An investigation of the impact of Darvill WWTW effluent on the Msunduzi River ecosystem

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Dissertation accepted in partial fulfillment of the requirements for the degree *Master of Environmental Management with Ecological Water Requirements* at the North-West University

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Graduation December 2022

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DECLARATION

I, Ntokozo Ziphora Sosibo, hereby declare that this dissertation is my own unaided work. All citations, references and borrowed ideas have been duly acknowledged. None of the present work has been submitted previously for any degree or examination at any University.

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Ntokozo Z.Sosibo

12/08/2022

Date

ACKNOWLEDGEMENTS

This dissertation has been very momentous to me and I am grateful for all the support and encouragement I got, especially from my family who gladly looked after my kids during the time I was trying to put this dissertation together. It was really the very strenuous moments of my life where I was ready to give up, but they gave me hope and encouraged me to see the end of my studies. To my mother and sister, Nqobile, thank you so much for taking care of my youngest son even when I had to leave home in the early hours and come back home very late.

I would like to pass my sincere gratitude to my Supervisor, Dr. CW. Malherbe for the support, and I must say patience, and input during my studies.

Last but not least, I would like to pass my great appreciation to friends (especially Martha) and colleagues for their support, prayers and pushing me to hang in there.

ABSTRACT

In South Africa, there are 824 wastewater collector and treatment systems. However, it is estimated that only 60 of these systems are effective. The rest of the systems are releasing effluent that is not of good quality to the environment. The poor quality of effluent being discharged to the water resources and other pollution sources have led to a significant decline in water quality of South Africa's water resources. The most affected rivers are those in the urban areas because of the many anthropogenic activities that are concentrated in these areas. The Msunduzi River is no exception as it emanates in the urban area of Pietermaritzburg. Various media platforms have reported on a number of pollution incidences that occur in the Msunduzi River. The Darvill Wastewater Treatment Works (WWTW) also discharges treated wastewater effluent into the Msunduzi River.

This study assessed the impact of effluent discharges from the Darvill WWTW on the Msunduzi River water quality and aquatic life. Existing water quality and biomonitoring data was obtained from the Umgeni Water Board. The water quality samples were collected at three (3) sites upstream of the Darvill WWTW, two (2) sites at the Darvill WWTW final effluent discharge point and one (1) site downstream of the Darvill WWTW. For the purpose of this study data was extracted from Umgeni Water and analysed for the parameters including pH, electrical conductivity (EC), suspendend solids (SS), chemical oxygen demand (COD), ammonia (NH_3), nitrate (NO_3), Soluble Reactive Phosphate (SRP) as orthophosphate and *Escherichia coli* (*E.col)i.* The concentration of each parameter was measured against the Darvill WWTW Water Use Licence (WUL) Limits issued by Department of Water Affairs (DWA) in 2010, General Limits (issued in 2013 by the then Minister of Water and Environmental Affairs), and as well as the Target Water Quality Range (TWQR) from the South African Water Quality Guidelines for aquatic ecosystems. Data was extracted for 2010-2015 period and again for 2016-2020 period. The 2010-2015 period was used as historical data to be compared with the 2016-2020 water quality data.

The biomonitoring data, available from 2010-2018, was assessed to identify changes to the organisms in the Msunduzi River in the study area. Biomonitoring results were analysed using the Integrated Habitat Assessment Scoring (IHAS), Biotic Index (BI) and Average Score Per Taxon (ASPT) scores. The available biomonitoring results were compared amongst the sample sites to identify changes from the points upstream of the Darvill WWTW and those downstream of the Darvill WWTW.

The results revealed that the Msunduzi River is generally polluted in the study area. This is shown by the results of the parameters at the points upstream of the Darvill WWTW. The pollution of the river in this area emanates from various sources including residential areas, industries and livestock presence. The pH and electrical conductivity parameters were mostly in compliance with the WUL, General Limit and TWQR set for surface water at the upstream points. However, few non-compliance instances were recorded for EC at the discharge point and downstream. The concentration of assessed parameters at upstream points suggests input from several sources as the main cause of their presence in the water and suggests an urban river that is currently modified but deteriorating. The deterioration of the Msunduzi River is also evident through the comparison of the two time periods, 2010-2015 and 2016-2020. Whilst the parameters still show compliance of the water quality with the standards, a closer look at the data reveals that the concentration levels keep increasing in the water.

The biomonitoring data showed that the aquatic life in the Msunduzi River is in a moderate condition. Even though the results were moderate for the biological data, the Darvill WWTW effluent discharges have little direct impact on the aquatic ecosystem of the Msunduzi River. This is because the results show significant improvement in the aquatic life and water quality condition at the downstream point. The downstream point scored higher in all three indices when compared to the upstream points. However, if the water quality of the Msunduzi River is not improved, by managing the activities and eliminating pollution from the surrounding areas, in a long term, it will not be conducive to support the aquatic life of the Msunduzi River.

Key words
Water quality, pollution, surface water, wastewater, wastewater treatment works, effluent, disposal, parameters, river ecosystem, aquatic life, environment, impact.

LIST OF ABBREVIATIONS

ASPT: Average Score Per Taxon

BI: Biotic Index

COD: Chemical Oxygen Demand

DEA: Department of Environmental Affairs

DWA: Department of Water Affairs

DWAF: Department of Water Affairs and Forestry

DWS: Department of Water and Sanitation

EC: Electrical Conductivity

E. coli: *Escherichia coli*

EPA: Environment Protection Agency

et al. **:** et alia (and others)

GDP: Green Drop Program

IHAS: Integrated Habitat Assessment Score

NEMA: National Environmental Management Act

NH_3: Ammonia

NO_3: Nitrate

NWA: National Water Act (No. 36 of 1998)

pH: Power of Hydrogen

RQO: Resource Quality Objective

SASS5: South African Scoring System

SRP: Soluble Reactive Phosphate (as *Orthophosphate*)

SS: Suspended Solids

TWQR: Target Water Quality Range

WHO: World Health Organisation

WUL: Water Use Licence

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1. CHAPTER 1: INTRODUCTION

1.1. Background

The collection and treatment of wastewater has been around since the 19th century. In the beginning, wastewater was collected from people's residential and industrial areas for disposal away from these areas before it was even treated (Lofrano & Brown, 2010). Because it was disposed as untreated, wastewater caused serious health problems and nuisances to humans and animals (Riffat, 2012). This is because untreated or raw wastewater is hazardous due to its composition as it is typically contaminated with harmful physical, chemical and biological composition (Hegazy & Gawad, 2016). The effects of untreated or insufficiently treated wastewater directly discharged into the receiving resource environment leads to potential hazard to downstream users of the receiving environment or river (van Der Merwe-Botha, 2011).

The realization of the negative impacts that wastewater effluent has on the environment shaped the treatment processes of wastewater and aimed at ensuring that the effluent discharged at the end of the treatment process has minimal or no negative impact on the receiving environment. Thus, wastewater is treated in order to improve the physical, chemical and microbiological quality of water (Hansen, 2015). The treatment of wastewater in many areas is done by means of wastewater treatment plants/works. The main function of wastewater treatment plants is to treat water polluted through urban and industrial uses, systematically collected, by removing the pollutants before it is returned to the environment (rivers) (Mitchell *et al*. 2014) as effluent. **Figure 1** shows a typical example of a wastewater treatment process worldwide. The stages involved in the process are as the following:

Screening: The screens are placed at the head of works (the wastewater inlet). In this stage the large objects are trapped and removed before they go further into the process. Failure to remove the large objects may lead to technical failures in the following process stages (EPA, 1998).

Primary Treatment: The aim of this stage is to separate the solid matter (sludge) from liquid (water) that will be proceeded to the next stage (secondary treatment). In this stage the solid matter is allowed to settle at the surface of the settling tanks. It is then removed by large scrappers which then push it to the center of the cylindrical tanks and later pumped out of the tanks for further treatment. The remaining water is then pumped for secondary treatment (EPA, 1998).

Secondary treatment: After effluent leaves the sedimentation tank in the primary stage it flows or is pumped to the secondary treatment facility. The secondary stage removes organic matter in wastewater by making use of the bacteria in it. The techniques employed to perform this function are different depending on the technologies used for the plant. Generally, there are two types of facilities used at this stage, namely the trickling filter and the activated sludge process (EPA, 1998). Finally, the wastewater flows into a disinfection zone. In the disinfection zone the chlorination takes place in order to remove any present bacteria. The chlorine normally disappears as the bacteria are destroyed. In the case where there are still traces of chlorine, the treated water must be neutralized by adding other chemicals. This is done to prevent fish and other aquatic life from being harmed by chlorine traces (USGS, 2018). The final treated water is then discharged to the environment (a local river or the ocean).

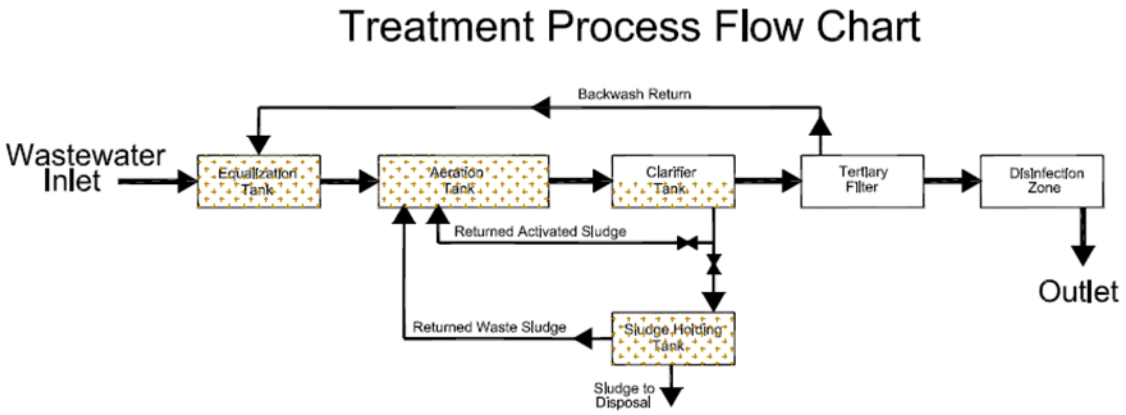

Figure 1: Diagram of typical wastewater treatment plant from around the globe (Pollution Control Systems Inc, 2020).

1.2. Effectiveness of a wastewater treatment process

The effectiveness of the wastewater treatment facility is often measured by the quality of the effluent that comes out in the end (Lester & Edge, 2007). A good quality effluent is that which has been through the treatement process and therefore no longer contain substances such as human waste, food scraps, oils and chemicals. It is imperative that the wastewater treatment facility removes such contaminants and produces effluent that will be in a condition acceptable to the receiving environment, which is often a river. Where the final effluent is not treated properly, pollution of the receiving environment occurs. Problems associated with this include eutrophication, oxygen depletion and proliferation of aquatic weeds and introduction of disease-causing organisms, all of which have a negative impact on the river ecosystem (Lester & Edge, 2007).

Rapid urbanisation, together with accelerated economic development in South Africa, is placing enormous strain/stress on urban, peri-urban and rural environments, especially in the underdeveloped areas of South African cities and towns (communities) (Herbing, 2019). Rapid housing development coupled with increased urbanization has exacerbated the situation (Akinluyi & Adedokum, 2014), since the water infrastructure has not kept pace with other development. In addition, much of the existing infrastructure has not been adequately maintained (Wall, 2006), thus further adding to the problem by putting a strain to the country's water resources (Kidd, 2011). It is estimated that during 2015, eighty percent (80%) of South Africa's freshwater resources were so badly polluted that no purification processes in the country could make it fit for consumption (Herbing, 2019). In this case one can only imagine how the aquatic life is affected by this and how much of it is able to survive such harsh conditions.

1.3. Problem statement

The decline in the water quality of South African water resources has been noted in many reports including media reports (Griffin *et al.,* 2014). The poor quality of South Africa's water resources is due to various sources of pollution. These include, direct disposal of substances into the river, storm-water inflows, incidental (e.g. leakages of underground diesel/petrol tanks), and sewage disposal from poor/deteriorated sewage infrastructure (Chapman, 1996). Two of the most concerning sources of pollutants of the South Africa's scarce freshwaters are acid mine drainage and sewage from wastewater systems that are not functioning properly (Kidd, 2011). This research focuses on the latter, in terms of the effect on aquatic ecosystems.

Municipal WWTW in South Africa have, for many years, raised concerns because of their state which leads to poor quality of effluent being discharged into the rivers (Kidd, 2011). This is because most of the WWTW in South Africa have proven to be inadequate to handle the rapidly increasing urbanization and to avoid the strict environmental requirements

(Herbing, 2019). South Africa has 824 recorded wastewater treatment plants (DWS, 2012). It is estimated that of the 824 wastewater treatment plants, only 60 wastewater treatment plants are releasing effluent of acceptable water quality. The rest of the 764 wastewater treatment plants release partially treated sewage which flows into the river throughout South Africa (DWS, 2012). Kleynhans (2015) stated that 74% of South Africa's wastewater treatment systems are illegally polluting our waterbodies. Furthermore, approximately "3 642 ML/day (million litres per day) of sewage effluent that does not comply with safety standards is discharged into our rivers and dams by the government (municipalities). That means that 74% of wastewater treatment facilities are unlawfully polluting our water, which is criminal (Kleynhans, 2015)".

The state of the WWTW in South Africa has been further exposed by the Green Drop initiative which was incepted in 2008. The Green Drop regulation programme sought to identify and develop the core competencies that, if strengthened, would gradually and sustainably improve the standard of wastewater management in South Africa (DWS, 2022). Since the inception of the Green Drop Programme, 5 series of reports have been released, including the Green Drop Report 2009, the Green Drop Report 2011, the Green Drop Progress Report 2012, the Green Drop Report 2013 and currently the Green Drop Report 2022. During the baseline assessment report (Green Drop Report 2009), this initiative exposed many WWTW which release effluent that is not conforming to the legal requirements, including water use licenses with specific limits for determinants subjected to the particular WWTW and the watercourse in which the effluent is discharged (DWS, 2009).

The wastewater treatment system qualifies to obtain a Green Drop Certification and incentive if it met a minimum score of 90% during the audit. With regards to the Darvill WWTW, the overall scores in the 2009, 2011, 2013 and 2021 audits were, 43%, 79%, 79% and 78% respectively. Therefore, the Darvill WWTW has never been awarded with a Green Drop Certificate. The scores for the cumulative risks rating in the same audits, but from 2011, were, 45.0 %, 69.0%, and 53.1% respectively (DWS, 2022).

The quality and quantity of effluent from most wastewater treatment works have various impacts on the receiving freshwater as well as marine environment. The Msunduzi River is one of the rivers where final effluent is discharged from the Darvill WWTW.

1.4. Research Question, Aim and Objectives

1.4.1. Research Question

How has the Darvill WWTW effluent discharge impacted on the aquatic ecosystem of the Msunduzi River over the past 10 years?

1.4.2. Aim

The aim of the study is to investigate the impact caused by the effluent discharge from the Darvill WWTW on the aquatic ecosystem of the Msunduzi River.

1.4.3. Objectives

- To understand the quality of the Darvill WWTW effluent released into the Msunduzi River, and
- To analyse past and present water quality data in order to compare changes that may have affected the aquatic ecosystem of the Msunduzi River.

1.5. Structure and outline of the dissertation

The overall study is presented in six (6) chapters. These are outlined as follows:

Chapter 1: Introduction

This chapter introduces the rationale for undertaking the study by discussing the origin of wastewater management, the process of wastewater management leading to the effluent discharges. This chapter also briefly introduces the problem generally caused by wastewater management systems on the environment. This formed a theoretical framework for wanting to understand the impacts caused by the Darvill WWTW effluent discharges to the Msunduzi River.

Chapter 2: Literature Review

This chapter provides a review of the literature related to the topic. It provides insight about water quality parameters and their concentration in relation to the existence of aquatic ecosystem. This chapter also discusses the general contaminants found in wastewaters and their effects on aquatic ecosystem.

Chapter 3: Methodology

This chapter described the methods used to answer the research question. Methods were selected to achieve the aim and the objectives described in chapter 1. Methods focussed on the water quality and statistical analysis to determine the effects on the Msunduzi River.

Chapter 4: Results/Data Analysis

This chapter presents the overall research results. The results are presented by means of tables and graphs. The presentation of the results is done for each water quality parameter at each sampling site. The graphs are used to present the data comparison of the 2010-2015 period and the 2016-2020 period. The comparison is also presented for the concentration levels of the water quality parameters used for this study from upstream, discharge and downstream points.

Chapter 5: Discussions

The results of the study as presented in chapter 4 are discussed in this chapter. Basic analyses methods were used to interpret and give meaning to the data presented in chapter 4. This chapter provides discussions in relation to the changes in the aquatic ecosystem of the Msunduzi River based on a comparison of the sample sites data and over the studied period.

Chapter 6: Conclusion and Recommendations

This chapter summarizes the study results and provides conclusions and recommendations about how the negative impacts associated with effluent discharges from Darvill WWTW can be minimised and how the positive impact can be utilised to improve the water quality of the effluent discharges to the Msunduzi River.

2. CHAPTER 2: LITERATURE REVIEW

South Africa's municipalities provide wastewater services via a network of 824 (DWS, 2012) collector and treatment systems. The wastewater treatment industry is comprised of extensive pipe networks, pump stations and municipal wastewater treatment plants for transporting and treating an average of 5258 mega-litres of wastewater on a daily basis (DWA, 2009). Even though there are systems in place for the collection of wastewater for treatment before being discharged into the natural water resources, several media platforms (Kleynhans, 2015) and the Green Drop report (DWS, 2012) have revealed that a significant amount of sewer ends up in water resources still in its raw state (untreated). This results in significant harm being received by the environment and, in other cases, by humans. In spite of the environmental right (section 24) stated in the Constitution of the Republic of South Africa, the environment is still incapacitated, either purposefully or unintentionally (e.g. accidentally spillage incidences).

2.1. Factors causing the disposal of untreated municipal sewage into water resources

- Old sewage infrastructure

Poor planning during the development of old infrastructure has resulted in the old sewage infrastructure being operated under a lot of stress. The demand for water has increased due to economic expansion and population growth. As a result, most old wastewater and sewage systems are increasingly operated under stress. This leads to sewage systems' failure or deteriorating and then leakages of raw sewage into the environment, including water resources (Mema, 2010).

- Inadequate planning

Some sewage systems were poorly designed, with insufficient capacity to deliver and treat large volumes of wastewater and sewage influents, as well as a lack of consideration for future population expansion (Gopo, 2013). Poor design in the construction of the houses under the Reconstruction and Development Programme (RDP) , according to Morrison *et al*. (2001), exacerbated the situation. Some RDP houses are built in regions where the sewage system does not have the ability to handle them.

- Lack of skilled personnel to operate the sewage system

Most facilities in the rural areas and smaller towns are not adequately equipped with staff possessing appropriate skills and this constrains the performance of these sewage systems. As a result, many facilities are not operating properly, and the effluent water quality is no longer acceptable (News24, 2010).

- Financial allocations

Kidd (2011) describes sewage as “unsexy” as a result it is normally the least of peoples’ worries. Once one managed to get sewage out of their backyard, their least concern is where it ends up. To this, Kidd (2011) suggests that, if sanitation failures manifested themselves in households being unable to flush their waste, expenditure on sanitation would be prioritized. Because it is less prioritized, there is less resources, budget, allocated to it.

Peyper (2015) expressed a concern over the government's failure to spend R2 billions of its budget despite major wastewater treatment plant failures in South Africa. This demonstrates the government's lack of care for South Africa's inadequate sewage infrastructure, which results in pollution of water resources and substantial harm to the environment.

2.2. Legal requirements for preventing water resources pollution in South Africa

In South Africa, the national government, acting through the Minister of Water and Sanitation, is the public trustee of the nation’s water resources. In this responsibility, the national government is obligated to ensure that water is protected, used, conserved, managed and controlled in a sustainable manner. In alignment with this responsibility, the Department of Water and Sanitation (DWS) develops and ensures implementation of the policies governing the use of water. The onus for water service to the local government (municipalities) is provided for by the constitution and can also be as per the Minister of Water and Sanitation delegation. Some of the municipalities are also responsible for the provision of sanitation in areas under their jurisdiction.

2.2.1. Constitution of South Africa, 1994

- Section 24 of the Bill of Right and Sustainable Development

Environmental right is enshrined in the Bill of Rights in the constitution. The Bill of Rights states that:

> Everyone has the right— (a) to an environment that is not harmful to their health or wellbeing; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that— (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development (Constitution of South Africa, 1994).

The inclusion of the environmental right in the constitution is essential because the state has a responsibility to safeguard the environment through legislation and other means. Water that is clean and clear is linked to a healthy environment and the need to avoid pollution. Water is crucial for human health and the environment, and precautions must be made to prevent it from becoming too polluted (Kanamugire, 2008).

2.2.2. The National Water Act (NWA) 36 of 1998

The pollution of water is made an offence in terms of section 151 of the National Water Act (NWA), 36 of 1998. Section 19 puts the responsibility of pollution prevention and remediation to the landowner, a person in control of land or a person who occupies or uses the land. A catchment management agency has the power to issue a directive for the prevention and/or remediation of pollution to the person responsible for such pollution. With regards to water, the National Department of Water and Sanitation is the institution primarily responsible for the prevention of water pollution as provided in the NWA. The Department of Water and Sanitation has officials tasked with compliance and enforcement under the NWA. Section 54(1) provides that responsible person has the powers to suspend or cancel an authorisation where non-compliance has been detected and may issue a rectification notice to a person who has contravened various provision NWA.

Section 7 of the Water Services Act, 108 of 1997, provides that no person may dispose of industrial effluent in any manner other than that approved by the water services provider nominated by the Water Services Authority (WSA) having jurisdiction in the area in question. As mentioned above, in South Africa municipalities are responsible for, amongst other functions, sewage and sanitation, storm water systems and refuse removal. With regards to the function of sewage and sanitation, municipal treated effluent is discharged from specified point-sources and channelled into the receiving waters such as streams, rivers, lakes, ponds and ground water.

This water use must be authorised and regulated to ensure that discharges are controlled and have manageable or less harm to the environment and human health. The wastewater treatment processes are designed to comply with the determinant limits specified in particular authorisations (General Authorisation (GA) or Water Use Licences (WUL)). The determinants specified in the authorisations are those expected to be found in the effluent and limits are set taking into consideration the receiving environment water quality during discharges.

2.2.3. The National Environmental Management Act (NEMA), 107 of 1998

The National Environmental Management Act (NEMA), 107 of 1998, defines an incident as ‘an unexpected sudden occurrence, including a major emission, fire or explosion leading to serious danger to the public or potentially serious pollution of or detriment to the environment, whether immediate or delayed. Where the raw sewage discharges to the environment are regarded as incident, NEMA imposes the duty of containing and minimising the effect of the incident to the responsible persons. According to section 30, an incident includes any person who, (i) is responsible for the incident (ii) owns any hazardous substance involved in the incident; or (iii) was in control of any hazardous substance involved in the incident at the time of the incident. In the case of municipality sewage system, based on the definition provided above, the municipality can be regarded as the ‘responsible person’ since they are in control of the operation of the sewage systems. Although the release of effluent from sewage system is technically pollution, it is permitted under specified circumstances including, filled up stormwater dams located at the WWTW, releases due to emergency maintainance and releases under the conditions setout in the WUL and GA.

2.3. Water Quality

Water quality relates to the fitness of the water for an intended use by humans (for domestic, industrial agricultural and commercial purposes) or natural environment (aquatic life). To assess fitness for use of water the analyses include chemical, physical, biological and aesthetic elements which are either dissolved or suspended in the water (Mandal *et al.,* 2019). With regards to the use for human purposes the main concern of the quality of water is its safety from any pathogens (i.e. it should be free from disease-causing pathogens that can potentially affect human health). Microbiological examinations are undertaken to monitor the quality of water for human consumption (Barell & Glober, 2000). However, from aquatic ecosystem point of view, water quality parameters of the waterbody need be at concentration levels suitable for survival and support of the organisms to protect the integrity of the ecosystem.

The quality of freshwater worldwide is deteriorating due to pollution including wastewater disposal (Mateo-Sagasta *et al*., 2017), and South Africa is no exception (Kidd, 2011). This in turn leads to changes faced with regards to the supply of potable water as the state of South Africa's freshwater becomes costly to treat (Otieno & Ochiego, 2004). The deteriorating state of freshwater does not only affect the supply of potable water but also affects the life of the aquatic ecosystem (Dube, 2020). The use of water as a universal medium for the transportation of most types of waste leads to it having poor quality to sustain aquatic life (Chapman, 1996). Edokpayi *et al.* (2017) states that freshwater sources serve as the best sinks for domestic and industrial wastewater discharges. As a result, it leads to freshwater contamination by wastewater.

2.3.1. Wastewater contaminants

The types of influents the wastewater treatment plants receive determine the quality of the wastewater (Edokpayi *et al.,* 2017). Influents may contain a combination of domestic wastewater, industrial wastewater, dry and wet atmospheric deposition, urban runoff which may contain traffic related pollution, and/or agricultural runoff. Industrial wastewater broadens the range of contaminants that may be found in the wastewater (Ratola *et al.,* 2012). There has been growing studies about emerging contaminants found in wastewater effluents. These emerging contaminants include brominated flame retardants, per-flourated compounds, persistent organic pollutants, and pharmaceuticals. These emerging contaminants have been found not being removed during the wastewater treatment process and they find their way to the environment where the effluent is discharged (Muller, 2013). South Africa has been reported to have less than half of its WWTPs treating wastewater to a safe and acceptable level (Kretzmann *et al.,* 2021).

Untreated or improperly treated wastewater effluent contains in it a variety of contaminants that pose negative impacts to the environment and can be toxic to humans and animals (Akpor *et al.,* 2014). Arist *et al.* (2015) refer to two categories of contaminants that are contributed by the wastewater treatment plants' effluent to waterbodies. These include organic contaminants and the toxic contaminants. Organic contaminants promote the biological activities of the river and include nutrients and organic matter. Toxic contaminants suppress biological activities in the receiving environment (Arist *et al.,* 2015). When pollutants are released into aquatic habitats, direct (toxic) effects on aquatic biota are possible (Fleeger *et al.,* 2004). Some of the contaminants in the wastewater effluent can change the way the water looks, smells and tastes while other contaminants may not be able to be observed by the human senses. Some contaminants affect the body while others bio-accumulate in aquatic biota e.g. fish (Akpor & Muchie, 2011).

2.3.2. Effect of common contaminants

The problems caused by untreated or improperly treated wastewater effluents include metal poisoning, nutrient overload, irritations and pathogenic infections on humans and animals. Nutrient overload leads to eutrophication as the nutrients could lead to the stimulation of the algae growth (Fleeger *et al.,* 2004). Toxic contaminants could result in direct effect on aquatic biota. Direct effects vary with the intensity and duration of exposure to a toxicant (Long *et al.,* 1995). The direct effects are mostly apparent on species that are less tolerant of the particular toxicant. Thus, the toxicant's effects are based on species responses to the toxicant. Therefore, to determine the risk and establish permissible levels of contaminants, the studies must be done for individual toxicants and species (Long *et al.,* 1995).

Other contaminants may result in indirect effects on aquatic biota. Indirect effects are experienced on species that have a high tolerant level (Fleeger *et al.,* 2004). The indirect effects are often not detected by the laboratory tests. This is because the direct effects (altered behaviour or lethality) on predator species can result in cascading indirect effects on more tolerant species. Indirect toxicant effects may lead to increased (e.g. via reduced competition) or decreased (e.g. via reduced availability of preferred food) abundance. Below are common contaminants and their effects on aquatic life are discussed.

2.3.2.1. Nutrients

The growth of algae and aquatic plants (eutrophication) in surface water is controlled by the two most important elements namely phosphorus and nitrogen (Rabinowitz *et al.,* 1990). Municipal sewage effluents and overflows of storm and sanitary sewers, wastewater from livestock farming, industrial wastewater effluents, and runoff from waste disposal sites, working mines and un-sewered industrial sites are the principal anthropogenic point sources of inorganic nitrogen and phosphorus found in aquatic ecosystems (de Villiers & Thiart, 2007). Thus, nitrogen and phosphorus are the two major eutrophic nutrients in wastewater effluents (Akpor *et al.,* 2014).

Nitrogen

In untreated wastewater, nitrogen is primarily in the form of ammonia and organic nitrogen. For the protection of aquatic life, the recommended concentration levels of organic nitrogen in a form of nitrate and nitrite are between 80–350 µg and 2000–3600 µg (Camargo *et al.,* 2005). In a form of unionized ammonia, the recommended nitrogen concentration level is 50–350 µg for short-term exposures and 10–20 µg for long-term exposures (Constable *et al.,* 2010). Unionized ammonia (NH_3) is the most toxic form of inorganic nitrogen to aquatic animals (de Villiers & Thiart, 2007). The guidelines allude to the effects of nitrogen in the form of unionized ammonia affecting the respiratory systems of many animals, either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes. Acute toxicity to fish may result in a loss of equilibrium, hyper-excitability, an increased breathing rate, an increased cardiac output and oxygen intake. In extreme cases acute effects may lead to convulsions, coma and even death. Chronic effects include reduced hatching success, reduction in growth rate and morphological development, and pathological changes in tissue of gills, liver and kidneys. However, fish may have an increased tolerance to ammonia if they have had prior exposure or acclimation. Thus, some fish may be able to with-stand concentrations of ammonia that may well have been acutely lethal to them. The Target Water Quality Range (TWQR) for ammonia is 7 mg/L (DWAF, 1996).

Ammonia

Ammonia is a gas that occurs as reduced forms of inorganic nitrogen as a result of aerobic and anaerobic decomposition of organic material. These forms are un-ionized form (NH_3) or in the ionized form as the ammonium ion ($NH4^+$) (DWAF, 1996). Ammonia, associated with clay minerals enters the aquatic environment through soil erosion. Ammonia may be found in household detergents and in industrial chemicals. Ammonia and nitrates are said to be positively correlated to wastewater treatment works because high levels of ammonia and/or nitrates are usually experienced (Dube, 2020).

The toxicity of ammonia and ammonium salts to aquatic organisms is directly related to the amount of free ammonia in solution (DWAF, 1996). Unionized ammonia affects the respiratory systems of many animals, either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes (Nordin, 2009). Acute toxicity to fish may cause a loss of equilibrium, hyper-excitability, an increased breathing rate, an increased cardiac output and oxygen intake, and in extreme cases convulsions, coma and death. Chronic effects include a reduction in hatching success, reduction in growth rate and morphological development, and pathological changes in tissue of gills, liver and kidneys (DWAF, 1996).

An increased ventilation of the gills following exposure to ammonia indicating a respiratory effect has been observed in mayfly larvae *Ecdyonurus despair* (DWAF, 1996). According to the South African Water Quality Guidelines for Aquatic Ecosystems proportion and toxicity of unionized ammonia in aquatic ecosystems is affected by the water temperature and pH (DWAF, 1996). If either of the two (2) increases, the unionized ammonia will increase in toxicity to aquatic organisms.

Orthophosphate as Soluble Reactive Phosphate (SRP)

Phosphorous is an essential element for life, both as a nutrient for plant life and as a key element in the metabolic processes of all living things. In its organic and inorganic forms, phosphorus may be found in waters as dissolved and particulate species (orthophosphates, polyphosphates, metaphosphates, pyrophosphates) (Prasad & Chakraborty, 2019). Orthophosphate, as Soluble Reactive Phosphate (SRP), is that phosphorus which is immediately available to aquatic biota and through naturally occurring processes can be transformed into an available form (Carlson & Simpson, 1996). Surface waters naturally contain levels of phosphorus in various compounds, which is an essential constituent of living organisms. The normal low phosphate (PO_4) level (less than 5 mg/L) in water inhibits the growth of plants (DWAF, 1996). Phosphorus is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems. Surface water, in South Africa, that has not been impacted has phosphorus seldomly present in high concentrations. This is because it is actively taken-up by plants. Concentrations between 10 and 50 mg/L are commonly found, although concentrations as low as 1 mg/L of soluble inorganic phosphorus may be found in "pristine" waters and as high as 200 mg/L of total phosphorus in some enclosed saline waters (DWAF, 1996).

In the study conducted by de Villiers & Thiart (2007) it was revealed that in the 20 largest catchments of South Africa, nutrient levels exceed recommended water quality guidelines for plant life. The study was conducted on the following catchments: Lower and Upper Orange, Upper Vaal, Harts, Riet, Wilge, Olifants, Berg, Breede, Gourits, Keurbooms, Gamtoos (Groot), Swartkops, Sundays, Great Fish, Keiskamma, Great Kei, Mzimvubu, Mkomazi, Tugela, Mfolozi, Phongolo, Komati and Limpopo. In terms of phosphorus, the study revealed that phosphorus levels were exceeding recommended concentrations in all of the studied catchments except in only six (6) of the catchments namely Gourits, Keurbooms, Gamtoos (Groot), Mkomazi, Mfolozi and Limpopo. The results of high phosphorus level were said to be caused by poor effluent water quality which showed high concentrations of nutrients.

