that the Inhlavini River may be negatively impacted by the effluent discharge from Piggery X. It is crucial to determine if the impact of the Piggery X is also notable on the uMkhomazi River. However, one cannot base the conclusion on the visual observations only that Piggery X is negatively impacting on the Inhlavini and uMkhomazi rivers. This point is located within the valleys and is inaccessible with a vehicle as there are no roads but only through foot paths.

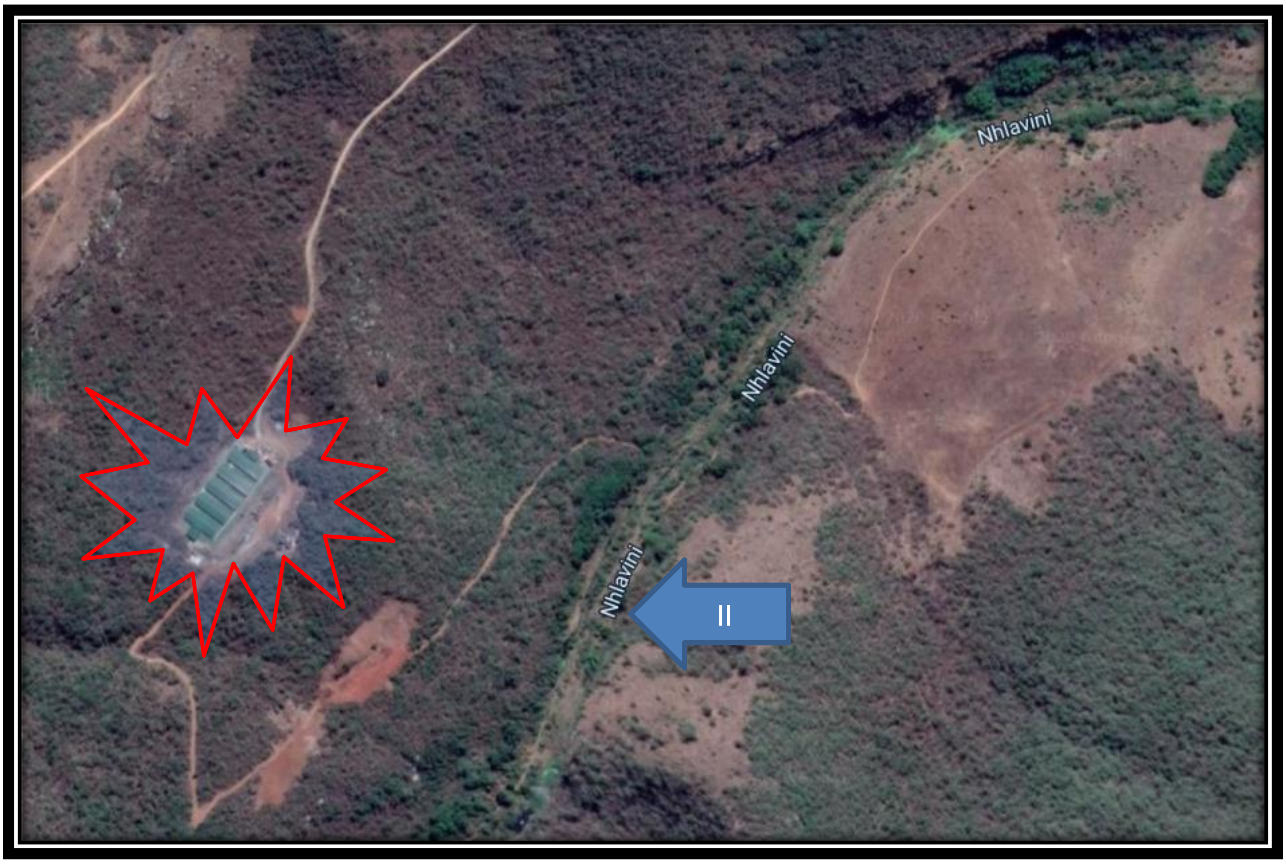

Figure 2- 6. Google Earth imagery showing Inhlavini Impact Monitoring Point (II), with the Piggery X marked with a red star (Google Earth, 09 October 2020).

C. Description of Inhlavini Downstream Monitoring Point (ID)

The downstream monitoring point on the Inhlavini River (ID) is located on the access path near a citrus orchard (**Figure 2- 7**). This monitoring point was selected to determine the change in water quality from the II before it discharges into the uMkhomazi River. The difference in water quality results between this monitoring point and II will indicate if the Inhlavini River is naturally rehabilitating itself from the impact caused by Piggery X.

Figure 2- 7. Google Earth imagery showing Inhlavini Downstream Monitoring Point (ID**)** (Google Earth, 09 October 2020).

D. Description of the uMkhomazi Upstream Monitoring Point (UU)

This monitoring point is located upstream of the confluence of Inhlavini and uMkhomazi rivers. This monitoring point was selected as the control point on the uMkhomazi River system as it is not affected by the Inhlavini River. The monitoring point is accessed through R56 provincial road and it is within the Valley View Farm (**Figure 2- 8**). The monitoring point is bordered by agricultural activities. There are two farm pump houses located in the vicinity of this monitoring point. The farmers draw water from the uMkhomazi River for irrigation purposes.

Figure 2- 8. Google Earth imagery showing uMkhomazi Upstream Monitoring Point (UU) (Google Earth, 09 October 2020).

E. Description of the UMkhomazi Downstream Monitoring Point (UD)

This monitoring point is located within the Duma Manzi Eco Lodge and game reserve. Access to this monitoring site is only through a private property, which is owned by Duma Manzi Eco Lodge and game reserve. Access to this monitoring point is extremely steep and can only be accessed by 4x4 vehicles. This monitoring point is located below the confluence of Inhlavini and uMkhomazi rivers (**Figure 2- 9**).

Figure 2- 9. Google Earth imagery showing uMkhomazi Downstream Monitoring Point (UD) (Google Earth, 09 October 2020).

2.4.2 Research design

This study concentrates on Piggery X, located in the southern part of KwaZulu-Natal, RSA. Piggery X, a small scale piggery with about 100, was discharging untreated piggery effluent into the Inhlavini River. The activity was said to have stopped discharging untreated effluent into the Inhlavini River in October 2019 – which was after a period of about three years. This piggery is located 295 metres (m) from the banks of the Inhlavini River, which discharges into the uMkhomazi River. The pipe that was discharging untreated piggery wastewater into the Inhlavini River is therefore assumed to be approximately the same length (295 m).

During this study, water quality variables (both *in situ* and laboratory analyses) and macro-invertebrate community composition using macro-invertebrates will be used to assess the possible recovery of the Inhlavini and uMkhomazi rivers.

In situ water quality sampling will be done on site using Hanna-H198194, salinity meter, and pH meter. Water Quality samples will be taken and forwarded to a South African National Accreditation System (SANAS) accredited laboratory.

Bio-monitoring using macro-invertebrate community composition will be used to assess possible recovery of the Inhlavini and uMkhomazi rivers. Macro-invertebrates are recognised as organisms that are valuable when performing bio-assessment due to their visibility to the naked eye, ease of identification, as well as their rapid life cycle (Dickens & Graham, 2002). Macro-invertebrate biodiversity and the associated community assemblages are used to determine the health of aquatic ecosystems (Begon *et al.,* 1996).

Even though Piggery X is regarded as a small piggery, it is understood that if it were to be authorised in terms of the NWA, the water uses undertaken at Piggery X may allow it to be authorised under General Authorisation (GA). The water quality results will be compared to the following South African Water Quality Guidelines:

- South African Water Quality Guidelines for Domestic Use.
- South African Water Quality Guidelines for Agricultural Use: Livestock Watering and Irrigation.
- South African Water Quality Guidelines for Aquatic Ecosystem.

As the surrounding area is largely rural and with no potable water, the above-mentioned guidelines will be used as they are most applicable. Analysis of data sampled during wet and dry seasons will give different scenarios, which will assist in drafting recommendations and conclusion in this regard. Bio-monitoring will be used by sampling macro-invertebrates. The change in the presence of these macro-invertebrates will assist in analysing the water quality and determining the ecological category as macro-invertebrates have been commended as good ecological indicators.

2.5 Data Collection

The sampling commenced in February 2020 (approximately four months after discharge ceased) to assess the impact caused by the discharging on the Inhlavini River and eventually into the uMkhomazi River. Samples for chemical and microbiological analysis were collected according to the standard procedures described in the sampling guide (DWAF, 1992). Appropriate sampling bottles were collected from the laboratory prior to all sampling schedules. Each one litre (l) chemical sample bottle was rinsed three times with river water at all monitoring points prior to filling the bottle. Sterilized 500 ml sample bottles were used for microbiological samples. As per sampling procedure for microbiological samples (Britton & Greeson, 1989), it was ensured that bottles were not rinsed, and no air was allowed to enter the sample during sampling. After collection, all water bottles were labelled accordingly. The information on the tags included the following: name of the sampler, date, and time the sample was taken, variables to be analysed and site name/description. The water bottles were stored in a cooler box with ice packs to allow for cooler conditions.

2.5.1 Water quality

A. Field measurements

The following water quality parameters were analysed on site using Hanna-H198194 multi-meter (**Figure 2- 10)**: temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS). These test parameters are commonly used in water quality assessments. In addition, TDS Tester/Meter and Salinity Tester/Meter were used to analyse TDS, salinity, and temperature. Instruments used to analyse water on site were calibrated prior to each field trip.

Figure 2- 10. In field sampling meters. a) Hanna-H198184 multi-parameter, b) TDS Tester/Meter and c) Salinity Tester/Meter (**Source:** Internet, 15 October 2020).

A salinity tester (H198319) was used to analyse salt content of water in each monitoring point. Both TDS and Salinity Testers/Meters were also used to determine the temperature of water (and compared with those of the multi-meter). The average temperature was then used in all monitoring points.

The *in situ* field analyses were conducted on 24 February 2020, 29 July 2020, and 15 October 2020. In February 2020, macro-invertebrates could not be sampled due to flooding of the Inhlavini and uMkhomazi rivers (**Figure 2- 11**). Only *in situ* sampling and laboratory water quality analysis was done during this survey.

Figure 2- 11. UMkhomazi River (Site UD) flooding in February 2020.

The Downstream Monitoring Point of the Inhlavini River (ID) was found to be dry during the monitoring in July 2020 and October 2020 (**Figure 2- 12**). The Inhlavini River was noted to have connection and disconnection as it meanders downstream as a result of the dry season. It was noted that seepage from springs also added to the flow of the Inhlavini River. Engagement with residents indicated a suspicion of water being abstracted upstream, for agricultural purposes.

Figure 2- 12. Image showing Site ID when it was dry, 15 October 2020.

B. Laboratory analysis

Water samples taken from all five monitoring points were sent to the SANAS accredited laboratory for analysis on the day of sampling to ensure that microbiological samples are analysed within twenty-four (24) hours, as per requirements. The list of parameters analysed at the laboratory were *Escherichia coli* (*E. coli*), faecal coliforms, nitrates and nitrites (NO_3^- and NO_2^-), orthophosphates (PO_4^{3-}), pH, electrical conductivity (EC), chemical oxygen demand (COD), copper (Cu), potassium (K), and total suspended solids (TSS) were analysed using standard accredited methodologies.

2.5.2 Macro-invertebrates

Macro-invertebrates were sampled and analysed using a standard SASS5 procedure as described by Dickens & Graham (2002); Dallas & Day (2004) and Kemp *et al*. (2014).

SASS5 macro-invertebrate sampling was only done for uMkhomazi River monitoring points (UU and UD). Sites UU and UD were good sites for SASS5 as they contain all three biotopes as per SASS5 requirements – i.e., Stones (S), Vegetation (Veg), and Gravel Sand and Mud (GSM). However, macro-invertebrates were not sampled on Inhlavini River due to high levels during February 2020. In July 2020 and October 2020, the Inhlavini River was not flowing and was not permitting for the sampling of macro-invertebrates.

According to Dickens and Graham (2002), floods and stagnant pools should be avoided as they are not a true indication of the river system. Thus, macro-invertebrate could not be sampled during the first wet season (February 2020) as the uMkhomazi River was flooding.

Table 2- 5. Ecological Categories (DWA, 2016).

Ecological Category	**Impact**	**Description**	**Colour**
A	Natural	Unmodified natural	Blue
B	Good	Largely natural with few modifications	Green
C	Fair	Moderately modified	Yellow
D	Poor	Largely modified	Red
E	Seriously modified	Seriously modified	Purple
F	Critically modified	Critically or extremely modified	Black

To interpret macro-invertebrate data, Dallas and Day (2004) developed a modified method that generates biological bands for both SASS5 score and Average Score Per Taxa (ASPT) values for spatial groups. The relevant biological band that was used for the study area was Eastern Escarpment Mountains – Upper. This method has each and every spatial group's reference information and also ecological categories which ranges from A – F. Categories are indicated on Table (**Table 2- 5**).

Macro-invertebrates using SASS5 Index

There are three parameters that are calculated when analysing macro-invertebrates, and these are: SASS Score, Number of Taxa (No. of Taxa) and Average Score per Taxa (ASPT) (Dickens & Graham, 2002), and the calculations were done as follows:

$$\text{ASPT} = \frac{\text{SASS Score}}{\text{No. of Taxa}}$$

A score was allocated to each taxon based on its sensitivity towards pollution. According to Dickens and Graham (2002) SASS score varies between 1 and 15. A score of 1 (low) refers to those taxa that are tolerant of pollution whilst the higher score refers to taxa that are sensitive to pollution. In other words, in polluted water one may find low scoring taxa but high scoring taxa will not be found.

2.6 Statistical Analysis

Paired sample t-tests (n=3) were done with GraphPad Prism to determine whether there were significant differences ($p<0.05$) in the water quality variables *E. coli* and faecal coliforms (microbiological), nitrates, nitrites, orthophosphates, pH, electrical conductivity, chemical oxygen demand, copper, potassium, and total suspended solids) above and below the inflow of Piggery X, as well as above and below the confluence of the Inhlavini with the uMkhomazi River.

Multivariate analyses were conducted with CANOCO 5 software to further investigate the results. A principle component analysis (PCA) was done to explain the variation in water quality variables in relation to sampling sites and a redundancy analysis (RDA) was conducted to investigate the distribution of macro-invertebrate taxa in relation to the influence of the measured water quality variables (i.e., *E. coli* and faecal coliforms (microbiological), nitrates, nitrites, orthophosphates, pH, electrical conductivity, chemical oxygen demand, copper, potassium, and total suspended solids) at the UU and UD sites, during both the wet and dry seasons.

Data analysis for water quality taken for both Inhlavini and uMkhomazi rivers analysed using PCA and RDA statistical techniques. The purpose was to determine the correlation between the Inhlavini and uMkhomazi rivers with regards to the impact of Piggery X on the Inhlavini River (Bhat *et al*., 2014). T-test with Graphpad Prism was also used to describe temporal variations of the sampled water quality parameters. Bhat *et al*. (2014) describes principal component assessment (PCA) as a statistical technique that indicates the number of important variables that explain the variance in the data and also to explain the variance with fewer variables hence PCA was used for the Inhlavini and uMkhomazi data.

2.7 Ethical Considerations

The investigation undertaken ensured that no names were mentioned. The piggery under investigation remained anonymous and referred to as Piggery X. The study also does not make use of humans and/or vertebrates, and thus no Ethical Clearance is needed.

2.8 Methodological Limitations

The only challenge experienced was the uMkhomazi and Inhlavini rivers flooding during the February 2020 monitoring and the Inhlavini River being dry during July 2020 and October 2020 monitoring schedule which hindered macro-invertebrates sampling on the Inhlaavini River. In addition, the

Inhlavini downstream monitoring point (ID) was dry during July and October 2020 sampling hence no water quality and macro-invertebrates sampling could be undertaken.

2.9 Chapter Summary

In this Chapter, a clear location of the study area was described and the type of environment that surround the study area. Furthermore, a detailed description of monitoring points was given for each monitoring point on both Inhlavini and uMkhomazi rivers. Instruments and methods that were employed to measure water quality and for bio-monitoring for macro-invertebrates were described in detail. Thus, all sets of samples collected were clearly described. Guidelines to be used to analyse water quality data and macro-invertebrates to assess the impact caused by Piggery X were clearly described in detail. Macro-invertebrates were sampled and analysed using SASS5 guidelines. The above mentioned information will assist in determining the impact caused by Piggery X on uMkhomazi River. Bio-monitoring using macro-invertebrates will assist in determining the ecological category of uMkhomazi River (as macro-invertebrate sampling could not be done for the Inhlavini River).

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

The volume of water used for agriculture has increased due to population growth which also increased the need for food and fibre (Ehrlich & Holdren, 1971). It is clear that population growth cannot be separated from agricultural use as they affect one another. Every person needs food daily and crops require water to grow. To cater for increase in demand, there is a need to also increase livestock production which also needs grass and water to grow. Large volumes of water are also used in abattoirs. In essence, as the population increases, the need to use water for agricultural activities also increases. The use of water for agriculture increases the production of agricultural effluent which requires to be properly disposed of. According to Qadir *et al*. (2003), agriculture commands more water than any other activity on this planet, which warrants agriculture as the highest water user. In addition, agriculture uses approximately two third of water in RSA (Wallace, 2000). Since it has been established that agriculture uses more water, it is therefore projected that the impact caused by agricultural uses in the soil as well as in water resources (including both surface and groundwater) will continue to increase as the population continues to increase.

Bahri (1999), suggests that agricultural reuse of wastewater must be integrated into comprehensive land and water management plans considering water supply, wastewater collection, reclamation, and reuse. The reuse of agricultural wastewater will assist in meeting the demand of water supply to agriculture and minimize wastewater discharged into water resources globally. It is therefore understood that some agricultural activities (e.g., irrigation for some crops, cleaning of piggery lots, etc.) do not necessarily require fresh water; hence water reuse is an option. Wastewater from agriculture is regarded as a worldwide problem. According to Cameron *et al.,* (1997) New Zealand and Australia are the largest producers of agricultural waste which warrants both countries to be anticipated to have wastewater management issues. Challenges faced by the two mentioned countries are expected in RSA as it uses two third of water for agriculture.

3.2 Global Perspective on Piggeries

According to de Oliveira *et al*., (2017), and Maraseni and Maroulis (2008), pigs produce waste of between 80% and 90%, by volume, of product consumed; thus, piggeries are the largest water users and effluent producers. It has been indicated that each pig uses an average of 15 litres of water per day (Steinfeld, 2006). The high quantity of water consumed by pigs result in direct discharge of piggery effluent into the receiving environment, which stimulate eutrophication in surface water due to nitrate discharge (Burger, 2018). The disposal of piggery effluent further result in water pollution (including both surface and groundwater) (Maraseni & Maroulis, 2008).

Run-off into water resources is regarded as the main cause of increasing concentration of phosphates and nitrates in drinking water (Patil *et al.*, 2012). Run-off mainly from livestock wastewater is classified as high-organic loading and high nutrient content wastewater (Adav *et al.*, 2010). Like many other wastewaters, piggery effluent contains several contaminants including suspended solids, phosphorus, sulphur, copper, and faecal bacteria (Selvarajah, 1999), which may all have a negative impact on downstream water users, aquatic ecosystems and become a major environmental concern (Patil *et al.,* 2012).

At a global scale, China is noted to be producing most pigs than any other country in the world, in order to meet the demand of meat supply (Choi, 2007). The reason for producing the most pigs in China is manly associated with the large population in the country (Jiang *et al*., 2019); whilst the same study found that other countries, such as Korea, largely prefer pork. Maraseni and Maroulis (2008) stated that pig industry contributes a high percentage of Australian rural economies and supplying the people of Australia with valuable employment; however, the environmental impacts thereof is notable.

Large number of pigs found and associated piggery effluent have been identified as the largest contributors to water pollution (both groundwater and surface water) compared to other livestock (Bhamidimarri & Pandey, 1996; Maraseni & Maroulis (2008); de Oliveira *et al*., (2017). This is even more important, as Hickey *et al*. (1989) also found that half of legal piggery farms in New Zealand were discharging directly into rivers. However, during the 1980's, there was a shift from direct river discharge to oxidation pond treatment systems, which is mainly used in recent years (Hickey *et al*., 1989). The shift was as a result of seeing the impact caused by piggery effluent into rivers; hence a better option was employed. However, partially treated or digested piggery effluent (via ponds) still represented a potentially large impact on receiving waters, especially small streams that may receive multiple discharges (Hickey *et al*., 1989). In particular, the organic matter, nutrients and/or suspended solids discharged into rivers may cause concern – either individually or combined (which may have a synergistic effect). Organic loading may result in de-oxygenation of river water and sediment, which may result in an increase in biological oxygen demand (BOD) (Hickey *et al.*, 1989). The current piggery waste disposal methods that are currently employed are mentioned to be resulting in the pollution of air by methane gas, which is said to have twenty-one (21) times more global warming potential than carbon dioxide and nitrous oxide (Maraseni & Maroulis, 2008).

In an effort to address the issue of pollution of the environment, especially water resources, by piggery effluent, many countries have adopted a number of ways of dealing with such.

Partially treated or digested piggery effluent (via ponds) represent a potentially large impact on receiving waters, especially small streams that may receive multiple discharges (Hickey *et al*., 1989). This partially treated effluent may then be used for irrigating agricultural lands (Chinivasagam *et al*., 2004). In particular, the organic matter, nutrients and/or suspended solids discharged into rivers may cause concern – either individually or combined (which may have a synergistic effect). Organic loading may result in de-oxygenation of river water and sediment, which may result in an increase in biological oxygen demand (BOD) (Hickey *et al.*, 1989).