Balanced concentration of phosphorus in water can be taken up by a population of living organism. However, when phosphorus input to waters is higher than it can be assimilated by a population of living organisms in the water, the problem of excess phosphorus content occurs (Rybicki, 1997). Excess phosphorus in surface water can result in the rapid increase in plant growth, such as blue-green algae, and other aquatic plants in dams (Chislock *et al.,* 2013). The water plants become overcrowded and die. When they die, the decomposing bacteria use up more oxygen and affects other forms of life negatively, e.g. fish suffocate. Emission of phosphate in surface waters has negative impacts on nature conservation, recreation and drinking water production due to it leading to eutrophication and algae bloom. Therefore, it is important to control the emission of phosphate from wastewater discharges (van Larsdrecht, 2005).

2.3.2.2. Microbiological Parameters

The presence of microorganisms (bacterial indicators) in water is identified by means of microbiological assessments (Ashbolt *et al.,* 2001). Faecal contamination in water is a global issue mostly affecting rural communities who depend on raw freshwater for consumption (Naidoo, 2013). There are health related risks that have been associated with the use of microbiologically contaminated water which is of great concern (Pandey, 2006). *Escherichia coli (E. coli)*, enterococci, total and faecal coliforms are the common indicator organisms in wastewater receiving environment. These coliforms indicate faecal pollution in water (Dube, 2020). Total and faecal coliforms in water indicates the general quality of water and assist in identifiying the potential source of faecal contaminant. The presence of faecal coliforms in the final effluent from the WWTW assist also in the determination of the efficiency of wastewater treatment facilities (Ashbolt *et al.,* 2001). It has been proven that coliform bacteria are in abundance on warm blooded mammals and then used to indicate sanitary quality of water resources since their presence indicates faecal contamination (Dube, 2020).

Escherichia coli (E. coli)

Escherichia coli (E. coli) is globally used as the most precise indicator of faecal contamination, especially in the drinking water sector (Odonkor & Ampofo, 2013). The government set allowable limits for the presence of these indicators in freshwater to ensure compliance. *Escherichia coli* is used as an indicator of faecal contamination in water quality environment (Meays, 2004). The presence of *E. coli* pathogens results in the deterioration in water quality due to unsecured faecal wastes (DWAF, 1996). These are released by humans and animals, or sewage leakages into water (DWAF, 1996)**.** The high concentrations of *E. coli* present at any influent, upstream and downstream points could be associated with the wastewater containing sewage and sanitary wastes and runoff into the river, respectively (Chapman, 1996).

2.3.2.4. Physical Parameters

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

Total dissolved solids/salts are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate anions. Most salts are essential nutrients and are needed by the body in relatively small amounts to maintain a balance of body fluids and keep muscles and nerves running smoothly (FDA, 2021). The

TDS occur in natural water because of natural processes, including the dissolution of minerals in rocks, soils and decomposing plant material (DWAF, 1996). In moving waters, TDS accumulates as water moves downstream (Bhateria & Jain, 2016). The concentration of TDS may increase due to domestic and industrial effluent discharges, surface runoff from urban, industrial, and cultivated areas. Evaporation also leads to an increase in the total salts (DWAF, 1996). The increase of chloride in freshwater due to anthropogenic activities threatens many aquatic organisms, including amphibians and fish (Corsi *et al*., 2010).

The TDS concentration is mostly measured by measuring the Electrical Conductivity (EC) of the water because it is much easier to measure the EC compared to measuring the TDS concentration (DWAF, 1996). The EC measures the total amount of material that is dissolved in a sample of water and is therefore often used in the general characterisation of water quality (Kriel, 2008). The value of EC is directly proportional to total dissolved solutes (TDS) in the water (DWAF, 1996). Electrical conductivity (EC) is the ability for water to pass an electrical current. The presence of material (dissolved salts/solids) or sediment, such as salt, in the water determines the amount of EC measured. Monitoring EC assists in the identification of saltwater intrusion and pollution events (Atkins, 2020). The EC is an early indicator of change in a water system. The changes may be as a result of natural flooding, evaporation, or human-made pollution and these lead to the concentration of dissolved salts that, depending on their concentration, can be toxic to the aquatic life (Kriel, 2008).

Turbidity

Turbidity is the amount of cloudiness in the water. Causes of turbidity include silt, sand and mud, bacteria and other germs and chemical precipitates (World Health Organization, s.a). Increased or high turbidity can harm fish and other aquatic life by reducing food supplies, degrading spawning beds, and affecting gill function (Mohammed, 2015). According to Minnesota Pollution Control Agency (2008), turbidity can be harmful to freshwater organisms in five ways including acting directly on fish (killing them or reducing their growth rate, resistance to disease), preventing successful development of fish eggs and larvae, modifying natural movements and migrations, reducing the amount of food available and affecting the efficiency of methods for catching fish.

Suspended solids (SS) refer to numerous particle types of both organic and inorganic matter such as suspended sediment that, after attaining a settling equilibrium per unit volume of water, remains suspended (Valentukeviciene *et al.,* 2011). As the sediments, suspended solid play an important role in ecological, chemical and physical processes in aquatic ecosystems (Whiles & Dodds, 2002). Suspended solids are responsible for transporting nutrients, providing microbial habitat, and serving as a food supply for many organisms. However, at high concentration suspended solids bring stresses on aquatic ecosystems (Capper, 2006). These stresses include benthic habitat alteration, changes in light attenuation and subsequent changes in primary productivity, and physiological effects on organisms ranging from growth and reproduction inhibition to mortality.

Aluminium

Aluminium is the third most abundant element in the earth's crust. Under acidic ($pH < 6.0$) or alkaline ($pH > 8.0$) conditions, or in the presence of complexing ligands, elevated concentrations may be mobilised to the aquatic environment (Government of Canada, 2017). The pH determines the solubility of aluminium. The toxicity of aluminium depends on the chemical species involved (World Health Organization, 2003). Aluminium mostly ends up in wastewater from the industries including the paper industry, the metal construction industry, the leather industry, and, the textile industry. Also, alum or aluminium sulphate is used in most water treatment processes as a flocculating agent for suspended solids, including colloidal materials, micro-organisms and "humic rich" dissolved organics (DWAF, 1996).

The toxic effects of aluminium on species depends on the type of species and the life stage of the organism, the concentration of calcium in the water, and pH (Igbonkwe *et al*., 2019). Increased toxicity of aluminium occurs at about a pH 5.0 - 5.2 (Gensemer & Playle, 1999). The mechanism of toxicity in fish seems to be related to interference with ionic and osmotic balance and with respiratory problems resulting from coagulation of mucus on the gills (Authman *et al*., 2015).

Dissolved Oxygen (DO)

The effects of excess nitrogen and phosphorus is mostly evidence in slow-moving streams and rivers as they can lead to an increase in primary productivity which stimulates excessive plant growth (algae and nuisance plants and weeds), thereby degrading water quality (Meyer & Barclay, 1990). The presence of algal blooms in water has been indicated to lead to non-linear decrease in water clarity levels (Giovanni *et al*., 2021). The recognizable effect of eutrophication is the occurrence of algal blooms, which in turn leads to the depletion of dissolved oxygen (DO) concentration in receiving water bodies. A low DO in water bodies is known to lead to the death of aquatic life (Meyer & Barclay, 1990), muddy water and drastic reduction of desirable flora and fauna (Jack *et al*., 2009).

2.3.2.5. Toxic contaminants commonly found in wastewater effluent

The toxic contaminants can have a more direct negative impact on the river ecosystem. The effect of toxic contaminant is direct and detrimental to the aquatic life (Hernando *et al*., 2006). The most effect can be observed when the toxic contaminants are mixed (Cleuvers, 2003). These contaminants affect the biofilms composition and the communities of the invertebrates found in the water (Arist *et al*., 2015). Micro-contaminants such as illicit drugs, personal care products, plasticizers, pharmaceuticals, and flame retardants are toxic contaminants that exist in the environment, as evidence from various studies (Kummerer, 2011). From these toxic contaminants, several transformation products can be formed. Transformation products may be more toxic compared to the parent compound. The level of toxicity maybe further exacerbated by the presence of potentially harmful unknown compounds that are simultaneously present in the environment together with priority contaminants (Eggen *et al*., 2014).

The South African Water Quality Guidelines for Aquatic Ecosystems provide the following contaminants as typical toxic constituents of aquatic ecosystem: Al, As, Cd, Cu, F, Hg, Mn, NH, phenol, atrazine. However, for the purpose of this research focus on the ones monitored as per licence requirements of the study area are discussed. Toxic contaminants seldom occur in high concentrations in un-impacted systems. These become toxic when in high concentration and at a specific level of risk associated with them (DWAF, 1996).

2.4. Biological Assessments

Surface water quality worldwide is deteriorating due to anthropogenic activities, including generation and disposal of wastewater. These activities put a strain on the aquatic ecosystem (Samways & Taylor, 2004). Ways of assessing the impacts of anthropogenic activities on aquatic life are necessary and important to ensure improved decision-making about the protection of rivers' health. One of the traditional methods is the physio-chemical method (Solihu & Bilewu, 2022). However, aquatic ecosystems are highly complex involving the interaction of physical, chemical and biological factors. The physio-chemical method became difficult and expensive to use for monitoring (Samways & Taylor, 2004).

The impacts of different contaminants or the combination of contaminants on waterbodies can be reflected through the assessment of aquatic organisms exposed to them (Dallas, 2021). Organisms are good indicators of the river quality because of their biological endpoints, and they assist in reflecting the overall ecological integrity of their environment (Roux, 1999). The use of one or more component of the biota to assess the effect of a change in another component such as water quality is referred to as bioassessment (Dallas, 2021).

In Southern Africa, benthic macroinvertebrates have been used as biological indicators for assessing river quality (Dallas, 2021). Benthic macroinvertebrates are good in long-term trends monitoring and for comparing river systems (Malakane *et al.,* 2020). Whilst there are other bioassessment methods used for monitoring aquatic ecosystems, the South African Scoring System (SASS) is the mostly used method. According to Smith (2005), SASS maybe used for the following assessments:

- ecological state of aquatic ecosystems
- spatial and temporal trends in ecological state
- emerging problems
- set objectives for rivers
- impact of developments; and
- to predict changes in the ecosystem due to developments

The SASS gained its popularity because of its advantages including:

- Being user-friendly in that it is quick and easy to use in the field.
- Requires use of few equipment and little expertise
- Less costly

- Does not cause further damage on the environment (Smith, 2005)

Whilst SASS has undergone extensive testing (Dallas, 2021) and is widely used (Dickens & Graham, 2002), no single measure is an acceptable surrogate for monitoring the biological state of a river. A more profound information can be obtained by integrating different techniques during river quality assessment. The SASS has its own shortcomings including (Smith, 2005):

- Being problematic in rivers with low biotope as it is highly reliable at increased numbers of available biotopes
- Is highly reliant on the stones-in-current biotopes, which lower river reaches often do not have
- Limited interpretation on invertebrates at finer taxonomic level because it only identifies invertebrates at family or higher taxonomic level.

Habitat quantity, quality and diversity factors may influence the SASS scores, as a result these factors must be assessed together with the SASS data in order to make it meaningful. Ancillary analyses including temperature, dissolved oxygen, conductivity and pH are also useful for the interpretation of SASS data (Dickens & Graham, 2002). For this study information on biomonitoring was obtained through data from the Integrated Habitat Assessment Scoring (IHAS), Biotic Index (BI) and Average Score Per Taxon (ASPT).

Habitat integrity refers to the maintenance of a balanced, integrated composition of physico-chemical and habitat characteristics on a temporal and spatial scale that is comparable to the characteristics of natural habitats of the region. Habitat integrity assessment is a precursor of the assessment of biotic integrity (Kleynhans, 1996). Biotic integrity has been defined as the ability to support an integrated, adaptive community of organisms with species composition, diversity, and functional organization comparable to that of a natural assemblage of the region. As such, a system with intact biotic integrity supports a complex of native biodiversity with natural processes and services.

3. CHAPTER 3: METHODOLOGY

3.1. Description of study area

The Msunduzi River (**Figure 2**) is contained within the U20J quaternary catchment. It passes through the centre of Pietermaritzburg City in KwaZulu-Natal. A portion of the river within the city has been dammed by weirs and is used for canoeing and rowing practice. The Msunduzi River, is a major tributary of the Umgeni River which serves as a major source of drinking water for rural communities residing in areas along the length of the river, such as those communities living in the Valley of a Thousand Hills (Wikipedia, s.a).

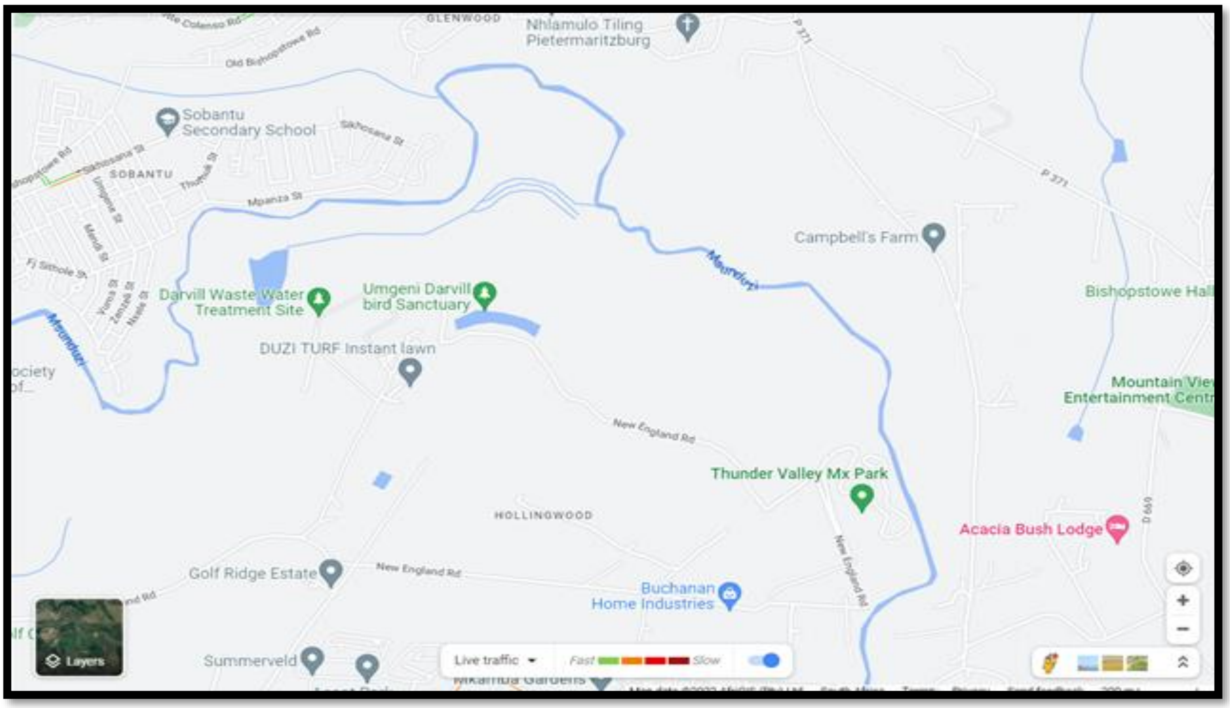

Figure 2: Google Maps photo showing the Msunduzi River and surrounding areas in the study area.

Darvill WWTW **(Figure 2 and 3)** is located to the east of the Pietermaritzburg Central Business District. The area on which the plant is situated is bound by the Msunduzi River on the north and east. Other nearby activities to the Msunduzi River and the Darvill WWTW include, the landfill site (west side of Darvill WWTW), residential areas (north and south) including Sobantu Township; Hollingwood and Lincoln Meade. Darvill WWTW was originally built in the mid-1950s (Mace Group, 2020) and was commissioned in 1958 with a capacity of 27 ML/day. Umgeni Water took over the operation and planning functions of this wastewater work in the early 1990s. Before Umgeni Water took over, this wastewater work had last been upgraded in the mid-1970s when the city increased the capacity to about 65 ML/day (Umgeni Water, 2017). It is currently being upgraded again from 65 ML/day to 100 ML/day (Naidoo, 2017). The upgrade is intended to ensure that the wastewater work comply with capacity constraints, and to produce a final effluent of an acceptable standard.

3.1.1. Climate

The study area has a warm climate with wet summers and dry, cold winters. The area has moderate rainfall of approximately 738 mm annually (Allan, 2016).

3.1.2. Biodiversity (Flora and Fauna)

The study area is situated at the edge of the subtropics consisting of three different veld types, including the Valley Bushveld, the Southern Tall Grassveld, and the Ngongoni Veld. Natural vegetation found on site falls into the category of KwaZulu-Natal Hinterland Thornveld. The vegetation biome is primarily bushed grassland and bushland. Indicator species include *Aristida junciformis (*Ngongoni Three-awn*), Panicum maximum (*Guinea Grass*), Acacia karroo (*Sweet Thorn*), Acacia nilotica (*Thorn mimosa*), Acacia sieberiana (*Paperbark Thorn*), Lantana camara (*Lantana*)*; and various other species types which comprise this Bio-resource group (Allan, 2016).

Lack of veld management (burning / mowing regimes, exclusion of fire) has led to a significant degradation of the area. About 98% of the vegetation is alien plants (Bugweed, lantana, Mulberry trees, *Morus alba, Cardiospermum grandiflorum*, etc (Bertolly & Pillay, 2016) . Illegal waste disposal and some subsistence grazing has added to the degradation of the vegetation (floristic composition) (Bertolly & Pillay, 2016). Nitrogen and phosphorus leaching from the wastewater treatment work contributes largely to the prevalence of alien plants in the area (Allan, 2016). With regards to fauna, the area is limited to small mammals and rodents. The area is listed as an International Birding Area. Waterfowl and waders, fish-eagle, black sparrow hawk, peregrine falcon, long-crested eagle and jackal buzzard are some of the species present in the area (Allan, 2016).

3.2. Data Collection

The study applied a qualitative research technique. Existing water quality and biomonitoring data was obtained from the Umgeni Water Board. Umgeni Water is responsible for the management and operation of the Darvill WWTW. As such Umgeni Water holds the water use license for the Darvill WWTW. The licence details the monitoring points and determinants associated with the discharges of the effluent from Darvill WWTW. Water samples were collected and analysed by Umgeni Water.

3.2.1. Sample Locations

The water quality samples were collected at the sites shown in **Table 1** and **Figure 3**. Samples were strategically selected to capture the true representation of the impact of the discharge/effluent from the Darvill WWTW. As such samples were selected upstream, downstream and at the discharge points.

Table 1: Sample sites location information.

Sampling Point	Position in relation to Darvill WWTW	Co-ordinate
RMD015	Upstream of Darvill WWTW	S 29°36'10.7" E 30°25'30"
RMD016	Upstream of the Baynespruit Stream	S 29°35'48.1" E 30°26'04.0"
RMD017	Upstream of Darvill Maturation River	S 29°35'48.7" E 30°26'21.1"
RMD018	Downstream of Darvill Maturation River	S 29°35'57.56" E 30°26'36.1"
WDV020	Darvill Final Effluent Discharge Point	S 29°36'4.8" E 30°25'37.8"
RMD019	Downstream of Darvill Discharge Point	S 29°36'27.5" E 30°27'0.5"

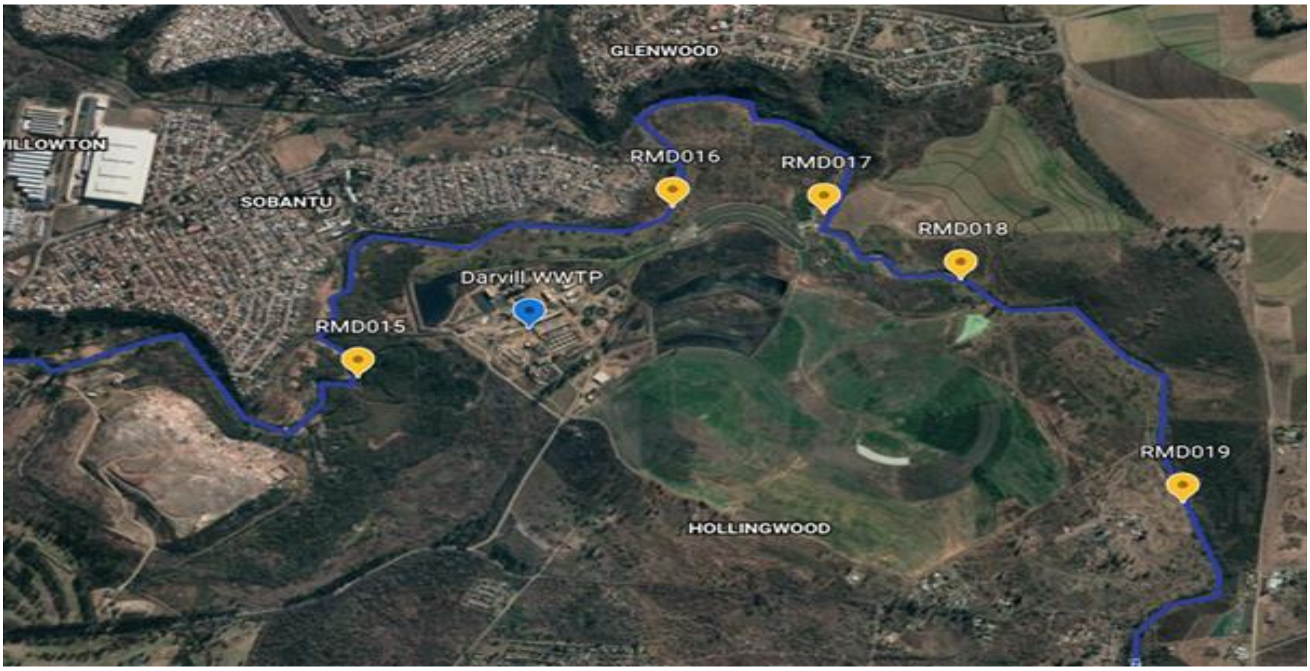

Figure 3: Location of monitoring points along the Msunduzi River as per the site specific 2010 WUL requirements.

3.2.2. Water quality parameters

For the purpose of this study, data was extracted from Umgeni Water and analysed for the parameters (determinants) in **Table 2**. These parameters are good indicators of pollution derived from wastewater handling (Dube, 2020). Data was extracted for 2010-2015 period and again for 2016-2020 period. The 2010-2015 period was used as historical data to be compared with the 2016-2020 water quality data. This was done to identify any changes to the results due to the Darvill WWTW upgrade that commenced in 2015. The upgrade was put on halt in 2019 due to internal and external matters. As a result, the Darvill WWTW is partially upgraded and may still be experiencing any of the issues that made the upgrade necessary.

Table 2: Water quality parameters and limits (Darvill WWTW WUL Limts and General Limits) analysed for this study.

Parameter Category	Determinants	Units	WUL Limit	General Limits	TWQR
Physical	pH		5.5-9.5	5.5-9.5	
	Electrical Conductivity (EC)	mS/m		70	
	Suspended Solids	mg/L		25	
Organic matter	Chemical Oxygen Demand (COD)	mg/L		75	
Nutrients	Ammonia (NH3)	mg/L	1-2	6	#7
	Nitrate (NO3)	mg/L	<6	15	10
	Orthophosphate (SRP)				
Microbiological	*E.coli*	MPN/100 ml			

3.2.3. Biomonitoring Data

Umgeni Water also conducted biomonitoring and the data is available from 2010 to 2018. Biomonitoring was conducted on some of the same sites as water quality monitoring. The biomonitoring data from this period was used to identify changes to the aquatic life in the Msunduzi River in the study area. Biomonitoring looked at the benthic macro-invertabrated. Benthic macro invertebrates are valuable organisms for bio assessments, due largely to their visibility to the naked eye, ease of identification, rapid life cycle and their largely sedentary habits. The composition of these communities can be used as an indicator of the water quality and general health at that site, due to the different sensitivities of the organisms to environmental stressors and pollutants (Wynne, 2015)

The Integrated Habitat Assessment Score was used to assess the specific habitat suitability for the survival of aquatic macro-invertebrates. The diversity and quality of the three habitat biotopes (Stone, Vegetation, and GSM) were recorded, assessed, and calculated for RMD015, RMD016, RMD017, RMD018, RMD019 and RMD024. The last point (RMD024) was introduced in order to assess the aquatic habitat status at an area away from the influx of urbanisation. All sampling was undertaken by an accredited SASS practitioner. The unnecessary material was cleared prior to invertebrate identification. The relative abundances of stipulated aquatic invertebrate taxa were then recorded within a specific time limit.The assessment involded a three-minute kick sampling at each site using the standard 1 mm mesh size net and sweeping net (Dickens and Graham, 2001). The substratum upstream was vigorously disturbed to dislodge invertebrates to flow into the net, in accordance with Mason (2002). Samples were emptied into a white dry and macroinvertebrates were sorted and identified to family level, counted and recorded in the field.

The IHAS score is presented as a percentage, where 90 -100% represents an unmodified (pristine) habitat quality and diversity. A score of above 40-59% represents a section of river that has been largely modified and there is an extensive loss of natural habitat, biota and basic systems functions. A score of between 0 and 19% is indicative of a river reach that is extremely modified with almost complete lack of certain biotopes. This infers poor habitat quality, which in turn will impact negatively on aquatic invertebrate community composition (Kleynhans, 2007).

The ASPT equals the average of the tolerance scores of all macroinvertebrate families found in each sample, and ranges from 0 to 10. Samples were analyzed by allocating a score between 0 and 10 to each group or family according to their sensitivity or tolerance of the macroinvertebrates to the pollution in an aquatic ecosystem. The average score per taxa (ASPT) is obtained by dividing each score by the total number of families in the sample (Kleynhans, 2007).

3.3. Data preparation and analyses

The data obtained were used to identify non-compliances against the limit values **(Table 2).** The data wer used to draw up graphs to show variations and trends with regards to the concentration of each parameter in water. This was done for each sampling point and for each parameter. The concentration of each parameter was measured against the Darvill WWTW WUL Limits issued by DWA in 2010, General Limits (issued in 2013 by the then Minister of Water and Environmental Affairs), and as well as the TWQR from the South African Water Quality Guidelines for aquatic ecosystems (DWAF, 1996)**.** This was done to evaluate the quality of the water upstream and downstream of the effluent discharge point as well as the quality of the effluent being discharged into the Msunduzi River by the Darvill WWTW. Furthermore, evaluation of the concentration levels of the parameters in the Msunduzi River over 10 years was also completed and depicted for each parameter at each sample point.

The available biomonitoring results were compared amongst the sample sites to identify changes from the points upstream of the Darvill WWTW and those downstream of the Darvill WWTW. Biomonitoring results were analysed using the Integrated Habitat Assessment Score (IHAS), Biotic Index (BI) and Average Score Per Taxon (ASPT) methods. This was done to interpret the meaning of the data and to understand the current status of the Msunduzi River in the study area.

4. CHAPTER 4: RESULTS AND ANALYSES

4.1. Water Quality Results

4.1.1. pH

<u>RMD015- Upstream of the Darvill WWTW</u>

Table 3 shows that a total of 567 pH analyses were conducted for the study period 2010-2020. All analyses complied with recommended upper and lower limits of pH as detailed in the WUL, guidelines and general limits. All analyses were within the recommended range of 5.5-9.5 **(Figure 4).**

Table 3: pH compliance statistics at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

No of Analyses	567
No of non-compliant	0
Minimum	6.9
Maximum	8.6

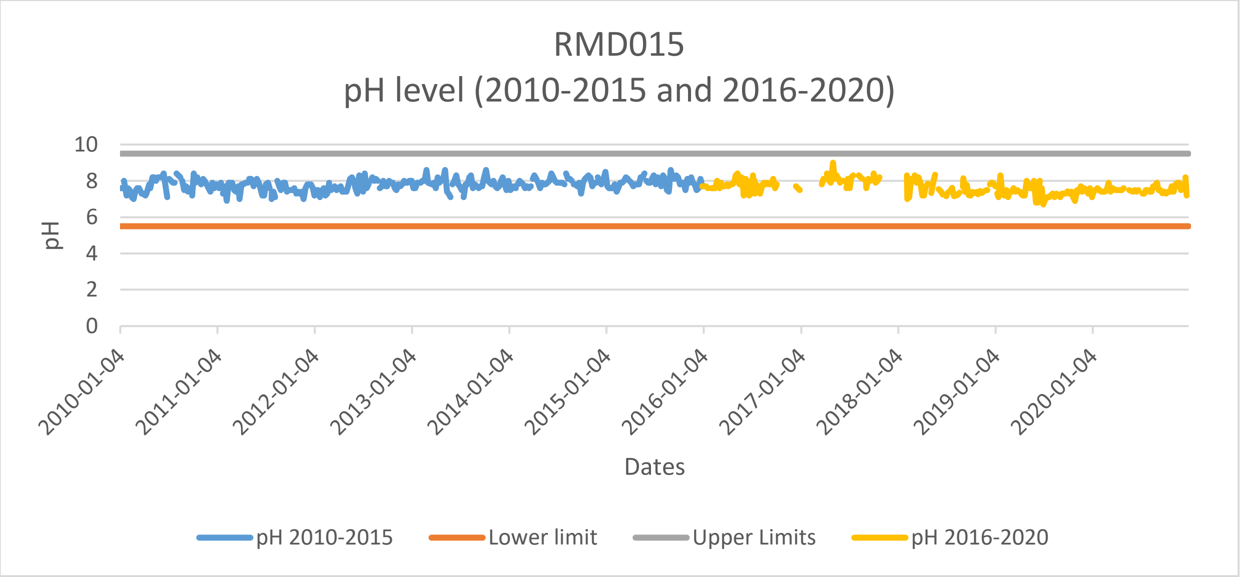

Figure 4: pH levels at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

A total of 602 pH analyses were conducted for the study period 2010-2020. All analyses complied with recommended upper and lower limits of pH as detailed in the WUL, guidelines and general limits **(Table 4). Figure 5** shows that all analyses were within the recommended range of 5.5-9.5 for both study periods.

Table 4: pH compliance statistics at the Msunduzi River, upstream of the Baynespruit Stream (2010-2020).

No of Analyses	602
No of non-compliant	0
Minimum	6.7
Maximum	8.8

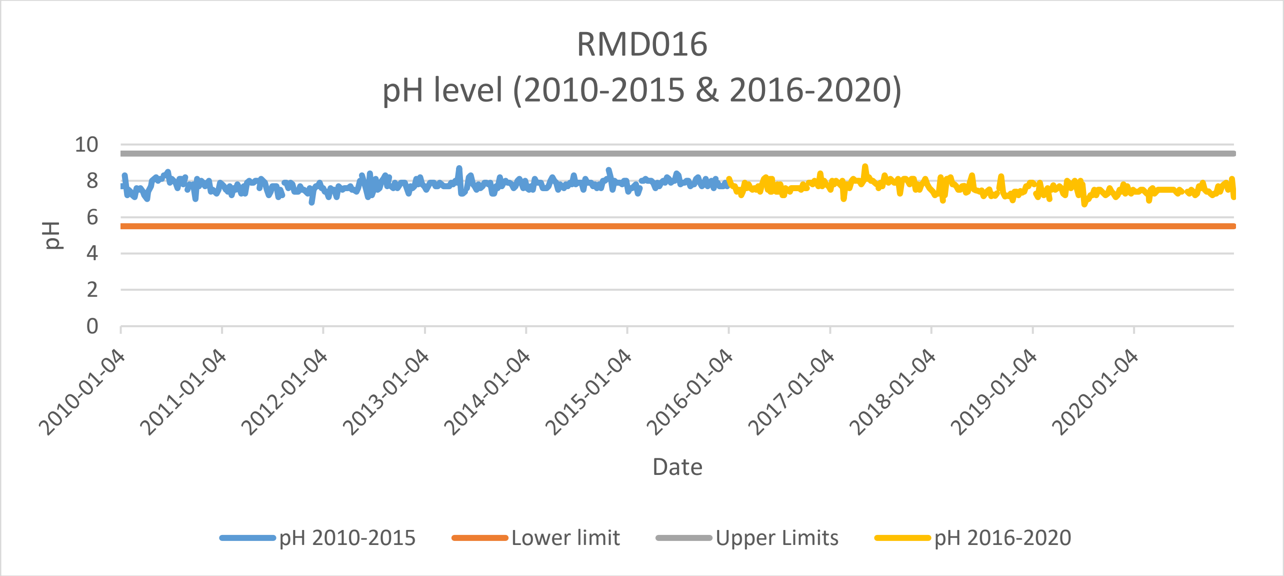

Figure 5: pH levels at the Msunduzi River, upstream of the Baynespruit Stream (2010-2020).