There has been a decline in pig farming; for example, New Zealand recorded a 50% decline in pig farming over a period of 12 years (between 1990 and 2002) (Wang *et al*., 2004); whilst Australia recorded a similar decline over 32 years (between 1960 and 1992) (Edgerton e*t al*., 2000). This is a similar decrease as the one noted in New Zealand, even though it was for over a much shorter period for New Zealand.

Other countries, such as Brazil, are also investing on the technology to try and mitigate the impact of piggery effluent (Von Sperling & de Lemos Chernicharo, 2005). For example, a case study was undertaken in Brazil, which was aimed at removing phosphorus from piggery effluent using lime (Girard *et al.,* 2009). The mentioned case study proved the method to be efficient as it removed 90% of phosphorus at pH of 8.5 (Girard et al., 2009).

3.3 South Africa

In South Africa, piggeries are known to have significant impact on the environment, including water resources (surface and groundwater). In terms of National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and National Environmental Management: Waste Act, (Act No. 59 of 2008) (NEMWA), such activities require an environmental authorisation prior to operation. The National Water Act, 1998 (Act No. 36 of 1998) (NWA) requires that such activities be authorised in terms of Section 21 water uses. Water use authorisations can either be in a form of General Authorisation (GA), Water Use License (WUL) and/or Existing Lawful Use (ELU) depending on the impact on water resources as described above. Piggeries are issued with a water use authorisation which has conditions that are attached to them. The common practise in South Africa is that piggeries use pond treatment and discharge into water resources as authorised under the NWA.

3.4 Water Quality Variables Related to Piggery Effluent

Water Quality is defined as chemical, physical, biological, and aesthetic properties of water (DWAF, 1996). These properties determine the fitness of water resources for different uses (i.e., agriculture, domestic, aquatic ecosystems, industrial, recreation, mining, etc.) (DWAF, 1996).

The most adopted strategy or method of piggery effluent treatment globally is through anaerobic ponds and/or lagoons. Schmidt and Engineer (2013) define an anaerobic pond or lagoon as an impoundment with a permanent liquid pool for encouraging biological breakdown of manure and a storage volume. Anaerobic lagoon treatment is aimed at using sunlight, oxygen, and carbon dioxide to treat wastewater (**Figure 3- 1**) (Schmidt & Engineer, 2013).

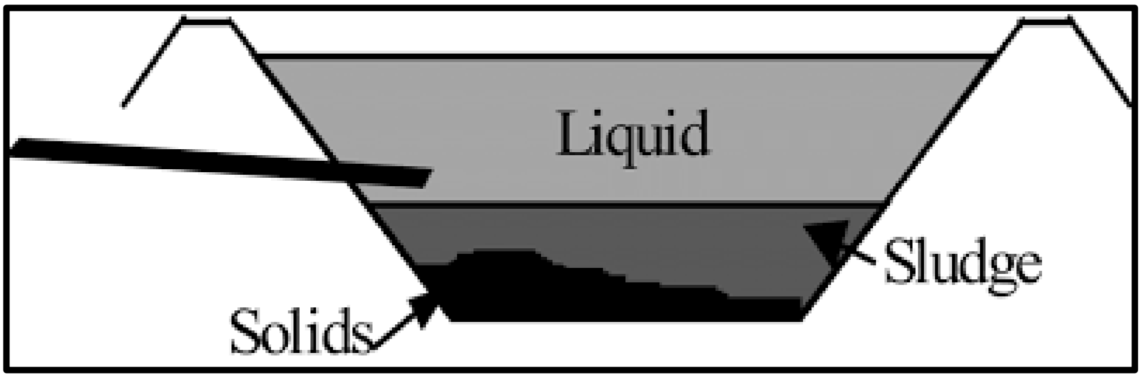

Figure 3- 1. Schematic representation of a typical anaerobic pond (adapted from Schmidt and Engineer (2013)).

Loyon (2018) adds that the livestock sector is considered as one of the principal sources of pollution leading to global warming, water, and soil contamination. Piggery effluent discharged into water resources pollutes surface and ground water and manure disposal together with irrigating with water containing waste result in soil and groundwater contamination.

Water quality variables related to piggery effluent in different parts of the world are similar and are as follows: chemical oxygen demand (COD), total nitrogen (TN), nitrate nitrogen (NO3-N), ortho-phosphate (PO_4-P) and suspended solids (SS) (Sezerino *et al*., 2003). According to Sezerino *et al.,* (2003), biochemical oxygen demand (BOD), *E. coli* and faecal coliforms should be part of variables to be analysed in piggery effluent. Some of the mentioned variables are described in detail below.

3.4.1 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is defined as a measure of organic pollution in water (i.e., human, industrial, and animal waste) (Chapman, 1996). This parameter indicates how polluted the water resource is, based on the chemical content. Based on the definition given for COD, it is therefore concluded that if water is clean or not polluted, the COD levels will be low, the higher levels of pollution will also increase the COD levels.

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

Total dissolved solids (TDS) are defined as a measure of the quantity of all the salts that have dissolved in the water that is analysed (DWAF, 1996). Thus, TDS could be regarded as a sum of all organic and inorganic matters dissolved in water. Electrical conductivity (EC) is directly proportional to TDS. It basically means that the higher the EC, the higher the TDS and vice versa. The relationship of TDS and EC is calculated by measuring the EC and multiplying by a factor of 0.7 to get TDS (Walton, 1989; Atekwana *et al.,* 2004); and therefore, EC is regarded as a measure of TDS (Mosoa, 2013). Very high levels of EC and TDS in the water resource may therefore be an indication of some pollution in the water. However, high values for these should be carefully interpreted, as some areas are affected by the geology of the drainage area (Rosen & Lapham, 2008). Both EC and TDS are controlled by different factors such as geology, runoff and wastewater from point sources, atmospheric inputs etc. (Pal *et al.,* 2015).

3.4.3 Copper (Cu)

Copper (Cu) is defined as an essential trace element for organisms (DWAF, 1996). Even though Cu is an essential element, it has been found to be toxic at high concentrations (Ochoa-Herrera *et al*., 2011). Copper is found in different forms but for the purpose of this study, the soluble form will be analysed. At a neutral pH, Cu is expected to be low in surface waters (Ochoa-Herrera *et al*., 2011). According to DWAF (1996), Cu can be treated or removed by increasing the pH levels.

3.4.4 Nutrients (Nitrates and Nitrites) and Dissolved Oxygen (DO)

Nutrients usually emanate from animal waste and vegetable/plant material oxidation (DWAF, 1996). Nitrates are excessive from runoff from agricultural fields as a result of fertilizers used to grow plants (Bouwer, 1990). According to Bouamra *et al*. (2012), nutrient is a collective scientific word for nitrogen, phosphates, and potassium. Excess nutrients in water resources encourage growth of aquatic plants as well as algae and are referred to as eutrophication (Novotny, 1999; Bouamra *et al*., 2012). It is, therefore, required that nutrients that are entering water resources are minimized as they have a potential to trigger proliferation of aquatic plants, and thus, negatively impact ecosystem. Eutrophication may cause a decrease in dissolved oxygen (DO) levels in water which may result in death of aquatic biota, (Ansari *et al*., 2010). Nitrates and nitrites also result from wastewater discharge from different sources, such as wastewater treatment plants, piggeries, etc., due to inadequate management.

3.4.5 pH

The pH is defined as a measure of acid-base equilibrium for dissolved compounds (Chapman, 1996; Mosoa, 2013). It is referred to as a measure of hydrogen ion activity in a substance (DWAF, 1996). According to the pH scale, 1-6.9 indicates that water is acidic, 7.1-14 indicates that water is alkaline and 7 indicate that water is neutral (i.e., neither acidic nor alkaline) (DWAF, 1996). Significant changes in the normal pH of the area negatively affect the organisms, whilst minor changes may not have a negative impact. Health impact to humans for change in pH is limited to irritation of mucous membrane as well as eyes irritation when swimming in these waters (DWAF, 1996; Mosoa, 2013). The pH is measured in the field using a pH meter and other portable water quality meters. It is also analysed in the laboratory.

3.4.6 Orthophosphates (PO_4^{3-})

Orthophosphates are analysed as phosphorus, which are known for triggering eutrophication of water resources (Povilaitis, 2004). Orthophosphates are described as salts from dissolved phosphorus. It has been said that water ecosystems are sensitive to changes in orthophosphates (Khan *et al*., 2014). According to Povilaitis (2004), phosphorus mostly reaches the rivers from sources such as agricultural activities, specifically livestock. It is of important that orthophosphates are analysed for the purpose of this study as it will indicate if the effluent from Piggery X does impact on the Inhlavini and uMkhomazi rivers.

3.4.7 Potassium (K)

This parameter is found in land that is being irrigated and/or from the runoff from irrigated land (DWAF, 1996). Fertilizers and domestic waste are known to have high levels of potassium, with the latter resulting mainly from urine (Mosoa, 2013). Potassium is said to cause a bitter taste in water which causes nausea and vomiting (DWAF, 1996). Thus, it is clear that potassium may affect both aquatic organisms, as well as humans.

3.4.8 Faecal Coliforms and Escherichia coli (*E. coli*)

According to DWAF (1996), faecal coliforms are an indication of the presence of bacterial pathogens including *E. coli*. It is therefore clear that the levels of faecal coliforms will always be equal or higher than *E. coli* levels based on the definition given. Faecal coliforms and *E. coli* are said to cause gastrointestinal effect when consumed (DWAF, 1996; Johnston *et al*., 2010).

3.4.9 Total Suspended Solids (TSS)

Solids are mostly analysed as suspended solids (SS) but actually reflect all three forms which are suspended, dissolved and volatile solids (Chapman, 1996; Bhateria & Jain, 2016). According to Bhateria and Jain (2016), suspended solids are unable to pass through a micro filter whilst dissolved solids do pass through a filter. Agricultural activities are amongst the activities that increase suspended solids due to direct effluent discharge, seeping and/or runoff.

3.5 Macro-invertebrates

Macro-invertebrates are found in almost all rivers and streams worldwide and can be used to indicate the quality of water (Dickens & Graham, 2002; Ogbeibu & Oribhabor, 2002; Dallas & Day, 2004; Thirion, 2007). Thirion (2007) refers to macro-invertebrates as communities that give a good reflection of the flow regime and water quality of a river. It is indicated that aquatic macro-invertebrates are organic matter processors of the river system they live in, purify water as well as provide food for larger animals that lives in and even outside the river system (Allan, 1995; Thirion, 2007). The entire world is facing the challenge of pollution of water resources as a result of point source activities therefore macro-invertebrates can be viewed as one way of fighting water pollution within river systems to a certain extent. The impact of water quality also affects aquatic ecosystem, such as macro-invertebrates; hence they are increasingly being used as a bio-indicator for evaluation of water quality in rivers (Custodio & Peñaloza, 2019). Macro-invertebrates are good indicators of water quality and in determination of ecological status as they live in water and are sensitive to water quality changes (Dickens & Graham, 2002). Advantages of using macro-invertebrates are that they varying degrees of sensitivities, visible with the naked eye, have a rapid lifecycle, and also rapid assessment process (Dickens & Grahams, 2002). According to Dickens and Graham (2002), the use of macro-invertebrates as the water quality indicator is inexpensive and advantageous. Macro-invertebrates are also easy to sample and are said to be the quickest way of determining the ecological state of the water resource. The South African Scoring System version 5 (SASS5) will be used in this assessment.

3.6 Legislation

In 2010, France conducted a census on piggeries; and they counted 22 300 pig farms, with a total of 13.8 million pigs (Loyon, 2018). This is an indication of the projection of the piggery effluent that could have entered into the rivers if there was no shift from direct surface water discharge to pond system.

Piggery effluent into water resources in France is regulated using French and European Regulations; these are aimed at protecting both the environment and local inhabitants (Loyon, 2018). Farmers in France are subjected to Department of Health regulations, which are referred to as Public Health Code.

In Thailand, piggery effluent is also regarded as one of the largest contributors in water pollution. The legislation that is used to manage piggery effluent in Thailand is the Enhancement and Conservation of National Environmental Quality Act, 1992 which is referred to as the umbrella act (Henderson *et al.*, 2018). From umbrella act, Thailand developed Ministry of Natural Resources and Environment Pollution Control Department, which sets piggery effluent standards as well as pig farm inspection procedure. The Public Health Act, 1992 authorises the government of Thailand to close piggeries that are violating environmental regulations and pose health hazards to humans and the environment (Khan & Ghouri, 2011).

Knight (2019) indicates that New Zealand uses the Resource Management Act, which repealed a number of earlier acts, in use since 1867 and have been changing. According to Knight (2019), even though the Resource Management Act proved to be effective in bringing point source discharges under control, the challenges of water pollution in the country will not be solved by a change in legislation. A change in mind-set is required to win the fight against water pollution in water quality challenges in New Zealand (Knight, 2019).

Like most countries, agricultural activities are increasing in South Africa, which may threaten water resources (Mofokeng *et al*., 2016). Pollution can have serious consequences on the environment, with negative impact on the aquatic life, from micro-organisms to insects, birds, and fish, and at the same time, and may also affect the health of terrestrial animals and plants (Pachepsky *et al*., 2006). A study that was conducted by Mofokeng *et al.* (2016) analysing the seepage from a pig farm in Agricultural Research Council, Pretoria concluded that seepage from the pig farm indeed degrades the quality of water resources by causing eutrophication, promoting toxic and algal blooms, increasing BOD and thus destabilizing the homeostatic balance of the receiving environment. The NWA is used for managing activities that have a potential to negatively impact the water resources. Different water uses are explained under Section 21 of the NWA, and indicated in **Table 1-1**, above. In terms of the National Environmental Management Act, 1998 (Act No. 107 of 1997) (NEMA), the owner of the piggery is required to obtain environmental authorisation prior to operation. The National Environmental Management: Waste Act No. 59 of 2008 (NEMWA) requires that any activity that is likely to have a detrimental effect on the environment obtain a Waste Management Licence (WML). A decision may be taken by the Department of Water (now DWS) and the Department of Forestry, Fisheries and the Environmental Affairs (DFFE) whether to issue only a Water Use Authorisation incorporating waste management conditions or vice versa. Depending on the size and the impact caused by the piggery on the environment, a General Authorisation (GA) or a Water Use Licence (WUL) will be required to be applied for by the facility owner.

The operation of such activities without an authorisation is regarded as unlawful and the facility owner may be liable to imprisonment or a fine as stipulated in Section 151 of the NWA. Unlawful activities are dealt with by the Compliance, Monitoring and Enforcement (CME) Directorate of the DWS.

3.7 Chapter Summary/Conclusion on Literature Review

Different countries agree that freshwater resources [that can be used without treatment] are declining and water pollution has been steadily worsening in most parts of the world, even though the water use efficiency has substantially increased (Fujii & Managi, 2017). Different countries also share the same observation regarding piggery effluent that it has a negative impact on water resources due to the large amount of waste produced by pigs, discharged into water resources and having a pungent odour (Girard *et al*., 2009). Water quality seems to be a looming challenge for most parts of the world because of effluent discharged into water resources. From the literature, it is clear that the impact of piggery effluent on water resources is a universal one.

In most countries, an anaerobic pond system is regarded as the most used and effective method to treat piggery effluent. Treated effluent is therefore discharged into water resources and/or used for irrigation on farmland whilst solids are used as manure on agricultural fields. The discharge of untreated piggery effluent to water resources increases chances of deoxygenation, which results in eutrophication (Hickey *et al*., 1989).

The literature review indicated that discharging piggery effluent into the water resource has a negative impact to the environment, humans, and aquatic life. According to Girard *et al.* (2009) livestock is regarded as high water consumers and promotes effluent that is high in organic loading and has high organic content wastewater. The piggery effluent is classified as having high loading compared to other livestock and requires to be improved to protect water resources and human health (Girard *et al*., 2009).

The interesting part is that pigs, like other livestock, are more resilient to poor water quality compared to humans (Mosoa, 2013). In addition, livestock easily adapt to a change of water quality from good to poor (Mosoa, 2013). The water quality and macro-invertebrates will therefore assist in the analysis to determine the health of the Inhlavini and uMkhomazi rivers.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The visual observation done during the February 2020 sampling was that the water in the uMkhomazi River was brown because of flooding. The upstream monitoring point of Inhlavini River (IU) was reddish in colour which reflected the geology of the area and possibly because of small scale sand mining upstream of the monitoring point. The Impact and downstream monitoring points (II and ID) of the Inhlavini River were both greyish in colour.

In July 2020, the uMkhomazi River at the upstream monitoring point was very clear whilst the uMkhomazi downstream was clear to greyish. There was a little change in the colour on the uMkhomazi River between UU and UD. The IU site was observed to have muddy pools, with clear water in areas where water was seeping through. Livestock was noted grazing and some reaching to the stream for drinking purposes. Residents of the Inhlavini area were observed collecting water from the Inhlavini River for domestic use.

During October 2020 monitoring, the uMkhomazi River was very clear at both UU and UD sites. Water levels within the system were lower than usual and some stones were exposed. The Inhlavini River had not been flowing again as noted during the July 2020 monitoring schedule. IU and II sites had a trickle amount of water with very shallow pools, whilst ID was completely dry.

4.2 Water Quality

Temperature for Inhlavini and uMkhomazi Rivers

Water temperature for the Inhlavini River ranged between 23.3°C and 24.4°C during the February 2020 monitoring, between 8°C and 15°C during the July 2020 monitoring schedule and between 24.7°C and 27.3°C during October 2020 (**Figure 4- 1**). Temperature for the uMkhomazi River ranged between 20.5°C and 21.0°C during the February 2020 monitoring, between 14.8°C and 16°C during the July 2020 monitoring schedule and between 24.4°C and 26.1°C during October 2020. The relative change in temperature was due to different times of the day for sampling as the first point monitored in the morning and the last monitoring point being monitored in the late afternoon. Both the wet seasons' temperatures were higher than the dry seasons' temperature. This can be attributed to wet seasons being hot season and dry season being winter and cooler season. The temperature for the Inhlavini River was also higher than the temperature of the uMkhomazi River which can be attributed to the Inhlavini River being smaller with limited water compared to uMkhomazi River which is bigger and a having large volume of water.

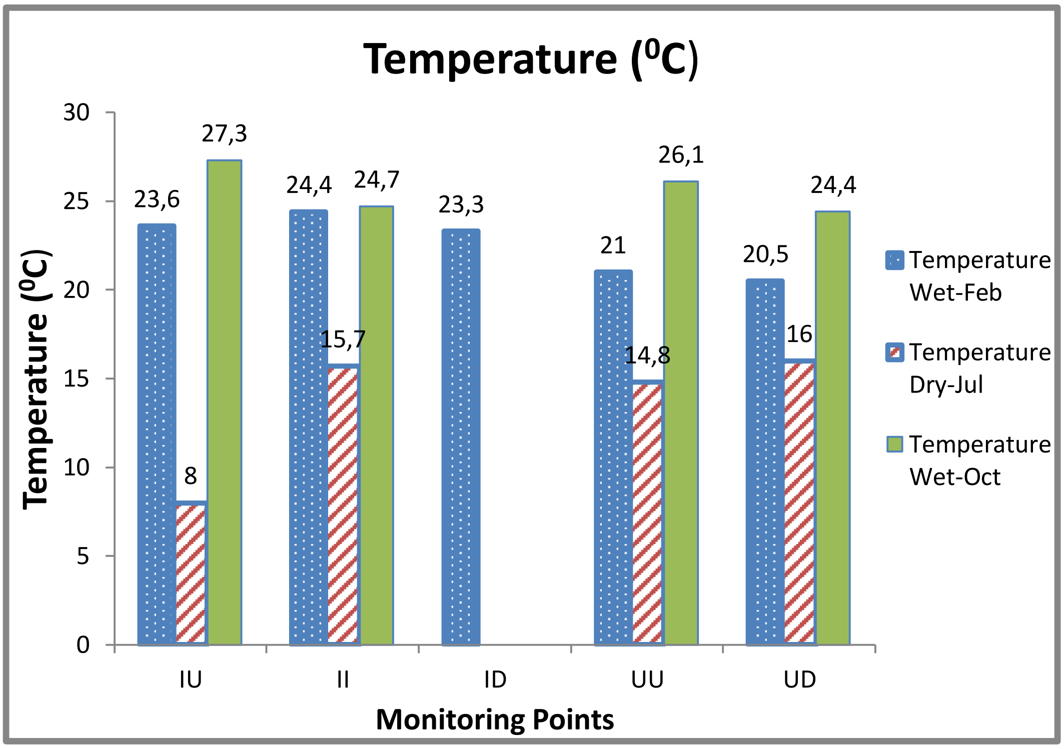

Figure 4- 1. Temperature of Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

There was a slight change in temperature between UU and UD. It was noted that temperature at UU was a slightly higher compared to the UD. This change was observed for February 2020 and October 2020 monitoring schedule (which are both wet seasons) whilst vice versa was noted during the dry season in July 2020. The same pattern was observed at the Inhlavini River, as temperature was higher at the IU and decreases as the river meanders downstream for October 2020 monitoring schedule. During February 2020 and July 2020, temperature was increasing as the Inhlavini River meanders down. It must be noted that even though change was noted, the difference was relatively small.