RMD017- Upstream of the Darvill Maturation River

Table 5 shows that 592 pH analyses were conducted for the study period 2010-2020 for RMD017. All analyses complied with recommended upper and lower limits of pH as detailed in the WUL, guidelines and general limits. All analyses were within the recommended range of 5.5-9.5 **(Figure 6).**

Table 5: pH statistics upstream of the Darvill Maturation River (2010-2020).

No of Analyses	592
No of non-compliant	0
Minimum	6.5
Maximum	8.8

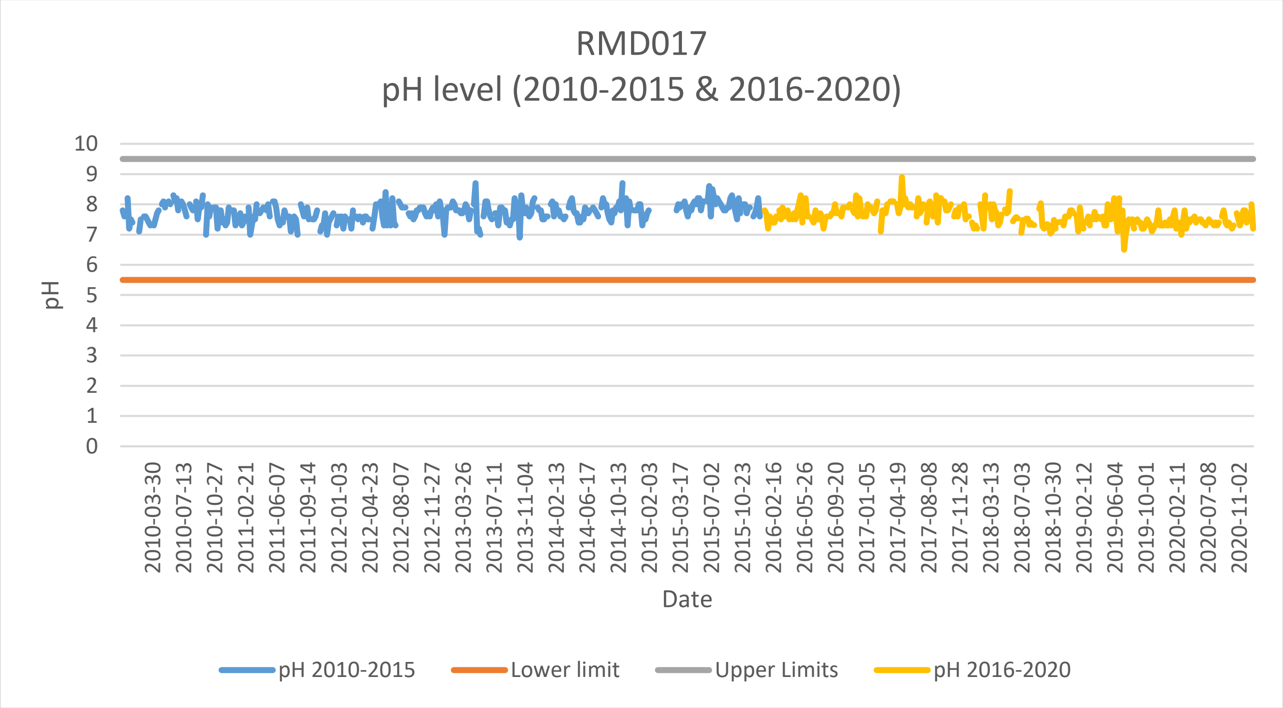

Figure 6: pH level at upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River]

Table 6 shows that a total of 132 pH analyses were conducted for the study period 2010-2015 for RMD018. All analyses complied with recommended upper and lower limits of pH as detailed in the WUL, guidelines and general limits. All analyses were within the recommended range of 5.5-9.5 **(Figure 7)**. Whilst analyses are conducted daily for this site, **Figure 7** shows a gap in the month of February 2015, where no analyses were conducted.

Table 6: pH statistics of the Msunduzi River downstream of the Darvill Maturation River (2010-2015).

No of Analyses	132
No of non-compliant	0
Minimum	6.8
Maximum	8.10

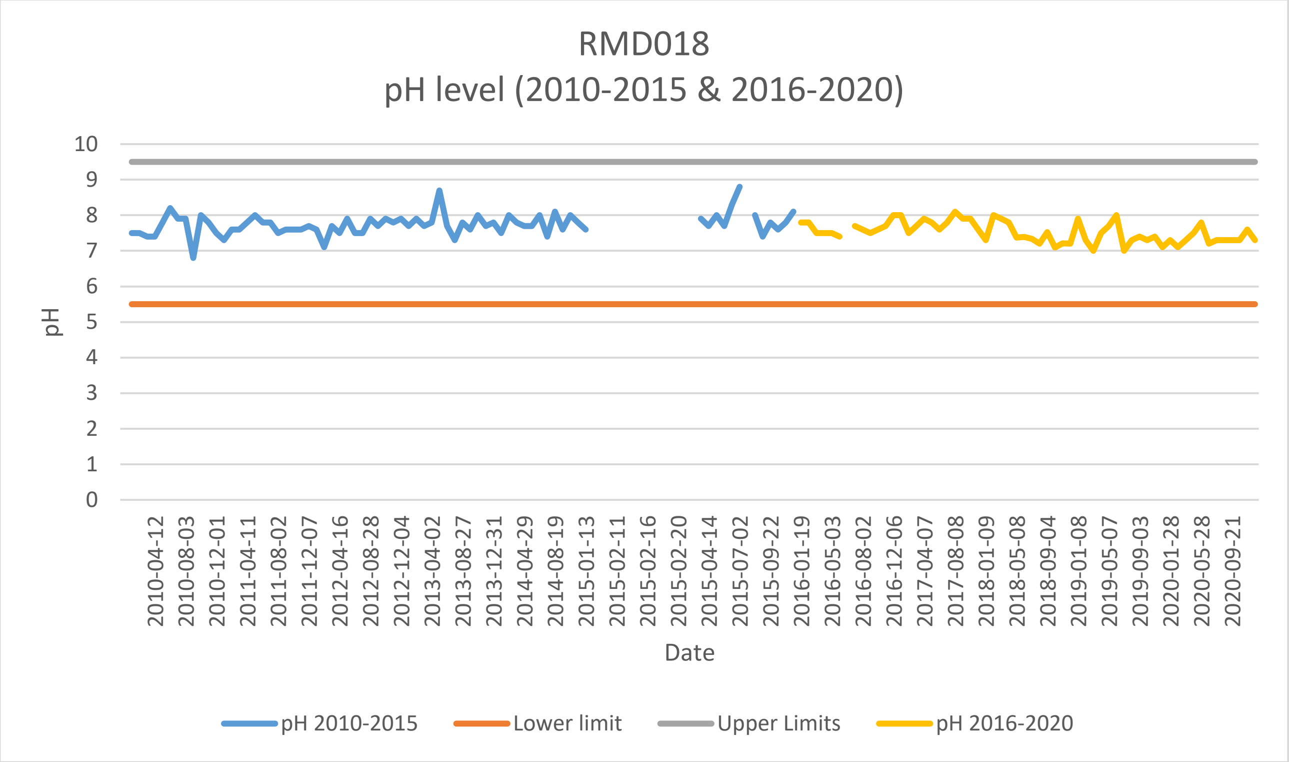

Figure 7: pH level of the Msunduzi River downstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

A total of 586 pH analyses were conducted for the study period 2010-2020. Only one analysis did not comply with recommended lower limits of 5.5 **(Table 7 and Figure 8).** The non-compliance happened on the 07 March 2011.

Table 7: pH statistics of the Msunduzi River downstream of the Darvill Discharge Point (2010-2020).

No of Analyses	586
No of non-compliant	1
Minimum	2.5
Maximum	9.00

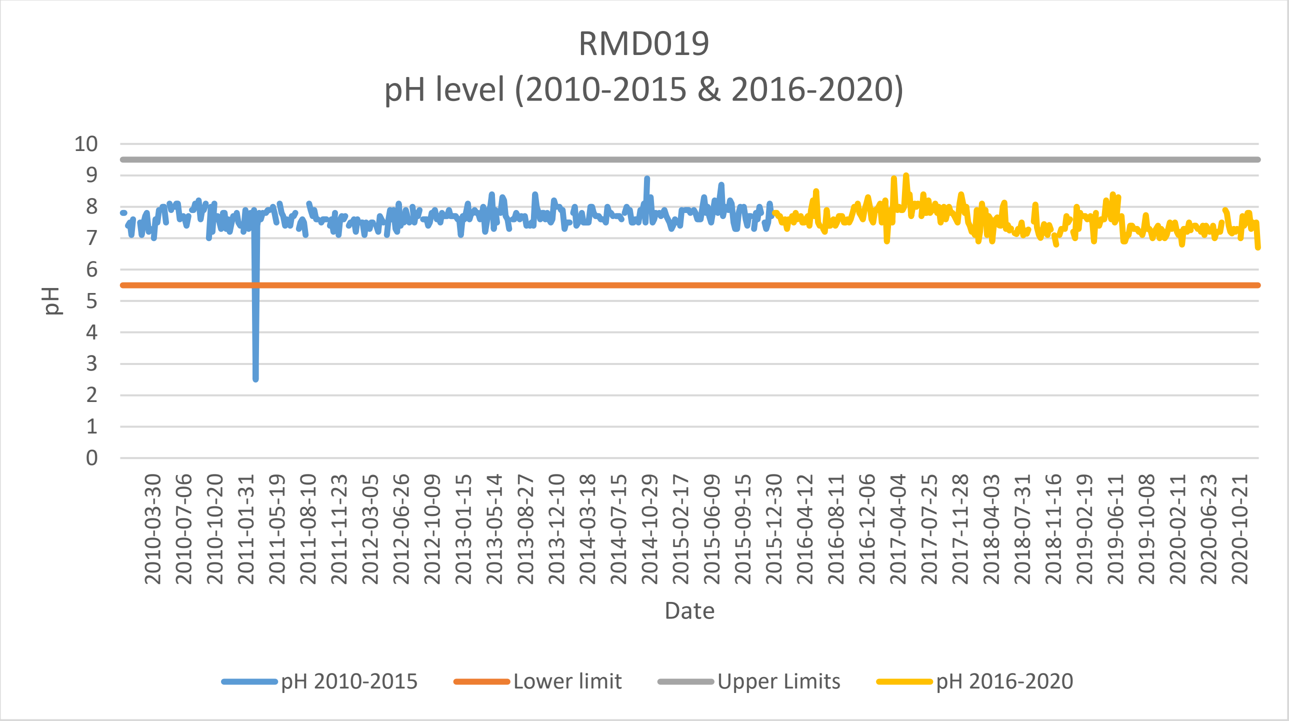

Figure 8: pH level of the Msunduzi River downstream of the Darvill Discharge Point (2010-2020).

WDV020- Darvill WWTW Final Effluent

At this sample point pH analyses are conducted daily and a total of 2639 analyses were conducted for the study period 2010-2020 **(Table 8).** Three of the analyses were recorded missing (MR-X) during the 2010-2015 period and are shown as non-compliances on the **Figure 9** below because it picks them up as zero (0) values.

Table 8: pH statistics at the Darvill WWTW final effluent (2010-2020).

No of Analyses	2639
No of non-compliant	0
Minimum	6.50
Maximum	8.90

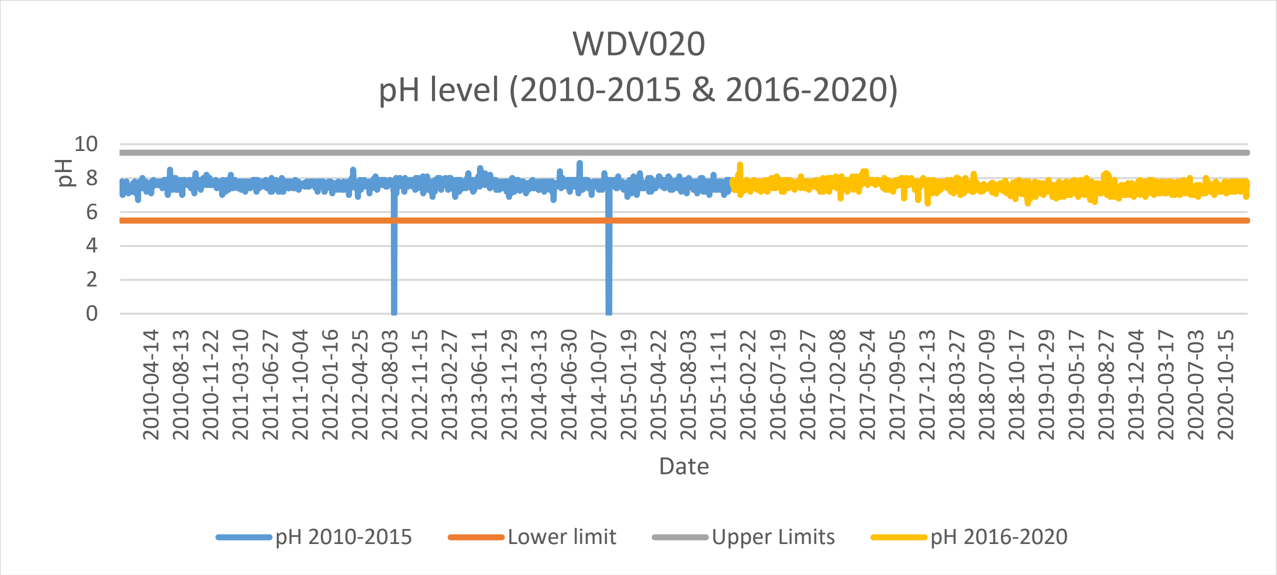

Figure 9: pH level at the Darvill WWTW final effluent (2010-2020),

The bar chart above **(Figure 10)** shows pH levels at all the study sites and also shows the changes in pH levels on these sites over 10 years. From this chart it is evident that the pH levels at the Msunduzi River are gradually decreasing. The pH levels in 2016-2020 period are lower compared to the pH levels in the 2010-2015. What it also evident from the chart is that the upstream water had a slightly higher level of pH compared to the downstream points.

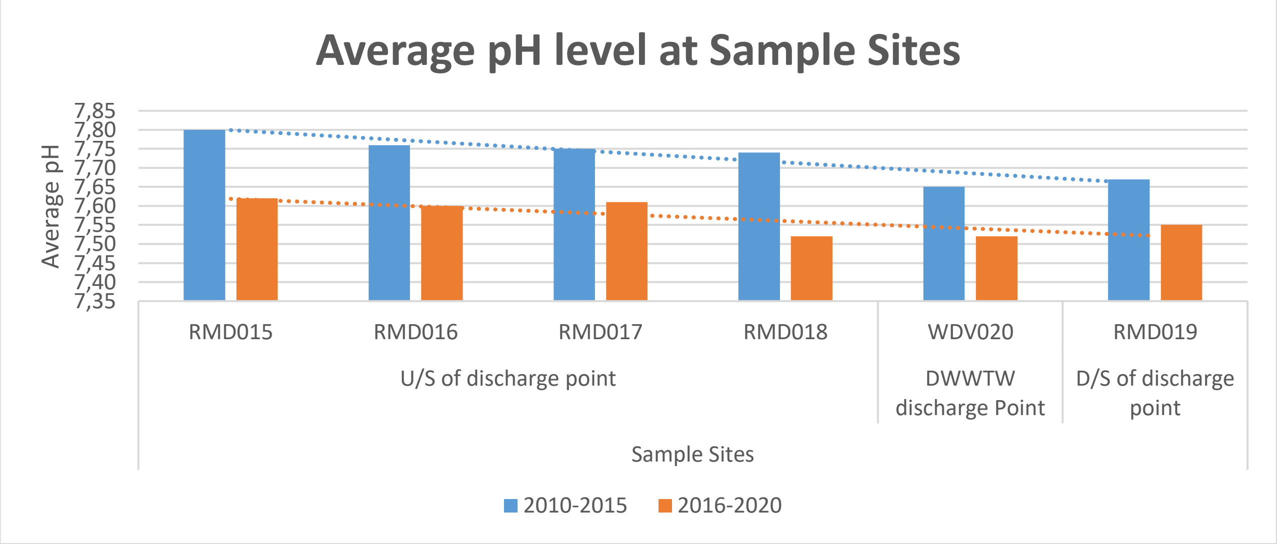

Figure 10: A comparison of pH levels at different monitoring sites and two time periods (2010-2015 and 2016-2020).

4.1.2. Suspended Solids (SS)

<u>RMD015- Upstream of the Darvill WWTW</u>

Suspended Solids analyses were conducted on weekly frequency. A total of 537 SS analyses were conducted for the study period 2010-2020 **(Table 9).** A total of 240 analyses were out-of-range when evaluated against the WUL limit and General Limits of 25 mg/L **(Figure 11).** The maximum out-of-range result was 1908 mg/L **(Table 9).**

Table 9: Suspended solids statistics at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

No of Analyses	537
No of non-compliant	240
Minimum	4.00 mg/L
Maximum	1908 mg/L

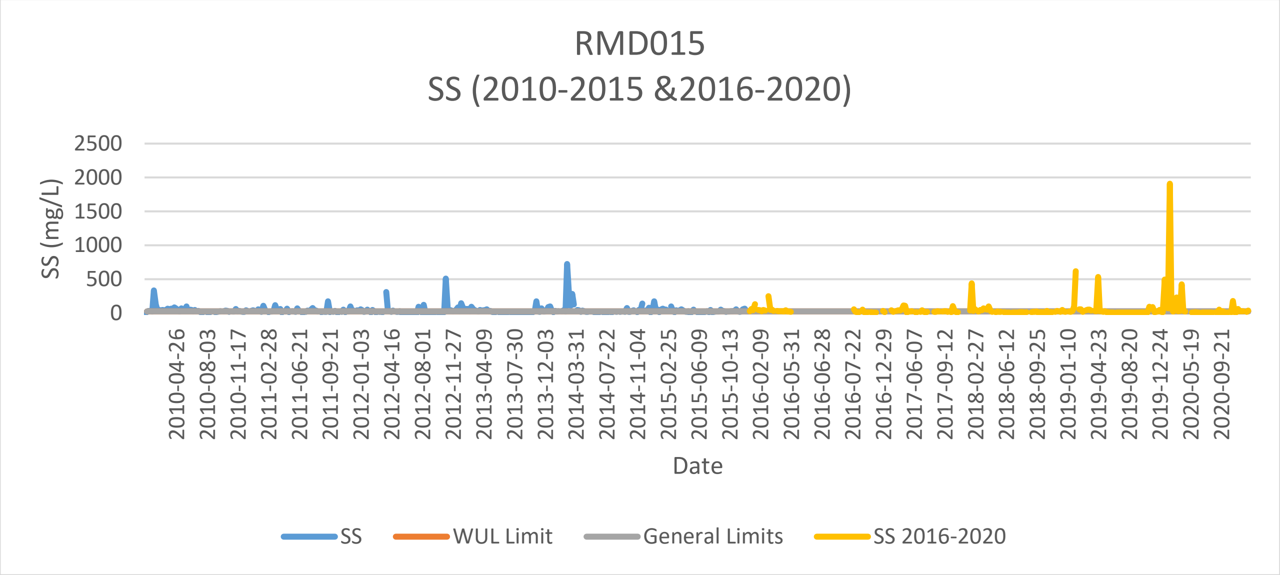

Figure 11: Suspended solids concentration at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

<u>RMD016- Upstream of the Baynespruit Stream</u>

Suspended solids analyses were conducted on weekly frequency. A total of 566 SS analyses were conducted for the study period 2010-2020. **Table 10** shows that a total of

259 analyses were out-of-range when evaluated against the WUL limit and General Limits of 25 mg/L. The maximum out-of-range result recorded was 1900 mg/L. **Figure 12** shows that most non-compliances were experienced in the 2016-2020 period.

Table 10: Suspended solids statistics at the Msunduzi River, upstream of the Baynespruit Stream (2010-2020).

No of Analyses	566
No of non-compliant	259
Minimum	4.00 mg/L
Maximum	1900 mg/L

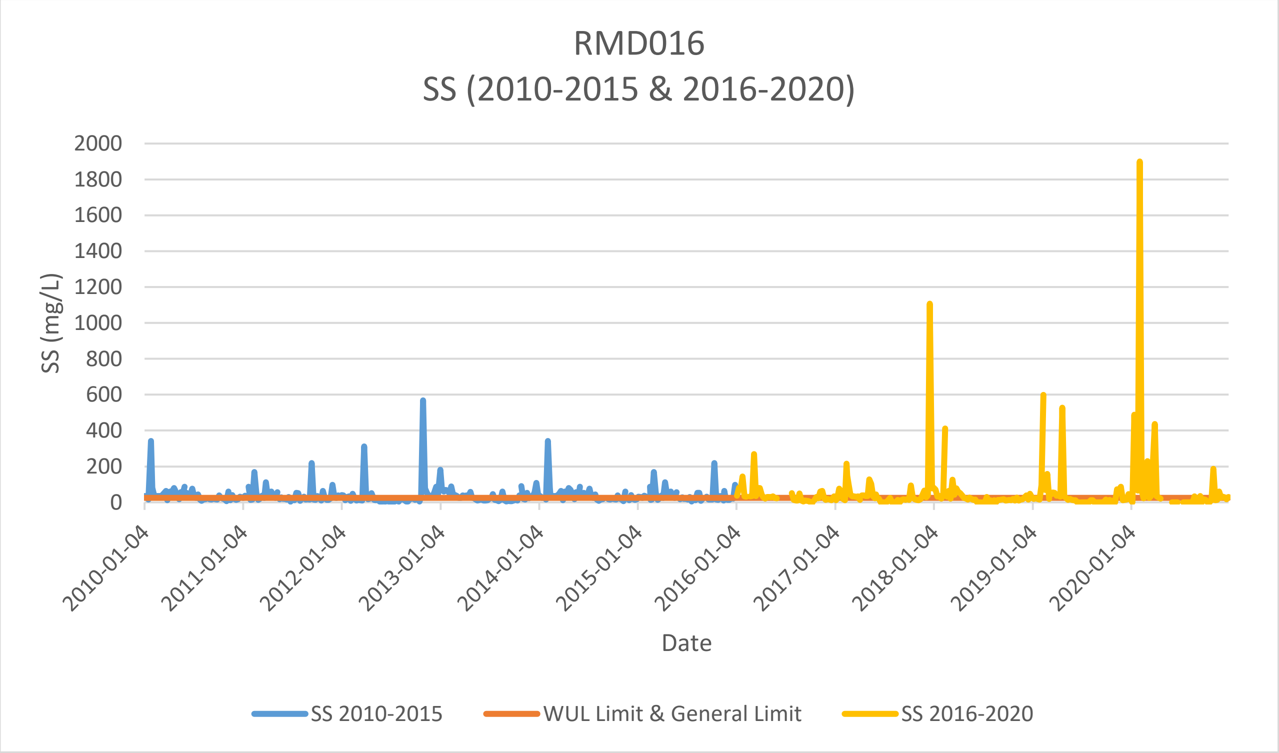

Figure 12: Suspended solids concentration at the Msunduzi River, upstream of the Baynespruit Stream (2010-2020).

RMD017- Upstream of the Darvill Maturation River

Suspended solids analyses were conducted on weekly frequency. A total of 588 SS analyses were conducted for the study period 2010-2020. A total of 260 analyses were out-of-ranges when evaluated against the WUL limit and General Limits of 25 mg/L **(Table 11).**

The highest recorded out-of-range result was 1926 mg/L in the 2016-2020 period **(Figure 13).**

Table 11: Suspended solids statistics upstream of the Darvill Maturation River (2010-2020).

No of Analyses	588
No of non-compliant	260
Minimum	4.40 mg/L
Maximum	1926.00 mg/L

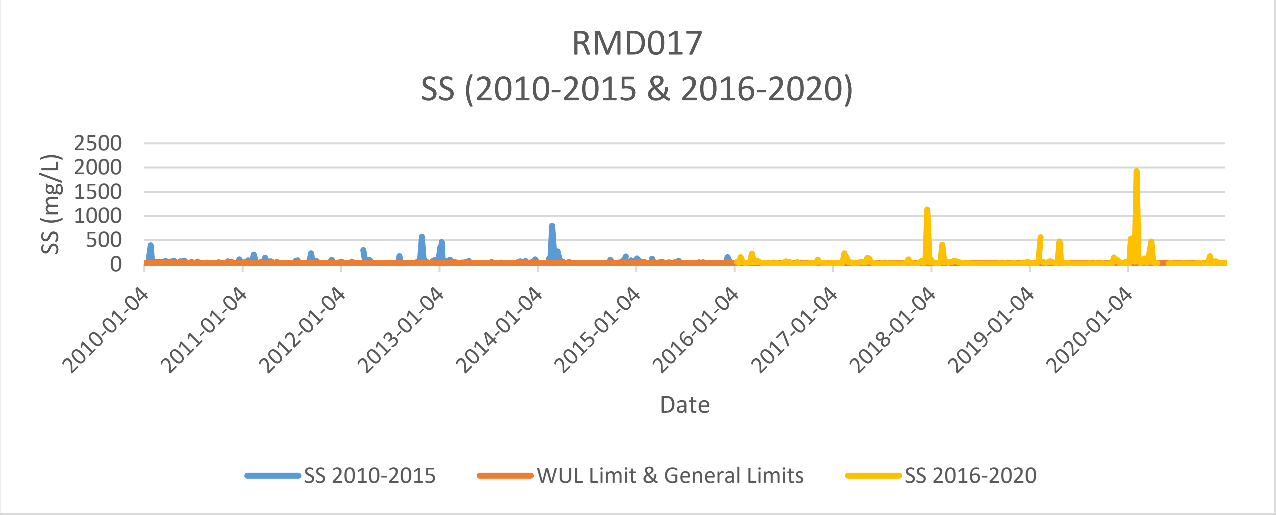

Figure 13: Suspended solids concentration upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River

Suspended solids analyses were conducted on monthly frequency from January 2010-November 2014. No analyses were conducted December 2014 and January 2015, and only 1 analysis was conducted in February 2015. This is shown by the large gap in **Figure 14.** From March 2015 suspended solids analyses were conducted at various frequency. More analyses were conducted on monthly bases. . In total 139 suspended solid analyses were conducted for the study period 2010-2020. **Table 12** shows that 51 analyses were out-of-range when evaluated against the WUL limit and General Limits of 25 mg/L. The highest recorded out-of-range result was 308 mg/L.

Table 12: Suspended solids statistics downstream of the Darvill Maturation River (2010-2020).

No of Analyses	139
No of non-compliant	51
Minimum	4.80 mg/L
Maximum	308 mg/L

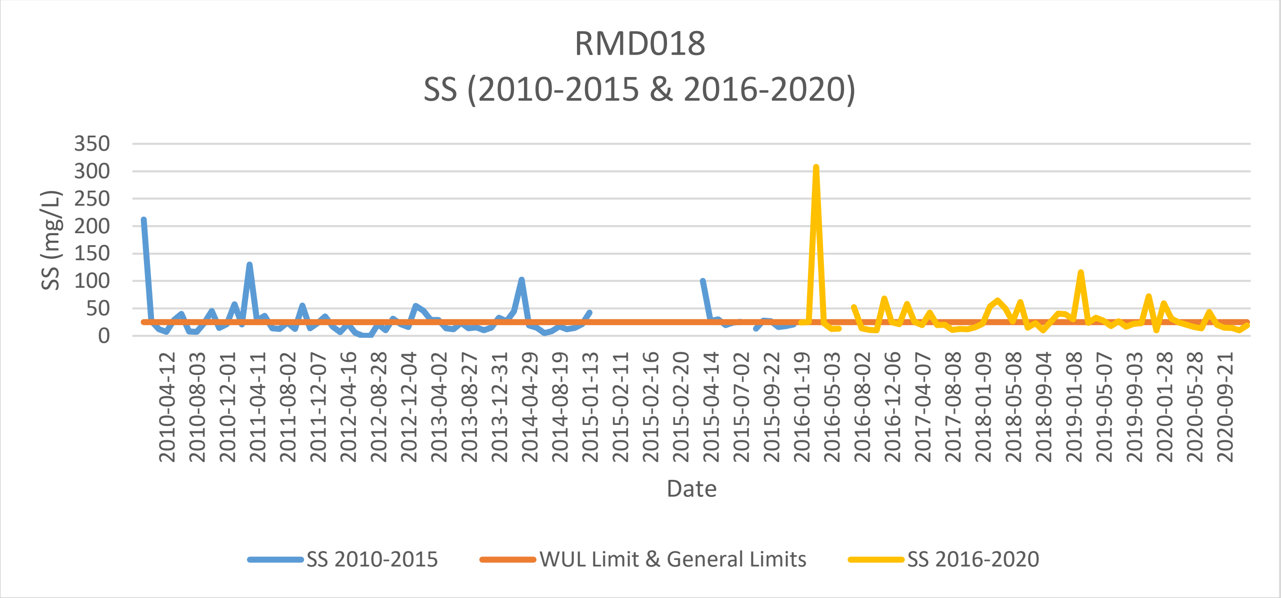

Figure 14: Suspended solids concentration downstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

Suspended solids analyses were conducted on weekly frequency. A total of 583 SS analyses were conducted for the study period 2010-2020. A total of 119 analyses were out-of-range when evaluated against the WUL limit and General Limits of 25 mg/Las shown in **Table 13**. The highest recorded out-of-range result was 1930 mg/L.

Table 13: Suspended solids statistics downstream of the Darvill Discharge Point (2010-2020).

No of Analyses	583
No of non-compliant	211
Minimum	4.00 mg/L
Maximum	1630 mg/L

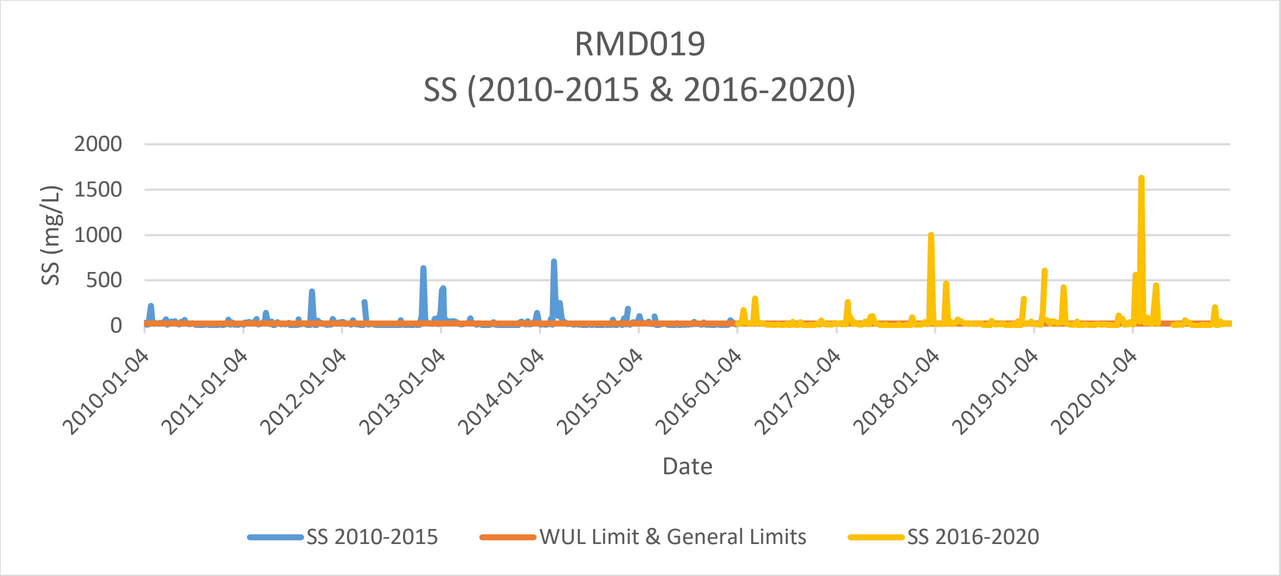

Figure 15: Suspended solids concentration downstream of the Darvill Discharge Point (2010-2020).

<u>WDV020- Darvill WWTW Final Effluent</u>

Suspended solids analyses were conducted on daily frequency. **Table 14** shows that a total of 2636 suspended solid analyses were conducted for the study period 2010-2020. A total of 1029 analyses were out-of-range when evaluated against the WUL limit and General Limits of 25 mg/L. **Figure 16** shows that the elevated concentration of suspended solids were experienced in the 2016-2020 period. The highest recorded out-of-range result was 600 mg/L.

Table 14: Suspended solids statistics at the Darvill WWTW final effluent (2010-2020).

No of Analyses	2636
No of non-compliant	1029
Minimum	4.00 mg/L
Maximum	600.00 mg/L

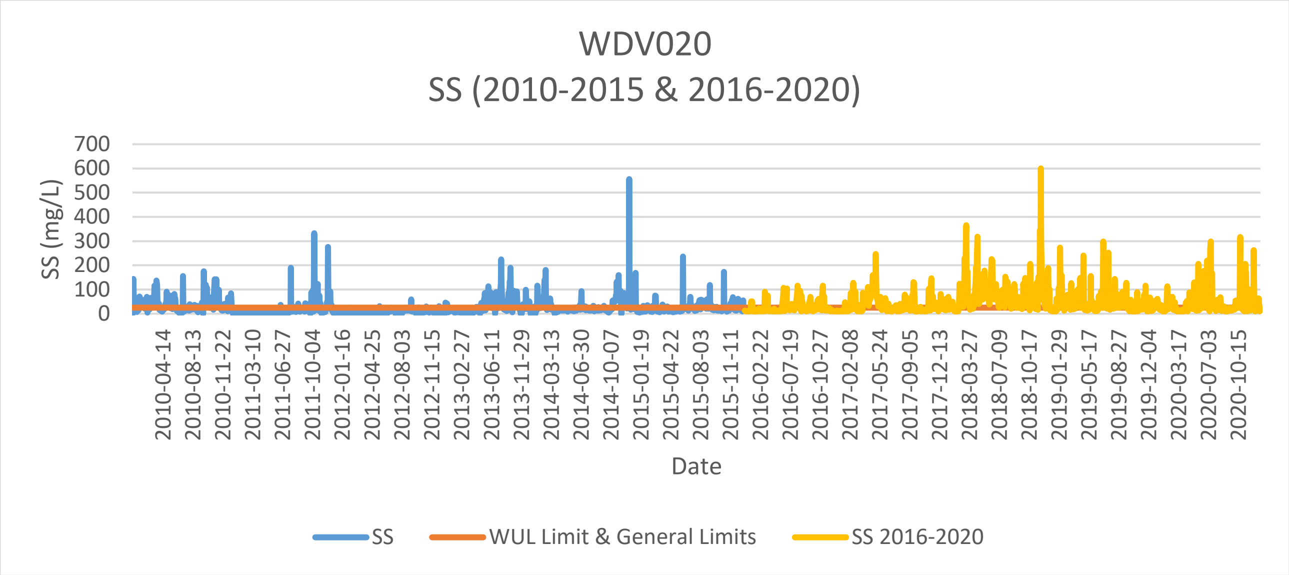

Figure 16: Suspended solids concentration at the Darvill WWTW final effluent (2010-2020).

The graph below **(Figure 17)** shows elevated suspended solids at all sites in the 2016-2020 period. The upstream points showed higher levels of suspended solids at the upstream, except at RMD018 where there were lower suspended solids. The discharge from WDV020 had an influence on the Msunduzi River suspend solids levels. This was due to an increase of suspended solids at the discharge point and at the downstream point.

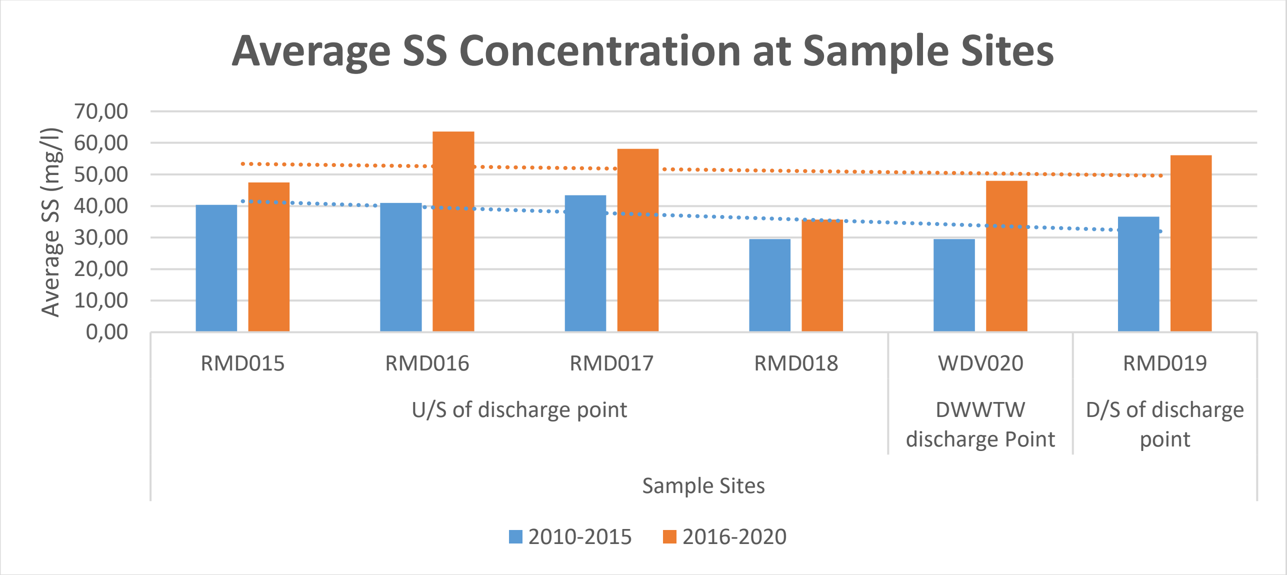

Figure 17: A comparison of SS concentration at different monitoring and two time periods (2010-2015 and 2016-2020).

4.1.3. Electrical Conductivity (EC)

RMD015- Upstream of the Darvill WWTW

Electrical Conductivity analyses were conducted on a weekly frequency for this site. **Table 15** shows a total of 568 EC analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL limit of 75 mS/m and General Limits of 150 mS/m **(Figure 18)**. The highest result was 30.30 mS/m. **Figure 18** also shows a gap in the 2016-2020 period where only 5 analyses were conducted between June and July 2016.

Table 15: Electrical Conductivity statistics at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

No of Analyses	568
No of non-compliant	0
Minimum	11.70 mS/m
Maximum	38.90 mS/m

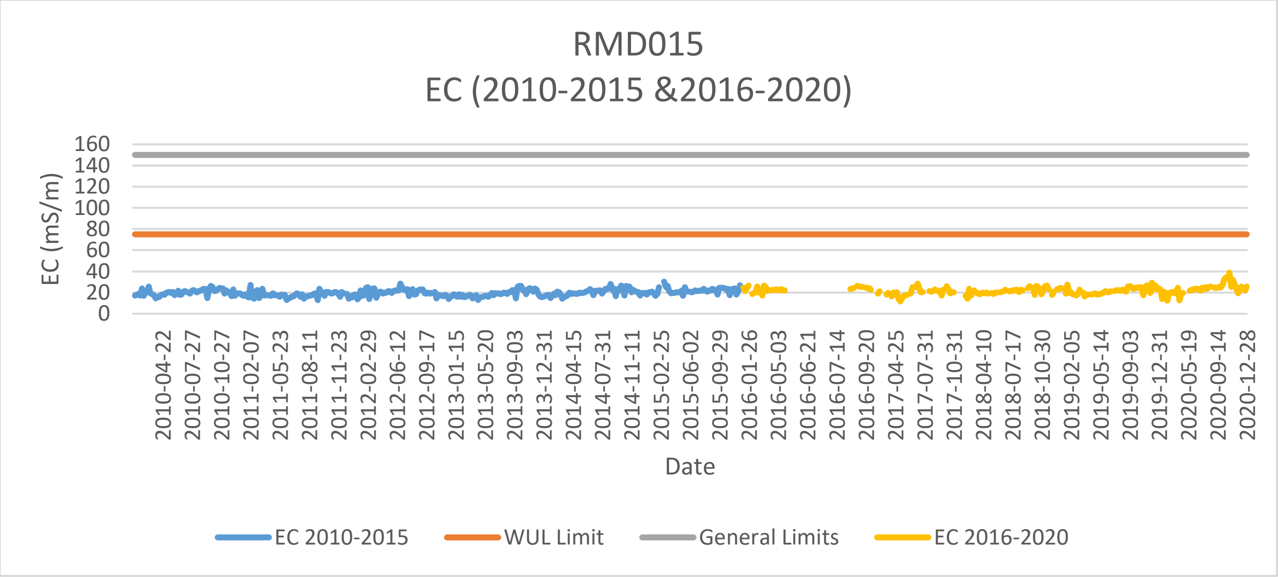

Figure 18: Electrical Conductivity concentration at the Msunduzi River, upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

Electrical Conductivity analyses were conducted on weekly frequency for this site. A total of 584 EC analyses were conducted for the study period 2010 -2020. All analyses complied when evaluated against the WUL Limit of 75 mS/m and General Limits of 150 mS/m. The highest result was 48.80 mS/m.

Table 16: Electrical Conductivity upstream of the Baynespruit Stream (2010-2020).

No of Analyses	584
No of non-compliant	0
Minimum	12.20 mS/m
Maximum	48.80 mS/m

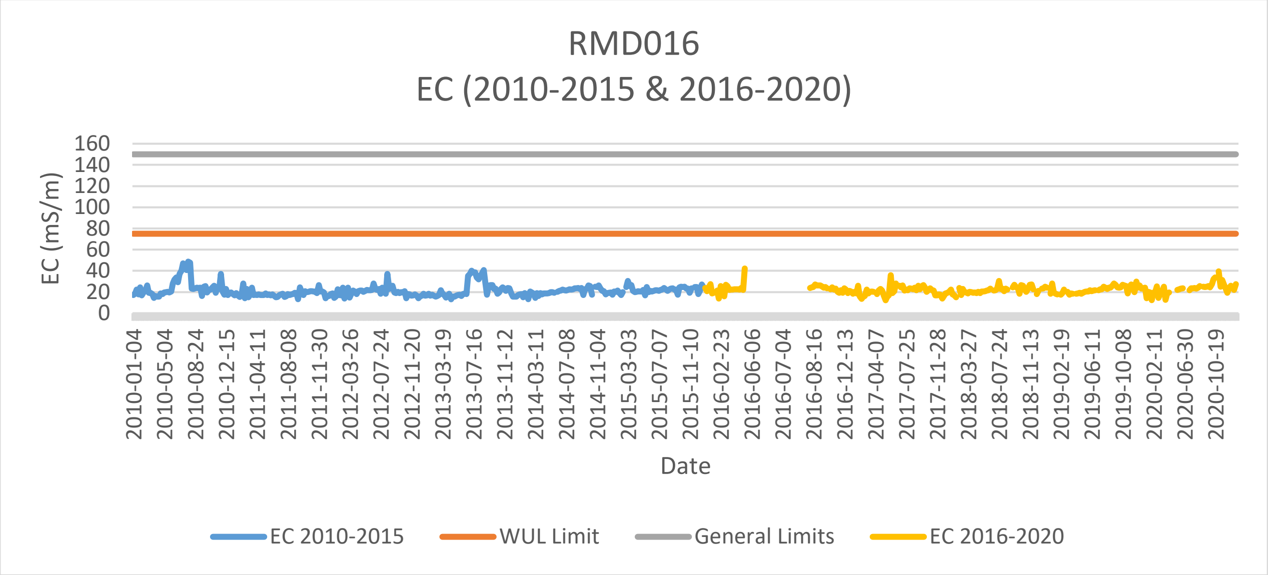

Figure 19: Electrical Conductivity concentration upstream of the Baynespruit Stream (2010-2020).

RMD017- Upstream of the Darvill Maturation River

Electrical Conductivity analyses were conducted on a weekly frequency. **Table 17** shows that a total of 624 EC analyses were conducted for the study period 2010-2020 and all analyses complied when evaluated against the WUL limit of 75 mS/m and General Limits of 150 mS/m. The highest result was 72.50 mS/m and occurred in the 2016-2020 period **(Figure 20).**

Table 17: Electrical Conductivity statistics upstream of the Darvill Maturation River (2010-2020).

No of Analyses	624
No of noncompliant	0
Minimum	12.24 mS/m
Maximum	72.50 mS/m

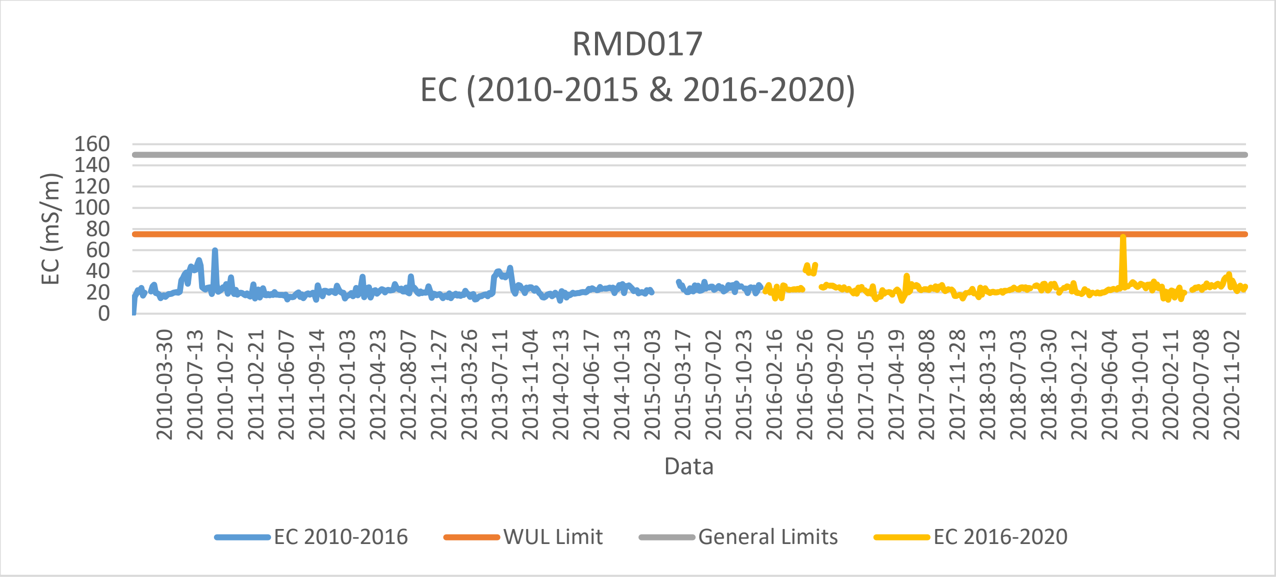

Figure 20: Electrical Conductivity concentration upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River

Electrical Conductivity analyses were conducted on a monthly frequency from January 2010- November 2014. No analyses were conducted in December 2014 and January 2015, and only 1 analysis was conducted in February 2015. From March 2015 EC analyses were conducted at various frequencies with the monthly frequency being prominent. In total 131 EC analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL Limit of 75 mS/m and General Limits of 150 mS/m. The highest result was 55.60 mS/m (**Table 18 and Figure 21**).

Table 18: Electrical Conductivity statistics for downstream of the Darvill Maturation River (2010-2020).

No of Analyses	131
No of non-compliant	0
Minimum	15.10 mS/m
Maximum	55.60 mS/m

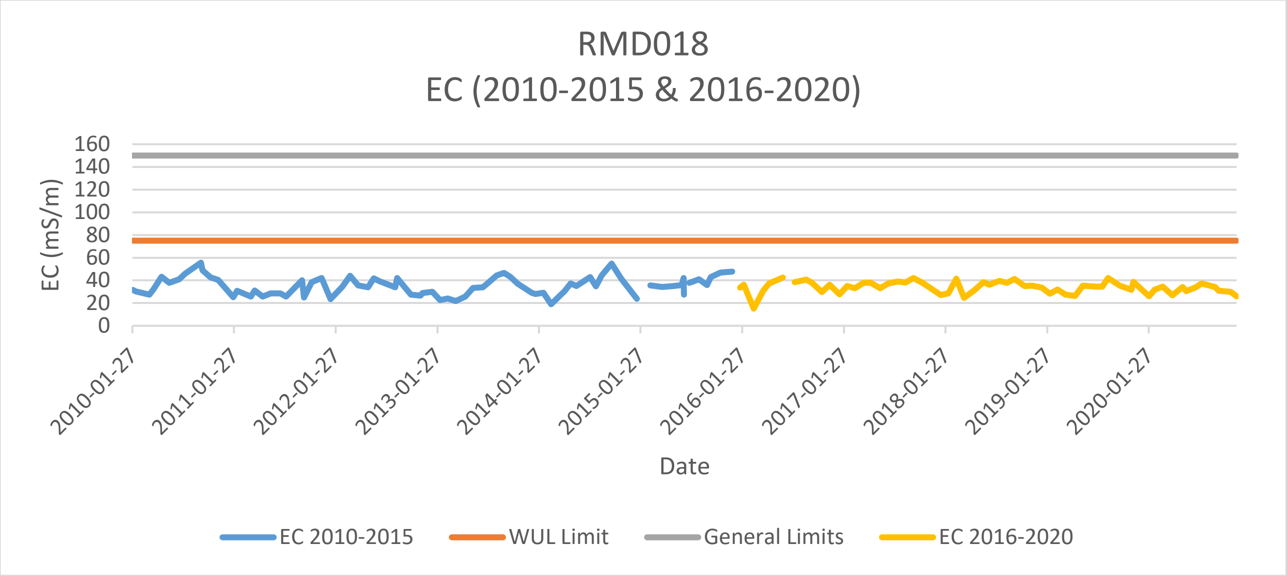

Figure 21: Electrical Conductivity concentration downstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

Electrical Conductivity analyses are conducted on a weekly frequency for this site. **Table 19** shows that a total of 617 EC analyses were conducted for the study period 2010-2020. A total of three analyses did not comply with the WUL Limit of 75 mS/m and one of the three analyses did not comply with the General Limits of 150 mS/m **(Figure 22).** The highest result was 151 mS/m **(Table 19)** and occurred in the 2010-2015 period **(Figure 22).**

Table 19: Electrical Conductivity statistics for downstream of the Darvill Discharge Point (2010-2020).

	WUL Limit	General Limits
No of Analyses	617	
No of non-compliant	3	1
Minimum	15.10 mS/m	
Maximum	151.00 mS/m	

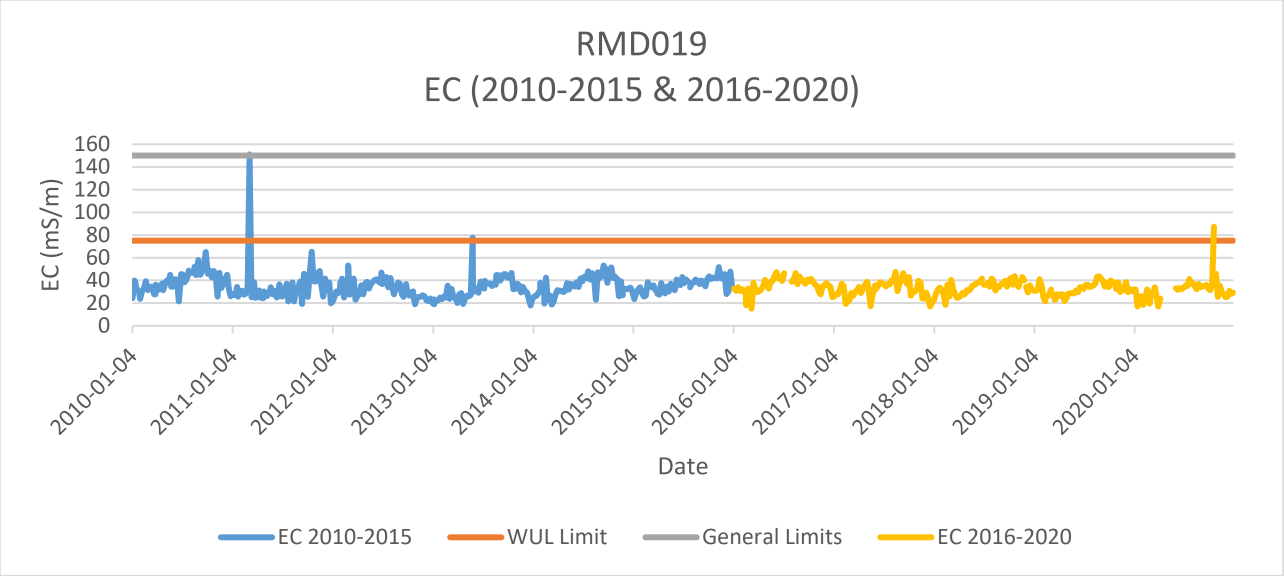

Figure 22: Electrical Conductivity concentration downstream of the Darvill Discharge Point (2010-2020).

WDV020- Darvill WWTW Final Effluent

Electrical Conductivity analyses were conducted on a daily frequency. A total of 2636 EC analyses were conducted for the study period 2010-2020. A total of 1219 analyses were out-of-ranges when compared to the WUL Limits **(Table 20)**. A total of 645 analyses were out-of-ranges during the 2016-2020. There were no out-of-ranges against the General Limits of 150 mS/m for the 2010-2015 period and only one analysis did not comply with the General Limit in the 2016-2020 period **(Figure 23).** The highest recorded out-of-range result was 216 mS/m.

Table 20: Electrical Conductivity statistics for Darvill WWTW Final Effluent (2010-2020).

No of Analyses	2636
No of non-compliant	1219
Minimum	9.20 mS/m
Maximum	216 mS/m

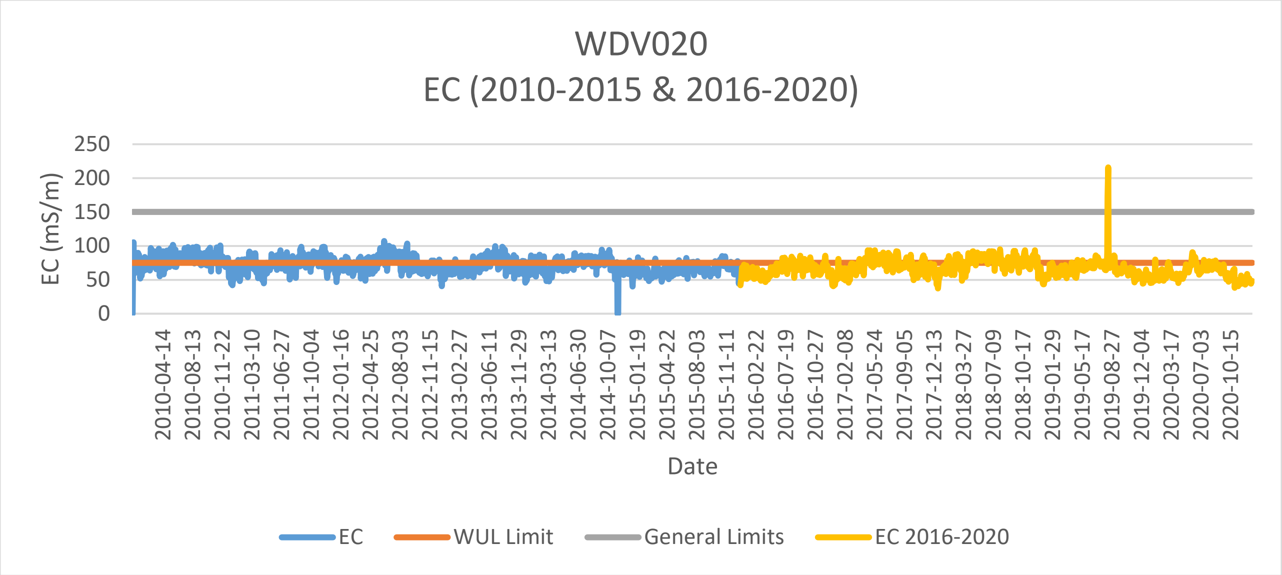

Figure 23: Electrical Conductivity concentration at Darvill WWTW Final Effluent (2010-2020).

Figure 24 shows that the EC was lower at the upstream points, except at RMD018 where there was a noticeable increase. The effluent discharge point (WDV020) had much elevated levels of EC. However, the EC levels from WDV020 seemed to have decreased when the water flows down the river as the water downstream (RMD019) of the effluent discharge point showed improvement in terms of the EC level when compared to the WDV020.

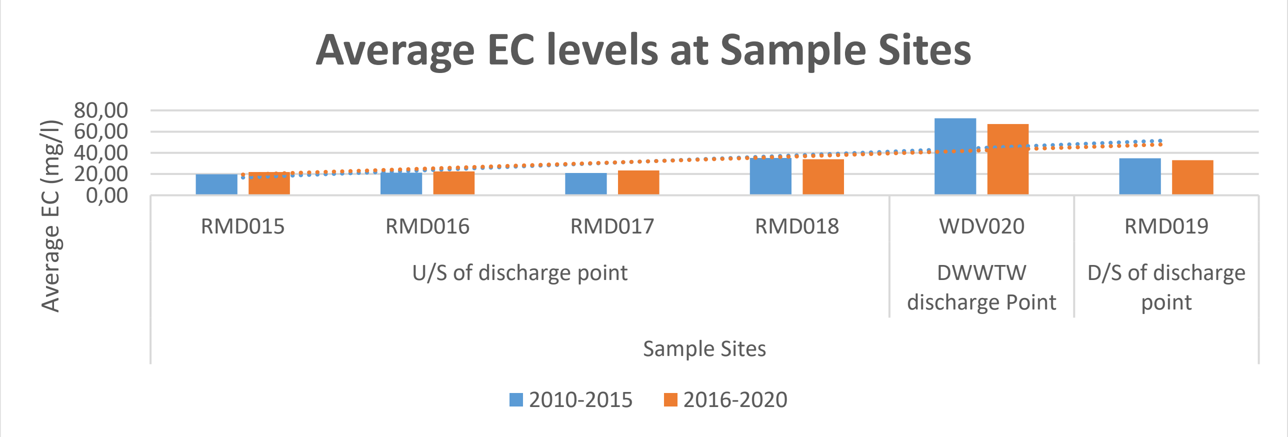

Figure 24: A comparison of EC levels at different monitoring and two time periods (2010-2015 and 2016-2020).

4.1.4. Orthophosphate as Soluble Reactive Phosphorus (SRP)

RMD015- Upstream of the Darvill WWTW

The analyses for SRP were conducted on a weekly frequency. A total of 537 SRP analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL limit of 1000 µg/L **(Table 21 and Figure 25).** However, all 537 analyses did not comply with the General Limits of 0.01µg/L. The highest result was 592.96 µg/L **(Table 21).**

Table 21: Soluble Reactive Phosphorus statistics upstream of the Darvill WWTW (2010-2020).

	WUL limit	General Limits
No of Analyses	537	
No of non-compliant	0	537
Minimum	3.21 µg/L	
Maximum	592.96 µg/L	

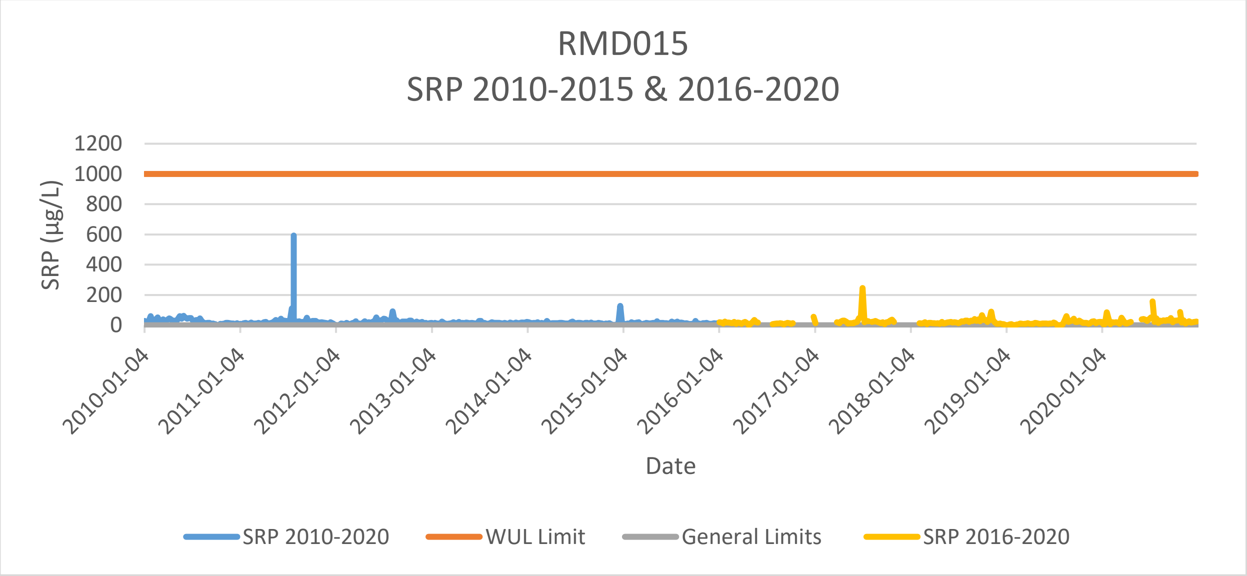

Figure 25: Soluble Reactive Phosphorus concentration upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

The SRP analyses were conducted on a weekly frequency. A total of 570 SRP analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL limit of 1000 µg/L. However, all 570 analyses did not comply with the General Limits of 0.01 µg/L **(Table 22 and Figure 26)**. The highest result was 745 µg/L.

Table 22: Soluble Reactive Phosphorus statistics for upstream of the Baynespruit Stream (2010-2020).

	WUL limit	General Limits
No of Analyses	570	
No of noncompliant	0	570
Minimum	3.00 µg/L	
Maximum	745.00 µg/L	

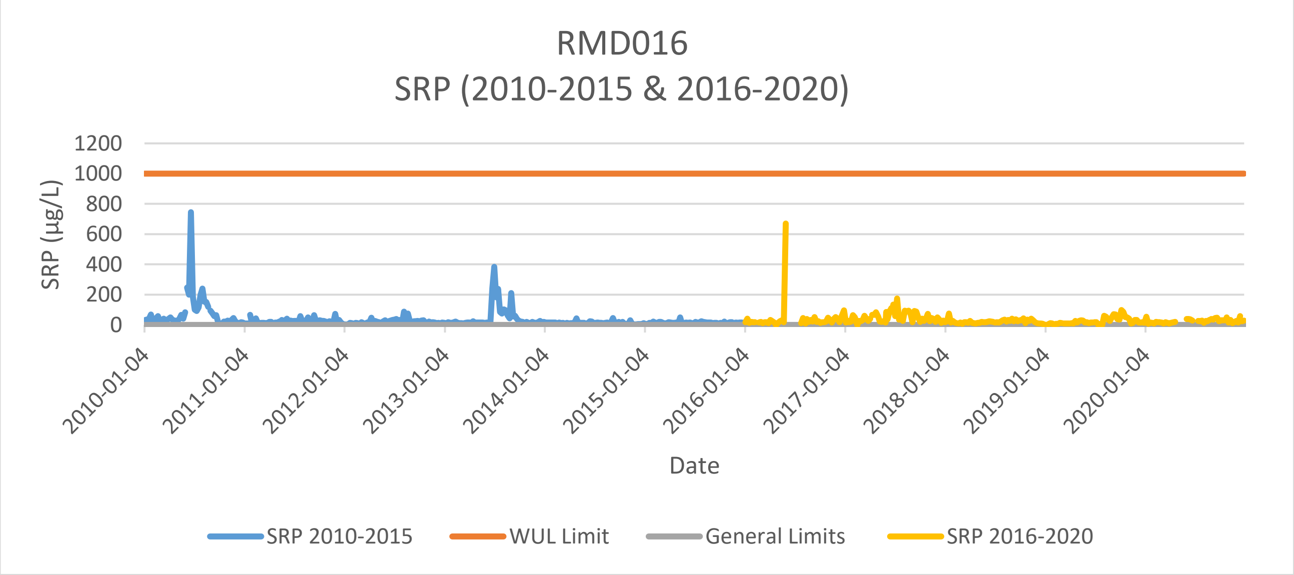

Figure 26: Soluble Reactive Phosphorus concentration at upstream of the Baynespruit Stream (2010-2020).

RMD017- Upstream of the Darvill Maturation River

The SRP analyses were conducted on a weekly frequency. **Table 23** shows that a total of 588 SRP analyses were conducted for the study period 2010-2020. Only one analysis did not comply when evaluated against the WUL Limit of 1000 µg/L in the 2010 – 2015 period

(Figure 27), and 585 analyses did not comply against the General Limits of 0.01 µg/L. The highest result was 1200 µg/L.

Table 23: Soluble Reactive Phosphorus statistics for upstream of the Darvill Maturation River (2010-2020).