The slight change in both Inhlavini and uMkhomazi rivers is attributed to the time of the day when the temperature was recorded. The location of monitoring points also affected temperature as some monitoring points are located within forested areas (i.e., II) which provides for cooler conditions. The change in temperature impact on aquatic organisms as colder water dissolve oxygen and warmer waters hold less oxygen for aquatic organisms to survive compared to cold waters (Butcher & Covington, 1995).

pH for Inhlavini and uMkhomazi Rivers

The pH for the wet season in February 2020 for Inhlavini and uMkhomazi Rivers ranged between 6.7 and 7.4, dry season in July 2020 ranged between 7 and 7.5 and wet season in October 2020 ranged between 7.9 and 8.7 (**Figure 4- 2**). The pH values for all three surveys ranged between 6.7

and 8.7, which is acceptable in terms of general limits as per GA for discharge into the water resources which is 5.5 and 9.5 (NWA, 1998; Hansen, 2015). The pH for the South African Water Quality Guidelines should be between 6.0 and 8.0 for Aquatic Ecosystems. For the Aquatic Ecosystems limits, the UU, UD and IU monitoring points slightly exceeded the upper limit which is 8 during the October 2020 monitoring schedule. A slight non-compliance for the UU was observed for Irrigation and livestock watering limits (DWAF, 1996). The pH of the Inhlavini and uMkhomazi is within acceptable levels for the requirements of water uses as it is close to neutral for both seasons. The pH was noted following a slight pattern of increasing from February 2020 to October 2020. The trend was noted in all four monitoring points i.e., IU, II, UU and UD. It can thus be assumed that the ID would have followed the same pattern if it were not dry. This is attributed to the water levels within both Inhlavini and uMkhomazi rivers and limited dilution therein. As much as October was a wet season, rains had not been intense hence the Inhlavini River was still not flowing. The pH limits for aquatic ecosystems between 6 and 8, however, IU, UU and UD for the wet season in October 2020 exceeded this limit. The literature indicated that small change may not affect humans and organisms whilst big change in pH may cause irritation of eyes when swimming (Mosoa, 2013). In terms of water for domestic use, no negative effects may be associated with only pH, except for change in taste (DWAF, 1996).

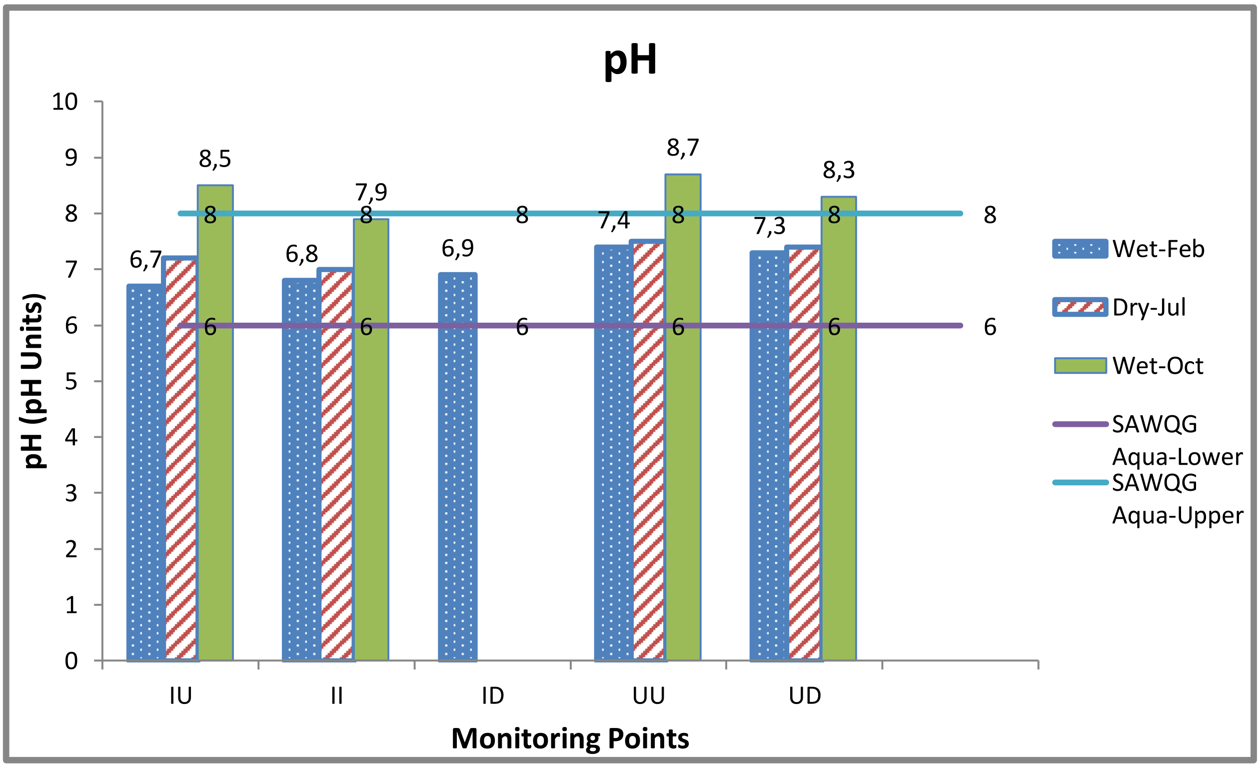

Figure 4- 2. pH of the Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Percentage Oxygen Saturation for uMkhomazi and Inhlavini Rivers

The percentage of oxygen saturation ranged between 49% and 120.3% for the Inhlavini River and 7.97% and 99.5% for the uMkhomazi River (**Figure 4- 3**). Low levels of saturated oxygen were noted during the dry season (July 2020) as it ranged between 49% and 82%. During the wet season (February 2020) levels ranged between 56.4% and 92.3%. Aquatic life depends on oxygen that is dissolved in the water for survival and the acceptable percentage of saturated oxygen is between 80% and 120% (DWAF, 1996). Eutrophication may thus result in high (during the day/photosynthesis) and very low (at night) oxygen saturation; which may then negatively affect aquatic ecosystem if it increases continuously (DWAF, 1996; Ukiwe & Ogukwe, 2007).

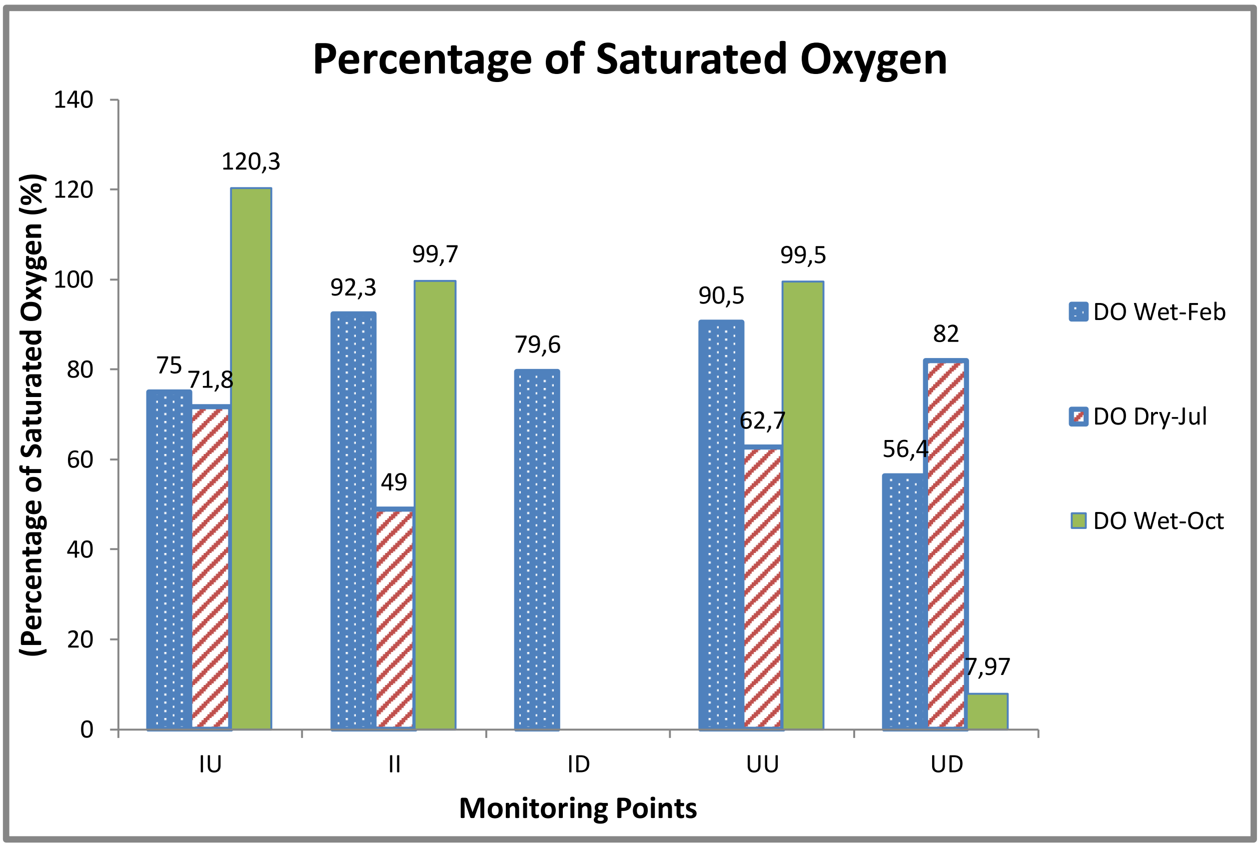

Figure 4- 3. Percentage of saturated oxygen for both Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Electricity Conductivity (EC)

Electrical conductivity (EC) in the Inhlavini River was mostly within the acceptable levels as according to South African Water Quality Guidelines for Domestic use (DWAF, 1996), except for the II site, which was slightly above. The highest levels of EC were recorded at the II site for all three sets of monitoring, which were between 70.7 mS/m and 73.7 mS/m during both wet and dry seasons (**Figure 4- 4**). In the Inhlavini River, EC values were much higher compared to the EC values of the uMkhomazi River. The impact was noted at the II but the decrease at the ID was also noted. The EC levels at the uMkhomazi River were very low (i.e., between 5 mS/m and 21.8 mS/m). It was noted that the UD had higher levels of EC compared to UU in both wet and dry seasons. The EC seem to increase slightly from February 2020 to October 2020 at four monitoring points, where sampling was done. It could then be assumed that similar trend would have happened at ID. Such increase in EC could be ascribed to decrease in water levels due to low rainfall – thus limited dilution. The Inhlavini River appears to have higher impact than uMkhomazi River; however, the impact is still not significant in terms of South African Guidelines for Domestic Use. Elevated EC values can cause unpleasant taste and also can affect the functioning of kidneys (DWAF, 1996).

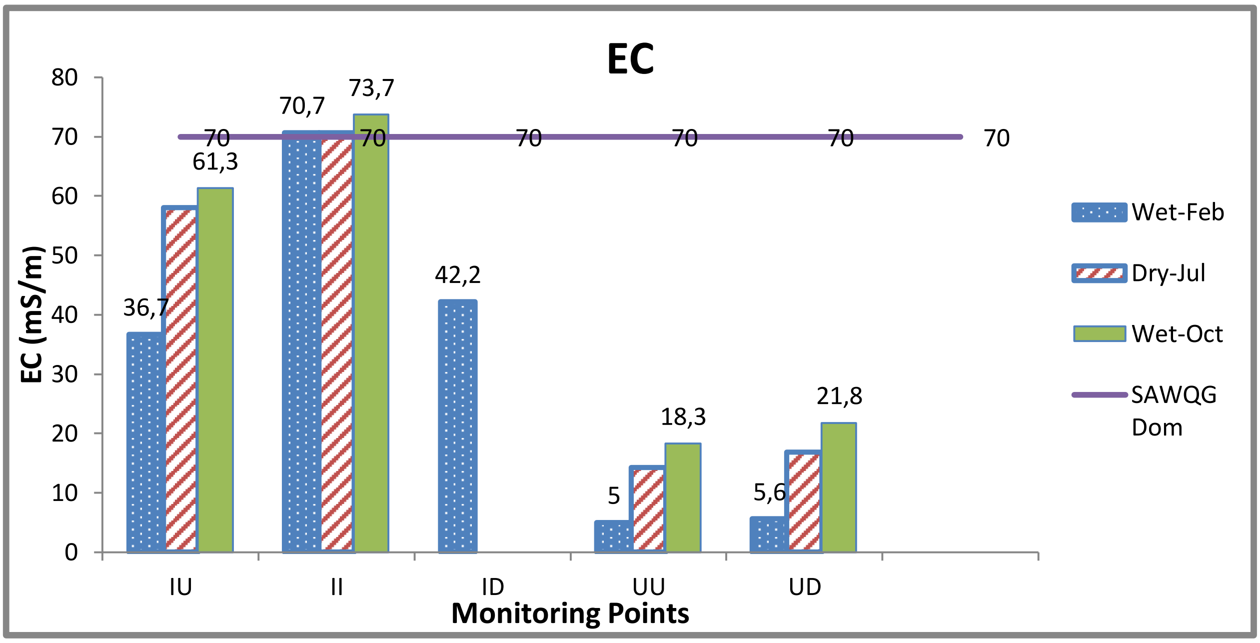

Figure 4- 4. Electrical conductivity of Inhlavini and uMkhomazi rivers recorded during the February, July and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Total Dissolved Solids (TDS)

Higher levels of total dissolved solids (TDS) were observed in the Inhlavini River compared to the uMkhomazi River, which was expected when observing the EC levels on both Inhlavini and uMkhomazi rivers. The TDS ranged between 177 mg/L and 345 mg/L (during wet seasons) and between 267 mg/L and 327 mg/L (during dry season) for Inhlavini River; whilst for uMkhomazi River, it ranged between 23 mg/L and 98 mg/L (during wet seasons) and between 65 mg/L and 74 mg/L (during the dry season) (**Figure 4- 5**). There was a slight decrease in TDS from the II towards ID. A slight increase for TDS was observed at all four monitoring points from February 2020 to October 2020 except for II and ID. It is anticipated that lower levels of TDS would have been recorded at the ID if the monitoring point were not dry would have been also following the same trend. A slight increase in TDS from the UU to UD was noted. There was also an increase in TDS on both Inhlavini and uMkhomazi rivers from February 2020 to October 2020 monitoring schedule. This slight increase can be attributed to low water levels which result in low dilution.

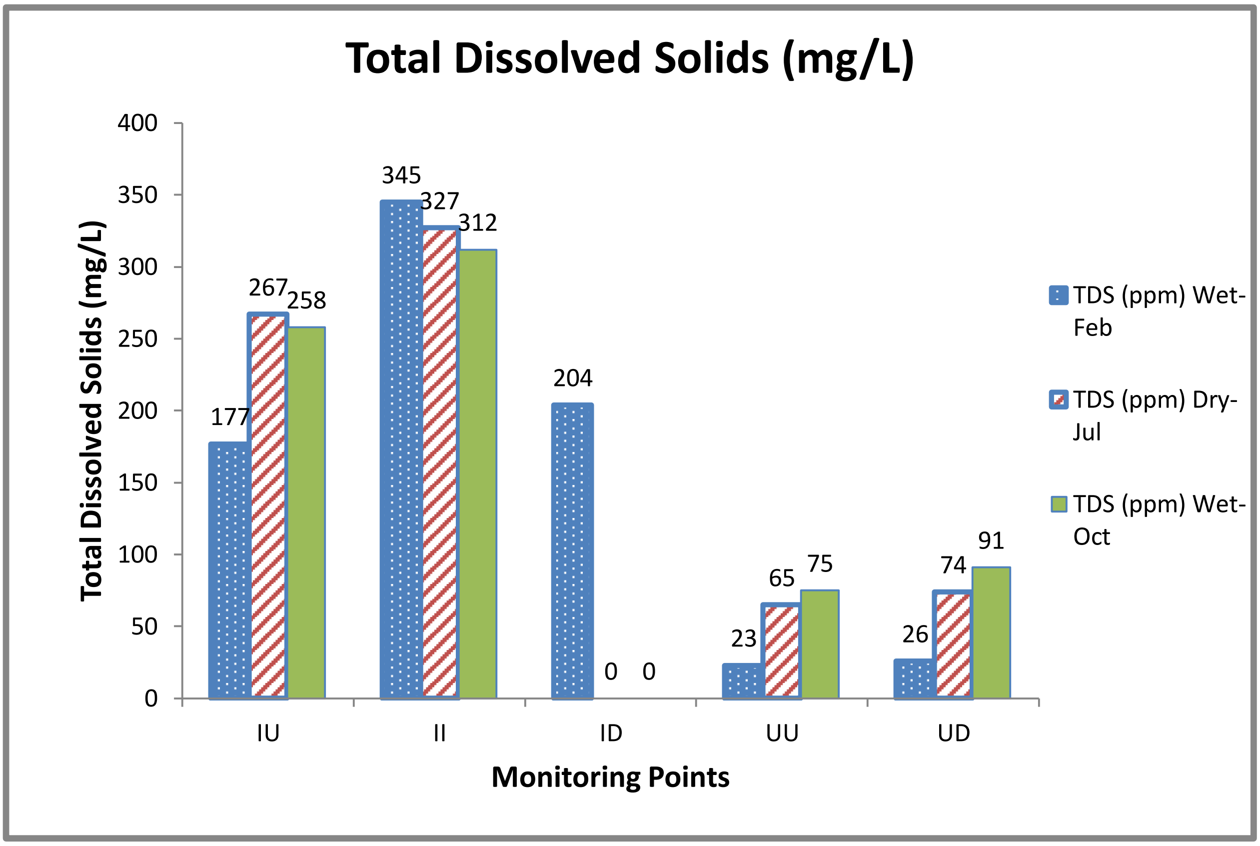

Figure 4- 5. Total Dissolved Solids (TDS) of the Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) in the Inhlavini River was slightly higher compared to the COD in the uMkhomazi River (**Figure 4- 6**). A spike of COD at IU was noted during October 2020 monitoring compared to COD levels analysed during February 2020 and July 2020. The COD levels at the II were slightly higher compared to ID during February 2020 monitoring. COD in the Inhlavini River during the dry season monitoring was low ranging between 12 mg/L and 16 mg/L. COD levels in the uMkhomazi River ranged between 7 mg/L and 20mg/L for both wet and dry seasons.

On the uMkhomazi River, the same pattern of a slight increase as the river meanders downstream was observed on both wet and dry seasons. The acceptable general limit for COD for discharging treated effluent into water resources is 75 mg/L. The South African Water Quality Guidelines for Domestic Use, Aquatic Ecosystem and Agricultural Use does not have limits for COD. Levels of COD were observed to be lower during the dry season schedule compared to both wet seasons monitoring schedules. It is understood that general limits are applicable for discharge into the water resource however it was used as an indication as South African Guidelines does not contain COD levels. Levels of COD were all very low except for that one odd COD analysis during October 2020 monitoring schedule, where the II was recorded at 94 mg/L. The high levels are attributed to stagnant water and pools as were noted during October 2020 monitoring schedule. Levels of COD on the uMkhomazi River were lower than that of the Inhlavini River. At the IU, COD levels also appeared to be slightly higher compared to the II which could be due activities (such as cattle grazing, sand mining, etc.) upstream of the II site. Higher values of COD cause a decrease in DO which creates anaerobic conditions in the system (DWAF, 1996).

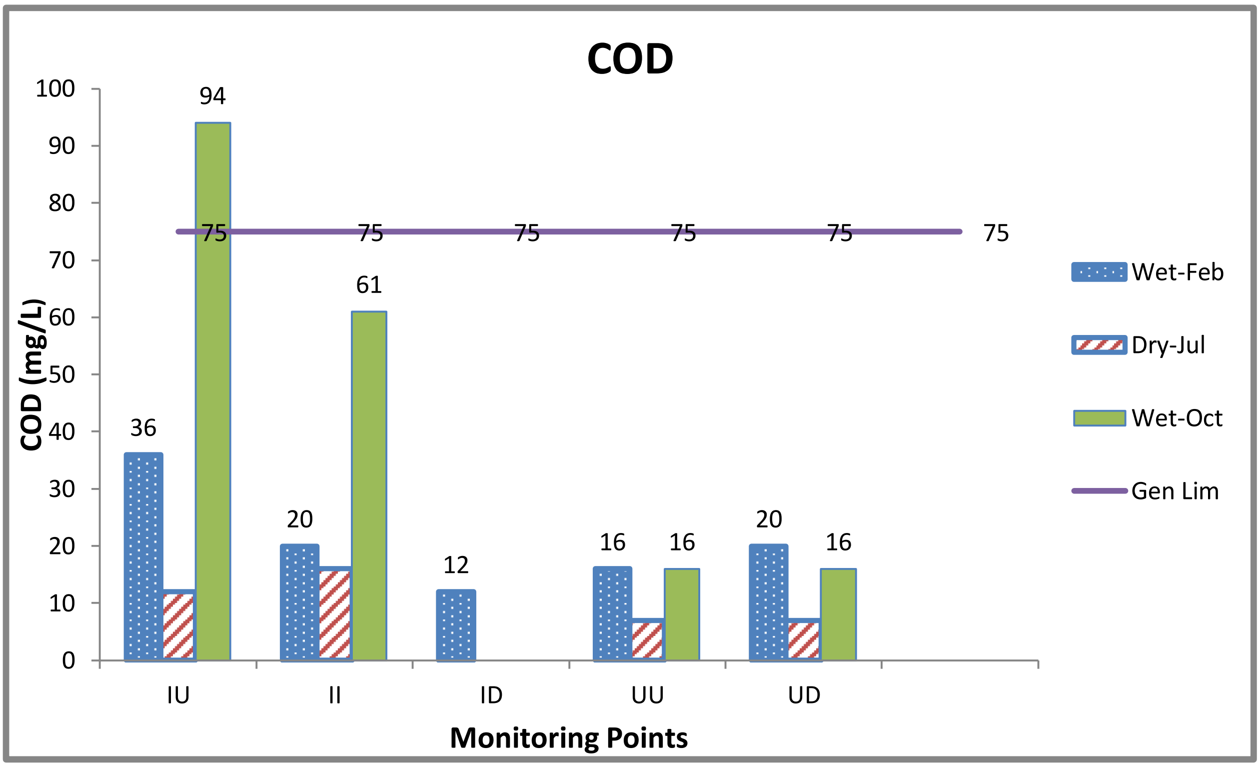

Figure 4- 6. Chemical Oxygen Demand for Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Nitrates and Nitrites

Nitrates and nitrites at the Inhlavini River were noted to be low at all monitoring points except for one odd incident at IU during October 2020 monitoring schedule (1.58 mg/L). This unusual level could be associated with cattle grazing and agricultural activities upstream of the control point. High levels of nitrates and nitrites could also be due to sewage and agricultural activities near Ixopo. Nitrates and nitrites ranged between 0.04 mg/L and 0.23 mg/L during both wet and dry seasons except that one spike indicated above (**Figure 4- 7**). The mentioned spike is also very low when comparing with the limit for South African Water Quality Guidelines for Domestic Use (DWAF, 1996). Nitrates and nitrites levels were also low on the uMkhomazi River compared to that recorded at the Inhlavini

River. A slight increase from UU to UD during October 2020 monitoring was observed. It must be noted that despite the spike, all five monitoring points were found to be below South African Water Quality Guidelines for Domestic Use which is 6mg/L (DWAF, 1996). The limit for agricultural use, specifically livestock watering, is between 100 mg/L and 250 mg/L. The nitrates and nitrites were compliant for South African Water Quality guidelines for Agriculture, Domestic, Ecological use and Recreational use (DWAF, 1996). Nitrates and nitrites were noted to be relatively higher in the dry season compared to the wet seasons even though the levels are still within the limits. The II site was noted to have very low nitrates and nitrites levels. Slightly higher levels at the IU are associated with cattle grazing and drinking at the monitoring point especially during October 2020 where the dilution was limited due to low flow. Nitrates and nitrites recorded were within acceptable limits and as a result cannot cause negative impact when water is used for domestic purposes. It is also indicated that high nitrates and nitrites could cause anaerobic conditions which may result in loss of aquatic life and algae growth in water resources (Chapman, 1996). Intake of nitrates and nitrites could be hazardous to infants under three years old and could cause irritation of mucous membrane when recorded above 20 mg/L (DWAF, 1996). A case study that was conducted in Eskopazar (Karabuk, Turkey) indicated that nitrates pollution reduces oxygen levels in blood and can cause blue disease (methemoglobinaemia) (Keskin, 2010). The case study also revealed that babies under the age of six years are at risk as lack of oxygen as a result of nitrate intake causes difficulties in breathing (Keskin, 2010).

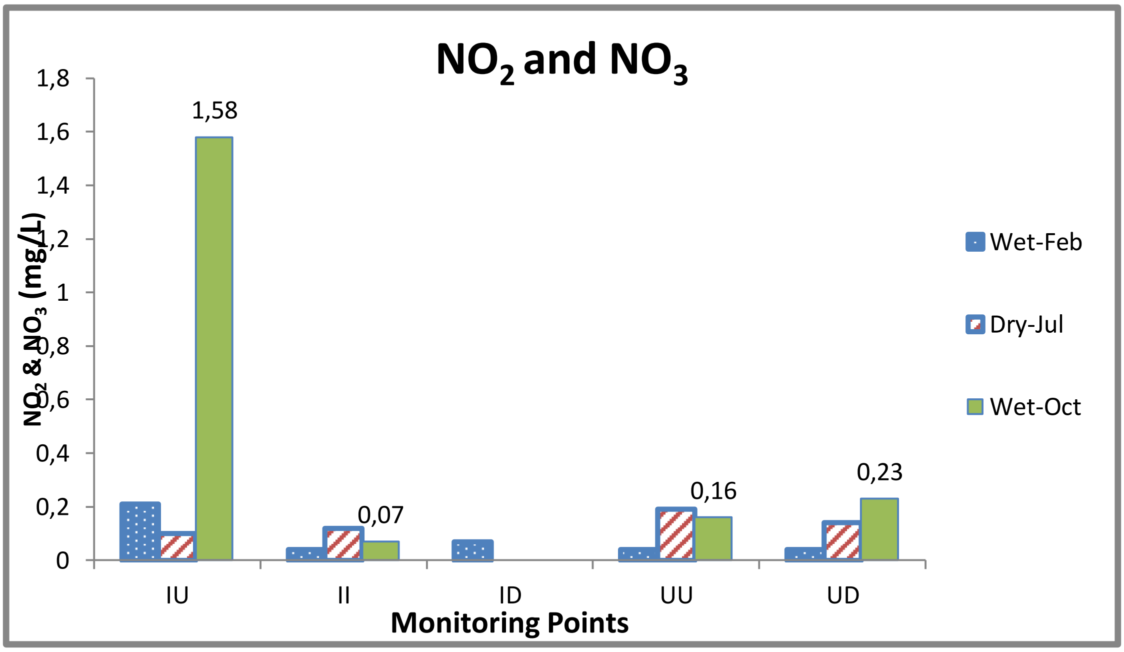

Figure 4- 7. Nitrates and Nitrites of the Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Suspended Solids

During the wet season in February 2020, at the IU, water was reddish in colour and suspended solids (SS) were recorded at 260 mg/L. Suspended solids were noted to be decreasing as the Inhlavini River meanders downstream. At the II, the SS levels dropped and picked up again at the uMkhomazi River. In February 2020, the uMkhomazi River was flooding and water was brownish in colour and SS levels were expected to be high. Suspended solids at the II were low due to gentle slope associated with II. The II is bounded with valleys and the area is flat and meandering; the II is associated with wetland systems. This assist in filtering the system and as a result SS values were low at the II and ID. The high SS levels at IU is associated with sand mining activities, and also trampling by both cattle and humans (fetching water and also children swimming) at this reach of the Inhlavini River. The uMkhomazi River was clear during the dry and wet seasons (July 2020 and October 2020) (**Figure 4- 8**) which is associated with low levels of SS within the system. The acceptable level for SS for South African Water Quality Guidelines for Domestic Use is 25 mg/L. February 2020 monitoring schedule revealed that all five monitoring points were non-compliant for Domestic Use. For the dry season (July 2020), only the Inhlavini Upstream Monitoring Point was non-compliant whilst all other four monitoring points were compliant. The October 2020 monitoring results were compliant except for a slight increase at the IU. Suspended solids have been indicated to be the cause of water quality deterioration which as a result causes a number of issues including aesthetic issues, a decline in fisheries as well as ecological degradation of aquatic ecosystem (Kirk, 1985). High SS levels were noted for the uMkhomazi River and for the IU during wet season, which may cause challenges such as clogging of gills of aquatic biota (Cavanagh & Harding, 2014). It should be noted that many of South African rivers are naturally more turbid during the wet season due to the underlying geology. The higher SS levels in international literature commonly refers to other sources such as increases in algae etc.

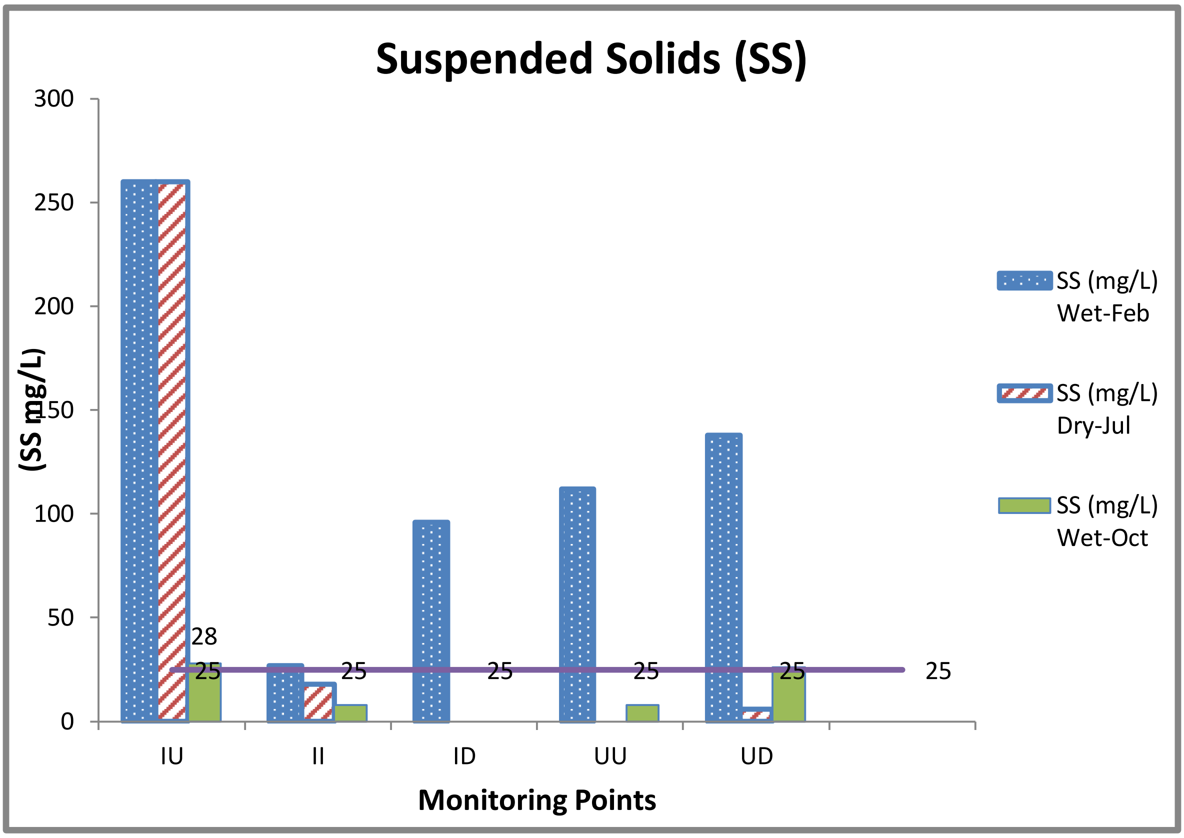

Figure 4- 8. Suspended Solids for Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Faecal Coliforms

Faecal Coliforms of the Inhlavini River ranged between 4 per 100 ml and 248 per 100 ml in both wet and dry seasons. At the II, 4 per 100 ml of faecal coliforms were recorded in February 2020 and 51 per 100 ml in October 2020. The lower levels of faecal coliforms at II are associated with rainy season and the delay in sampling the site i.e., between October 2019 and February 2020, when the discharge ceased. It can also be noted that the Inhlavini River is managing to rehabilitate itself from the piggery effluent. The highest was recorded at the IU at 248 per 100 ml for February 2020 which was the only spike compared to all five monitoring points during both seasons (**Figure 4- 9**). The possible explanation for this is the presence of activities that may contribute to such (i.e., poor sanitation services, cattle, etc.). The uMkhomazi River recorded the highest of 4 per 100ml and 13 per 100 ml during the wet seasons (February 2020 and July 2020 respectively). The Inhlavini River recorded higher values of Faecal Coliforms compared to uMkhomazi River. During the dry season monitoring (July 2020), the highest that was recorded at UD was 23 per 100 ml. In February 2020 and July 2020, there was a slight increase from the UU to UD in October 2020; there was a decrease from the UU to UD.

Water quality results were interpreted against South African Water Quality Guidelines for Domestic use, which is set at 100 per 100 ml. As for Domestic use, the IU was non-compliant for February 2020 (wet season). All other monitoring points were compliant with domestic use for both wet and dry season. For Agricultural Livestock Use, Faecal Coliforms were noted to be within acceptable levels as it is set between 200 and 600 per 100 ml (DWAF, 1996). As for recreational full contact, it was also complied with and non-compliant for intermediate contact. Intake of faecal coliforms above 100 mg/L may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera, and typhoid fever (DWAF, 1996).

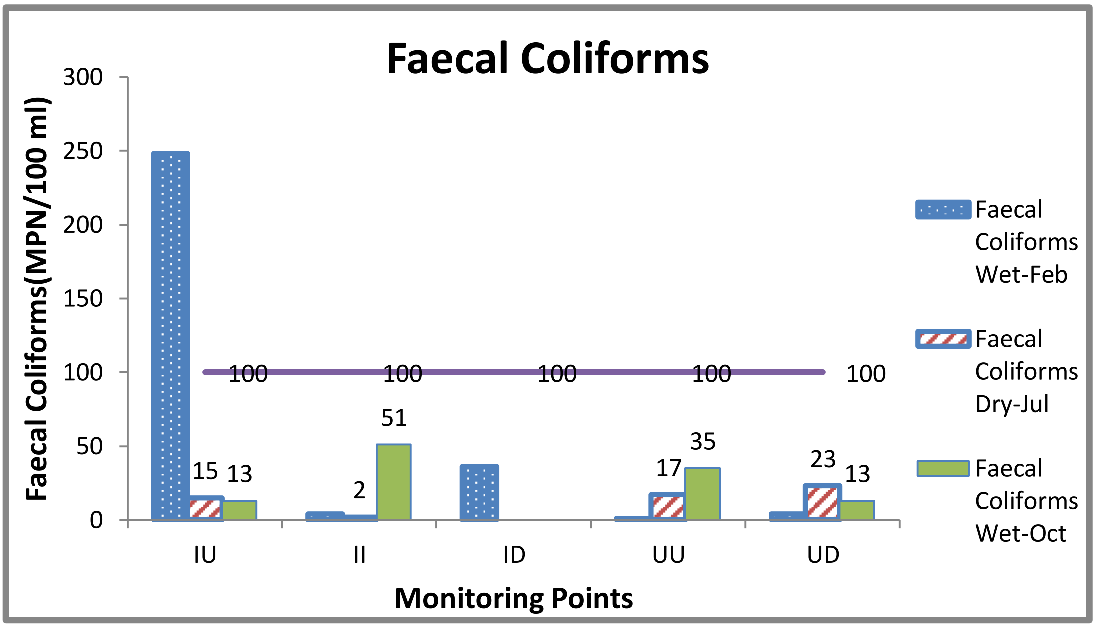

Figure 4- 9. Faecal Coliforms of the Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Escherichia coli (E. coli)

Escherichia coli (E. coli) are not indicated on any of the above South African Water Quality Guidelines. The variable that is used is Faecal Coliforms which also includes the *E. coli*. For the purpose of this study, the *E. coli* was also analysed in order to determine whether Piggery X and associated infrastructure were negatively affecting the Inhlavini River. The highest level of *E. coli* was recorded at the IU at 96 per 100 ml during wet season (**Figure 4- 10**). The II recorded 0 to 42 per 100 ml levels of *E. coli* during wet and dry seasons. The *E. coli* levels on the uMkhomazi River were not detected in February 2020 and very low levels were detected during the dry season. Both the Inhlavini and uMkhomazi Rivers recorded very low levels of *E. coli* counts. It can be concluded that no intentional discharge of human waste was noted on both Inhlavini and uMkhomazi rivers.

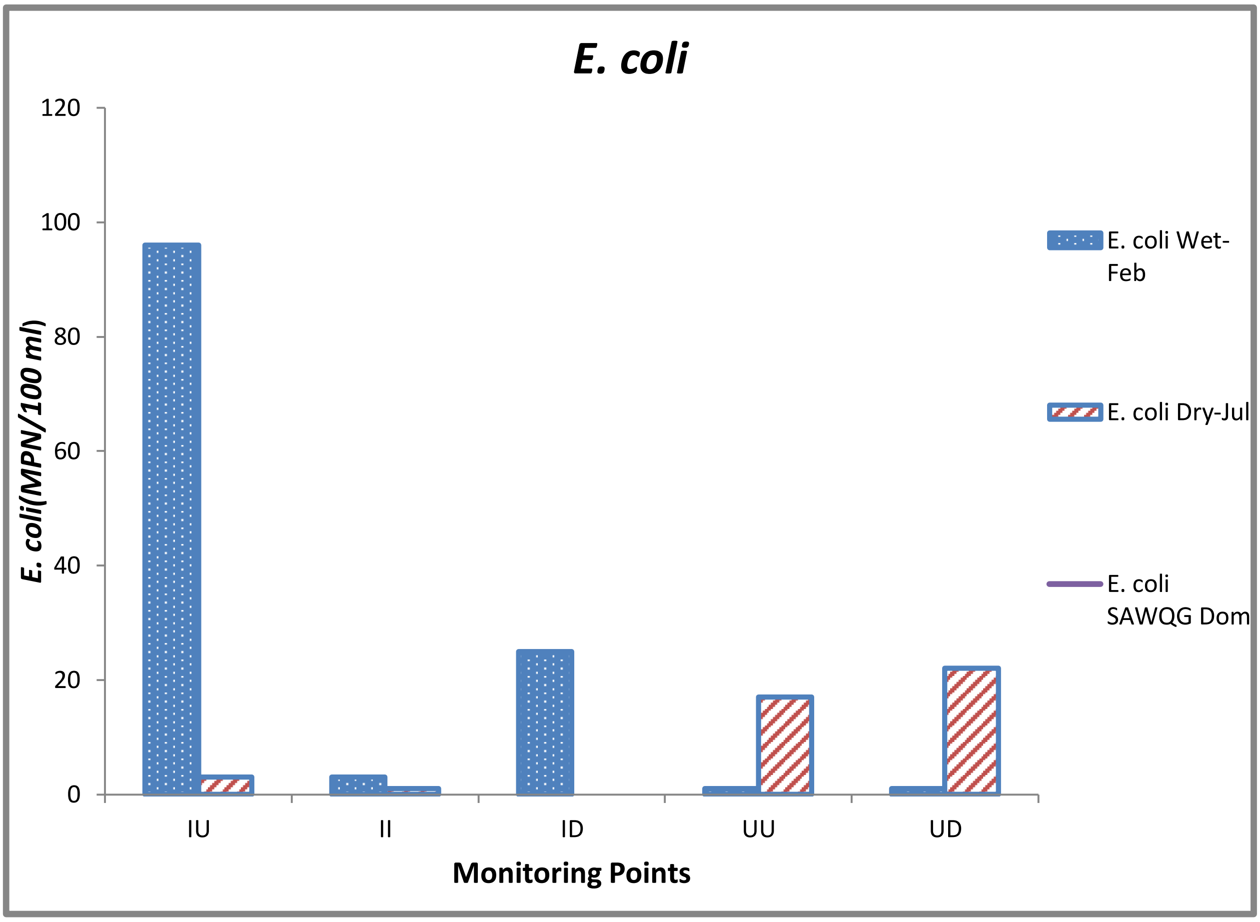

Figure 4- 10. *E. coli* on the Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Phosphates

The orthophosphates were analysed for both the Inhlavini and uMkhomazi rivers. It was observed that orthophosphate levels were mostly recorded below 0.04 mg/L detection limit during both wet and dry seasons (**Figure 4-11**). Slightly higher levels were noted during the wet seasons where 0.2 mg/L was recorded at the IU and 0.12 mg/L at UD. The II did not indicate elevated levels and the levels remained lower downstream of the Inhlavini River. This could be attributed to the fact that the discharge of piggery effluent ceased four months ago. In addition, the site is located within the wetland riverine system which might have assisted with the filtration of water at II site. A slight increase was observed in orthophosphate levels between UU and UD.

The orthophosphates analysed were in compliance with the GA discharge general limits. The orthophosphates values are not indicated in the Water Quality Guidelines (Agriculture, Domestic) however, with the exception of Ecological Use. The guidelines refer to phosphorus which requires to be less than 5mg/L for aquatic ecosystem (DWAF, 1996). The IU recorded at 0.2 mg/L. It must be noted that phosphates are an indicator for inorganic nutrient contamination.