	WUL Limit	General Limits
No of Analyses	588	
No of non-compliant	1	585
Minimum	3.00 µg/L	
Maximum	1200.00 µg/L	

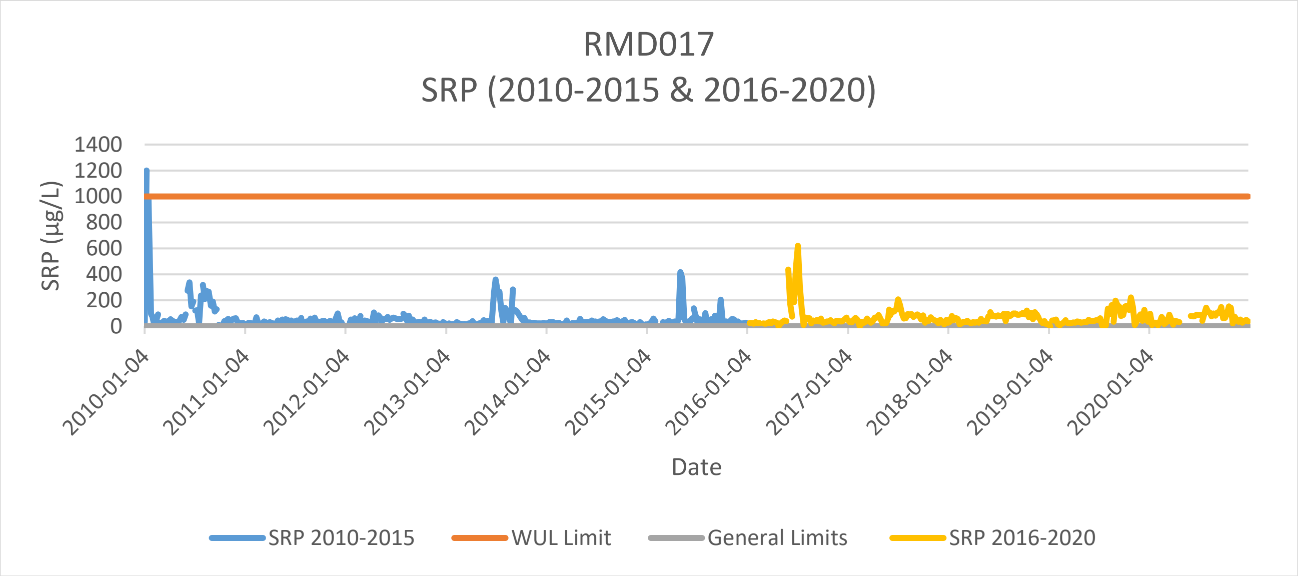

Figure 27: Soluble Reactive Phosphorus concentration at upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River

Table 24 shows that a total of 132 SRP analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL Limit of 1000 µg/L. All 132 analyses did not comply with the General Limits of 0.01µg/L **(Figure 28)**. The highest result was 712 µg/L.

Table 24: Soluble Reactive Phosphorus statistics for upstream of the Darvill Maturation River (2010-2020).

	WUL Limit	General Limits
No of Analyses	132	
No of non-compliant	0	132
Minimum	4.64 µg/L	
Maximum	712.00 µg/L	

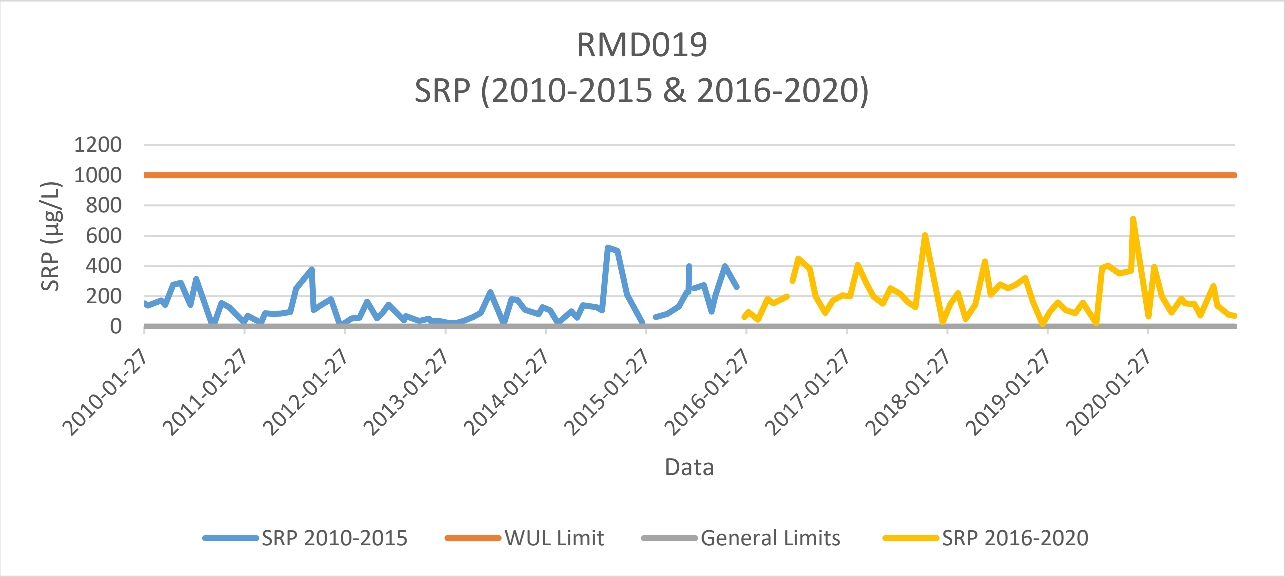

Figure 28: Soluble Reactive Phosphorus concentration at upstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

The SRP analyses were conducted on a weekly frequency. A total of 583 SRP analyses were conducted for the study period 2010-2020 **(Table 25).** Out of the total analyses, two analyses did not comply with the WUL limit of 1000 µg/L **(Figure 29).** Also, 580 analyses did not comply against the General Limits of 0.01 µg/L. The highest result was 1100 µg/L.

Table 25: Soluble Reactive Phosphorus statistics for downstream of the Darvill Discharge Point (2010-2020).

	WUL limit	General Limits
No of Analyses	583	
No of non-compliant	2	580
Minimum	4.77µg/L	
Maximum	1100.00 µg/L	

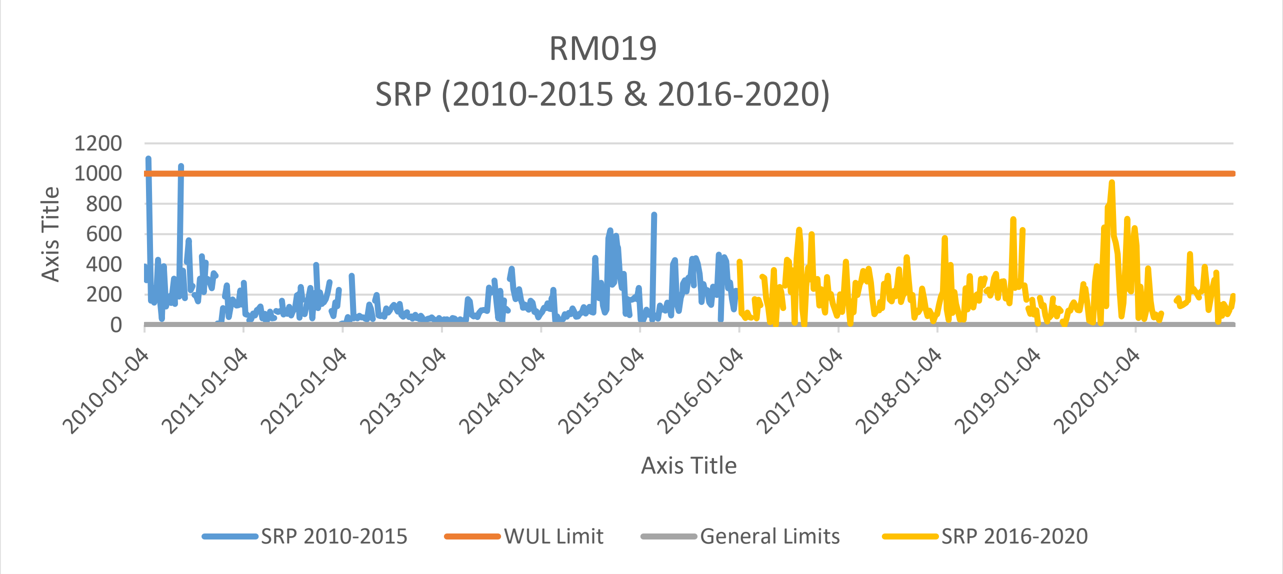

Figure 29: Soluble Reactive Phosphorus concentration at downstream of the Darvill Discharge Point (2010-2020).

WDV020- Darvill WWTW Final Effluent

The SRP analyses were conducted on a daily frequency. **Table 26** shows that a total of 2637 SRP analyses were conducted for the study period 2010-2020. Out of the overall analyses, 455 analyses did not comply when evaluated against the WUL Limit of 1000 µg/L and 2298 analyses did not comply with the General Limits of 0.01 µg/L **(Figure 30)**. The highest result was 19368.00 µg/L.

Table 26: Soluble Reactive Phosphorus statistics for Darvill WWTW Final Effluent (2010-2020).

	WUL Limit	General Limits
No of Analyses	2637	
No of non-compliant	455	2298
Minimum	100.00 µg/L	
Maximum	19368.00 µg/L	

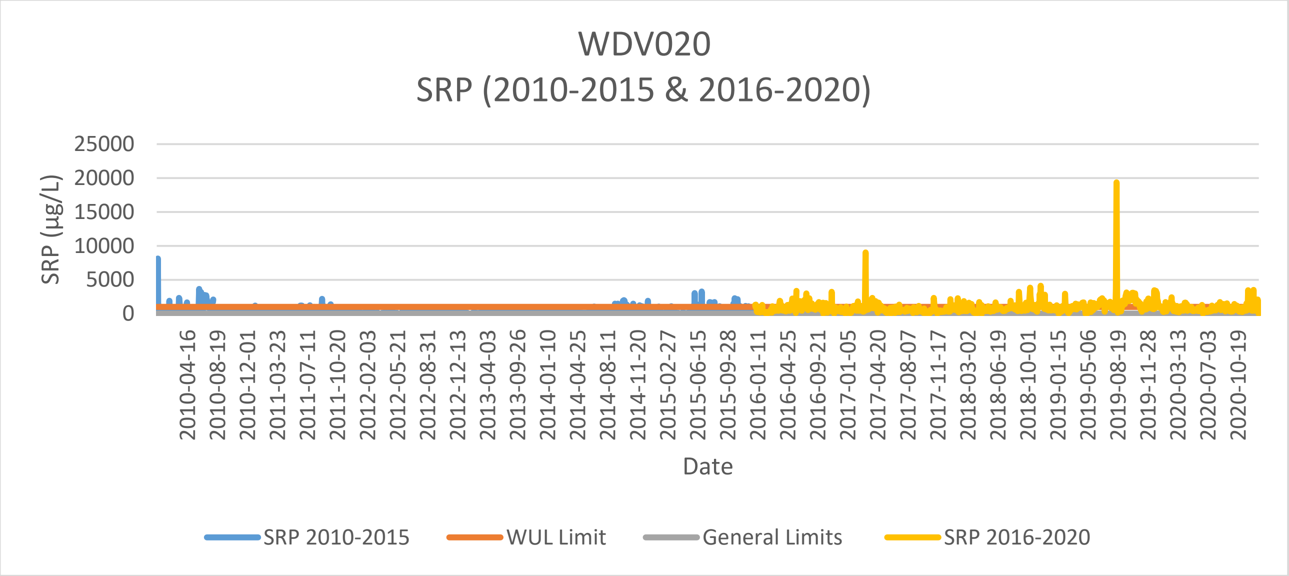

Figure 30: Soluble Reactive Phosphorusconcentration at Darvill WWTW Final Effluent (2010-2020).

The SRP concentrations **(Figure 31)** in the river were generally lower at the upstream points. However, the concentrations started increasing as the water flows down towards the effluent discharge point where there was an increase in SRP levels. In the 2016-2015 period, SRP is much more visible and significantly higher at the effluent discharge point.

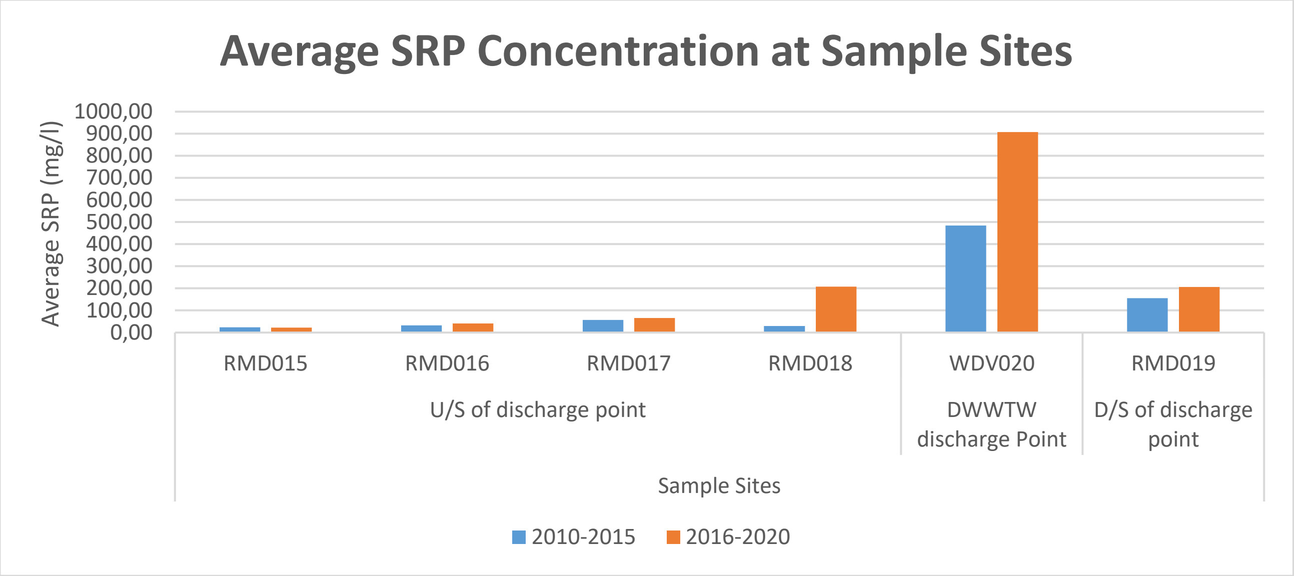

Figure 31: A comparison of SRP concentration at different monitoring and two time periods (2010-2015 and 2016-2020).

4.1.5. Ammonia (as NH3)

RMD015- Upstream of the Darvill WWTW

Ammonia (NH_3) analyses were conducted on a weekly frequency. A total of 537 NH_3 analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL and General Limits of 6 mg/L. Analyses also complied when evaluated against the TWQR (7 mg/L) of the guidelines **(Table 27 and Figure 32)**. The highest result was 4.12 mg/L.

Table 27: Ammonia statistics for upstream of the Darvill WWTW (2010-2020).

No of Analyses	537
No of non-compliant	0
Minimum	0.04 mg/L
Maximum	4.12 mg/L

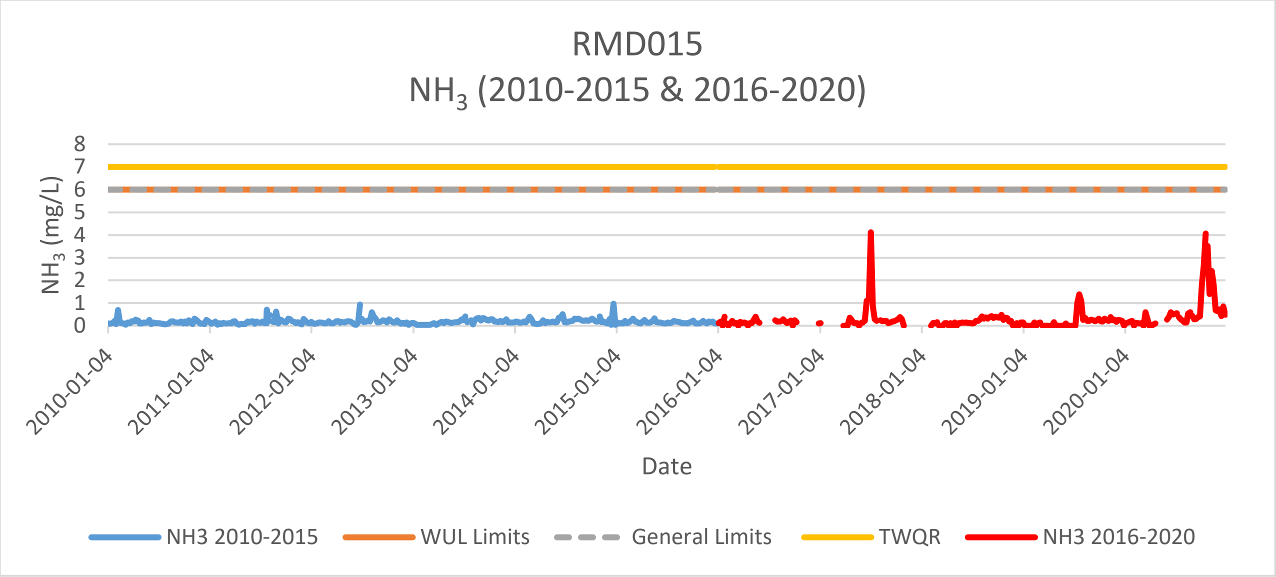

Figure 32: Ammonia concentration at upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

Analyses for NH3 were conducted on a weekly frequency. **Table 28** shows that there were 570 NH3 analyses that were conducted for the study period 2010-2020. However, 11 of the analyses did not comply when evaluated against the WUL and General Limits of 6 mg/L. Then seven of the non-compliances also did not comply when evaluated against the TWQR (7 mg/L) of the guidelines during the 2010-2015 period **(Figure 33)**. Only one analysis did not comply with the TWQR (7 mg/L) in the 2016-2020 period. There were eight analyses that did not comply with the TWQR. The highest result was 10.95 mg/L.

Table 28: Ammonia statistics for upstream of the Baynespruit Stream (2010-2020).

	WUL & General Limits	TWQR
No of Analyses	570	
No of non-compliant	11	8
Minimum	0.04 mg/L	
Maximum	10.95 mg/L	

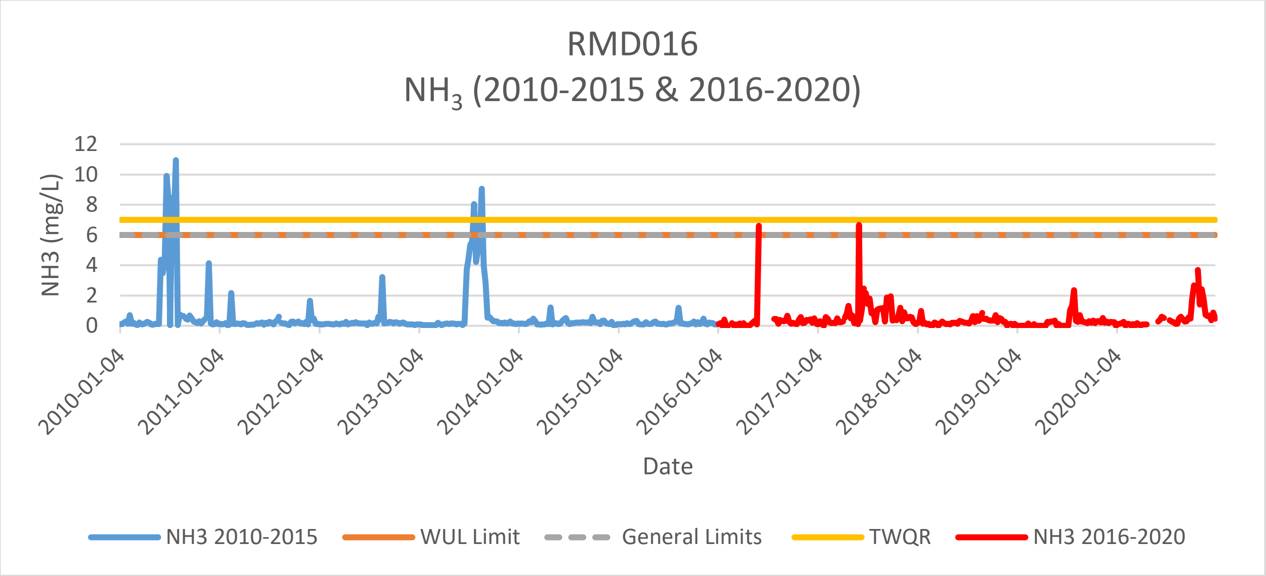

Figure 33: Ammonia concentration at upstream of the Baynespruit Stream (2010-2020).

<u>RMD017- Upstream of the Darvill Maturation River</u>

The NH_3 analyses were conducted on a weekly frequency. A total of 588 NH_3 analyses were conducted for the study period 2010-2020. Out of the total analyses, 13 did not comply with the WUL and General Limits of 6 mg/L and eight of these analyses also did not comply when evaluated against the TWQR (7 mg/L) of the guidelines. The highest result was 10.65 mg/L.

Table 29: Ammonia statistics for upstream of the Darvill Maturation River (2010-2020).

	WUL & General Limits	TWQR
No of Analyses	588	
No of non-compliant	13	8
Minimum	0.04 mg/L	
Maximum	10.65 mg/L	

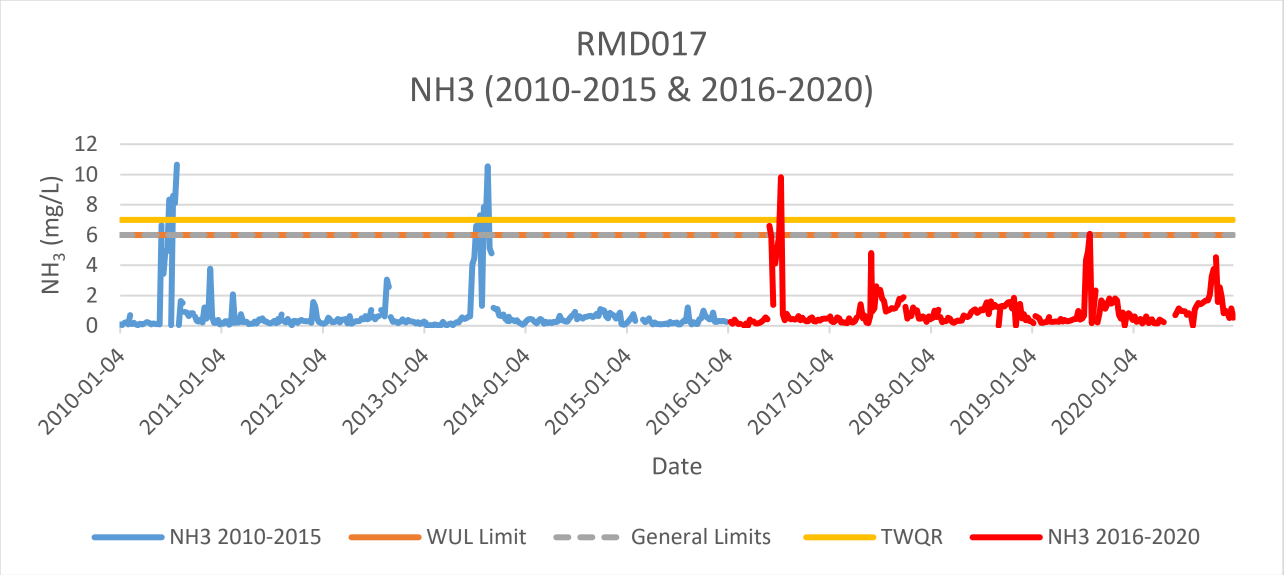

Figure 34: Ammonia concentration at upstream of the Darvill Maturation River (2010-2020).

<u>RMD018- Downstream of the Darvill Maturation River</u>

The NH_3 analyses were conducted on a weekly frequency. **Table 30** shows that a total of 132 NH_3 analyses were conducted for the study period 2010-2020. Out of the total analyses, 14 did not comply with the WUL and General Limits of 6 mg/L and nine of these analyses also did not comply when evaluated against the TWQR (7 mg/L) of the guidelines **(Figure 35)**. The highest result was 11.00 mg/L.

Table 30: Ammonia statistics for downstream of the Darvill Maturation River (2010-2020).

	WUL & General Limits	TWQR
No of Analyses	132	
No of non-compliant	14	9
Minimum	0.18 mg/L	
Maximum	11.00 mg/L	

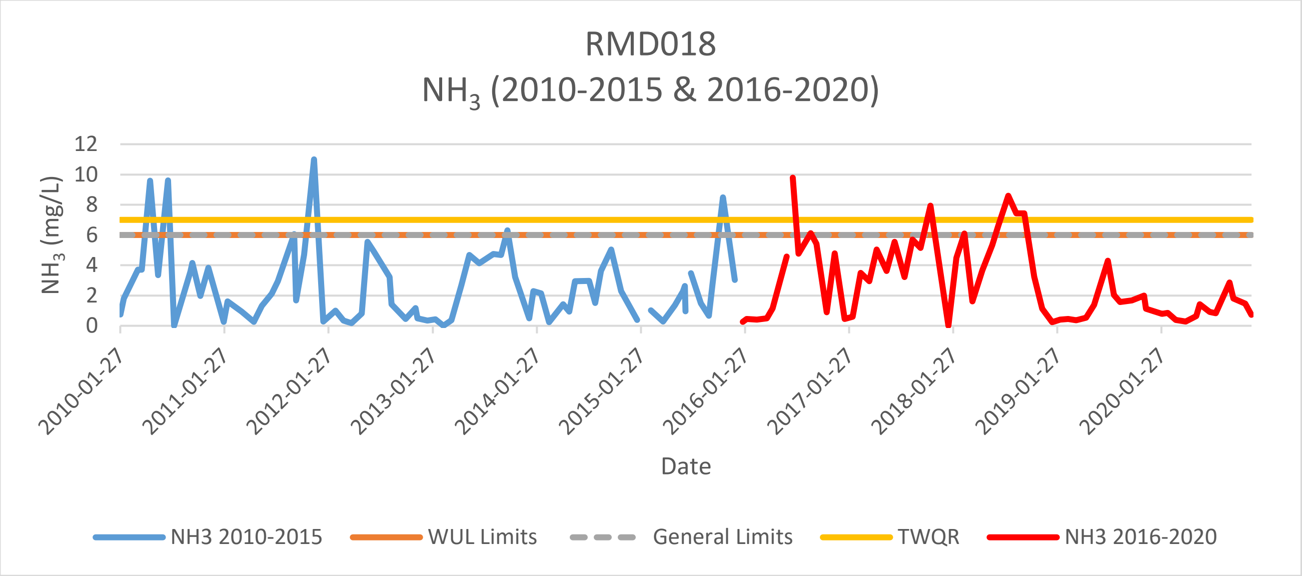

Figure 35: Ammonia concentration at downstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

The NH_3 analyses were conducted on a weekly frequency. **Table 31** shows that a total of 583 NH_3 analyses were conducted for the study period 2010-2020. Out of the total analyses, 63 did not comply with the WUL and General Limits of 6 mg/L and 27 of these analyses also did not comply when evaluated against the TWQR (7 mg/L) of the guidelines **(Figure 36).** The highest result was 14.60 mg/L.

Table 31: Ammonia statistics for downstream of the Darvill Discharge Point (2010-2020).

	WUL & General Limits	TWQR
No of Analyses	583	
No of non-compliant	63	27
Minimum	0.07 mg/L	
Maximum	14.60 mg/L	

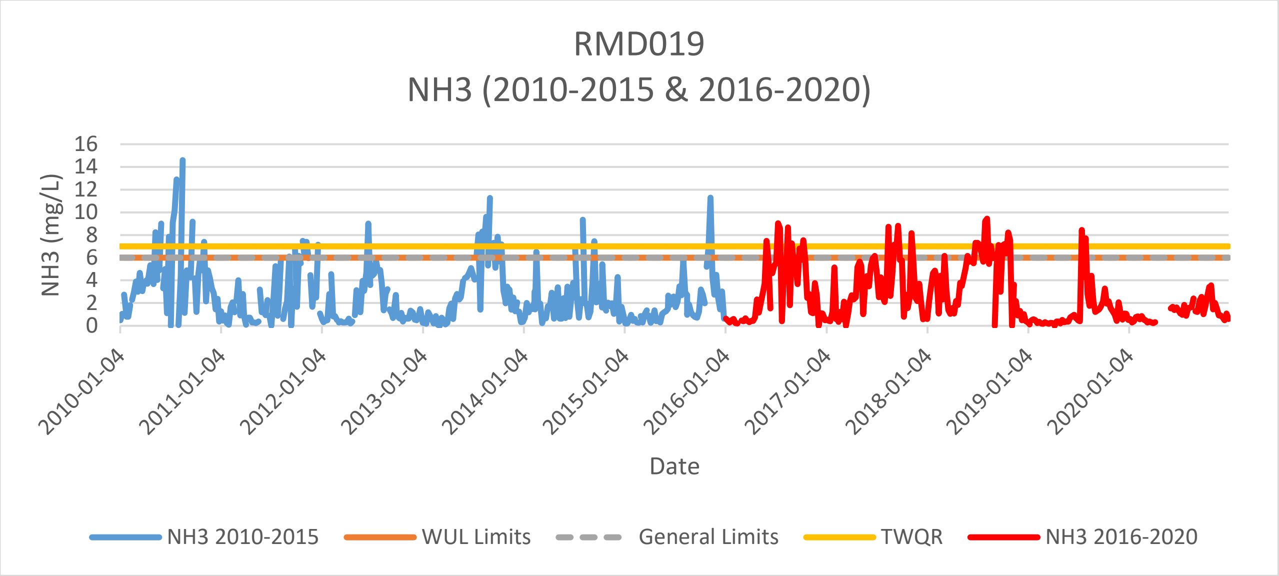

Figure 36: Ammonia concentration at downstream of the Darvill Discharge Point (2010-2020).

WDV020- Darvill WWTW Final Effluent

The NH_3 analyses were conducted on a daily frequency. A total of 2637 NH_3 analyses were conducted for the study period 2010-2020. Out of the total analyses, 1398 did not comply with the WUL and General Limits of 6 mg/L and 1284 of these analyses also did not comply when evaluated against the TWQR (7 mg/L) of the guidelines. The highest result was 31.60 mg/L.

Table 32: Ammonia statistics for Darvill WWTW Final Effluent (2010-2020).

	WUL & General Limits	TWQR
No of Analyses	2637	
No of noncompliant	1398	1284
Minimum	0.50 mg/L	
Maximum	31.60 mg/L	

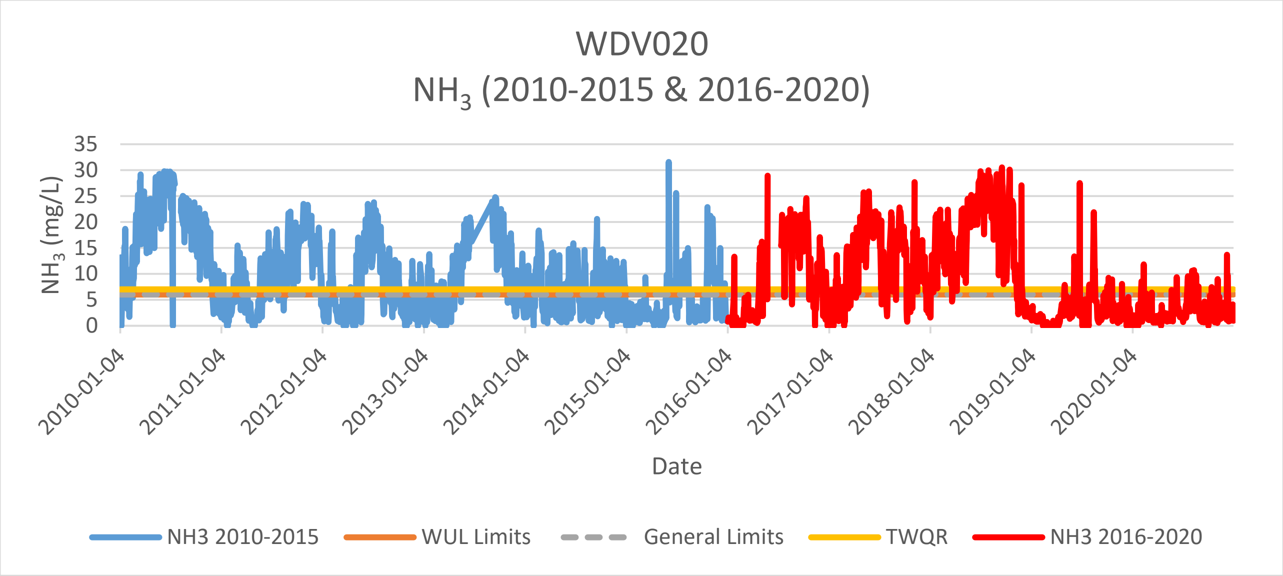

Figure 37: Ammonia concentration at Darvill WWTW Final Effluent (2010-2020).