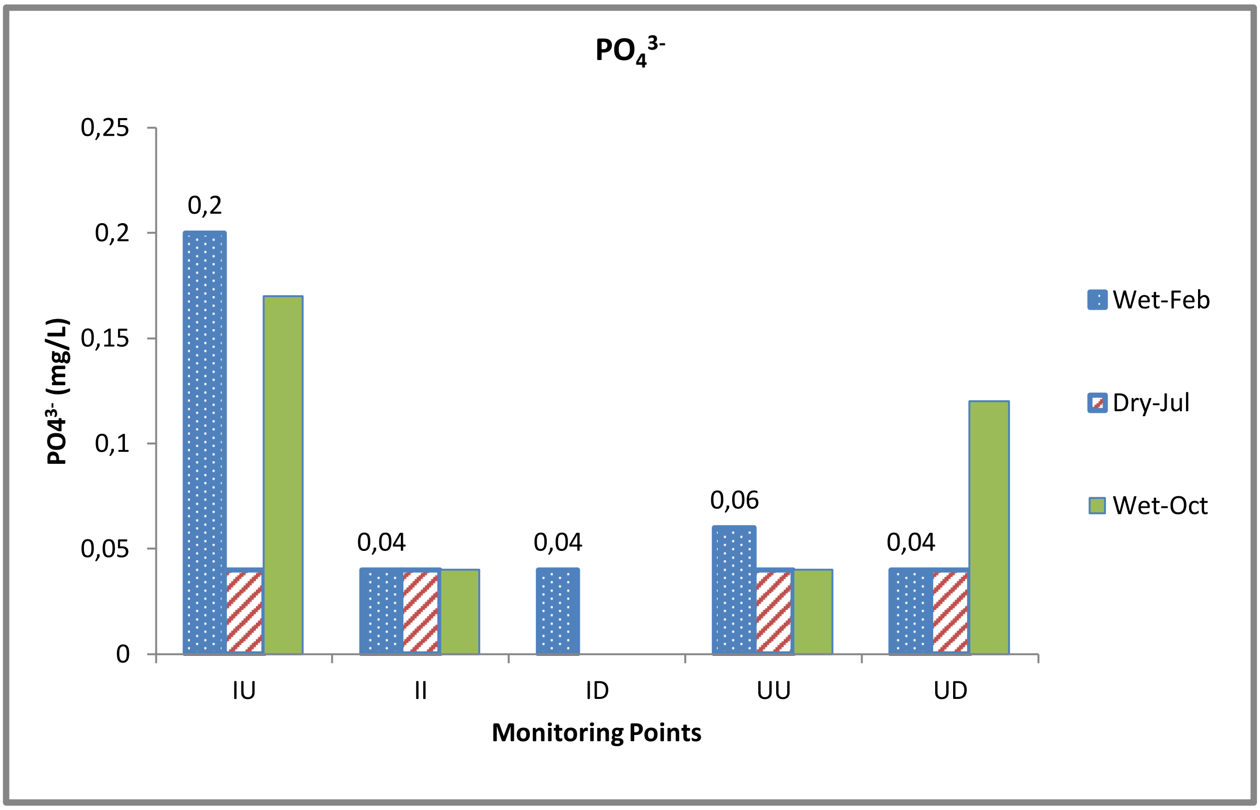

Figure 4- 11. Orthophosphates for Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Potassium

Levels of potassium on both Inhlavini and uMkhomazi rivers were recorded between 0.94 mg/L and 5.54 mg/L during both wet and dry seasons (**Figure 4- 12**). Potassium in the Inhlavini River is three to five times higher than the values analysed for the UMkhomazi River. The highest level, which is 5.54 mg/L, was recorded for the II which is slightly higher than 4.94 mg/L analysed for the IU. A slight decrease is noted at the ID. The levels of potassium in the Inhlavini River decreases as the river meander into the UMkhomazi River. This could be attributed to wetland riverine system as the Inhlavini River meanders into the uMkhomazi River. The lowest value (less than 1 mg/L) was recorded for the UD. It was also noted that the there is a slight increase from the UU to the UD. During the October 2020 monitoring, a decrease from the UU to UD was recorded. The agricultural impact from the upstream of the Inhlavini River is indicated on the IU. The impact as a result of the discharge from the Piggery X is also noted at the II as potassium levels slightly increases. All recorded for potassium levels in all three monitoring points were far below 50 mg/L which is set as under South African Water Quality Guidelines for Domestic Use. Potassium intake at high concentrations imparts a bitter taste and also has been indicated to cause nausea and vomiting (DWAF, 1996).

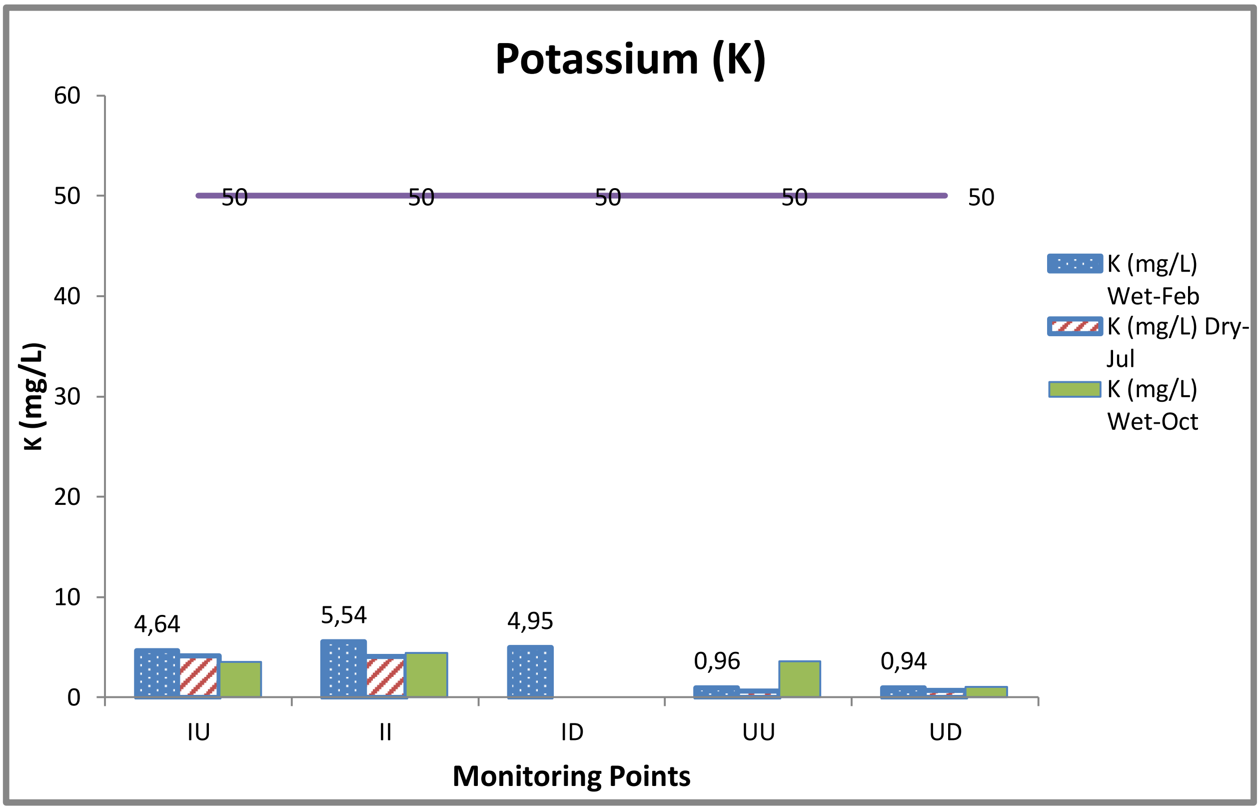

Figure 4- 12. Potassium for Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

Copper

The copper concentrations for both rivers, Inhlavini and uMkhomazi, were found to be very low. At all five monitoring points, copper levels were well below the general limits for discharge of effluent into the water resource (which is set at 0.01 mg/L); with the highest concentration of 2.108 µgCu/L (recorded for II during dry season) (**Figure 4- 13)**. The South African Water Quality Guidelines for the Domestic Use requires the Cu limits to be at a maximum of 1 mg/L. The measured levels were thus far below the limit. All three monitoring points at Inhlavini River and two on the uMkhomazi River were therefore below the general limits and South African Water Quality Objectives for Domestic Use and Irrigation Livestock. It was observed that levels of copper were slightly higher during July 2020 and October 2020, where water levels were low compared to February 2020 monitoring where water levels were high. Despite the increase noted above, the levels for copper were extremely low in both Inhlavini and uMkhomazi rivers. The intake of Cu below 1 mg/L does not have negative effects; however, between 30 mg/L and 200 mg/L it causes nausea and vomiting as well as staining problems (DWA, 1996).

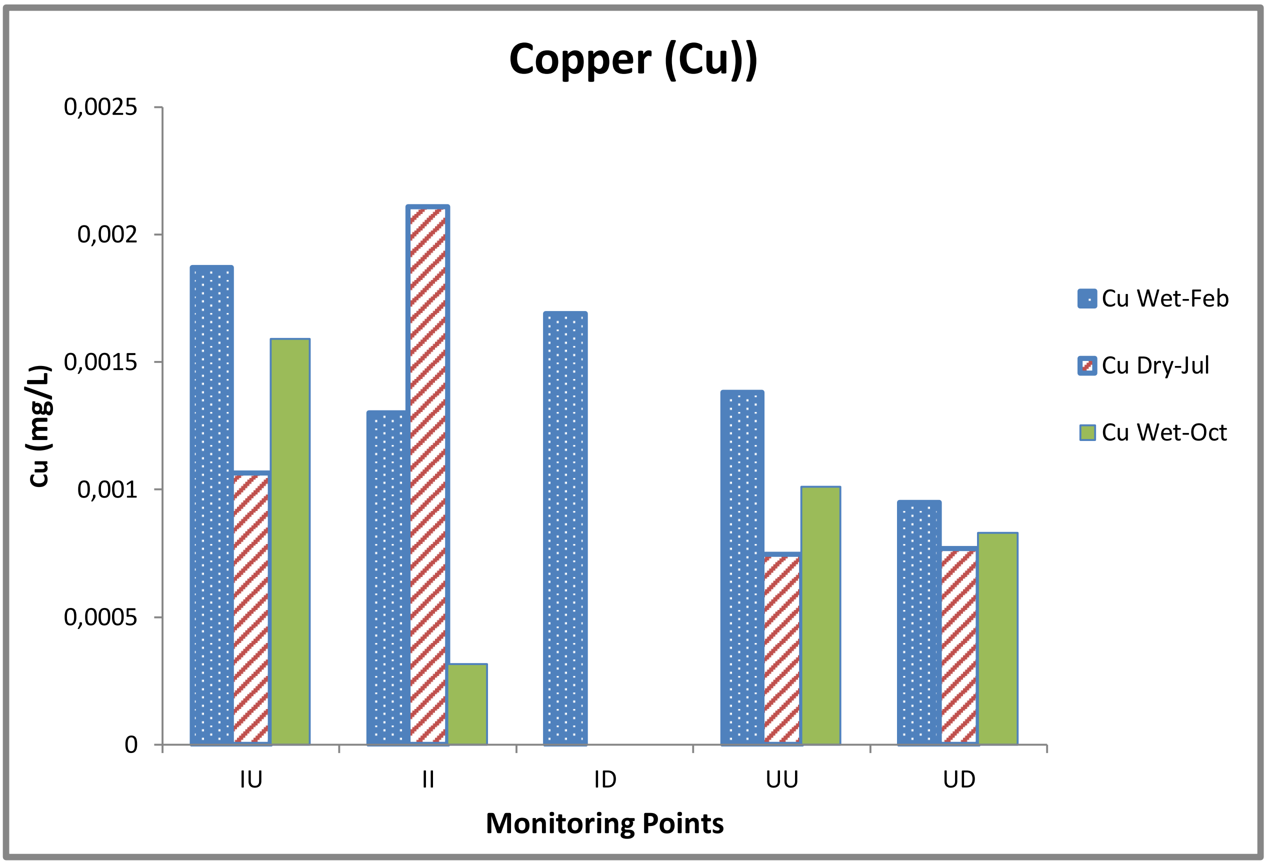

Figure 4- 13. Copper on Inhlavini and uMkhomazi rivers recorded during the February, July, and October 2020 sampling. **IU** = Inhlavini Upstream site; **II** = Inhlavini Impact site; **ID** = Inhlavini Downstream site; **UU** = uMkhomazi Upstream site, and **UD** = uMkhomazi Downstream site.

4.2.1 Water Quality Challenges

The study area is dominated by agriculture and has several tributaries emanating from undeveloped areas which results in high turbidity, salts and microbial contamination due to erosion from agricultural fields, sewage discharge from Ixopo town, and sand mining. The impact of agriculture specifically erosion is observed as there was an increase in turbidity on the Inhlavini and uMkhomazi rivers during wet season. The small scale mining (sand) also adds to turbidity of the Inhlavini River. The Ixobho River has sewage related challenges due to ageing sewerage infrastructure in the area and releases sewage into the Ixobho River, a tributary of the Inhlavini River. Turbidity in the uMkhomazi River will cause sedimentation challenge in the upcoming dams. The upstream of the uMkhomazi River is also dominated by the agricultural activities. Salts from pesticides and herbicides are expected to increase due to impacts within the study area. The uMkhomazi River has a number of tributaries upstream of the study area which increases the solids discharged into the uMkhomazi River. Microbial contamination is expected from the Inhlavini and uMkhomazi Rivers and near the IU as a result of livestock and human impacts upstream of Inhlavini River.

Even though levels of variables were elevated at IU compared to other monitoring points, the difference was relatively small. The impact at the IU is related to the upstream sewage and agricultural impact emanating from the Ixopo and the surrounding areas. The community located near the IU also uses water (from the Inhlavini River) for domestic use. Their cattle are also grazing nearby and drink water from the Inhlavini River. Since the Inhlavini is a small stream, the dilution factor may not be enough to eliminate the impact by the nearby community.

4.3 Macro-invertebrates

uMkhomazi River Monitoring Points for Dry Season

Both the UU and UD were dominated by stones (cobbles and bedrock) which are favourable habitat for macro-invertebrates. The UU site had limited marginal vegetation whilst the UD site had average vegetation. A total of 26 taxa occurred at the UU, whilst 24 taxa were present at the UD (**Figure 4-14**). Diptera were the most abundant order with five families recorded at both UU and UD. Ephemeroptera were represented by five and four families for UU and UD, respectively. Coleoptera remained the same for both UU and UD, with four families present at each site. Four Trichopteran families were sampled at UU, whilst none were found at UD. Turbellaria, Plecoptera, Gastropoda and Pelecypoda were represented by one family each at both UU and UD. Annelida and Crustacea were both found at the UD but not at the UU.

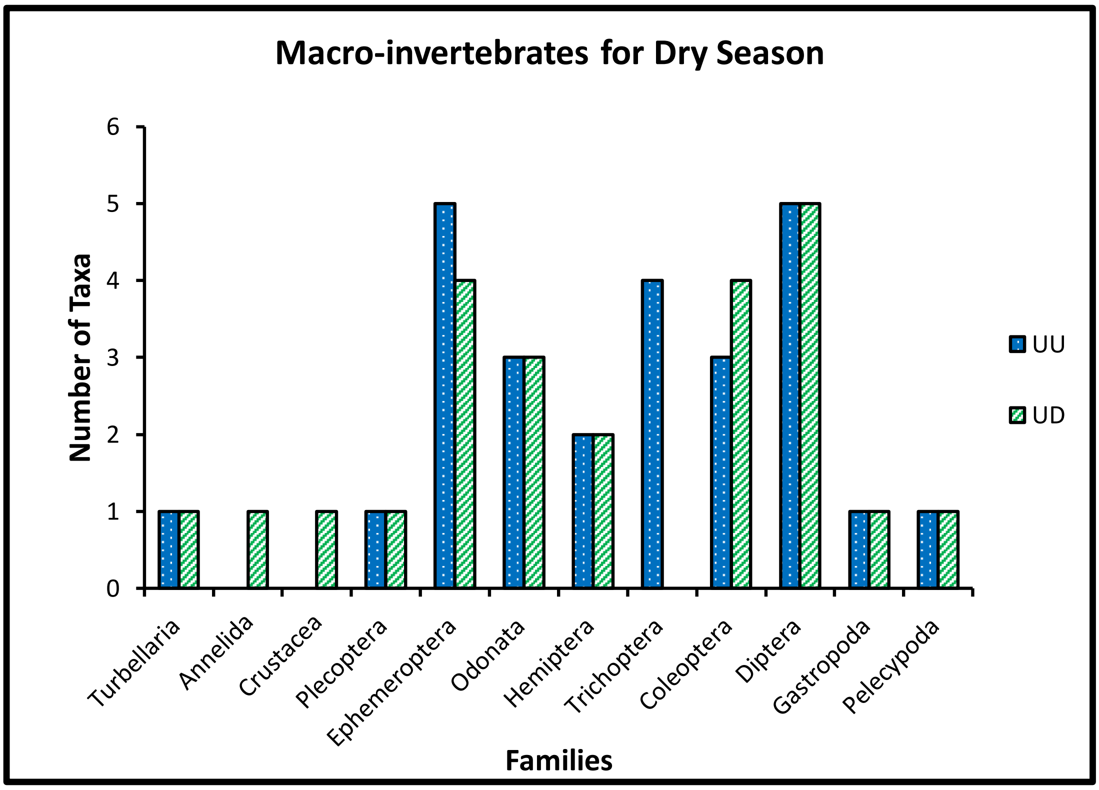

Figure 4- 14. Number of taxa per order represented for each site, during the dry season.

The Average Score Per Taxon (ASPT) for the UU was 6.92 and 6.41 for the UD (**Table 4- 1**).

Table 4- 1. Summary of macro-invertebrate index scores in the uMkhomazi River.

	uMkhomazi Upstream Monitoring Point (UU)		uMkhomazi Downstream Monitoring Point (UD)	
	Dry	Wet	Dry	Wet
SASS Score	180	189	154	211
No. of Taxa	26	29	24	33
ASPT	6.92	6.52	6.41	6.39

Dominance of Macro-invertebrates

Macro-invertebrates sampled indicate that the dominating order is Ephemeroptera (20%), followed by Hemiptera (16.7%), Diptera (13.3%), Coleoptera (10%), Odonata, Gastropoda and Trichoptera (6.7%) and Porifera, Turbellaria, Annelida, Lepidoptera, Plecoptera and Crustacia (3.3%) (**Figure 4-15**). Ephemeroptera was represented by Baetidae, Caenidae, Heptageniidae, Leptophlebiidae, Prosopistomatidae, and Trycorythidae. Ephemeroptera, Plecoptera and Trichoptera are known to contain highly sensitive families as they have a SASS score that ranges between 6 and 15 which are mostly found in good water quality and are very sensitive to polluted water therefore are intolerant to organic pollution (Patang *et al*., 2018). Based on the sampled families, it was observed that pollution sensitive macro-invertebrates i.e., Ephemeroptera, Trichoptera, Plecoptera, and Coleoptera were found at UU and UD during the dry season. These pollution sensitive macro-invertebrates are referred as group 1 due to their sensitivity to polluted water (Chadde, 2005). Group 2 macro-invertebrates which are known for being moderately sensitive were also found at UU. Group 2 macro-invertebrates include Coleoptera and Odonata (Chadde, 2005). Group 3 families were also found, and it is understandable since these macro-invertebrates can be found in both polluted and unpolluted water. The UU indicated to be a less polluted site as sensitive macro-invertebrates were found.

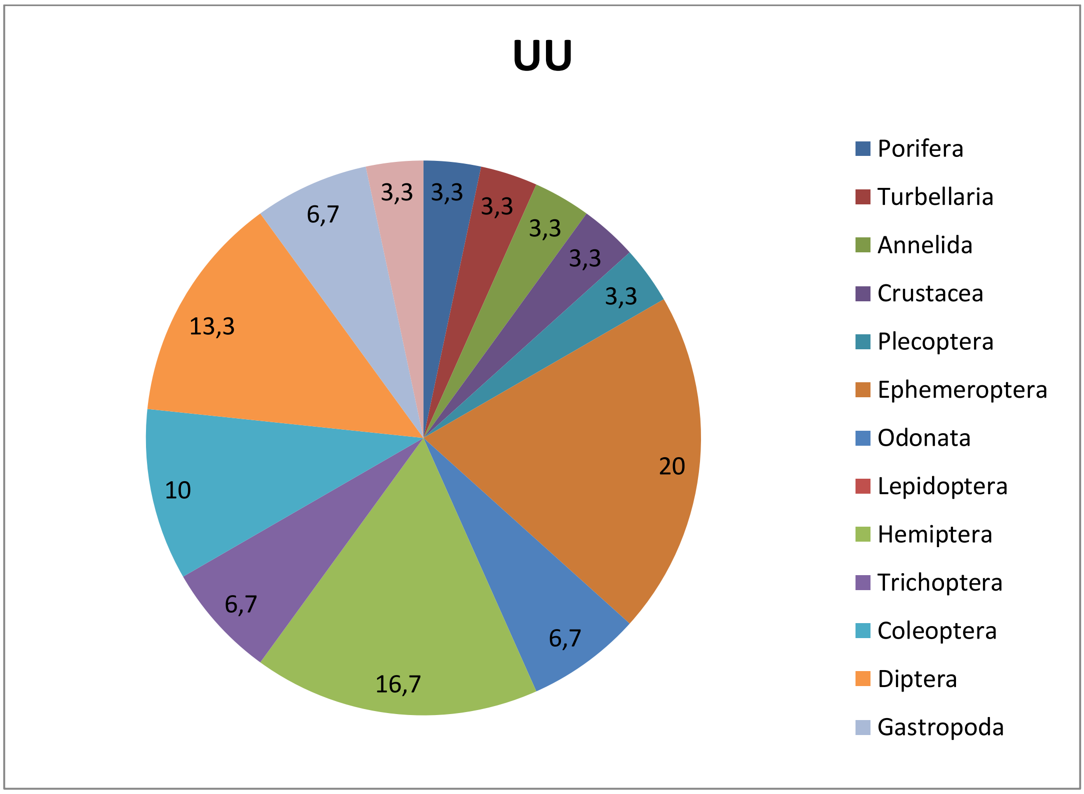

Figure 4- 15. UU macro-invertebrate dominance for Dry Season.

uMkhomazi River Monitoring Points for Wet Season

It was observed that flows were lower than usual at uMkhomazi River during the wet season sampling in October 2020, this is due to the fact that rains had not been intense. During this season, a total number of 29 taxa were sampled at UU and a total of 33 taxa were sampled at UD **(Figure 4- 16**). Ephemeroptera was the most dominant taxon with six families at UU and five families at UD, which is viewed as a decrease from UU to UD. The second order was Hemiptera with five families for both UU and UD. Diptera followed with four families at UU and five families at UD. This indicates an increase in the families from UU to UD. Coleoptera remained the same for both UU and UD, with three families represented at each site. Gastropoda remained the same at UU and UD with two families. Four Trichoptera families were sampled at UU site, and none were found at UD. There was therefore a decrease on Trichoptera from UU to UD. Turbellaria, Plecoptera, Gastropoda, and Pelecypoda maintained the appearance of one family each at both UU and UD. Annelida and Crustacea were found at the UD site, whilst were not found at the UU site. Porifera, Turbellaria, Annelida, Crustacea and Plecoptera all had one taxon each.