Figure 38 shows that NH_3 concentration are increasing from upstream waters to downstream waters. The effluent from Darvill WWTW has significantly elevated levels of NH_3. The NH_3 levels decrease at the downstream sites and become slightly lower than the concentration in the RMD018.

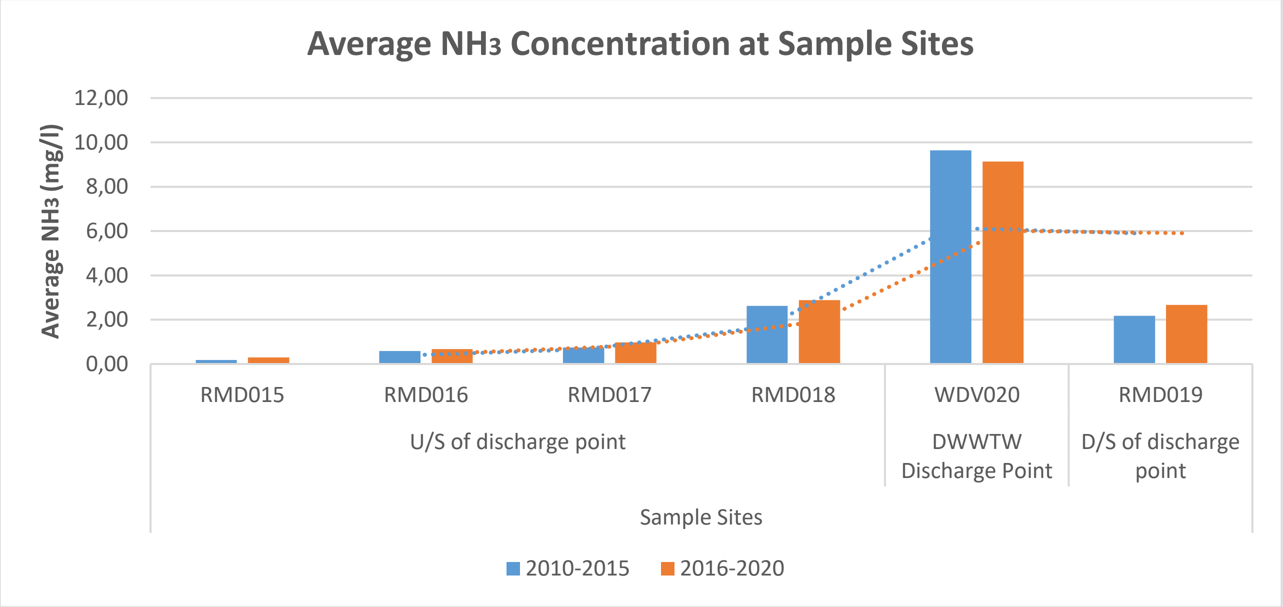

Figure 38: A comparison of NH_3 concentration at different monitoring and two time periods (2010-2015 and 2016-2020).

4.1.6. Nitrates

RMD015- Upstream of the Darvill WWTW

Analyses for NO_3 were conducted on s weekly frequency. **Table 33** shows that a total of 539 analyses were conducted for the study period 2010-2020. Only one analysis did not comply when evaluated against the WUL and General Limits of 15 mg/L in the 2010-2015 period **(Figure 39).** The highest result was 19.20 mg/L.

Table 33: Nitrates statistics for upstream of the Darvill WWTW (2010-2020).

No of Analyses	539
No of non-compliant	1
Minimum	0.05 mg/L
Maximum	19.20 mg/L

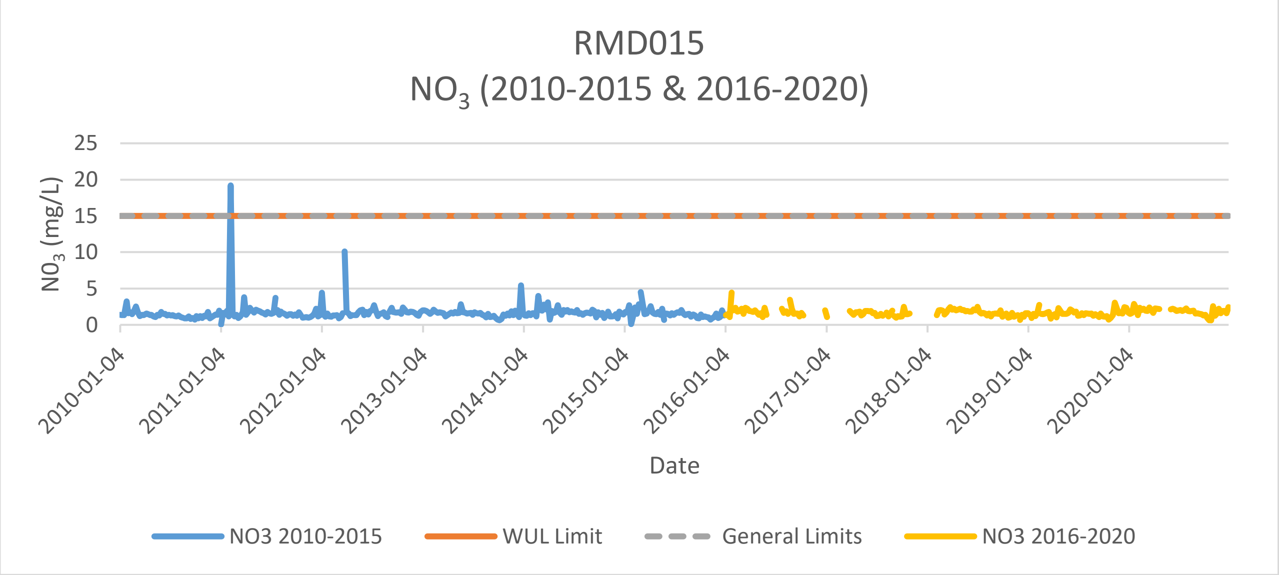

Figure 39: Nitrate concentration at upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

Analyses for this site monitoring point were conducted on a weekly frequency. **Table 34** shows that 570 analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL and General Limits of 15 mg/L **(Figure 40).** The highest result was 7.33 mg/L.

Table 34: Nitrate statistics for upstream of the Baynespruit Stream (2010-2020).

No of Analyses	570
No of non-compliant	0
Minimum	0.27 mg/L
Maximum	7.33 mg/L

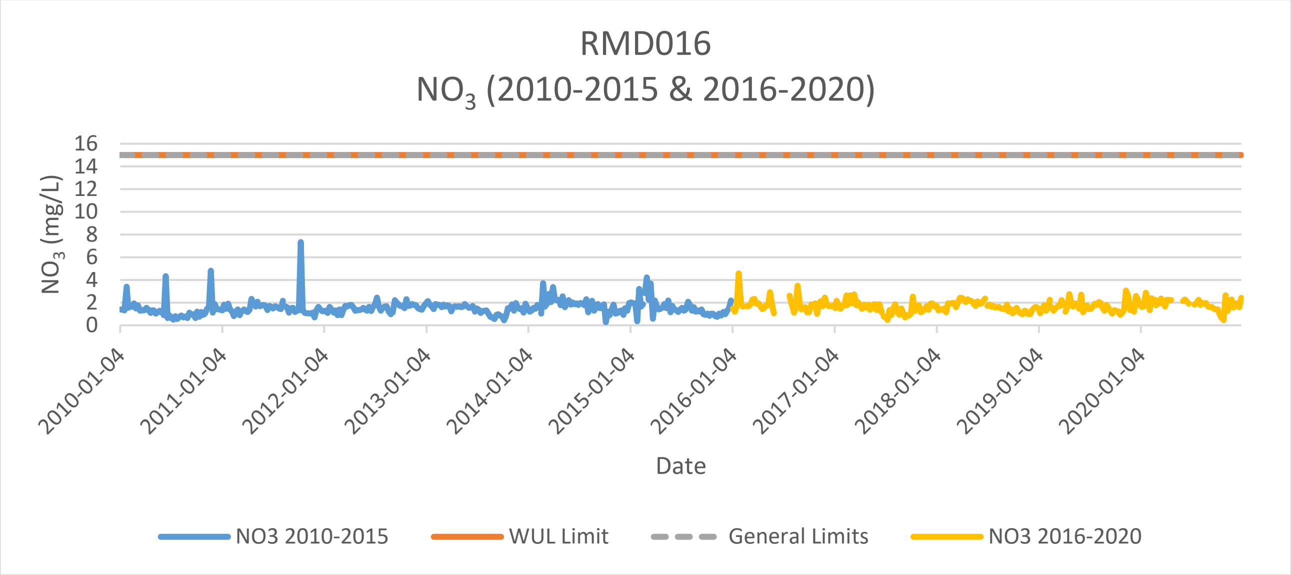

Figure 40: Nitrates concentration at upstream of the Baynespruit Stream (2010-2016).

<u>RMD017- Upstream of the Darvill Maturation River</u>

The NO_3 analyses were conducted on a weekly frequency. **Table 35** shows that a total of 588 analyses were conducted for the study period 2010-2020. All analyses complied when evaluated against the WUL and General Limits of 15 mg/L **(Figure 41).** The highest result was 9.9 mg/L.

Table 35: Nitrates statistics for upstream of the Darvill Maturation River (2010-2020).

No of Analyses	588
No of non-compliant	0
Minimum	0.16 mg/L
Maximum	9.9 mg/L

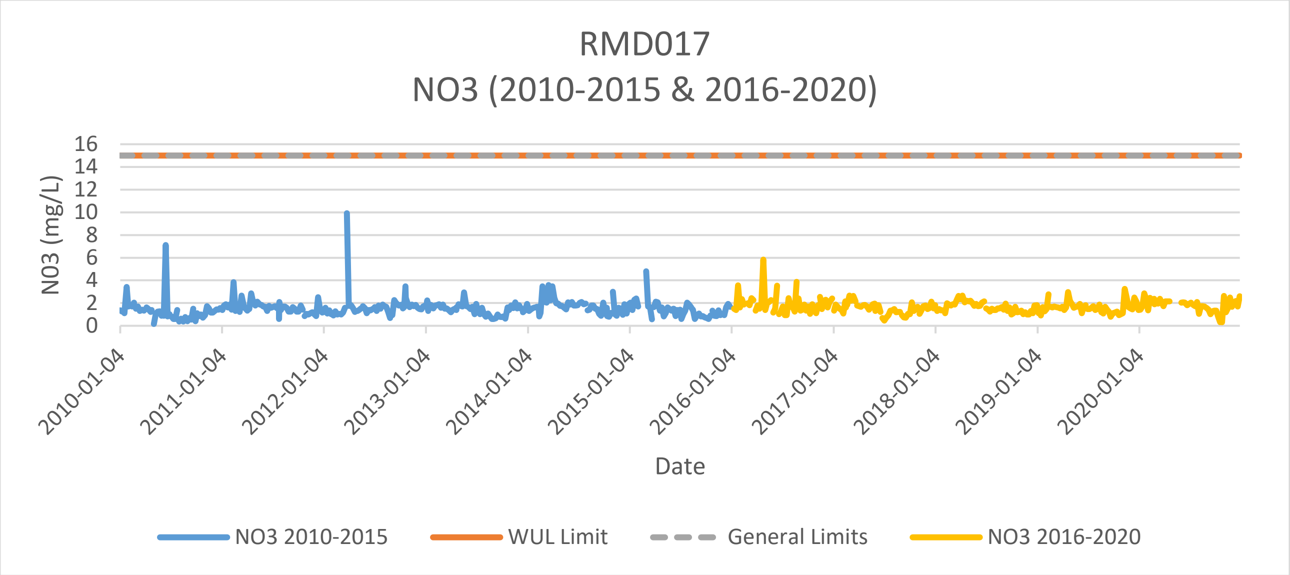

Figure 41: Nitrate concentration at upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River

The NO_3 analyses were conducted on a monthly frequency. A total of 132 analyses **(Table 36)** were conducted for the study period 2010-2020. Only one analysis did not comply when evaluated against the WUL and General Limits of 15 mg/L in the 2016-2020 period **(Figure 42)**. The highest result was 15.90 mg/L.

Table 36: Nitrate statistics for downstream of the Darvill Maturation River (2010-2020).

No of Analyses	132
No of non-compliant	1
Minimum	0.12 mg/L
Maximum	15.90mg/L

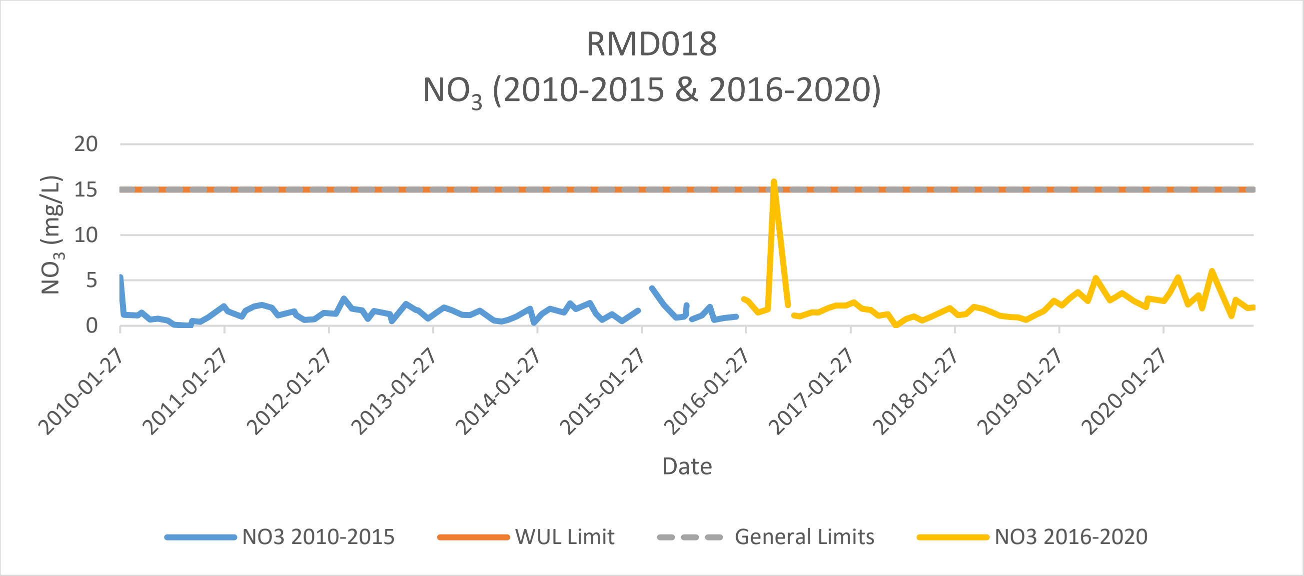

Figure 42: Nitrate concentration at downstream of the Darvill Maturation River (2010-2020).

<u>RMD019- Downstream of the Darvill Discharge Point</u>

The NO_3 analyses were conducted on a weekly frequency. A total of 582 analyses were conducted for the study period 2010-2020 **(Table 37).** Only one analysis did not comply when evaluated against the WUL and General Limits of 15 mg/L **(Figure 43)**. The highest result was 75.70 mg/L.

Table 37: Nitrate statistics for downstream of the Darvill Discharge Point (2010-2020).

No of Analyses	582
No of non-compliant	1
Minimum	0.08 mg/L
Maximum	75.70 mg/L

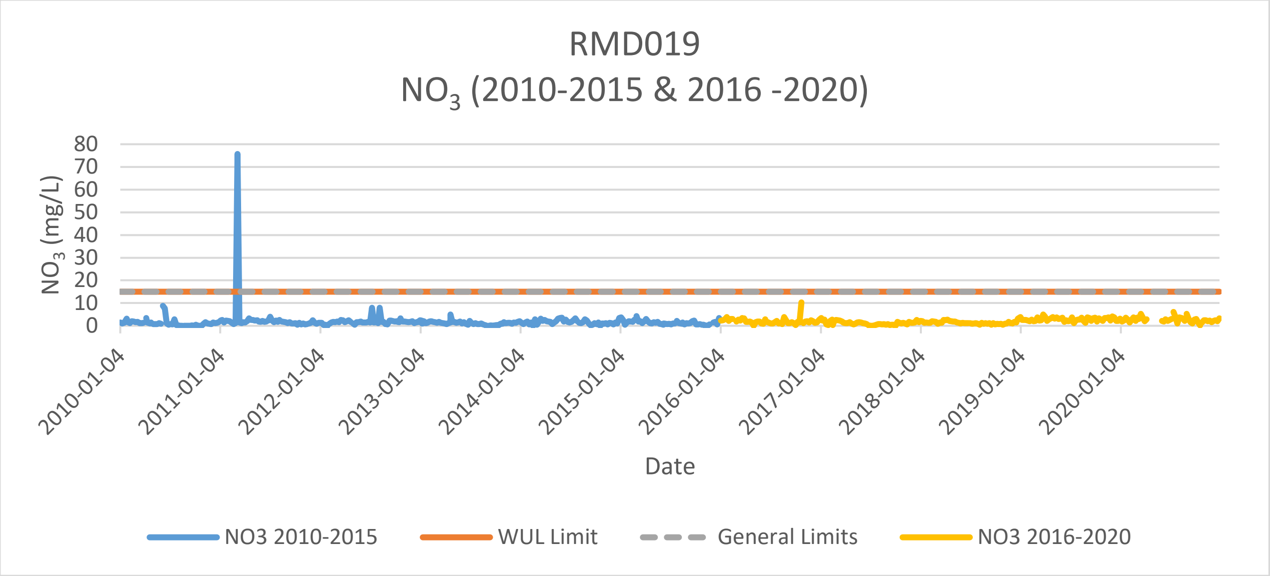

Figure 43: Nitrate concentration at downstream of the Darvill Discharge Point (2010-2020).

WDV020- Darvill WWTW Final Effluent

The NO3 analyses were conducted on a daily frequency. A total of 2635 analyses were conducted for the study period 2010-2020 **(Table 38).** All analyses complied when evaluated against the WUL and General Limits of 15 mg/L in the 2010-2015 period. In the 2016-2020 study period nine analyses did not comply when evaluated against the WUL and General Limits of 15 mg/L. The highest result was 9.55 mg/L. **Figure 44** shows that the majority of the results that were over the limits occurred in the 2016-2020 period.

Table 38: Nitrate statistics for Darvill WWTW Final Effluent (2010-2020).

No of Analyses	2635
No of non-compliant	9
Minimum	0.50 mg/L
Maximum	9.55 mg/L

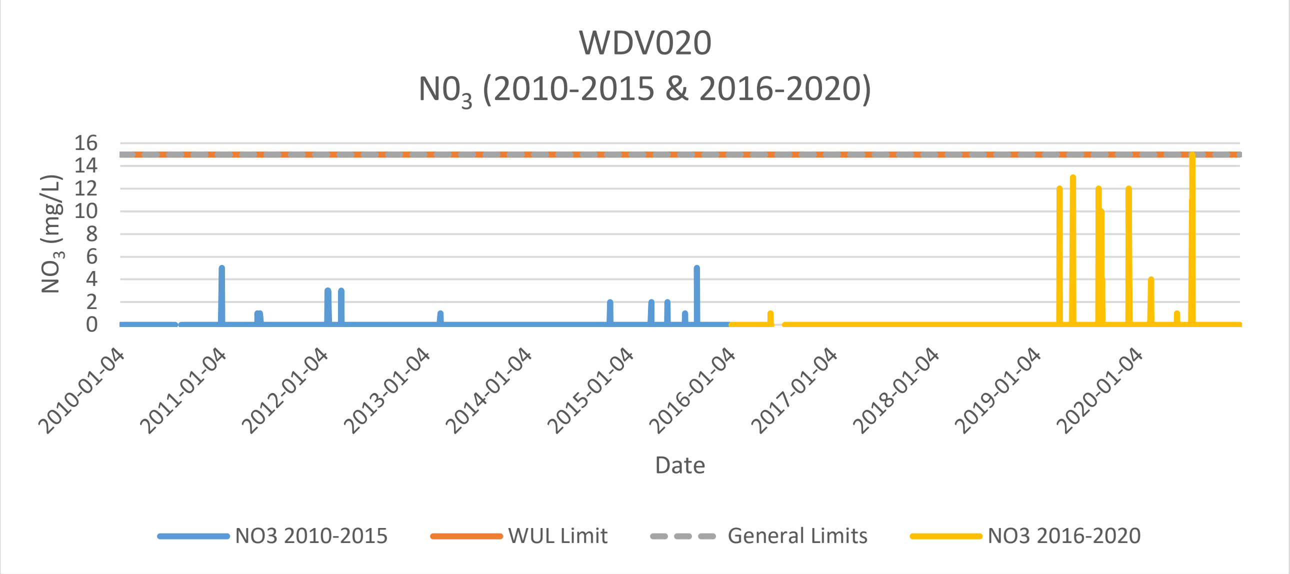

Figure 44: Nitrate concentration at Darvill WWTW Final Effluent (2010-2020).

Figure 45 shows a gradual increase in the concentration of NO_3 from the upstream sample point of the Darvill WWTW discharge points to the downstream point. A large NO_3 concentration was observed at the effluent discharge point. However, the concentration decreased at the downstream point. Noticeable from the graph was a large concentration increase of NO_3 in all the points, in the 2016-2020 period. A decrease in NO_3 concentration was evident at the discharge point in the 2016-2020 period.

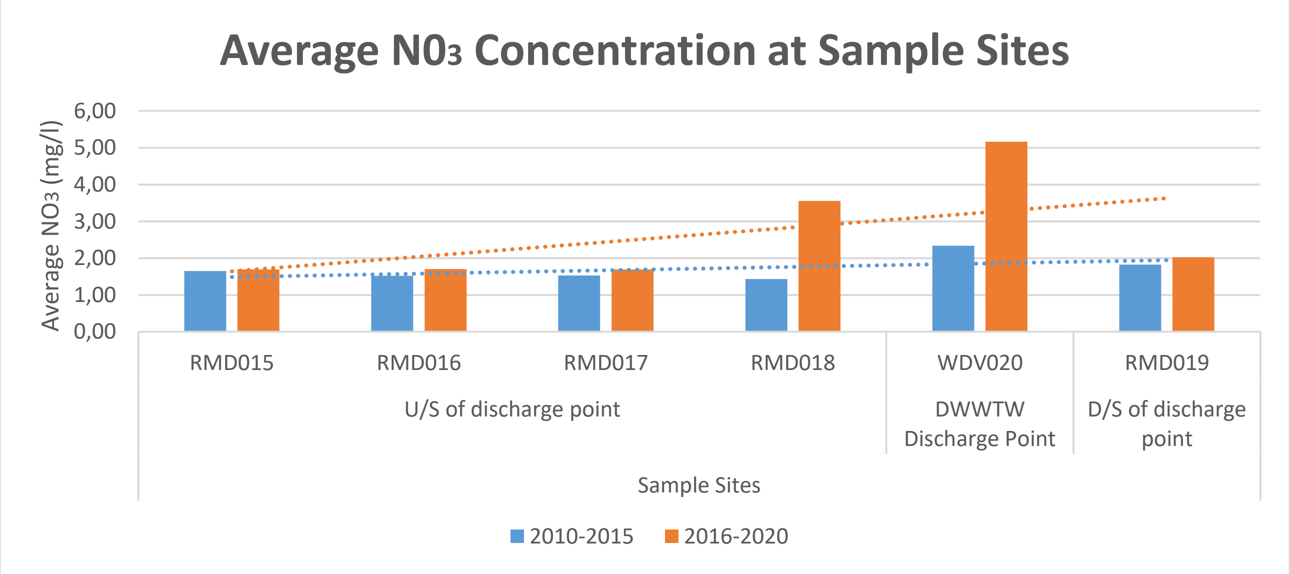

Figure 45: A comparison of NO_3 concentration at different monitoring and two time periods (2010-2015 and 2016-2020).

4.1.7. Chemical Oxygen Demand (COD)

<u>RMD015- Upstream of the Darvill WWTW</u>

The COD analyses were conducted on a weekly frequency. A total of 564 analyses were conducted for the study period 2010-2020. A total of 10 analyses did not comply when evaluated against the WUL and General Limits of 75 mg/L. The highest result was 144 mg/L.

Table 39: Chemical Oxygen Demand statistics for upstream of the Darvill WWTW (2010-2020).

No of Analyses	564
No of non-compliant	10
Minimum	20.00 mg/L
Maximum	144 mg/L

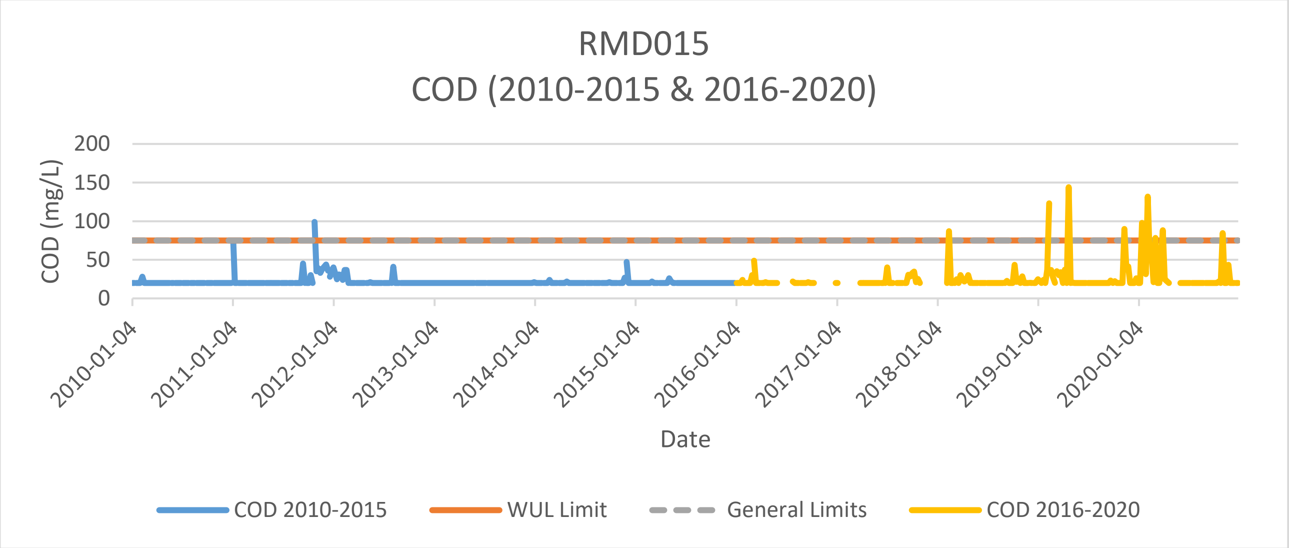

Figure 46: Chemical Oxygen Demand levels at upstream of the Darvill WWTW (2010-2020).

<u>RMD017- Upstream of the Darvill Maturation River</u>

The COD analyses were conducted on a weekly frequency. A total of 587 analyses were conducted for the study period 2010-2020 **(Table 40)**. Out of all the 587 analyses, eight analyses did not comply when evaluated against the WUL and General Limits of 75 mg/L **(Figure 47).**

Table 40: Chemical Oxygen Demand statistics for upstream of the Darvill Maturation River (2010-2020).

No of Analyses	587
No of non-compliant	8
Minimum	20.00 mg/L
Maximum	277.00 mg/L

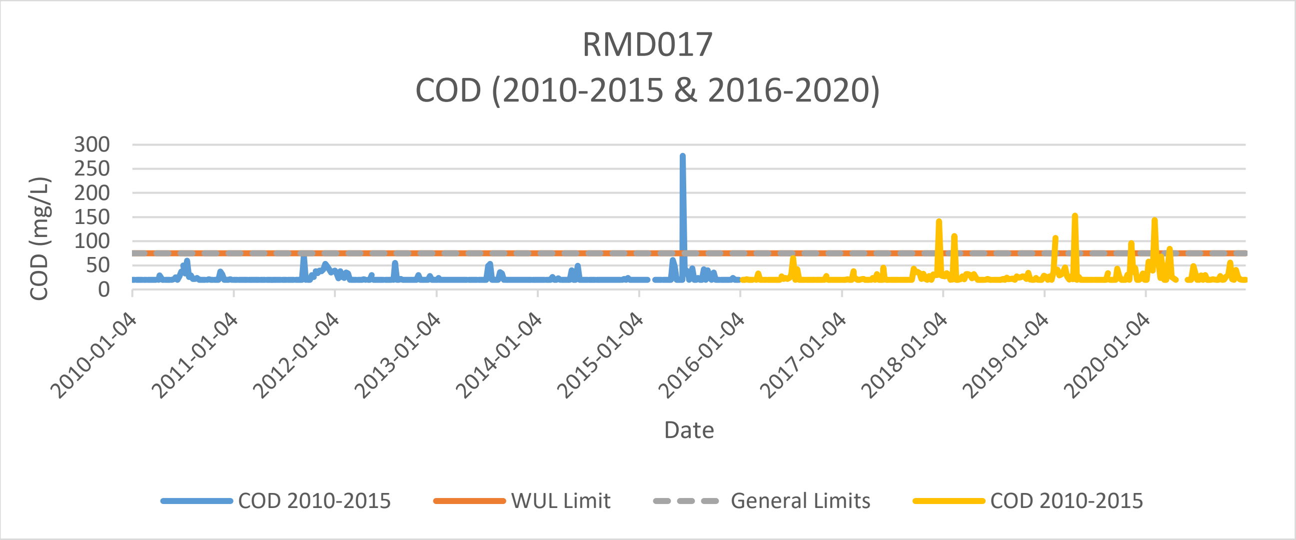

Figure 47: Chemical Oxygen Demand levels at upstream of the Darvill Maturation River (2010-2020).

RMD018- Downstream of the Darvill Maturation River

Table 41 shows that a total of 132 COD analyses were conducted for the study period 2010-2020. Only two analyses did not comply when evaluated against the WUL and General Limits of 75 mg/L **(Figure 48).** The highest result was 127 mg/L.

Table 41: Chemical Oxygen Demand statistics for downstream of the Darvill Maturation River (2010-2020).

No of Analyses	132
No of non-compliant	2
Minimum	20.00 mg/L
Maximum	127.00 mg/L

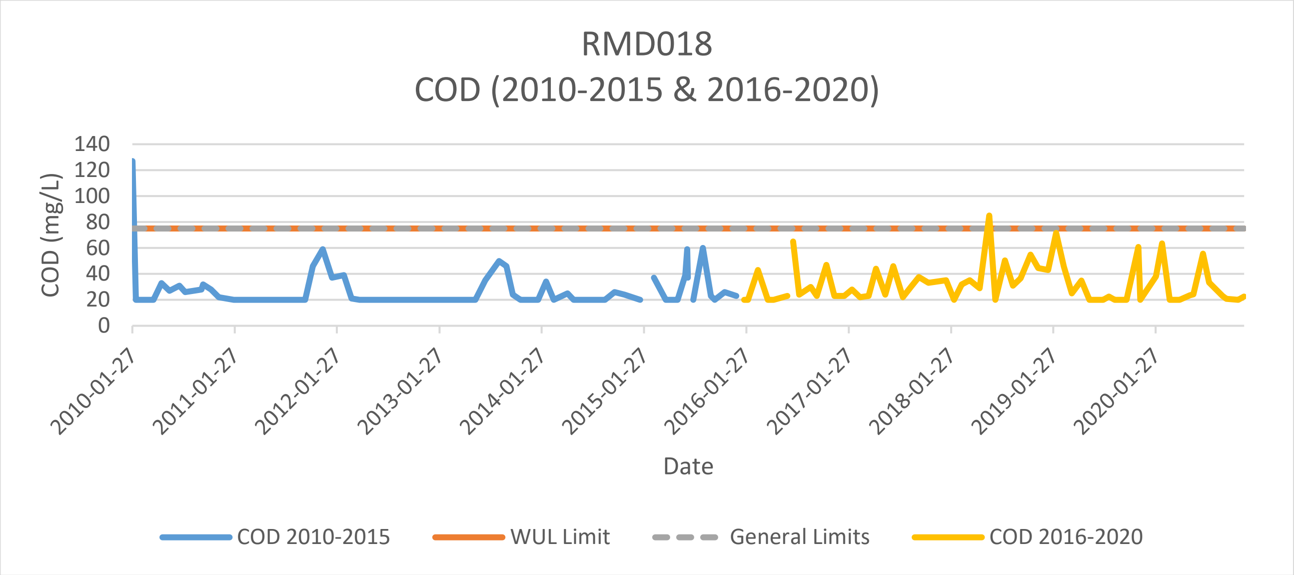

Figure 48: Chemical Oxygen Demand levels at downstream of the Darvill Maturation River (2010-2020).