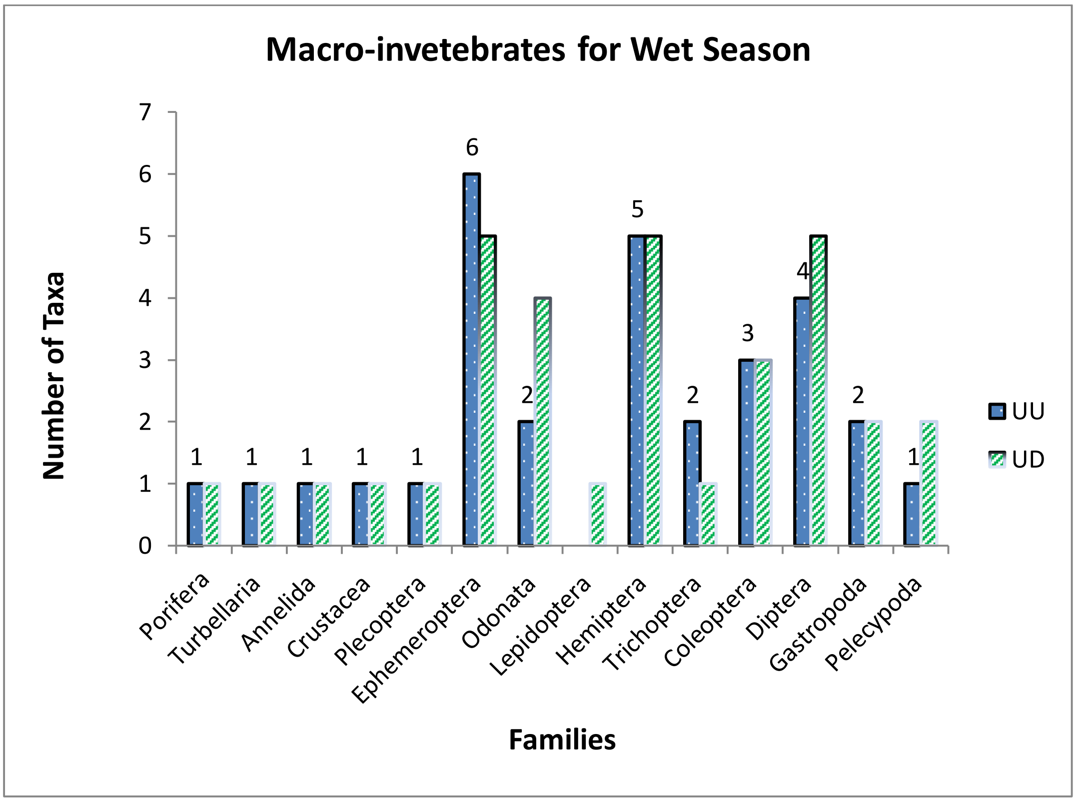

Figure 4- 16. Number of taxa per order.

Dominance of Macro-invertebrates at UD

The dominance of macro-invertebrate families at the UD were as follows: Ephemeroptera, Diptera and Hemiptera, with slightly more than 15% each. Odonata follows with 12% and Coleoptera with 9%. Gastropoda and Pelecypoda were at 6% each. Plecoptera, Porifera, Turbellaria, Annelida, Crustacea, Lepidoptera and Trichoptera occurred at 3% each (**Figure 4- 17**). The dominance of families at UD follows the same pattern as at the UU. Macro-invertebrate sampled at UU were also found at UD. A minor change was noted due to change in season and a small change in habitat in both sites. There is only one family (Lepidoptera) that was found in the wet season but not in the dry season and only occurred at UD. Both UU and UD sites were found to be less impacted, as they had good water quality and ecological state – with both sites having representation of some of the most sensitive taxa (such as Perlidae, Heptageniidae, and Baetidae (>2 species).

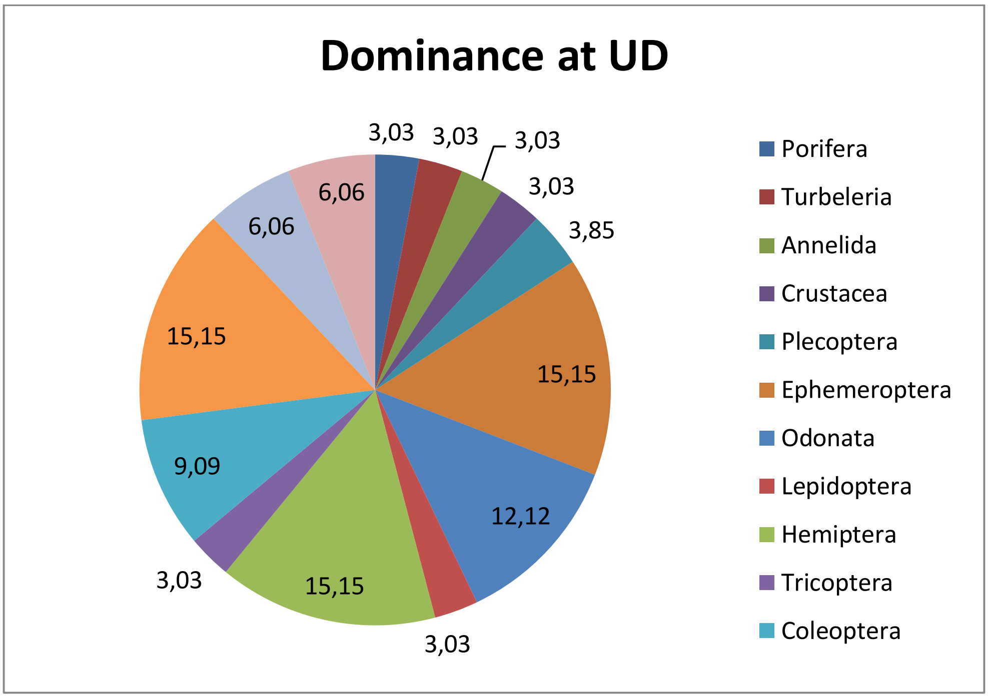

Figure 4- 17. Dominance of macro-invertebrates at UD.

Overall Bio-monitoring results for UU and UD for both seasons

The SASS Score for the UU site was calculated to be 189 with an ASPT of 6.52 for wet season. A SASS Score of 211 and ASPT of 6.39 was also calculated in the UD for the wet season. The UU had a slightly higher ASPT compared to UD. There was an increase in the number of taxa at the UU from 26 to 29 from the dry to wet season. The same increase was also noted at the UD from 24 to 33 also from dry to wet season. The SASS Score also increased for the UU from 180 to 189 from dry to wet season. At the UD site, there was also an increase in SASS5 from 154 to 211 from dry to wet season. The ASPT for UU decreased from 6.92 to 6.52 and for UD there was a decrease from 6.41 to 6.39 respectively from dry to wet season.

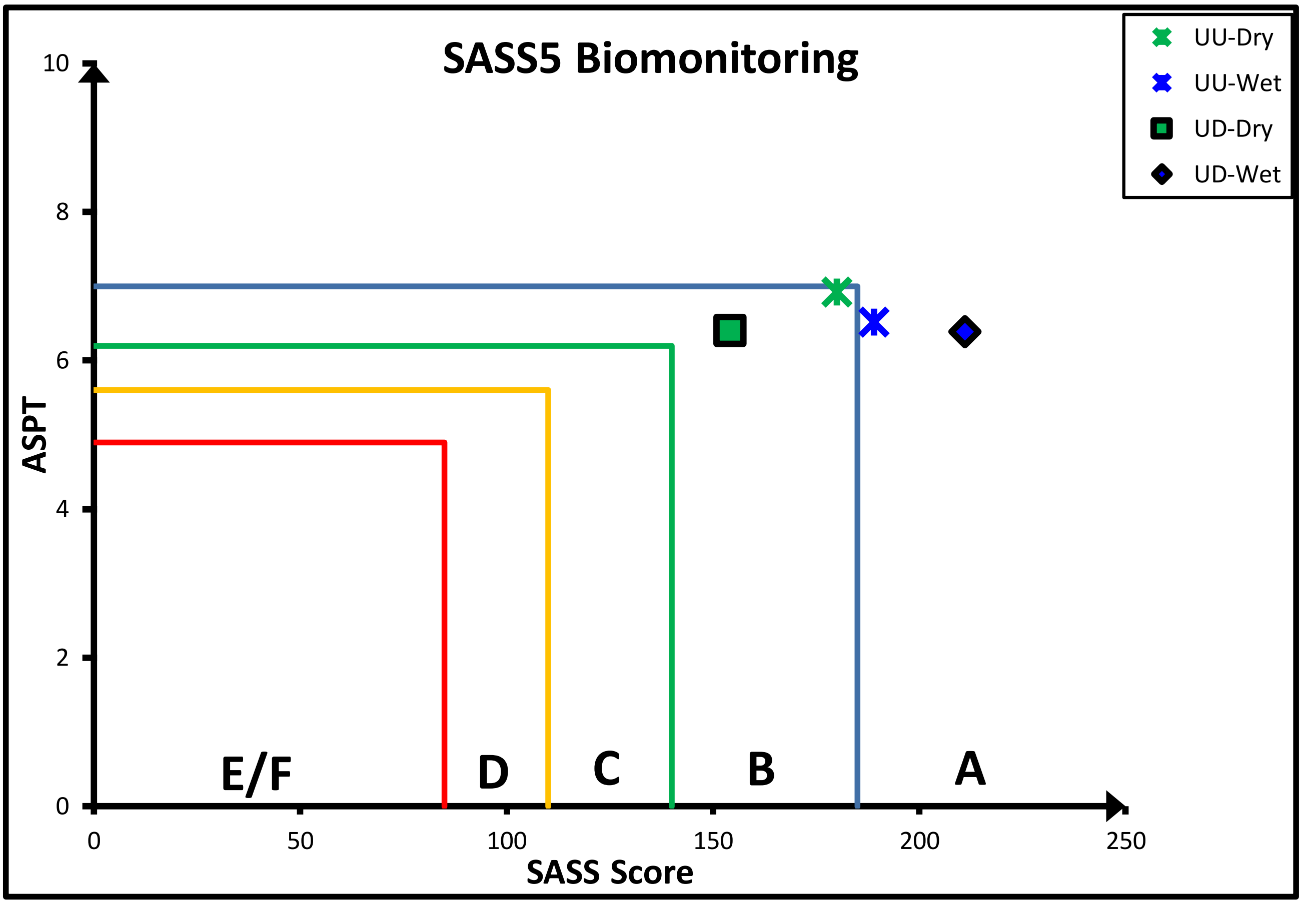

Figure 4- 18. Eastern Escarpment Mountains Upper used for the uMkhomazi River - Overall SASS5 bio-monitoring results for two sites on uMkhomazi River (UU and UD) – results for both dry (July 2020) and wet (October 2020) seasons.

Macro-invertebrate results for UU placed the uMkhomazi River in ecological category A/B (EC A/B) for both seasons (wet and dry); whilst, UD for wet and dry seasons placed the uMkhomazi River in EC A and EC B, respectively (**Figure 4-18**). However, it should be noted that the changes between UU site for dry and wet seasons were not that pronounced – i.e., UU (wet) fell on lower EC A, and UU (dry) fell on upper EC B. Thus, it can be concluded that there were no major changes between wet and dry seasons for UU. On the other hand, UD (dry) fell in the EC B – this was a rather drop from the wet season's results (of upper EC A). Since the uMkhomazi River is a major river system, there was not too much changes related to seasonality expected; and thus slightly lower score for UU (wet) as compared to UD (wet) might be ascribed to the fact that UU had limited vegetation at this site.

One can thus attribute these changes to the presence of agricultural activities (fertilizers and pesticides runoffs from the fields) between the two sites, as well as the changes in the season (more dilution in wet versus less dilution in dry), and changes in habitat availability. Being the second largest river in KZN, the uMkhomazi River has been recorded to show very little seasonal variation, and hence small change in categories was observed during wet and dry season (Du Bois, 2015).

The fact that the uMkhomazi River catchment is not well developed also assist in keeping the category in a good state.

4.4 Statistical Analysis

T-tests were conducted, by making use of GraphPad Prism, to test for possible significant differences ($p<0.05$) in the water quality variables between IU and II. The pH (p=0.3688), electrical conductivity (p=0.1111), potassium (p=0.2068), chemical oxygen demand (p=0.2958), turbidity (p=0.3953), nitrates and nitrites (p=0.3694), orthophosphates (p=0.1878), potassium (p=0.2068), copper (p=0.7350), suspended solids (p=0.2958), *E coli* (p=0.1508) and faecal coliforms (p=0.4887) (**Figure 4- 19**), all showed no significant difference between the two monitoring points.

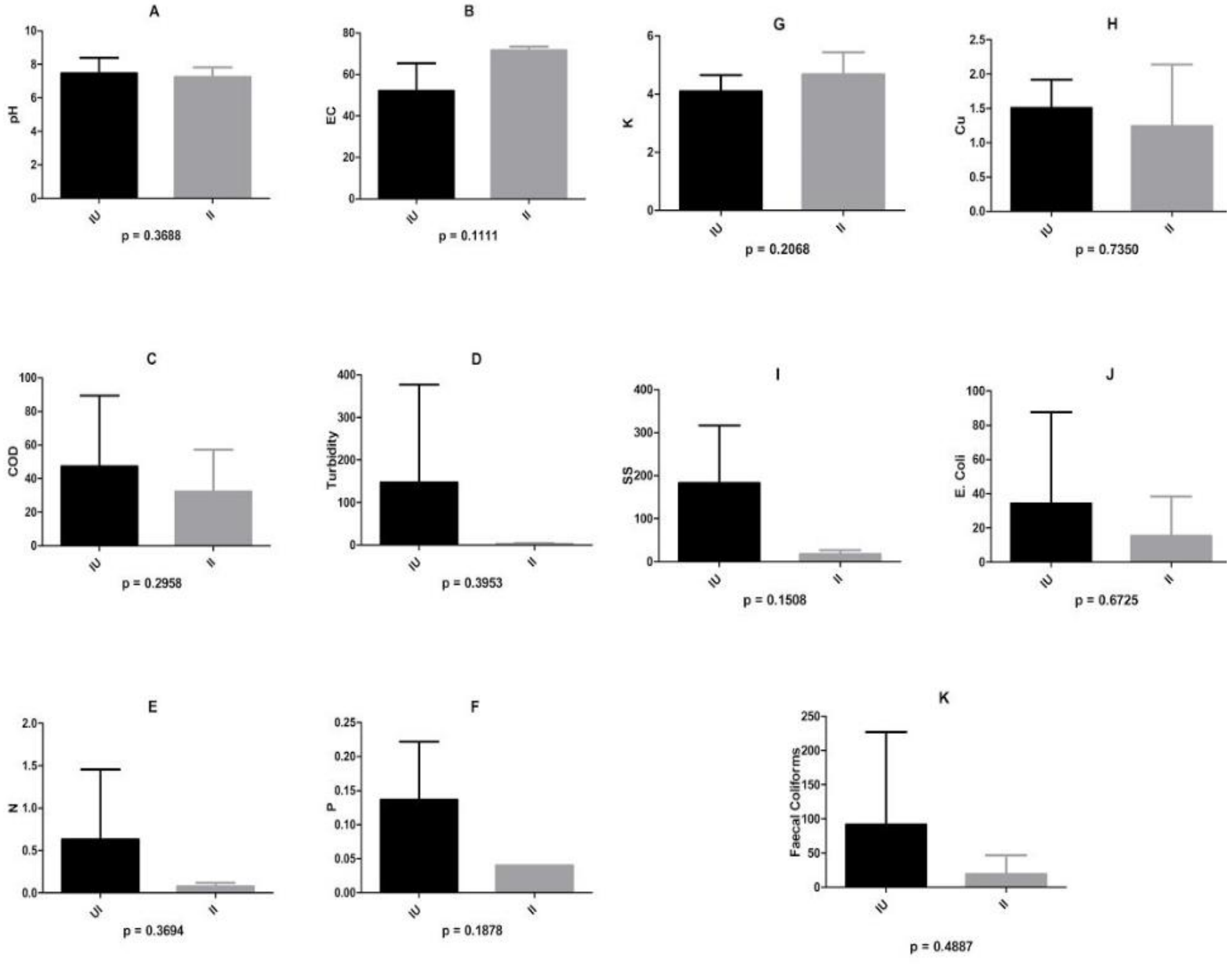

Figure 4- 19. Mean, standard deviation and p-value (n=3) of various water quality variables measured at Inhlavini Upper (IU) and Inhlavini Impact (II) sites.

All measured values have the p-value above 0.05 and as a result indicate no significant impact of the piggery effluent from Piggery X on any water quality variables assessed. It should however, be noted that even though there was no significant difference between IU and II, the following variable showed some level of difference (namely, turbidity, suspended solids, nitrates and nitrites, orthophosphates, *E. coli* and faecal coliforms) – all of which were less for II than IU.

T-tests were also conducted to test for possible significant differences ($p<0.05$) in the water quality variables between UU and UD. However, all analysed water quality variables (i.e. pH ($p=0.1835$), electrical conductivity ($p=0.1226$), chemical oxygen demand ($p=0.776$), turbidity ($p=0.8178$), nitrates and nitrites ($p=0.8658$), orthophosphates ($p=0.5779$), potassium ($p=0.4341$), copper ($p=0.2752$), suspended solids ($p=0.1618$), *E. coli* ($p=0.5650$) and faecal coliforms ($p=0.6737$)) for UU and UD monitoring sites were found to show no significant differences (**Figure 4- 20**).

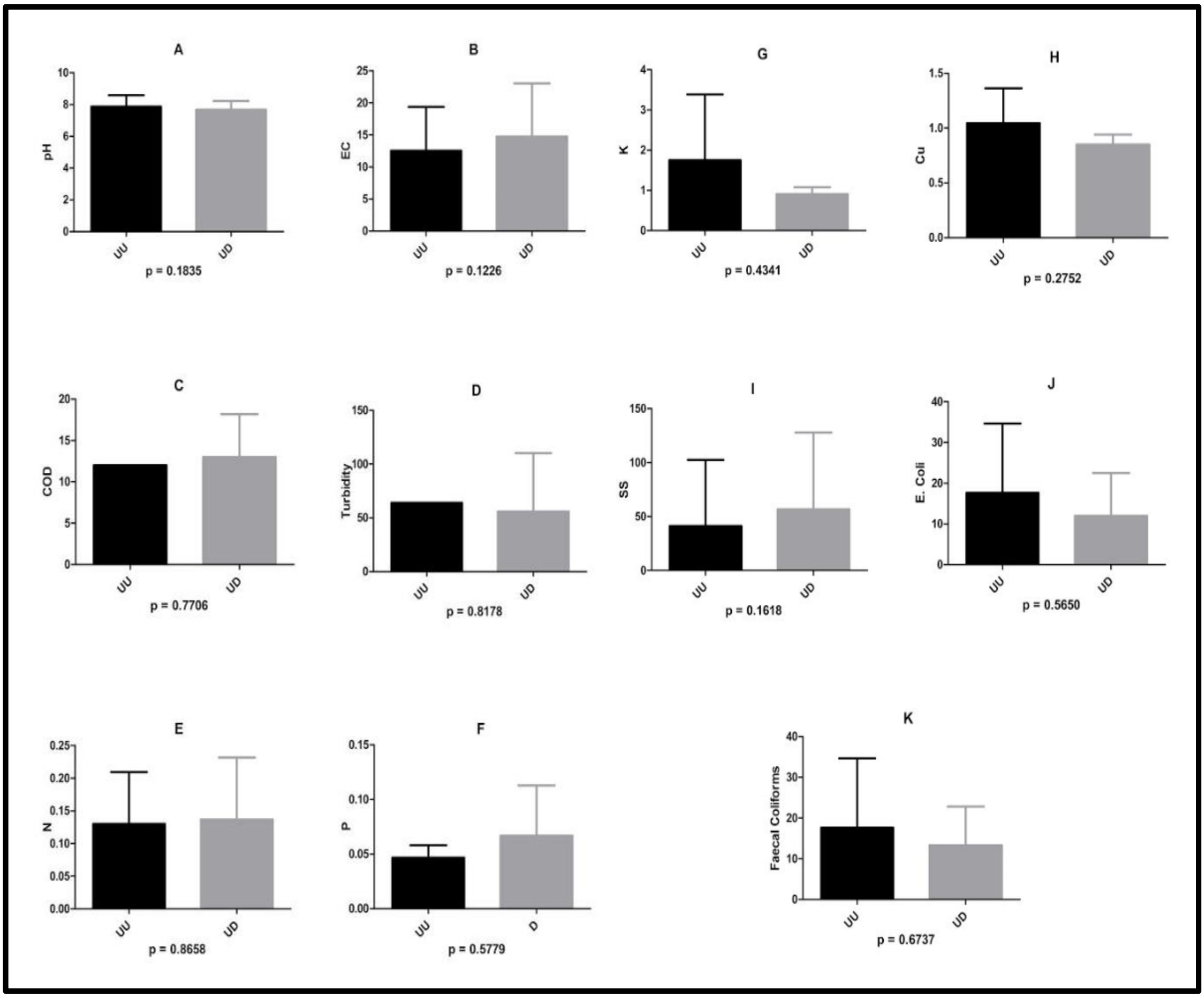

Figure 4- 20. Mean, standard deviation and p-value (n=3) of various water quality variables measured at uMkhomazi Upper (UU) and uMkhomazi Downstream (UD).

Contrary to the findings of the Inhlavini, where there were some differences in some variable, albeit not significant, uMkhomazi River sites (UU and UD) did not show such.

In the Redundancy Analysis (RDA) triplot (**Figure 4- 21**), the plot explains 81.01% of the variation in the data, with 51.18% being described on the first axis and 24.83% on the second axis. This triplot revealed that there was a strong association between water quality variables (turbidity, total coliforms, electrical conductivity, suspended solids, and phosphorus) with site UD during the wet season and taxa Oligochaeta, Atyidae, Sphaeriidae, Chlorocyphidae, Crambidae, Corixidae, Baetidae>2sp and Heptageniidae. It is evident that Hydrophilidae, Ephydridae, Athericidae, Coenagrionidae, Simuliidae, Elmidae, and Turbellaria are associated with the UD site during the dry season. Baetidae, Heptageniidae, Atyidae, Chlorocyphidae are relatively sensitive to poor water quality, and prefer neutral pH and are also associated with warmer temperatures (Flores & Zafaralla, 2012) – and such was noted at UD which makes the association evident. Low scoring macro-invertebrates which are sensitive to poor water quality were also sampled at UD. The length of arrows indicates that water quality (pH, chemical oxygen demand, nitrates and nitrites, potassium, and copper) played a role in the occurrence of Tipulidae, Hydropsychidae>1, Porifera, Physidae, Gerridae, Dytiscidae and Prosopistomatidae, while *E. coli* and faecal coliforms played a lesser role at UU during the wet season. This is due to the fact that these macro-vertebrates are less sensitive to pollution, hence these were not dominating.

It was also noted that Perlidae, Gyrinidae, Lepidostomatidae, Leptoceridae, Muscidae, Trycorythidae and Hydropsychidae>2sp were associated with UU site during the dry season. Chemical oxygen demand, nitrates, potassium, copper, pH and faecal coliforms are strongly associated with Tipulidae, Dytiscidae, Porifera, Hydropsychidae (=1sp) and Caenidae and are also associated with UU site. The length of arrows indicates that electrical conductivity, suspended solids, vegetation, and turbidity played a role in the occurrence of Oligochaeta, Atyidae, Crambidae, Sphaeriidae and Chlorocyphidae, whilst orthophosphates played a lesser role at UD during the wet season. Majority of these are medium to high scoring macro-invertebrates (with the exception of Oligochaeta and Sphaeriidae – which are low scoring), which are generally associated with good water quality; therefore, the dissimilarities between UU and UD could not be explained as the sites had relatively similar except for the vegetation which was slightly different and are close to one another (with no major changes within the system itself, such as presence of wetlands, etc.). Thus, the probably explanation could be that of possible diffuse pollution from agricultural activities (linked to fertilisers and/or pesticides) and a small change in habitat between UU and UD. The impact associated with the Inhlavini River is excluded as the river was not discharging (dry) into the uMkhomazi River during July 2020 and October 2020.

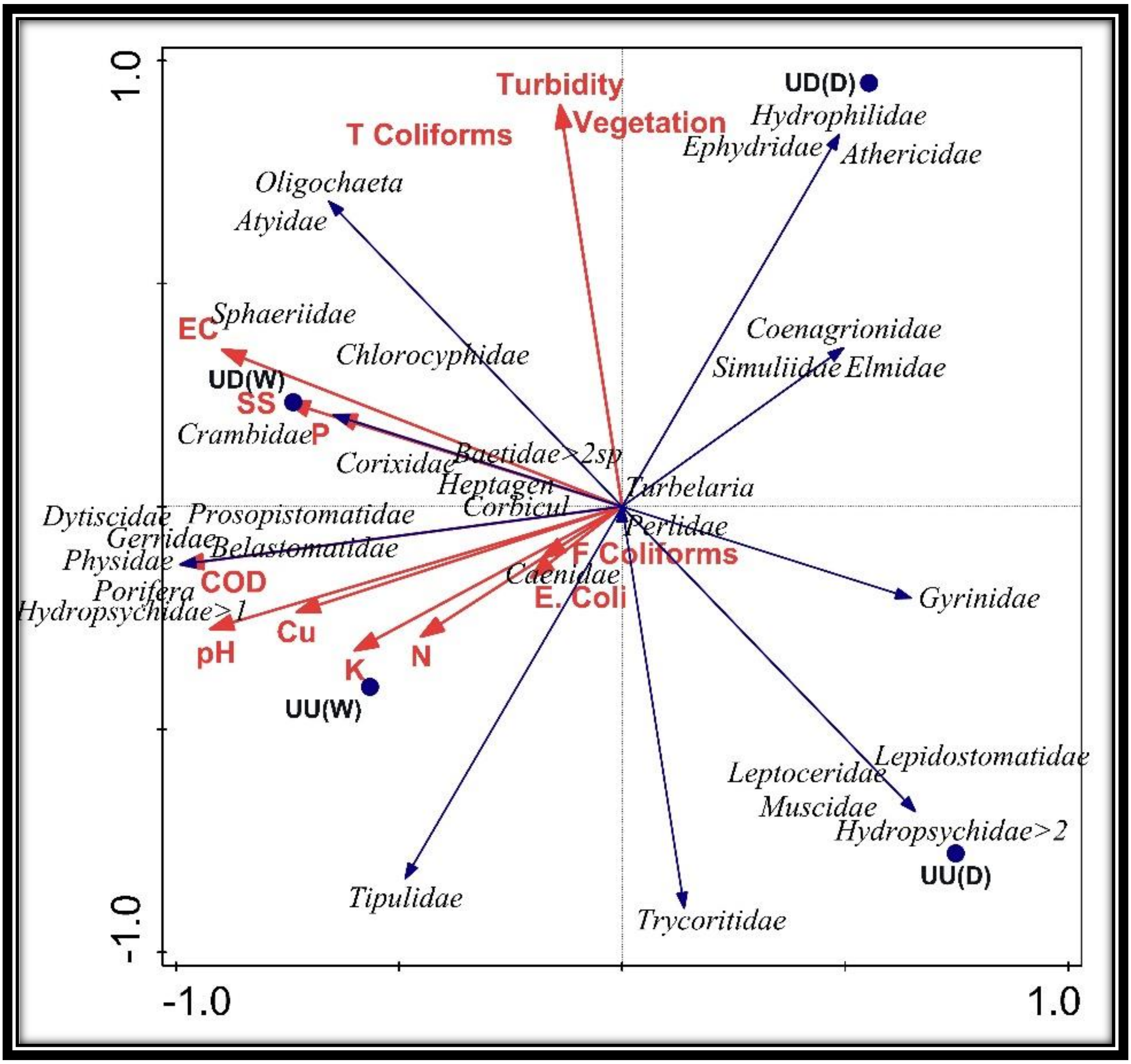

Figure 4- 21. RDA triplot (with supplementary variables) illustrating associations between sampling sites (during wet and dry season) (blue circles), water quality variables (red arrows) and macro-invertebrate taxa (red arrows). The triplot describes 81.01% of the total variation, with 56.18% being described on the first axis and 24.83% on the second axis.

A Principal component analysis (PCA) biplot was generated to illustrate associations between sampling sites (IU, II, UU and UD) during both wet and dry seasons and water quality variables (suspended solids, copper, turbidity, potassium, phosphorus, nitrates and nitrites, chemical oxygen demand, pH, and electrical conductivity). The biplot indicates 69.54% of total variation with 41.98% on the first axis and 27.56% on the second axis (**Figure 4- 22**). There is a weak association between orthophosphates and ID site during both wet season samplings (February and October 2020). The biplot also indicates a weak association between nitrates and nitrites, chemical oxygen demand and pH in relation to UD site during both dry and wet seasons (July and October 2020). No association was noted between all monitoring sites and water quality variables. The possible explanation could be that there was not any significant impact observed on any of the water quality variables.

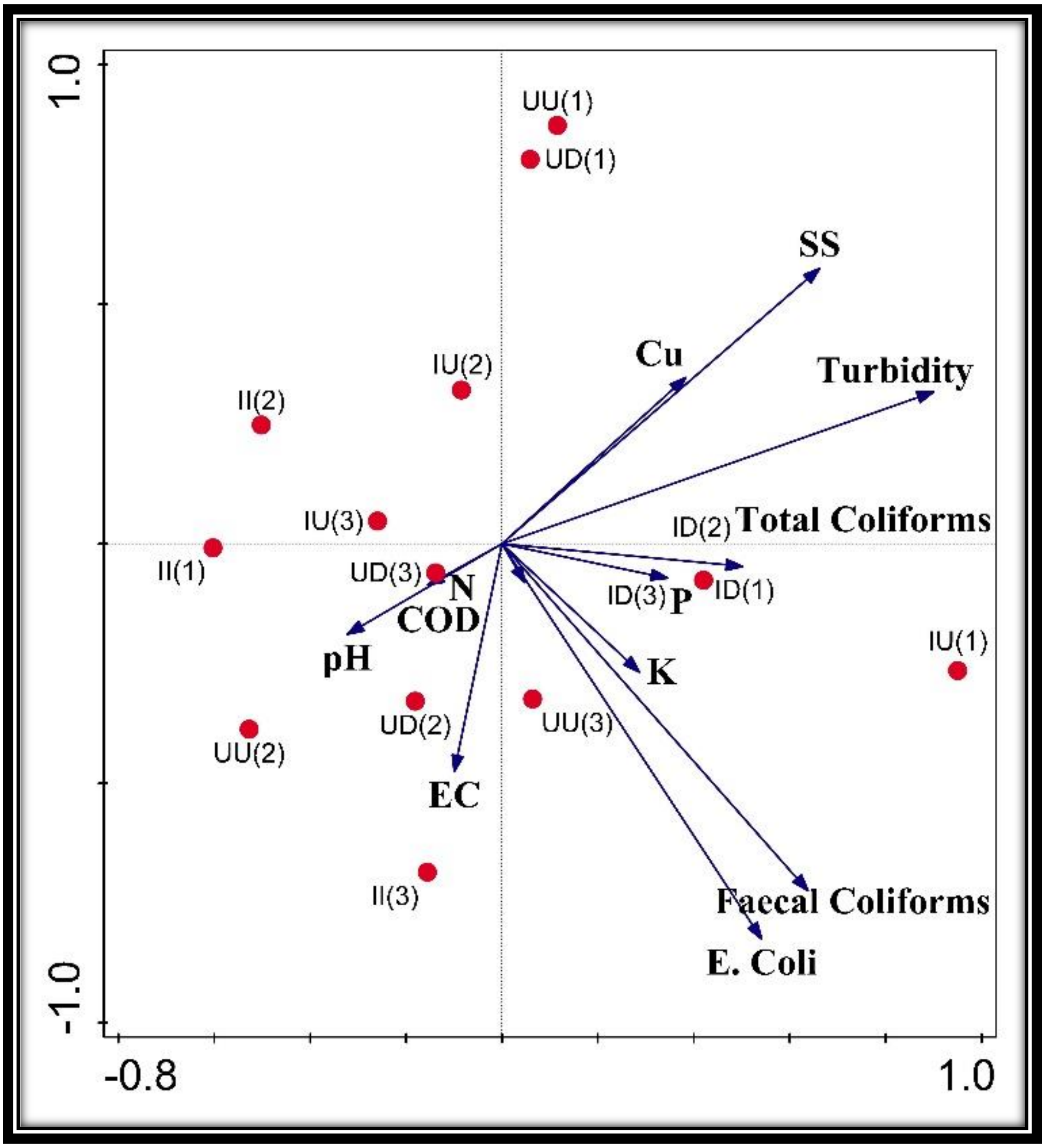

Figure 4- 22. PCA biplot illustrating associations between sampling sites [during wet (1 = February and 3 = October 2020), and dry (2 = July 2020) seasons] (red circles), water quality variables (blue arrows). The biplot describes 69.54% of the total variation, with 41.98% on the first axis and 27.56% on the second axis.

4.5 Chapter Summary

The water quality of the Inhlavini River was noted to be mostly compliant with South African Water Quality Guidelines for domestic use, agricultural use, and aquatic ecosystem. As much as the parameters fell within the limits, it was noted that the uMkhomazi River recorded lower values for similar parameters compared to Inhlavini River. The IU was observed to be more impacted than the II when comparing variables sampled. Elevated levels of water quality variables at IU are due to activities upstream of the IU site i.e., sand mining, abstraction of water for domestic use, cattle grazing, and sewage discharge from Ixopo area. It must be noted that these activities are continuous hence the impact remains on the system. The lower levels at II are associated with the fact that piggery discharge ceased in October 2019. The gap between the October 2019 and February 2020 allowed the system to recover from the piggery effluent that was discharged. In addition, the II site is located on a gentle slope with wetland riverine system which also assisted with filtration of pollutants. The pH, COD, turbidity, NO_3^- and NO_2^-, PO_4^{3-}, Cu, SS, *E. coli* and faecal coliforms were higher than all other four monitoring points at IU except for K and EC, which were slightly elevated at II compared to IU.

Statistical analyses revealed that there is no significant difference ($p<0.05$) between II and IU, as well as between UU and UD – thus no significant impacts by either the piggery on the Inhlavini River, as well as the Inhlavini on the uMkhomazi River on any of the water quality variables were observed.

The improvement between the IU and II, as well as ID can be associated with the long distance between monitoring points, meandering of the river and the wetlands associated with the Inhlavini River. These wetlands act as filters and assist in the improvement of water quality (Shutes, 2001; Moshiri, 2020). A further slight improvement in water quality, between II and ID, was observed; and this could be explained by the fact that this stretch of the river is largely riverine wetland (with a lot of sedges, reeds, and common grasses), which aided in the filtration and assimilation.

Almost all analysed parameters in the UU were lower than the UD, except for SS and Cu values. The difference was very small and the uMkhomazi River appeared to be less impacted compared to Inhlavini River. The uMkhomazi River is impacted by turbidity during the wet season since it is a big river and has a number of tributaries discharging into it. Runoff from agricultural fields also increases levels of turbidity on water resources. The Impact of the Piggery X on the Inhlavini River is minimal, and the ID indicates the improvement of water quality before the Inhlavini discharges into the uMkhomazi River. The turbidity on the uMkhomazi River is also attributed to erosion as a result of agricultural activities within the area.

Statistical analyses further revealed that there is no significant difference between II and IU as well as between UU and UD, as all measured water quality variables indicated a p-value that is above 0.05. Macro-invertebrates sampled at UU were also found at UD during both seasons. Biological bands by Dallas and Day (Eastern Escarpment Mountains Upper) were used to determine the ecological category for the uMkhomazi River which was category A (EC A) for the wet season and class B (EC B) for the dry season for UD site. Biological bands placed UU site on ecological category A/B (EC A/B) for both seasons.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The absence of potable water near the IU is a concern for humans, as they have to rely on the river water, which also sometimes dries up. The drying up of the river also affects the ecology of Inhlavini River. The II was found not to be highly impacted as most assessed water quality variables were found to be within the South African Water Quality Guidelines for Agriculture, Recreation, Domestic and Aquatic Ecosystem. Wetlands associated with the Inhlavini River seemed to have assisted in the treatment of piggery effluent that was discharged into the Inhlavini River as well as the impact from the Upstream of the Inhlavini River. The ID indicated a decrease in the impact from the II which is attributed to the slope of the Inhlavini River between the two points (gentle slope) and wetlands, which assist with filtering pollutants.

With it having several tributaries emanating from less polluted areas, the uMkhomazi River was noted to have very low levels of analysed variables (i.e., EC, COD, TDS, pH, PO_4^{3-}, Cu, K, faecal coliforms, *E. coli*, NO_3^- and NO_2^-) compared to the Inhlavini River. This study revealed that the uMkhomazi River is slightly impacted by agricultural activities which surrounds the study area and further upstream of the study area. This is also indicated by high turbidity which is due to erosion from agricultural fields, cattle grazing as well a small scale mining.

Macro-invertebrates were analysed for wet and dry seasons only on the uMkhomazi River, and during those periods, the Inhlavini River was not discharging into the uMkhomazi River. In essence, the impact of the Inhlavini River was not accounted for during these two sets of monitoring (i.e., July 2020 and October 2020). However, water quality sampled included the discharge of the Inhlavini River. Water Quality analysis for February 2020 indicated that there was an impact which was slightly decreasing the water quality in the uMkhomazi River at the UD when comparing with UU; however, the impact is minimal as water quality results followed the same pattern even when the Inhlavini River was not discharging. The impact noted at IU indicates that the Inhlavini River is also negatively impacted by other activities like agriculture, sewage, sand mining activities, domestic use and cattle grazing upstream of Piggery X. The impact of Piggery X indicated to be minimal at the II and decreased at ID. Therefore, the impact of Piggery X on the Inhlavini River was found to be minimal, and the system managed to recover and rehabilitate itself from the discharge by Piggery X. It was noted the Inhlavini River was not negatively impacting the uMkhomazi River and during two sets of monitoring (July 2020 and October 2020) was not discharging into the uMkhomazi River.

Bio-monitoring using macro-invertebrates confirmed the ecological category of the uMkhomazi River to be in ecological category A/B (EC B) for both wet and dry seasons at UU; ecological category A (EC A) for the wet season and category B (EC B) for the dry season at UD.

5.2 Recommendations and Areas of Future Research

There were some negative impacts from Piggery X, especially on the Inhlavini River; thus, the **six key recommendations** are drawn from this study:

- There **does not seem to be a need for any manual/physical rehabilitation of the Inhlavini River**, as the system seem to have managed to recover – i.e., naturally and the discharge has ceased;
- Piggery X was undertaking an illegal activity (operating without a water use authorisation) for over three years without being reported to the authorities, **it is therefore important to create further awareness to the communities**, so that they may report offenders as soon as possible;
- Whilst the laws in South Africa are most progressive; **there is a need for firmer enforcement** thereof;
- This activity needs to be monitored/inspected closely, as there is a high possibility of Piggery X resuming the discharge, especially since the area is remote;
- **Acting swiftly following any form of possible pollution is of paramount importance**, as time is of essence, especially if one is to take the matter for legal action; and
- **There is a need to address issues that are affecting the Inhlavini River system at a much higher level** – e.g., over-abstraction, sand mining, etc.

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ANNEXURES

ANNEXURE A: THE *IN SITU* WATER QUALITY RESULTS FOR FIRST WET SEASON (FEBRUARY 2020 (F)), DRY SEASON (JULY 2020 (J)) AND SECOND WET SEASON (OCTOBER 2020 (O)).

Sampling Site	**pH**			**EC**			**TDS**			**%DO**			**Temperature**			**Salinity**		
	Wet (F)	**Dry (J)**	**Wet (O)**	**Wet (F)**	**Dry (J)**	**Wet (O)**	**Wet (F)**	**Dry (J)**	**Wet (O)**	**Wet (F)**	**Dry (J)**	**Wet (O)**	**Wet (F)**	**Dry (J)**	**Wet (O)**	**Wet (F)**	**Dry (J)**	**Wet (O)**
IU	6.9	8.3	8.9	35.4			177	267		75	72	120	24	8	29.5	0.1	0.2	0.3
II	7.4	7.6	7.92	69.1			345	327		92	49	99.7	24	16	21.7	0.3	0.3	0.3
ID	7.3	-	-	40.7			204	-		80	-	-	23	-	-	0.1	-	-
UU	7.4	8.2	7.89	4.6			23	65		91	63	99.5	21	15	24.7	0.0	0.0	0.0
UU	7.5	7.3	7.7	5.3			26	74		56	53	49	20	16	25.2	0.0	0.0	0.0

ANNEXURE B: WATER QUALITY FOR INHLAVINI AND UMKHOMAZI RIVERS FOR WET SEASON (FEBRUARY 2020).

Water quality sampling conducted in July 2020 and analysed at the laboratory.