RMD019- Downstream of the Darvill Discharge Point

The data for COD is not available for the period 2016-2020. A total of 327 analyses were conducted for the study period 2010-2015. A total of four analyses did not comply when evaluated against the WUL and General Limits of 75 mg/L. The highest result was 127 mg/L.

Table 42: Chemical Oxygen Demand statistics for downstream of the Darvill Discharge Point (2010-2015).

No of Analyses	327
No of non-compliant	4
Minimum	20.00 mg/L
Maximum	97.00 mg/L

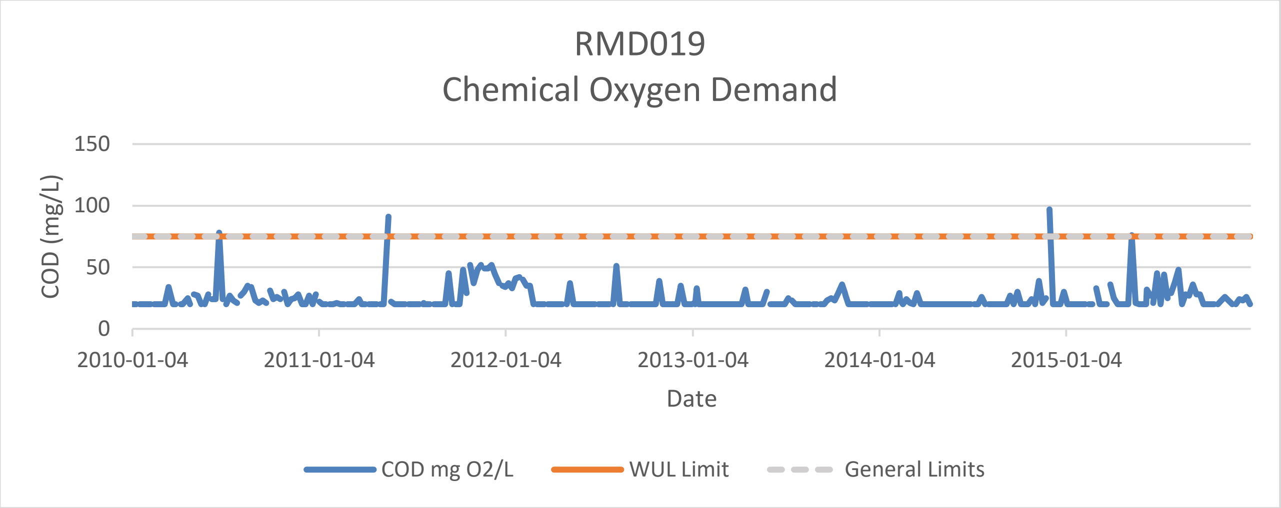

Figure 49: Chemical Oxygen Demand levels at downstream of the Darvill Discharge Point (2010-2015).

WDV020- Darvill WWTW Final Effluent

The data analyses for COD was not available for the period 2016-2020 for this site. **Table 43** shows that a total of 1432 analyses were conducted for the study period 2010-2015. Out of the total analyses conducted, 192 analyses did not comply when evaluated against the WUL and General Limits of 75 mg/L **(Table 43 and Figure 50)**. The highest result was 682 mg/L.

Table 43: Chemical Oxygen Demand statistics for Darvill WWTW Final Effluent (2010-2015).

No of Analyses	1432
No of non-compliant	192
Minimum	20.00 mg/L
Maximum	682.00 mg/L

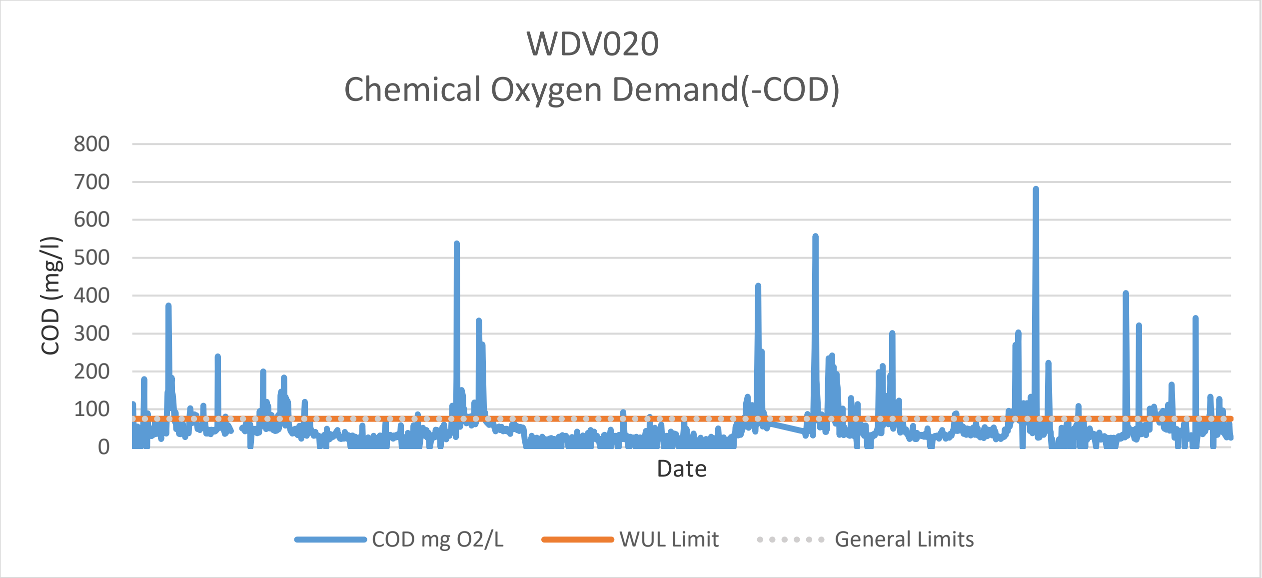

Figure 50: Chemical Oxygen Demand levels at Darvill WWTW Final Effluent (2010-2015).

Figure 51 shows an increase in the COD concentration levels at the first three upstream sample points in the 2016-2020, when compared to the data for the 2010-2015 period. However, a slight decrease in the COD concentration was noticed at RMD018, which was the closest by point to the effluent discharge point (WDV020). The COD concentration also showed a larger decrease at the downstream sample point during the 2010-2015 period.

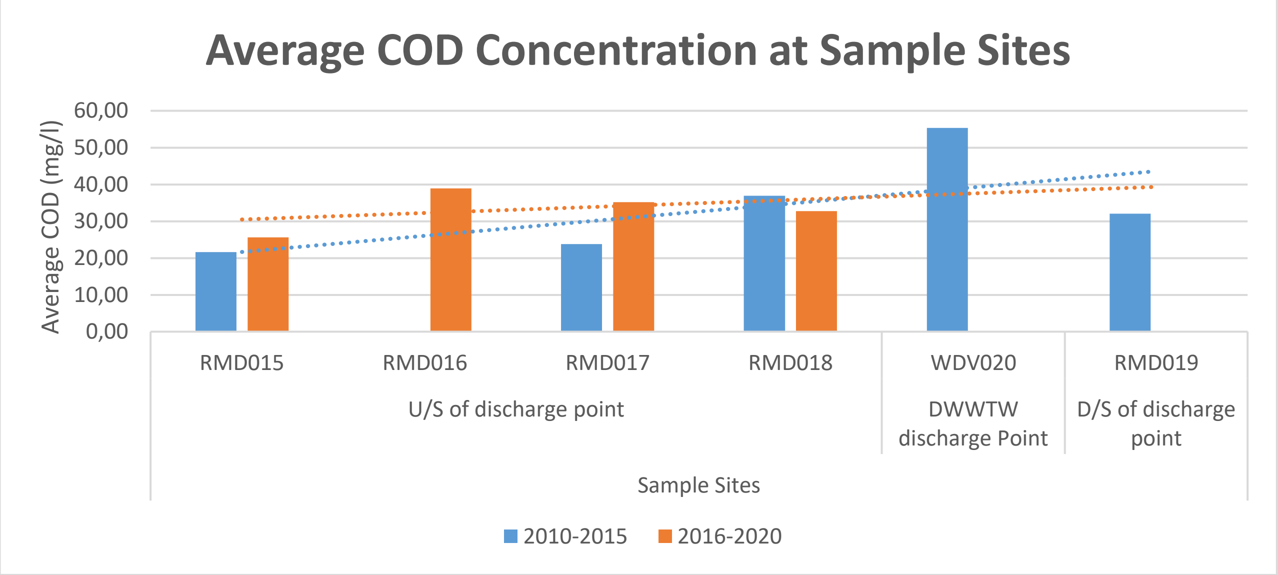

Figure 51: A comparison of COD concentration at different monitoring and two time periods (2010-2015 and 2016-2020),

4.1.8. Escherichia coli (E. coli)

RMD015- Upstream of the Darvill WWTW

The *E. coli* analyses were conducted on a weekly frequency. **Table 44** shows the statistics of *E. coli* presence in the Msunduzi River at RMD015. The table also shows the number of analyses compliances against the WUL and the General Limits. A total of 567 analyses were conducted for the study period 2010-2020. A total of 559 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 531 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100 mL. Whilst the majority of non-compliances with the limits was recorded in the 2010-2015 period, an increase in the *E. coli* present is seen in the 2016-2020 period **(Figure 52).** The highest result was 307600 MPN/100 mL.

Table 44: *Escherichia coli* statistics for upstream of the Darvill WWTW (2010-2020).

	WUL limits	General Limits
No of Analyses	567	
No of non-compliant	559	531
Minimum	63 MPN/100 mL	
Maximum	488400 MPN/100 mL	

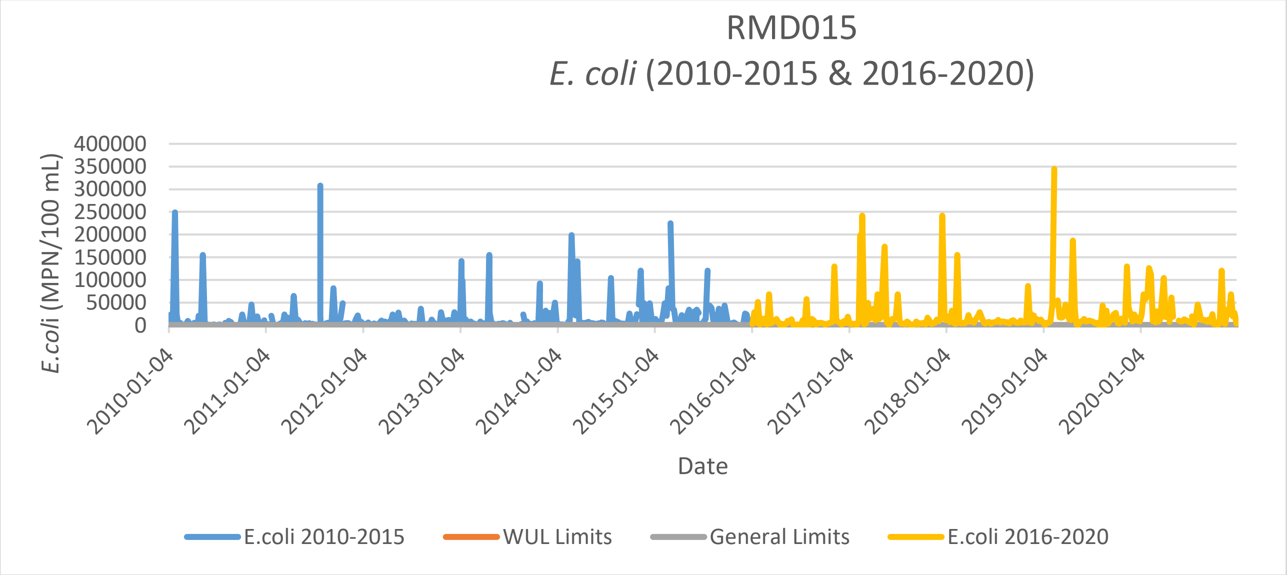

Figure 52: *Escherichia coli* concentration at upstream of the Darvill WWTW (2010-2020).

RMD016- Upstream of the Baynespruit Stream

The *E. coli* analyses were conducted on a weekly frequency.A total of 601 analyses were conducted for the study period 2010-2020. A total of 554 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 531 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100mL **(Table 45).**. The highest result was 435200 MPN/100 mL **(Figure 53)**.

Table 45: *Escherichia coli* statistics for upstream of the Baynespruit Stream (2010-2020).

	WUL limits	General Limits
No of Analyses	601	
No of non-compliant	554	531
Minimum	0 MPN/100 mL	
Maximum	435200 MPN/100 mL	

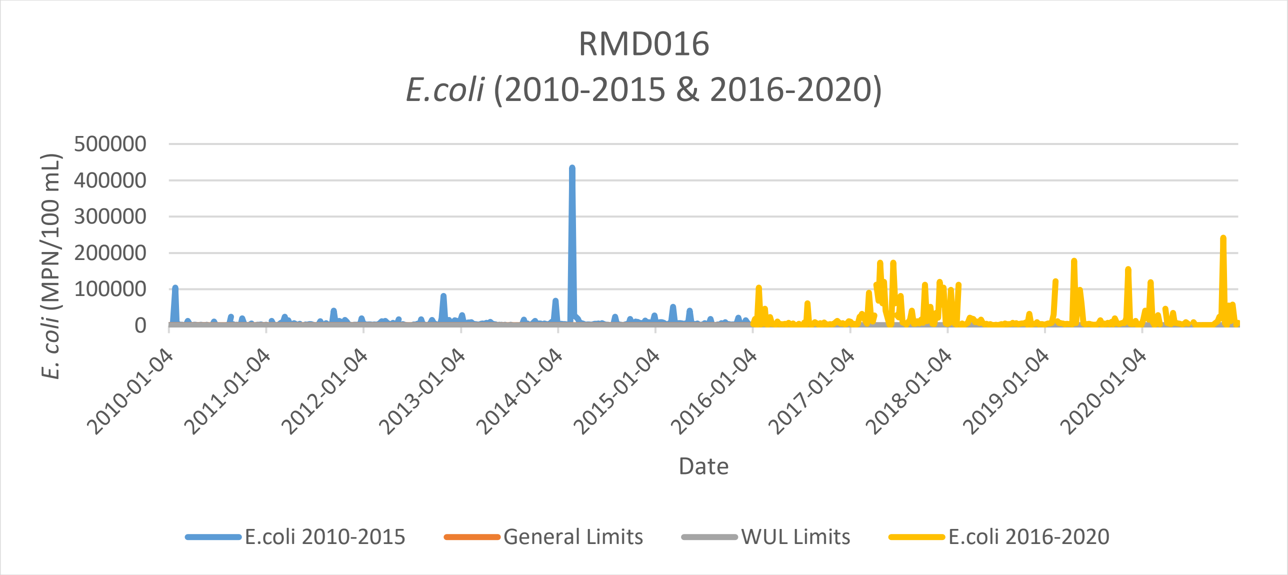

Figure 53: *Escherichia coli* concentration at upstream of the Baynespruit Stream (2010-2020).

RMD017- Upstream of the Darvill Maturation River

The *E. coli* analyses were conducted on a weekly frequency. A total of 605 analyses were conducted for the study period 2010-2020. A total of 592 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 585 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100 mL **(Table 46).** The highest result was 241920 MPN/100 mL in the 2016-2020 period **(Figure 54).**

Table 46: *Escherichia coli* statistics for upstream of the Baynespruit Stream (2010-2020).

	WUL limits	General Limits
No of Analyses	605	
No of non-compliant	592	585
Minimum	40 MPN/100 mL	
Maximum	241920 MPN/100 mL	

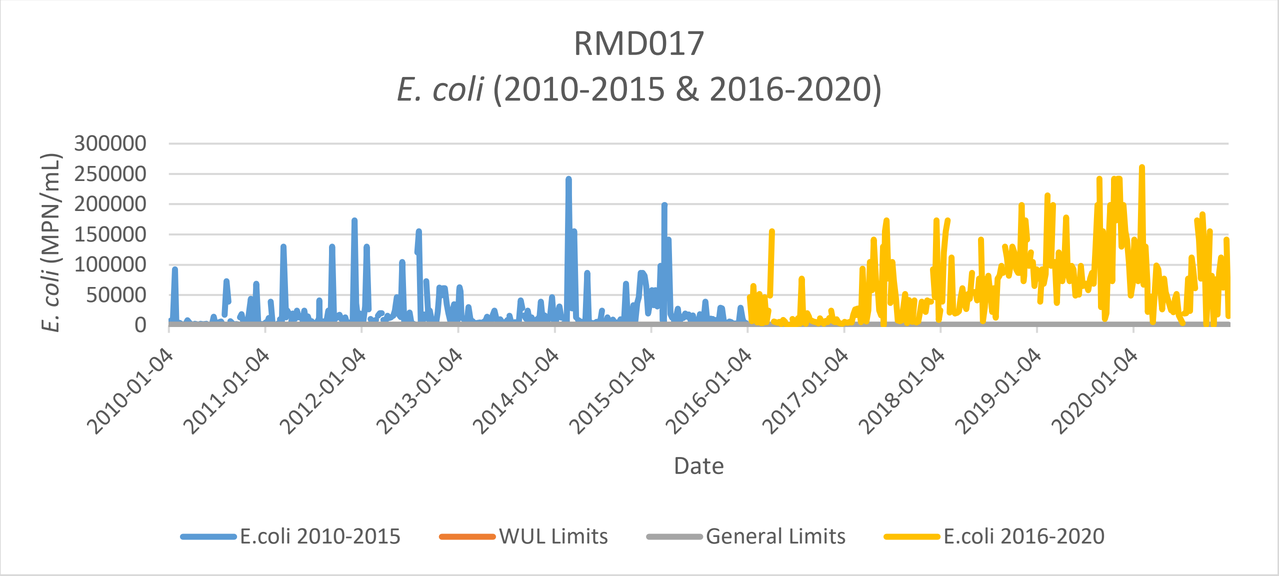

Figure 54: *Escherichia coli* concentration at upstream of the Baynespruit Stream (2010-2020).

<u>RMD018- Downstream of the Darvill Maturation River</u>

Analyses for *E. coli* were conducted on a monthly frequency. A total of 146 analyses were conducted for the study period 2010-2020. A total of 140 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 138 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100 mL **(Table 47).** The highest result was 285000 MPN/100mL. **Figure 55** show elevated present of *E. coli* in the 2016-2020 period when compared to the 2010-2015 period.

Table 47: *Escherichia coli* statistics for downstream of the Darvill Maturation River (2010-2020).

	WUL limits	General Limits
No of Analyses	146	
No of non-compliant	140	138
Minimum	100 MPN/100 mL	
Maximum	285000 MPN/100 mL	

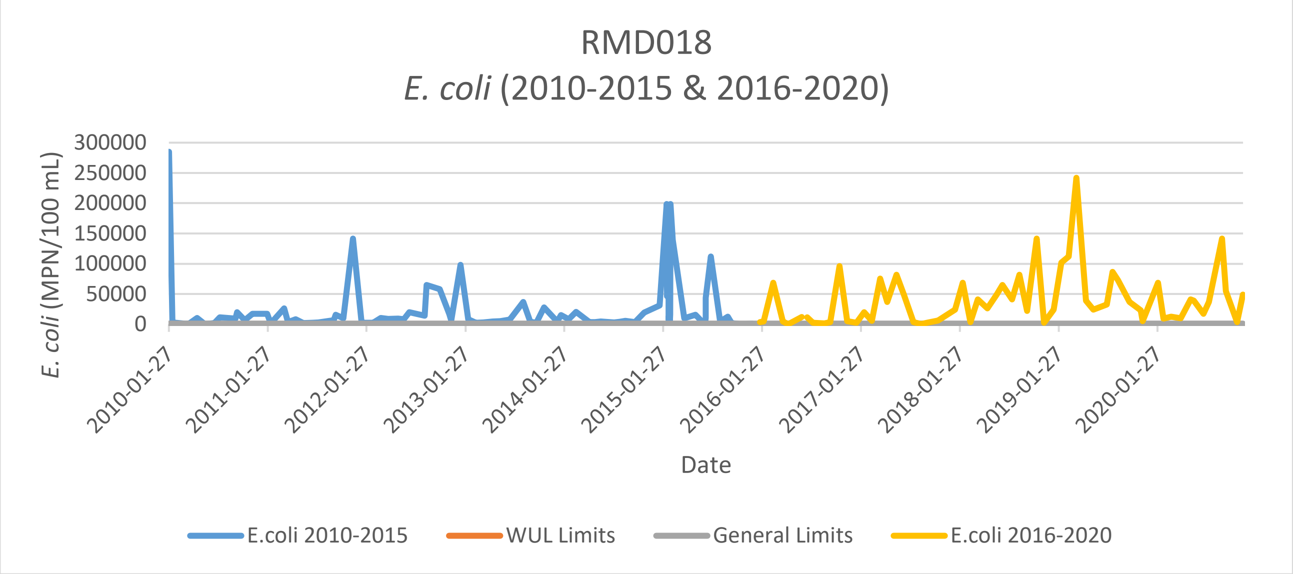

Figure 55: *Escherichia coli* concentration at downstream of the Darvill Maturation River (2010-2020).

<u>RMD019- Downstream of the Darvill Discharge Point</u>

The *E. coli* analyses were conducted on a weekly frequency. A total of 590 analyses were conducted for the study period 2010-2020. A total of 551 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 311 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100mL. The highest result was 344800 MPN/100 mL.

Table 48*: Escherichia coli* statistics for downstream of the Darvill Maturation River (2010-2020).

	WUL limits	General Limits
No of Analyses	590	
No of non-compliant	551	311
Minimum	1 MPN/100 mL	
Maximum	344800MPN/100mL	

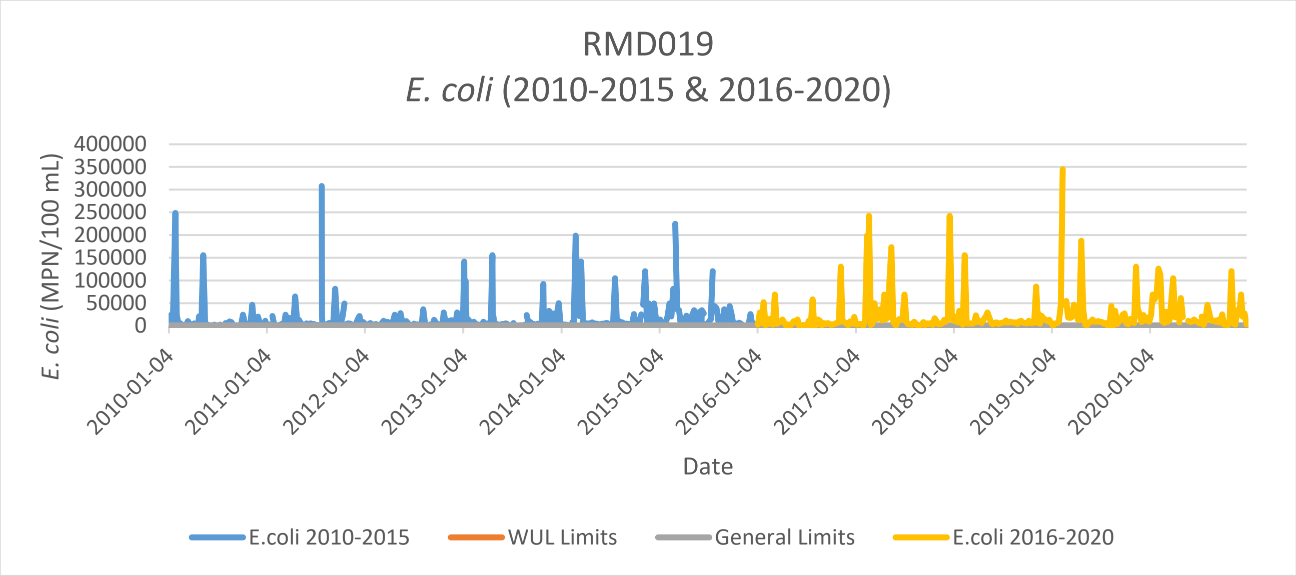

Figure 56: *Escherichia coli concentration* at downstream of the Darvill Maturation River (2010-2020).

WDV020- Darvill WWTW Final Effluent

The *E. coli* analyses were conducted on a weekly frequency. **Table 49** shows that a total of 2636 analyses were conducted for the study period 2010-2020. A total of 811 analyses did not comply when evaluated against the WUL Limit of 500 MPN/100 mL and 646 analyses did not comply when evaluated against the General Limits of 1000 MPLN/100 mL. The highest result was 6010000 MPN/100 mL and occurred in the 2016-2020 period **(Figure 57).**

Table 49. *Escherichia coli* statistics for Darvill WWTW Final Effluent (2010-2020).

	WUL limits	General Limits
No of Analyses	2636	
No of non-compliant	811	646
Minimum	0 MPN/100 mL	
Maximum	6010000 MPN/100 mL	

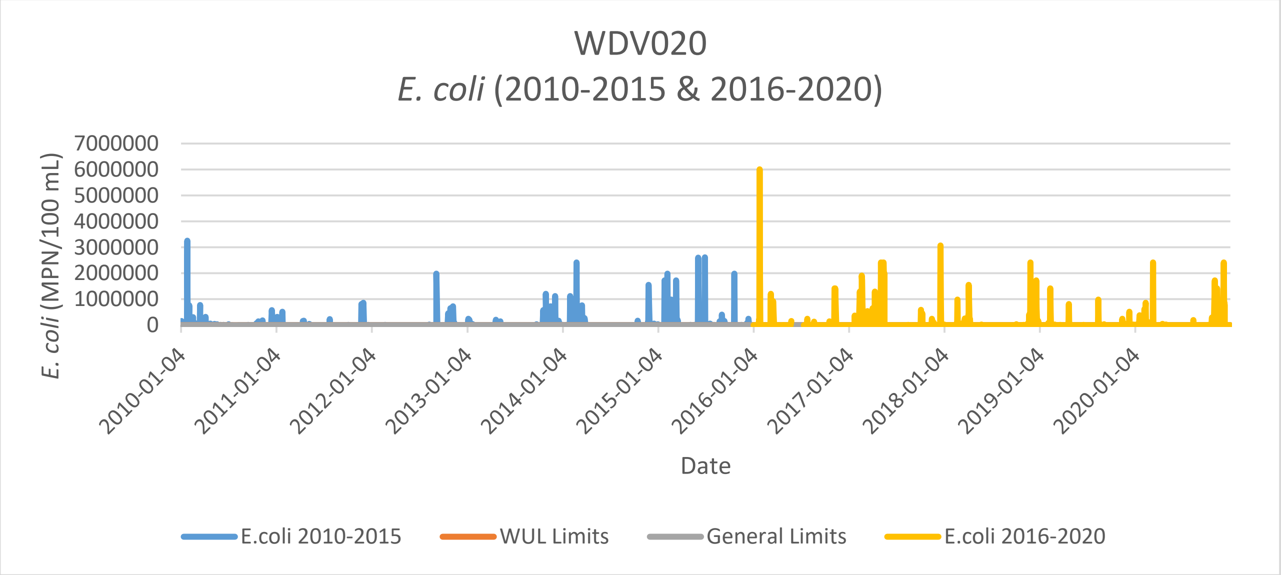

Figure 57: *Escherichia coli* concentration at Darvill WWTW Final Effluent (2010-2020).

Figure 58 shows that the *E. coli* levels were elevated when compared from the upstream points to the downstream point. It was also evident that effluent discharges from the Darvill WWTW was not the only source of pollution in the river as the RMD017 and RMD018 showed elevated levels of *E. coli* in the river. The downstream point showed a level of improvement in the water quality of the Msunduzi River when compared to the other three points. There was a large increase in the *E. coli* presence in the 2016-2020 period, in the Msunduzi River, when compared with the *E. coli* presence in the 2010-2015 period.

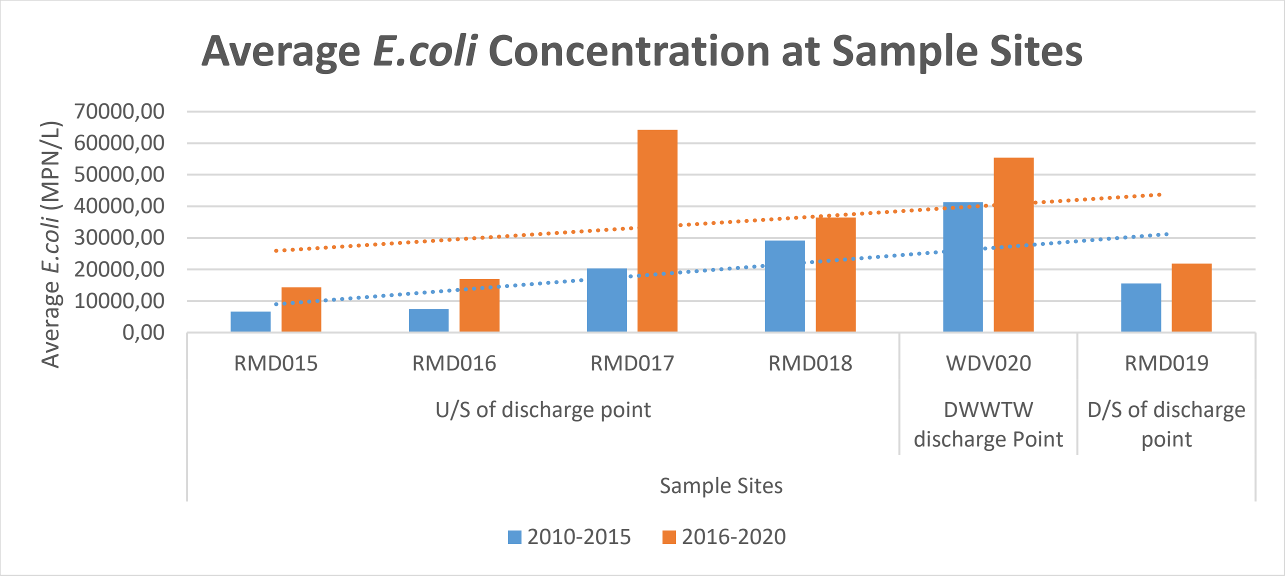

Figure 58: A comparison of *E. coli* concentration at different monitoring and two time periods (2010-2015 and 2016-2020).

4.2. Biomonitoring

The data for biomonitoring was available from RMD015, RMD016, RMD017 and RMD019. The available data is on monthly frequency as from May 2010 - June 2017. Results are presented for IHAS and BI, ASPT average scores for the 2010-2017 period. Habitat integrity index values are generically interpreted as per **Table 50** and the ASPT scores interpretation is provided in **Table 51.**

Table 50: IHAS Index provides the description of the category and meaning of the ratings based on Kemper (1999).

Habitat Integrity Category	Description	Rating (% of Total)
A	Unmodified, natural.	90-100
B	Largely natural with few modifications. The flow regime has been only slightly modified and pollution is limited to sediment. A small change in natural habitats may have taken place. However, the ecosystem functions are essentially unchanged.	80-89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic systems functions is extensive.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Critically/Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances, the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

Table 51: Interpretation of ASPT score.

ASPT Score	Ecological Category Name	Description
0 - 4.2	Critically modified	Critically modified
>4.2 – 4.5	Poor	Largely modified
>4.5 – 4.8	Fair	Moderately modified
>4.8 - 5.8	Good	Largely natural with few modifications
>5.8 - 8	Natural	Unmodified

The data for the biomonitoring assessment is provided in **Appendix 1**. Based on the average scores in **Table 52**, the study area has a moderately modified habitat with basic ecosystem functions unchanged. More improved habitat scores were observed at the extreme upstream point and downstream point of Darvill WWTW discharge point.

Table 52: Biomonitoring results presented as average scores from 2010-2017.

Sample Point	ASPT	BI Score	IHAS
RMD015 - upstream of Darvill WWW	5.85	62.98	70.18
RMD016 - upstream of Baynespruit	5.20	58.52	69.86
RMD017 - upstream of Darvill Maturation river	5.23	52.56	68.91
RMD019 – downstream of the Darvill Discharge Point	6.44	115.54	71.08

The figures **(Figure 59 to Figure 62)** show the scores of the three indices at the upstream points (RMD015 to RMD017) and the downstream point (RMD019). For the RMD015 and RMD016 the scores showed a fluctuating behaviour before the year 2016. Thereafter the scores showed a deteriorating status in the biological life in the Msunduzi River at upstream sites. The scores showed improvements from the last upstream point (RMD017) to the downstream point (RMD019). Data showed much more improved state of the Msunduzi River at the downstream site, which is a point after the Darvill WWTW final effluent discharge point.