Sampling Site	pH	EC (mS/m)	COD (mg/L)	Turbidity(NTU)	N (mg/L)	P(mg/L)	K (mg/L)	Cu (µg/L)	SS (mg/L)	*E. coli*	Faecal Coliforms	Total Coliforms
IU	6.7	36.7	36	413	0.21	0.2	4.64	1.87	260	96	248	687
II	6.8	70.7	20	0.04	0.04	<0.04	5.54	1.3	27	3	4	411
ID	6.9	42.2	12	64	0.07	0.04	4.95	1.69	96	25	36	1414
UU	7.4	5	16	110	<0.04	0.06	0.96	1.38	112	<1	<1	1214
UD	7.3	5.6	20	127	<0.04	<0.04	0.94	0.95	138	<1	4	76

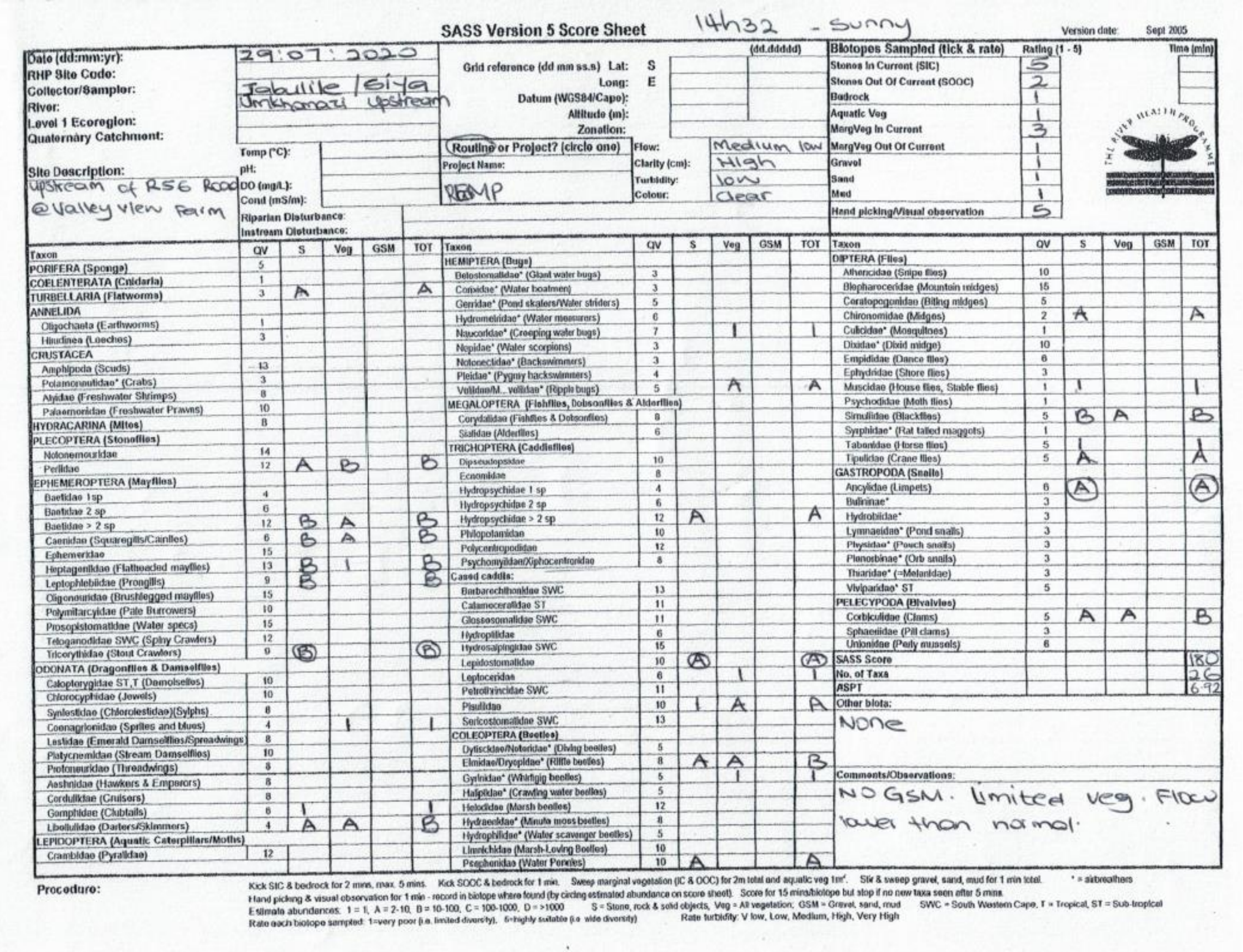
ANNEXURE C: WATER QUALITY FOR INHLAVINI AND UMKHOMAZI RIVERS FOR THE DRY SEASON (JULY 2020).

Water quality sampling conducted in July 2020 and analysed at the laboratory.												
Sampling Site	pH	EC (mS/m)	COD (mg/L)	Turbidity(NTU)	N (mg/L)	P(mg/L)	K (mg/L)	Cu (µg/L)	SS (mg/L)	*E. coli*	Faecal Coliforms	Total Coliforms
IU	7.2	58.1	12	14	0.10	<0.04	4.12	1.064	260	3	15	50
II	7.0	70.7	16	4.1	0.12	0.04	4.07	2.108	18	<1	2	387
ID	0	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
UU	7.5	14.3	<7	1.6	0.19	<0.04	0.66	0.746	<4	17	17	89
UD	7.4	16.8	7	11	0.14	<0.04	0.73	0.77	6	22	23	291

ANNEXURE D: WATER QUALITY FOR INHLAVINI AND UMKHOMAZI RIVERS FOR WET SEASON (OCTOBER 2020)

Sampling Site	pH	EC (mS/m)	COD (mg/L)	N (mg/L)	P(mg/L)	K (mg/L)	Cu (µg/L)	SS (mg/L)	E. coli	Faecal Coliforms
IU	8.5	61.3	94	1.58	0.17	3.53	1.59	28	4	13
II	7.9	73.7	61	0.07	<0.04	4.43	0.316	8	42	51
ID	-	-	-	-	-	-	-	-	-	-
UU	8.7	18.3	16	0.16	<0.04	3.63	1.011	8	35	35
UD	8.3	21.8	16	0.23	0.12	1.06	0.831	26	13	13

ANNEXURE E: SASS SHEETS FOR DRY AND WET SEASONS FOR BOTH INHLAVINI AND UMKHOMAZI RIVERS



SASS Version 5 Score Sheet

14h32 - sunny

Version date: Sept 2005

Date (dd:mm:yr): 29:07:2020
RHP Site Code:
Collector/Sampler: Jabulile / Siya
River: Umkhomazi upstream
Level 1 Ecoregion:
Quaternary Catchment:

Site Description: upstream of R56 Road @Valley view farm

Temp (°C):
pH:
DO (mg/L):
Cond (mS/m):
Riparian Disturbance:
Instream Disturbance:

Grid reference (dd mm ss.s) Lat: S (dd.ddddd)
Long: E
Datum (WGS84/Cape):
Altitude (m):
Zonation:

[✓ Routine] or Project? (circle one)
Project Name: REMP

Flow: Medium low
Clarity (cm): High
Turbidity: low
Colour: Clear

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	
Stones Out Of Current (SOOC)	2	
Bedrock	1	
Aquatic Veg	1	
MargVeg In Current	3	
MargVeg Out Of Current	1	
Gravel	1	
Sand	1	
Mud	1	
Hand picking/Visual observation	5	

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3	A			A
ANNELIDA					
Oligochaeta (Earthworms)	1				
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8				
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12	A	B		B
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12	B	A		B
Caenidae (Squaregills/Cainfles)	6	B	A		B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	B	1		B
Leptophlebiidae (Prongills)	9	B			B
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15				
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9	Ⓑ			Ⓑ
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4		1		1
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	1			1
Libellulidae (Darters/Skimmers)	4	A	A		B
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

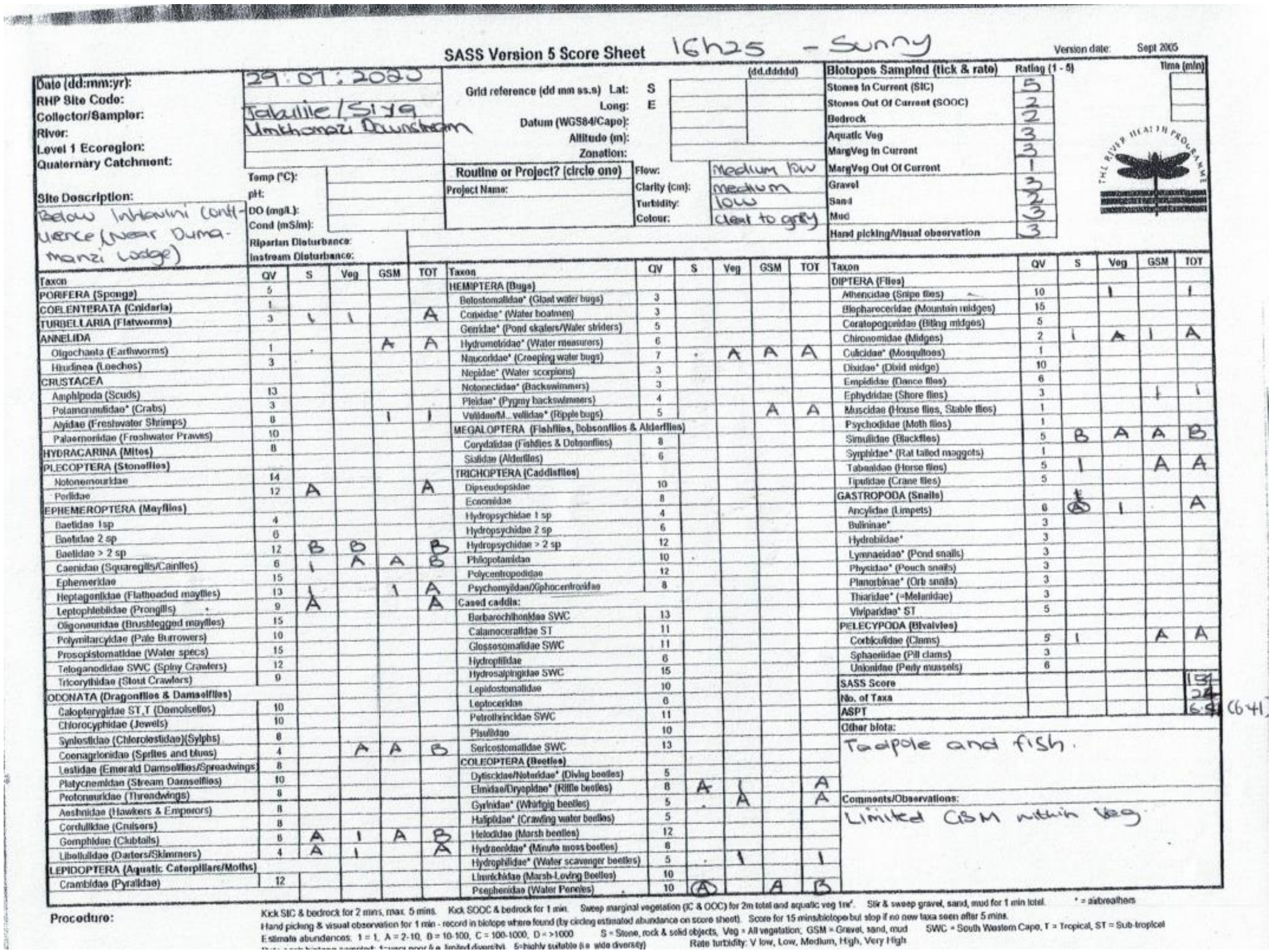
Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3				
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		1		1
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5		A		A
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12	A			A
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10	Ⓐ			Ⓐ
Leptoceridae	6		1		1
Petrothrincidae SWC	11				
Pisuliidae	10	1	A		A
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	A	A		B
Gyrinidae* (Whirligig beetles)	5		1		1
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5				
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10	A			A

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2	A			A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1	1			1
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	B	A		B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5	1			1
Tipulidae (Crane flies)	5	A			A
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	Ⓐ			Ⓐ
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5	A	A		B
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					180
No. of Taxa					26
ASPT					6·92

Other biota:
None

Comments/Observations:
NO GSM. limited veg. Flow lower than normal.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects, Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High



SASS Version 5 Score Sheet

16h25 - Sunny

Version date: Sept 2005

Date (dd:mm:yr): 29:07:2020
RHP Site Code:
Collector/Sampler: Tabulile/Siya
River: Umkhomazi Downstream
Level 1 Ecoregion:
Quaternary Catchment:
Site Description: Below Inhlavini Confluence (near Dumamanzi Lodge)

Grid reference (dd mm ss.s) Lat: S (dd.ddddd)
Long: E
Datum (WGS84/Cape):
Altitude (m):
Zonation:

Temp (°C):
pH:
DO (mg/L):
Cond (mS/m):
Riparian Disturbance:
Instream Disturbance:

Routine or Project? (circle one)
Project Name:

Flow: Medium low
Clarity (cm): medium
Turbidity: low
Colour: Clear to grey

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)	5	
Stones Out Of Current (SOOC)	2	
Bedrock	2	
Aquatic Veg	3	
MargVeg In Current	3	
MargVeg Out Of Current	1	
Gravel	3	
Sand	2	
Mud	3	
Hand picking/Visual observation	3	

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5				
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3	1	1		A
ANNELIDA					
Oligochaeta (Earthworms)	1			A	A
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3			1	1
Atyidae (Freshwater Shrimps)	8				
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12	A			A
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12	B	B		B
Caenidae (Squaregills/Cainflies)	6	1	A	A	B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	1		1	A
Leptophlebiidae (Prongills)	9	A			A
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15				
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4		A	A	B
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	A	1	A	B
Libellulidae (Darters/Skimmers)	4	A	1		A
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3				
Corixidae* (Water boatmen)	3				
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		A	A	A
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5			A	A
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	A	1		A
Gyrinidae* (Whirligig beetles)	5		A		A
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5		1		1
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10	Ⓐ		A	B

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10		1		1
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2	1	A	1	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3			1	1
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	B	A	A	B
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5	1		A	A
Tipulidae (Crane flies)	5				
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	Ⓐ	1		A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5	1		A	A
Sphaeriidae (Pill clams)	3				
Unionidae (Perly mussels)	6				
SASS Score					154
No. of Taxa					24
ASPT					6.4 (6.41)

Other biota: Tadpole and fish.

Comments/Observations: Limited GSM within Veg.

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects, Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

SASS Version 5 Score Sheet

Version date: Sept 2005

Date (dd:mm:yr): 15·10·2020
RHP Site Code: sHa -ntombi
Collector/Sampler: Umcomazi_upstream
River:
Level 1 Ecoregion:
Quaternary Catchment:

Grid reference (dd mm ss.s) Lat: S (dd.ddddd)
Long: E
Datum (WGS84/Cape):
Altitude (m):
Zonation:

Temp (°C):
pH:
DO (mg/L):
Cond (mS/m):

Routine or Project? (circle one)
Project Name:

Flow: low
Clarity (cm): 66
Turbidity: low
Colour: greyish

Site Description:
Above R56 Road
Bridge (to Ixopo)

Riparian Disturbance: NONE
Instream Disturbance: NONE

Biotopes Sampled (tick & rate)	Rating (1 - 5)	Time (min)
Stones In Current (SIC)		
Stones Out Of Current (SOOC)		
Bedrock		
Aquatic Veg		
MargVeg In Current		
MargVeg Out Of Current		
Gravel		
Sand		
Mud		
Hand picking/Visual observation		

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5	(A)			(A)
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3	A	1	1	A
ANNELIDA					
Oligochaeta (Earthworms)	1		1	1	A
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8			A	A
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14				
Perlidae	12	A			A
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4			A	
Baetidae 2 sp	6	B			
Baetidae > 2 sp	12		B		B
Caenidae (Squaregills/Cainfles)	6	B	A	A	B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	B	A	A	B
Leptophlebiidae (Prongills)	9	A		1	A
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15	A		1	A
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9	(A)			(A)
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Damselies)	10				
Chlorocyphidae (Jewels)	10				
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4				
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	A		A	B
Libellulidae (Darters/Skimmers)	4	A	A		A
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12				

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3		1		1
Corixidae* (Water boatmen)	3			1	1
Gerridae* (Pond skaters/Water striders)	5				
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		A	A	B
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5	A	A	A	B
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4	A	1		A
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10		A		A
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	B	1	A	B
Gyrinidae* (Whirligig beetles)	5		A		A
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5				
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10	A			A

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5	1			1
Chironomidae (Midges)	2	A	A	1	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5				
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5	B			B
Tipulidae (Crane flies)	5	1	-	1	A
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	A			A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3		1		1
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5	A		1	A
Sphaeriidae (Pill clams)	3	~~A~~			
Unionidae (Perly mussels)	6				
SASS Score					189
No. of Taxa					29
ASPT					6.52

6.52

Other biota:
Tadpole

Comments/Observations:

Procedure:
Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects, Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

SASS Version 5 Score Sheet

Version date: Sept 2005

Date (dd:mm:yr): 15-10-2020
RHP Site Code: Siya/ Ntombi
Collector/Sampler: Umkomazi - Downstream
River:
Level 1 Ecoregion:
Quaternary Catchment:

Site Description:
At DUMA MANZI LODGE

Temp (°C):
pH:
DO (mg/L):
Cond (mS/m):
Riparian Disturbance:
Instream Disturbance:

Grid reference (dd mm ss.s) Lat: S
Long: E
(dd.ddddd)
Datum (WGS84/Cape):
Altitude (m):
Zonation:

Routine or Project? (circle one)
Project Name:

Flow:
Clarity (cm): 77
Turbidity:
Colour:

Biotopes Sampled (tick & rate)	Rating (1 - 5)
Stones In Current (SIC)	
Stones Out Of Current (SOOC)	
Bedrock	
Aquatic Veg	
MargVeg In Current	
MargVeg Out Of Current	
Gravel	
Sand	
Mud	
Hand picking/Visual observation	

Time (min)

THE RIVER HEALTH PROGRAMME

Taxon	QV	S	Veg	GSM	TOT
PORIFERA (Sponge)	5	①			①
COELENTERATA (Cnidaria)	1				
TURBELLARIA (Flatworms)	3			1	1
ANNELIDA					
Oligochaeta (Earthworms)	1			A	A
Hirudinea (Leeches)	3				
CRUSTACEA					
Amphipoda (Scuds)	13				
Potamonautidae* (Crabs)	3				
Atyidae (Freshwater Shrimps)	8		A	A	A
Palaemonidae (Freshwater Prawns)	10				
HYDRACARINA (Mites)	8				
PLECOPTERA (Stoneflies)					
Notonemouridae	14	B			
Perlidae	12	B		A	B
EPHEMEROPTERA (Mayflies)					
Baetidae 1sp	4	B			
Baetidae 2 sp	6	B			
Baetidae > 2 sp	12		B	A	B
Caenidae (Squaregills/Cainfles)	6	A	A	A	B
Ephemeridae	15				
Heptageniidae (Flatheaded mayflies)	13	A	A	B	B
Leptophlebiidae (Prongills)	9			A	A
Oligoneuridae (Brushlegged mayflies)	15				
Polymitarcyidae (Pale Burrowers)	10				
Prosopistomatidae (Water specs)	15	1			1
Teloganodidae SWC (Spiny Crawlers)	12				
Tricorythidae (Stout Crawlers)	9				
ODONATA (Dragonflies & Damselflies)					
Calopterygidae ST,T (Demoiselles)	10				
Chlorocyphidae (Jewels)	10			1	1
Synlestidae (Chlorolestidae)(Sylphs)	8				
Coenagrionidae (Sprites and blues)	4		A	A	A
Lestidae (Emerald Damselflies/Spreadwings)	8				
Platycnemidae (Stream Damselflies)	10				
Protoneuridae (Threadwings)	8				
Aeshnidae (Hawkers & Emperors)	8				
Corduliidae (Cruisers)	8				
Gomphidae (Clubtails)	6	1		A	A
Libellulidae (Darters/Skimmers)	4	A	1	1	A
LEPIDOPTERA (Aquatic Caterpillars/Moths)					
Crambidae (Pyralidae)	12	A			A

Taxon	QV	S	Veg	GSM	TOT
HEMIPTERA (Bugs)					
Belostomatidae* (Giant water bugs)	3		A	1	A
Corixidae* (Water boatmen)	3	1		A	A
Gerridae* (Pond skaters/Water striders)	5		A		A
Hydrometridae* (Water measurers)	6				
Naucoridae* (Creeping water bugs)	7		A	1	A
Nepidae* (Water scorpions)	3				
Notonectidae* (Backswimmers)	3				
Pleidae* (Pygmy backswimmers)	4				
Veliidae/M...veliidae* (Ripple bugs)	5	B	B	B	B
MEGALOPTERA (Fishflies, Dobsonflies & Alderflies)					
Corydalidae (Fishflies & Dobsonflies)	8				
Sialidae (Alderflies)	6				
TRICHOPTERA (Caddisflies)					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6	A			A
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA (Beetles)					
Dytiscidae/Noteridae* (Diving beetles)	5				
Elmidae/Dryopidae* (Riffle beetles)	8	A		A	B
Gyrinidae* (Whirligig beetles)	5				
Haliplidae* (Crawling water beetles)	5				
Helodidae (Marsh beetles)	12				
Hydraenidae* (Minute moss beetles)	8				
Hydrophilidae* (Water scavenger beetles)	5				
Limnichidae (Marsh-Loving Beetles)	10				
Psephenidae (Water Pennies)	10	A			A

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5	A		1	A
Chironomidae (Midges)	2	1		A	A
Culicidae* (Mosquitoes)	1				
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	A			A
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5	A			A
Tipulidae (Crane flies)	5	A		A	A
GASTROPODA (Snails)					
Ancylidae (Limpets)	6	1	1	A	A
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3			1	1
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5		1	1	1
Sphaeriidae (Pill clams)	3			A	A
Unionidae (Perly mussels)	6				
SASS Score					211
No. of Taxa					33
ASPT					6.39

6.39

Other biota:
Frog.

Comments/Observations:
ATO

Procedure: Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers
Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.
Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects, Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical
Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High