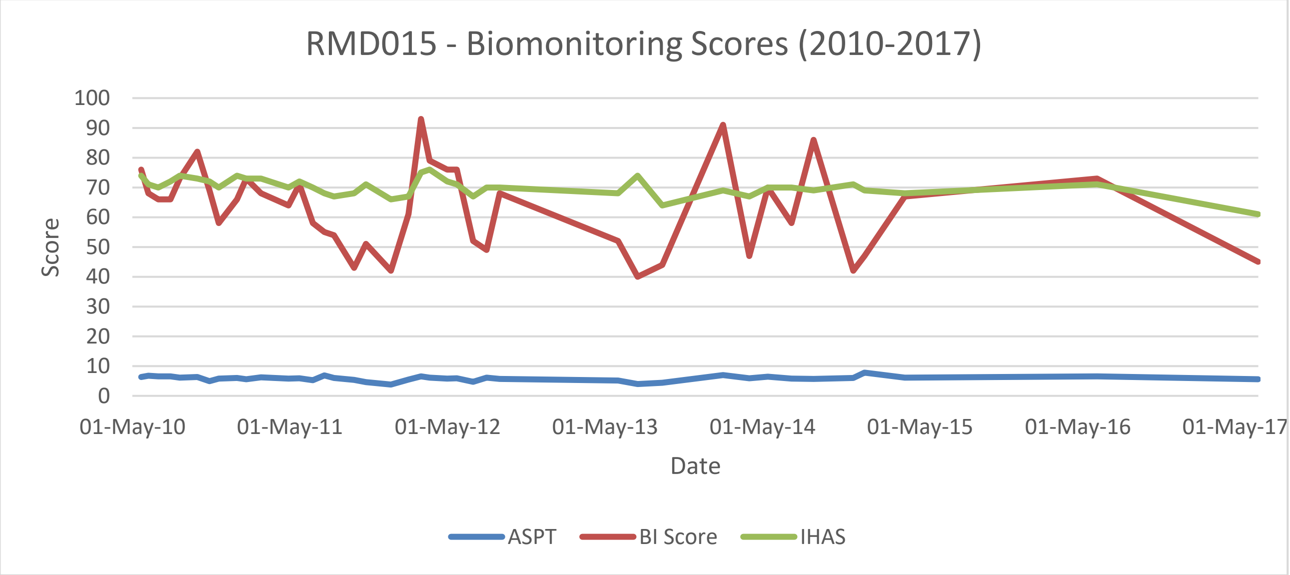

Figure 59: Scores for ASPT, BI and IHAS for 2010-2017 at RMD015.

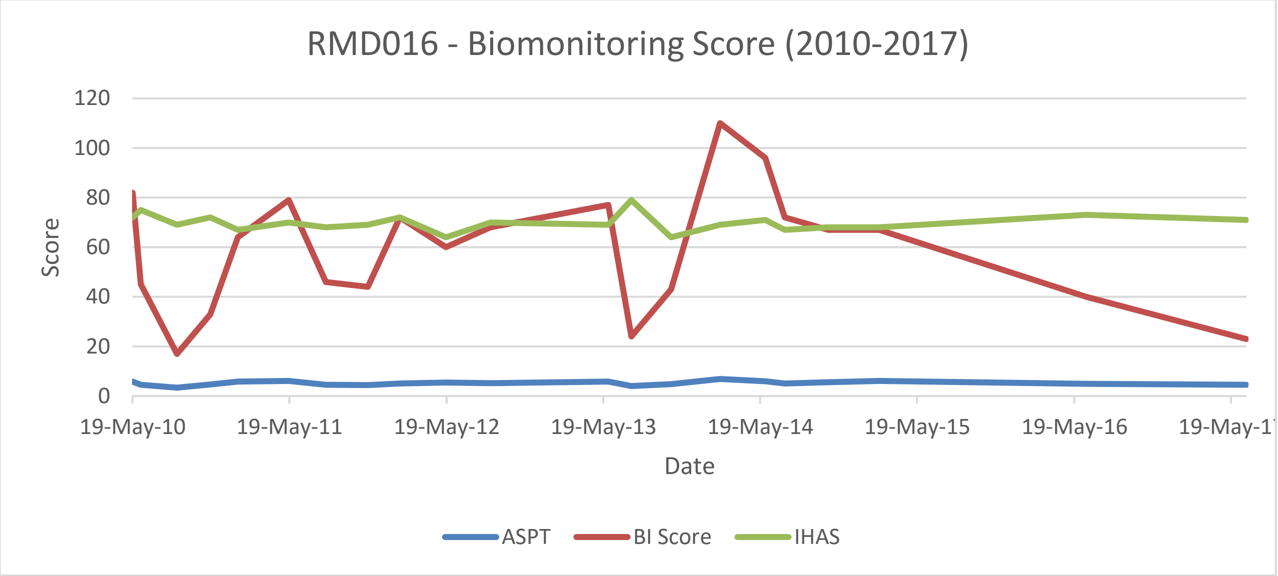

Figure 60: **Scores for ASPT, BI and IHAS for 2010-2017 at RMD016.**

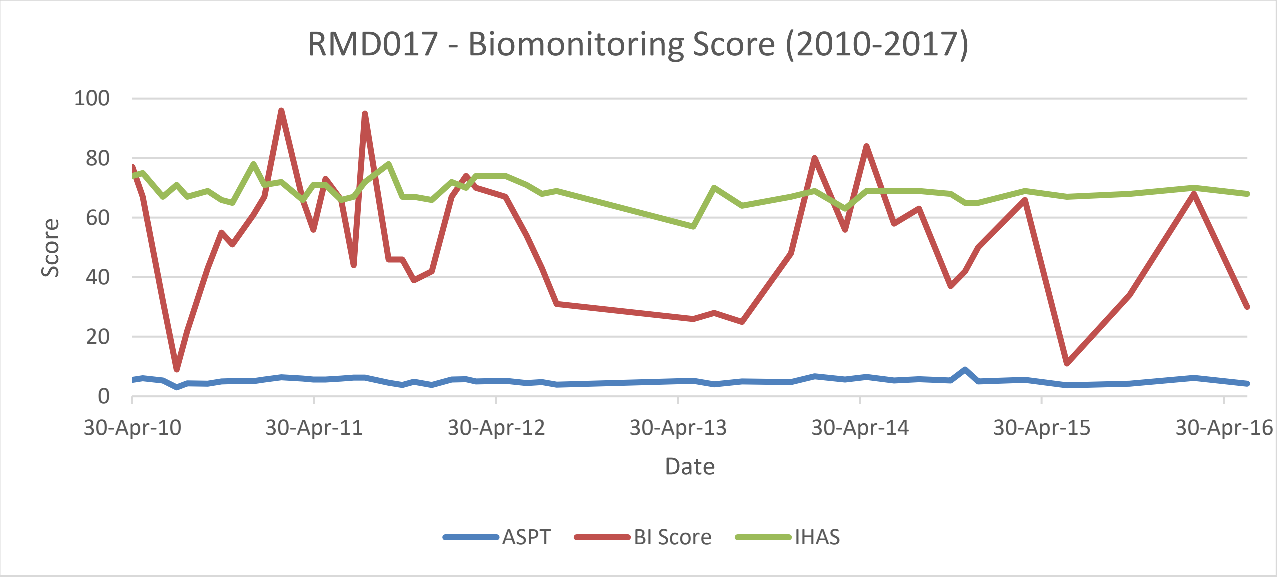

Figure 61: Score for ASPT, BI and IHAS for 2010-2017 at RMD017.

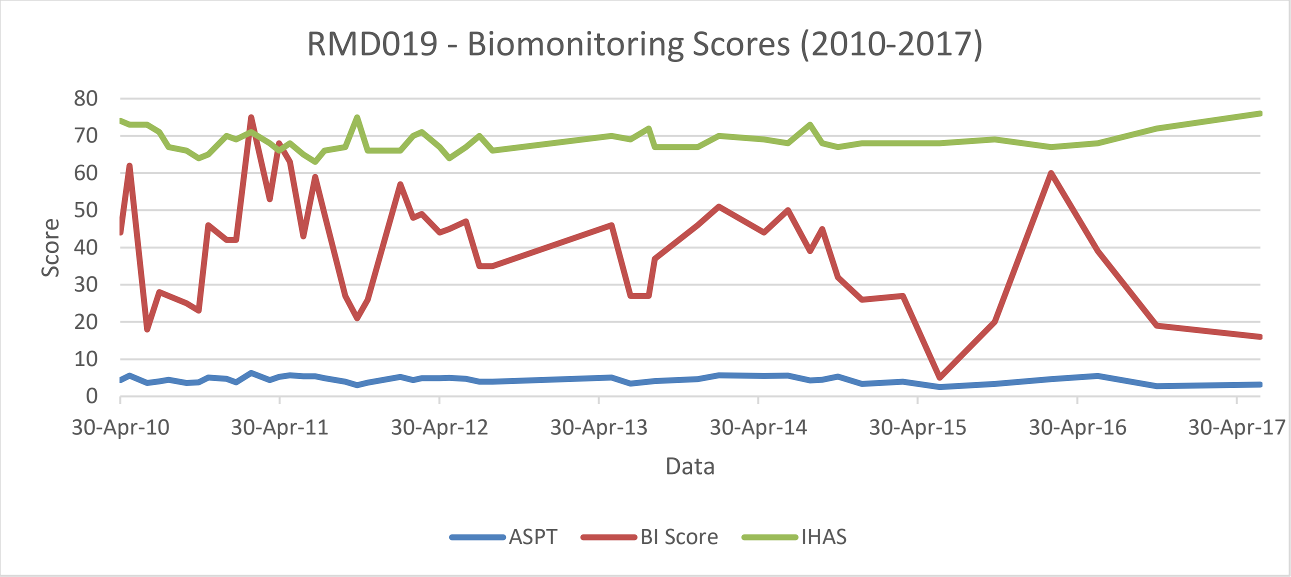

Figure 62: Scores for ASPT, BI and IHAS for 2010-2017 at RMD019.

5. CHAPTER 5: DISCUSSION

It is important to note that industries have increased in the study area over the years which may have been the reason for the poor water quality result in the upstream points of the Darvill WWTW. Most of the industries have been developed around the Baynespruit River which is a major tributary of the Msunduzi River. This has resulted in an increased pollution of the Baynespruit River and in turn some pollutants end up in the Msunduzi River thus affecting the water quality at the upstream points of the study area. As mentioned in the introduction there has been several incidences of pollution in the Msunduzi River, which have had significant contribution to the fish kills in the river (News24, 2010).

5.1. Water Quality

All the results were analysed with consideration that the samples are not conducted at the same frequency across sites. The RMD018 point is the least monitored site with a frequency of monthly monitoring, whilst WRD020 is monitored daily.

5.1.1. pH

According to Balachandran *et al*. (2012), the pH of natural waters ranges from 6 to 8.5 and values above 7 are considered alkaline and indicate the presence of CO_2 and more organic matter content. During 2010-2015 and 2016-2020, the pH level remained within the allowable range (5.5-9.5) as provided by the WUL, General Limits and TWQR across all sample sites upstream and downstream of the discharge point. One pH result of 2.5 was recorded downstream of the Darvill WWTW discharge point on the 7th March 2011. There is no available reason associated with this result as the results from other sites were within the limits during this day. However, in a similar study conducted by Dube (2020), a similar incident occurred where pH was recorded low at one of the sites downstream of the Darvill WWTW discharge points. In that study, it was stated that pH levels this low are usually an indication of artificial contamination due to discharge of industrial or wastewater effluents and are toxic to animals.

Apart from this one incident, pH ranged between 6.7 and 9 across all the sample sites during both the study periods. This, according to Mokgoebo (2019), is conducive to the survival of many macroinvertebrates. The pH results showed no significant difference when a comparison was done for upstream and downstream points of the discharge points. However, it was observed that the pH results lean towards alkaline values at the downstream point as there were more values of 8+, or even 9. With the final effluent also showing compliance when evaluated against the standards mentioned earlier, based on this study there does not appear to be a severe effect of the discharges on pH of Msunduzi River.

5.1.2. Suspended Solids

Suspended solids averaged at 53% compliance for upstream points in the 2010-2015 period when compared against both the WUL and the General limits of 25 mg/L. The majority of the analyses for the suspended solids were within the allocated limits in the 2010-2015 study period. However, in some cases the suspended solids were above 100 mg/L. The background SS concentration for all Aquatic Ecosystems must be <100 mg/L and TWQR of the SS concentration is limited to <10% of the background (DWA, 1996). Presuming that 25 mg/L is the background SS concentration in these sites, the results showed that 53% of the time the SS concentration was acceptable for the aquatic ecosystems of the Msunduzi River.

The highest recorded result in the 2010-2015 period was 794 mg/L at point RMD017, which was above the effluent discharge point and even upstream of the Darvill WWTW maturation plant. This indicates that the elevated suspended solids were not a result of effluent discharges or related to any activity associated with the operation of the Darvill WWTW, but could be related to other activities occurring upstream of the this WWTW. The fact is also proven by the concentration of the suspended solids at WDV020, which is the point measuring the final effluent itself. The suspended solids showed elevated compliance of 73% at point WDV020 in the 2010-2015 period. The highest result of suspended solids at this point was 556 mg/L, recorded on the 8th December 2015. This result was not related to the highest results of 794 mg/L recorded at RMD017. Compliance of suspended solids appeared to increase downstream in the river. RMD018 and RMD019 compliances were 62% and 64% respectively.

In comparison to the 2016-2020 period, compliance levels increased on the upstream points as they showed an average of 60% compliance against the WUL and General limits. However, the maximum SS concentration could reach up to 1926 mg/L in some cases. The highest recorded result was, again, at RMD017. The final effluent also showed a decline in compliance levels (46%) in the 2016-2020 period. Six hundred and forty-five (645) out of 1204 analyses were above the set limits. This indicates that during this period Darvill WWTW was discharging effluent that had an influence on the water quality of the Msunduzi River. Whilst that is the case, RMD019 indicated an improvement in compliance with 92 out of the 256 analyses not complying with the set limits. Because the frequency of monitoring at these sites is not the same, there is little confidence that the downstream water quality is not affected by the effluent discharges. However, according to (DWAF, 1996), as flow decreases the suspended solids settle out. This may be the case here because WDV020 sample is taken at a narrow point with fast flow and at the river where RMD019 sample was taken it was wider with decreased flows. This study did not focus on the flow levels and river banks or flood measurements.

5.1.3. Electrical Conductivity

In the 2010-2015 study period, the EC was within the limits for all the upstream points combined. Compliance with both the WUL and General Limits was 100%. The highest result of 59.80 mS/m was recorded in point RMD017 which is a point downstream of the Baynespruit River. This indicates that contamination at this point was due to the water from the Baynespruit River, which is a tributary of the Msunduzi River. The EC at the final effluent discharge point (WDV020) was always above the General Limit in the 2010-2015 study period. Five hundred and seventy-four (574) out of 1432 analyses did not comply with the WUL limits.. These results indicated a level of salts/solids still dissolved in the effluent that finally leaves the Darvill WWTW. While WDV020 showed elevated levels of EC in the final effluent, the water downstream (RMD019) of the discharge point showed decrease levels of EC. Only two out of 363 analyses did not comply with WUL and one of which also did not comply with the General Limits. Both the non-compliances recorded at RMD019 do not coincide with the concentrations from the final effluent because they occurred on days when EC was lower at WDV020. However, because all the upstream points showed 100% compliance to the standard, the non-compliances at WDV020 and RMD019 indicate some level of influence on the Msunduzi River water quality by the effluent from Darvill WWTW.

In comparison to the 2016 - 2020 study period, EC showed 100% compliance for all the upstream points. However, the results showed elevated concentration of EC in all the upstream points. This indicates changes in activities affecting the quality of the water in the

Msunduzi River. The elevated concentration of EC is also showing in the final effluent. However, the compliance improved at this point in the 2016 - 2020 period from 60% to 74%. This indicates an improvement in the effluent quality released by the Darvill WWTW. However, there is a concern with regards to the elevated concentration of EC as it indicates that even though the compliance is met the water quality is still affected and the salinity of the water is increasing. This then means the plants treat the wastewater to meet the standard but not to ensure water quality that is suitable for the receiving environment.

5.1.4. Chemical Oxygen Demand (COD)

Higher levels of COD indicate that there is a higher matter that is oxidisable in the water. The composition of communities and the distribution of numerous organisms in freshwater is largely influenced by the availability of oxygen (Connolly *et al.,* 2004).

All upstream points complied with the WUL and the TWQR limits of 75 mg/L in the 2010 - 2015 period. The results from the upstream sites combined indicates levels of moderately contaminated water in the Msunduzi River upstream of the Darvill WWTW. The highest COD result of 277mg/L was recorded at RMD017. Even though this was a single non-compliance occurrence, there were more elevated results at this point compared to the other upstream points. This indicates that the water from Baynespruit River is contaminated. The COD concentrations at the WDV020 86.6% compliant. At RMD019 the COD concentration ranged was98.8% compliant. This indicates that the final effluent has influence on the water quality of the Msunduzi River taking into consideration that WDV020 is monitored at higher frequency compared to the RMD019.

5.1.5. Ammonia

The Target Water Quality Range (TWQR) for ammonia is 7 mg/L (DWAF, 1996). In 2010-2015 ammonia concentration ranged from 0.04 to 11 mg/L with regards to all the upstream points combined. The RMD015 point, which is the most upstream point showed 100% compliance with the WUL, General Limits and TWQR. In WDV020 ammonia was 43% compliant. This indicates high concentration of ammonia contaminated effluent leaving the Darvill WWTW and discharged at the Msunduzi River. However, the downstream of the discharge point indicated decreased concentration of ammonia at 90% compliance. Whilst this showed improved water quality compared to the final effluent, RMD019 indicates elevated concentrations of ammonia after the effluent discharge. A total of 750 out of 1432 analyses were above the TWQR. The US EPA recommends an acute ammonia criterion of 2.9 or 5.0 mg N/L (for short-term exposure) and a chronic criterion of 0.26 or 1.8 mg N/L (for long-term exposure). Water with concentrations of less than 0.020 mg/L unionized ammonia is considered safe for fish reproduction (EPA, 1989).

In 2016 - 2020 ammonia concentration showed the same behaviour as with the 2010 - 2015 for all the sample points. However, as with the other parameters concentration levels per analyses increased. Minimum results increased to 0.1 mg/L from 0.04 mg/L in the 2010 - 2015 period. This indicates deteriorating water quality in the Msunduzi River not only due to the Darvill WWTW effluent discharges but also due to other pollution sources in the study area.

5.1.6. Nitrates

According to Nordic & Pommel (2009), in order to protect freshwater aquatic life, the average concentration of nitrate is 3.0 mg/L and the maximum concentration is 32 mg/L. In South Africa, pristine and aerobic surface waters are usually below 0.5 mg/L but may increase to above 5 - 10 mg/L in highly enriched waters (DWAF, 1996). Based on the averages the water quality of the Msunduzi River is deteriorating even at the sites upstream of the Darvill WWTW effluent discharge, concentration of nitrate shows a level of increase. The final effluent has higher concentrations of nitrates with an average above 9 mg/L on both study periods. However, there is a decrease of nitrates concentration at the point downstream of the effluent discharge point. This indicates that most nitrates in this study area is contributed by the Darvill WWTW effluent discharges. It also indicates that the Darvill WWTW releases effluent of poor quality in terms of nitrate limit when checked against the WUL and General Limits. According to the (DWAF, 1996), nitrate concentration between 0.5 - 2.5 mg/L average in summer have mesotrophic conditions associated with algal blooms, effect on organisms' productive systems and species diversity. Average concentration 2.5 – 10 mg/L results in eutrophic conditions associated with low species diversity.

5.1.7. Orthophosphate (SRP)

In the study period 2010-2015, SRP showed 100% compliance on most of the upstream points except on RMD017 which is downstream of the Baynespruit River. The compliance at RMD017 was 99.7% with only one analysis above the WUL limit. All upstream points were non-compliant with the General Limits for all analyses. In the WDV020, the final effluent was 93% compliant with the WUL limits and only 23% compliant with the General Limits of 0.01 µg/L. The lowest and highest SRP concentration recorded for the upstream points, in the 2010-2015 study period, were 3 µg/L and 1200 µg/L. The SRP concentration at RMD019 downstream of the discharge indicates an elevated concentration of SRP in the Msunduzi River after the effluent discharges, therefore it can be concluded that even at lower levels, the final effluent has a negative influence on the water quality of the Msunduzi River.

The above trend was also seen during the 2016-2020 study period. All upstream points were 100% compliant with the WUL, however, were non-compliant with the General limits. The lowest recorded concentration increase to 15.40 µg/L and the highest also decreased to 770 µg/L. This indicates a deteriorating state of water quality of the Msunduzi River which could be associated with other activities occurring upstream of the Darvill WWTW. Whilst there is evidently an elevation of SRP concentration in this study area before the discharge point, Darvill WWTW showed a deterioration in the quality of the effluent being released from the plant. This is because in the study period 2016-2020 the final effluent SRP concentration ranged between 100-19368 µg/L. This indicates that the effluent from Darvill WWTW further contributes to the deterioration state of the Msunduzi River water quality.

5.1.9. E. coli

The *E. coli* is frequently used as a faecal indicator bacterium (FIB) for assessing water quality (Jang *et.al*., 2017). The *E. coli* concentration are evidence throughout the study area, indicating that the river is contaminated by human and animal faeces. All upstream points were non-compliant with the WUL and General limits for both 2010-2015 and 2016-2020 study period. Upstream points combined had an average of 96.5% non-compliance for the 2010-2015 study period. In the 2016-2020 period the upstream points combined had an average non-compliance of 95.5%. This indicates that Msunduzi River is significantly contaminated before it makes contact with the Darvill WWTW effluent. The quality of the effluent from Darvill WWTW was 66% compliance in the 2010-2015 period and 71% compliant in the 2016-2020 study period. This indicated an improvement in the removal of bacteria by wastewater by the Darvill WWTW process.

5.2. Biomonitoring

5.2.1. Integrated Habitat Assessment Score (IHAS) and Average Score Per Taxon (ASPT)

The biological assessment data obtained from Umgeni Water indicates the presence of aquatic life in the Msunduzi River in moderate conditions. All the upstream points show ASPT of just above the score of 5. According to the interpretation in **Table 51**, the ecosystems of the Msunduzi River in these areas are good and with a few modifications. The score improved at the downstream point to 6.44 meaning an unmodified part of the river.

The same behaviour of the scores is seen with the BI and the IHAS in **Table 52**, where the downstream point shows a significant improvement when compared to the upstream points. For the BI, the highest score of 62.98 was experienced at RMD015. The downstream (RMD019) improved with 115.54 score.

The downstream point had higher scores in all three indices when compared to the upstream points. These results indicate that all upstream points are in a more impacted location when compared to the downstream point. This also indicates that the quality of the effluent from the Darvill WWTW has little impact on the aquatic ecosystem of the Msunduzi River. This is because the results show improvement downstream of the discharge point. However, the realized increases in the studied parameters presence or load put the aquatic ecosystems in the Msunduzi River under threat.

6. CHAPTER 6: CONCLUSION

The aim of the study was to investigate if the effluent from the Darvill WWTW has any impact on the aquatic ecosystem of the Msunduzi River. The outcomes of the investigation were realized by the objectives, which included the assessment of the quality of the final effluent coming out of the Darvill WWTW and looking at the changes in aquatic life of the Msunduzi River by considering the changes in biomonitoring results of the study area. The study compared the concentration levels of the water quality parameters to the WUL, General limits and where available the TWQR. Furthermore, comparison of the water quality was done between the upstream points and the downstream point of the Darvill WWTW effluent discharge points. This was done to identify any changes in the water quality at the downstream point as to indicate the influence made by the Darvill WWTW effluent discharge to the water quality of the Msunduzi River. The study compared two consecutive 5-year periods, including 2010-2015 and 2016-2020, to realise whether there is a change in the quality of the effluent, and subsequent the water quality in the Msunduzi River, over the years.

Msunduzi River is a polluted river. The sources of pollution include, residential areas, industries and the presence of livestock which roam the area. This was made evidence by the concentration levels of all the water quality parameters in the upstream points. Whilst most of the parameters were in compliant with the WUL, General Limits and TWQR set for surface water the concentration of these in the water of the Msunduzi River suggests input from several sources being the main cause of their presence in the water and suggests an urban river that is currently modified but deteriorating. The deterioration of the water quality is evident through the comparison of the two time periods, 2010-2015 and 2016-2020. Whilst the parameters still showed compliance of the water quality with the standards, a close look at the data reveals that the concentration level keep increasing in the water. This means the quality of water in the Msunduzi River will in a long term, if not improved now, it will not be conducive to support the aquatic life of the Msunduzi River.

The pH levels across all the sample sites during both the study periods, which based on the previous studies mentioned earlier, is conducive to support the aquatic ecosystem of the Msunduzi River in the study area. The pH result showed no difference when comparison was done for upstream and downstream points of the effluent discharge points. The final effluent also showed compliance when evaluated against the standards mentioned earlier. Based on the findings of this study the discharges from Darvill WWTW did not have much influence on the pH of the Msunduzi River. However, the gruadual increase of the pH level suggests a water that is becoming alkaline. Since all the upstream points showed EC being 100% compliant to the standards, the non-compliances at WDV020 and RMD019 indicate some level of influence of the Msunduzi River water quality by the effluent from Darvill WWTW. The final effluent was non-compliance with the nutrients (NH_3, NO_3 and SRP) when compared to the points upstream of the discharged points. This leads to conclusion that the effluent discharges contribute largely to the nutrients in the Msunduzi River, the effect of which can be realized in the feeding Inanda Dam. The contribution of the effluent discharges to the deteriorating water quality of the Msunduzi River is also realised through the non-compliance of the Darvill WWTW final effluent with regards to the *E. coli* concentration.

The biomonitoring scores at the upstream points suggest that the Msunduzi River is moderately modified in the study area. All the indices showed improved conditions of the river aquatic life at the downstream point (RMD019), when compared to the upstream points. The lower scores at the upstream points suggest the effect of anthropogenic activities to the Msunduzi River. The modification of the Msunduzi River is observed at the points before the effluent from the Darvill WWTW is released. The improved conditions are also evidence after the discharge point. This suggests that the Darvill WWTW effluent has minor influence on the aquatic ecosystem of the Msunduzi River.

Recommendations

The parameters concentrations continue to increase over the years at all study sites, including the upstream points. The following are the recommendations for improving the water quality of the Msunduzi River in the study area as well as downstream:

- Interventions by DWS and other stakeholders in the study area to improve water quality and prevent further deterioration of the river. This necessitates the development and implementation of the Resource Quality Objectives. Further licencing should be done based on these RQOs.
- Studies need to be conducted to investigate the causes/sources of contaminants at the upstream points of the, especially at the Baynespruit River which feeds the

Msunduzi River. The studies should assist in establishing the best suitable pollution control measures, mitigation measures, and river rehabilitation methods to be implemented in order to improve the water quality of Msunduzi River in these areas.

- The poor quality effluent necessitates the completion of the Darvill WWTW and should encourage the Umgeni Water to look for and implement innovative ways that improve the quality of the final effluent.
- Further studies need to be conducted on the exact concentration of water quality parameters that are conducive for the aquatic ecosystem. These studies should be conducted in order to inform decision makers on what discharge limits should be set for discharging to the environment.
- The studies to be conducted should also investigate the reasons for the studies parameters increase in concentration over the years
- Biomonitoring should be conducted more frequently, and compliance should be enforced with regards to the WULs to ensure that the water user complies with the limits and that data is used for re-evaluation where necessary.

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6. APPENDIX 1: BIOMONITORING RESULTS

Sample Point Description	Date	ASPT	BI Score	IHAS
RMD015 - Msunduzi upstream of Darvill WWW	30-Apr-10	Cancelled	Cancelled	Cancelled
	21-May-10	**6.3**	**76**	**74**
	07-Jun-10	**6.8**	**68**	**71**
	30-Jun-10	**6.6**	**66**	**70**
	28-Jul-10	**6.6**	**66**	**72**
	18-Aug-10	**6.1**	**73**	**74**
	28-Sep-10	**6.3**	**82**	**73**
	26-Oct-10	**4.9**	**69**	**72**
	17-Nov-10	**5.8**	**58**	**70**
	29-Dec-10	**6**	**66**	**74**
	20-Jan-11	**5.6**	**73**	**73**
	23-Feb-11	**6.2**	**68**	**73**
	28-Apr-11	**5.8**	**64**	**70**
	23-May-11	**5.9**	**71**	**72**
	23-Jun-11	**5.3**	**58**	**70**
	20-Jul-11	**6.9**	**55**	**68**
	11-Aug-11	**6**	**54**	**67**
	27-Sep-11	**5.4**	**43**	**68**
	24-Oct-11	**4.6**	**51**	**71**
	21-Dec-11	**3.8**	**42**	**66**
	31-Jan-12	**5.5**	**61**	**67**
	29-Feb-12	**6.6**	**93**	**75**
	20-Mar-12	**6.1**	**79**	**76**
	30-Apr-12	**5.8**	**76**	**72**
	22-May-12	**5.9**	**76**	**71**
	29-Jun-12	**4.7**	**52**	**67**
	30-Jul-12	**6.1**	**49**	**70**
	29-Aug-12	**5.7**	**68**	**70**
	31-May-13	**5.2**	**52**	**68**
	15-Jul-13	**4**	**40**	**74**

	10-Sep-13	**4.4**	**44**	**64**
	29-Jan-14	**7**	**91**	**69**
	31-Mar-14	**5.9**	**47**	**67**
	13-May-14	**6.4**	**70**	**70**
	07-Jul-14	**5.8**	**58**	**70**
	27-Aug-14	**5.7**	**86**	**69**
	27-Nov-14	**6**	**42**	**71**
	23-Dec-14	**7.8**	**47**	**69**
	27-Mar-15	**6.1**	**67**	**68**
	15-Jun-16	**6.6**	**73**	**71**
	23-Jun-17	**5.6**	**45**	**61**
Average Score		**5.85**	**62.98**	**70.18**
RMD016 - Msunduzi upstream of Baynespruit	19-May-10	**5.9**	**82**	**72**
	07-Jun-10	**4.5**	**45**	**75**
	30-Aug-10	**3.4**	**17**	**69**
	16-Nov-10	**4.7**	**33**	**72**
	19-Jan-11	**5.8**	**64**	**67**
	17-May-11	**6.1**	**79**	**70**
	12-Aug-11	**4.6**	**46**	**68**
	17-Nov-11	**4.4**	**44**	**69**
	31-Jan-12	**5.1**	**72**	**72**
	17-May-12	**5.5**	**60**	**64**
	29-Aug-12	**5.2**	**68**	**70**
	30-May-13	**5.9**	**77**	**69**
	23-Jul-13	**4**	**24**	**79**
	23-Oct-13	**4.8**	**43**	**64**
	14-Feb-14	**6.9**	**110**	**69**
	30-May-14	**6**	**96**	**71**
	15-Jul-14	**5.1**	**72**	**67**
	24-Oct-14	**5.6**	**67**	**68**
	20-Feb-15	**6.1**	**67**	**68**
	15-Jun-16	**5**	**40**	**73**

	23-Jun-17	**4.6**	**23**	**71**
Average Score		**5.20**	**58.52**	**69.86**
RMD017 - Msunduzi upstream of Darvill Maturation river	30-Apr-10	**5.5**	**77**	**74**
	21-May-10	**6.1**	**67**	**75**
	30-Jun-10	**5.3**	**32**	**67**
	28-Jul-10	**3**	**9**	**71**
	18-Aug-10	**4.4**	**22**	**67**
	28-Sep-10	**4.3**	**43**	**69**
	26-Oct-10	**5**	**55**	**66**
	17-Nov-10	**5.1**	**51**	**65**
	29-Dec-10	**5.1**	**61**	**78**
	20-Jan-11	**5.6**	**67**	**71**
	23-Feb-11	**6.4**	**96**	**72**
	07-Apr-11	**6**	**66**	**66**
	28-Apr-11	**5.6**	**56**	**71**
	23-May-11	**5.6**	**73**	**71**
	23-Jun-11	**6**	**66**	**66**
	18-Jul-11	**6.3**	**44**	**67**
	10-Aug-11	**6.3**	**95**	**72**
	26-Sep-11	**4.6**	**46**	**78**
	24-Oct-11	**3.8**	**46**	**67**
	16-Nov-11	**4.9**	**39**	**67**
	22-Dec-11	**3.8**	**42**	**66**
	31-Jan-12	**5.6**	**67**	**72**
	29-Feb-12	**5.7**	**74**	**70**
	20-Mar-12	**5**	**70**	**74**
	18-May-12	**5.2**	**67**	**74**
	29-Jun-12	**4.5**	**54**	**71**
	30-Jul-12	**4.8**	**43**	**68**
	29-Aug-12	**3.9**	**31**	**69**
	30-May-13	**5.2**	**26**	**57**
	11-Jul-13	**4**	**28**	**70**

	05-Sep-13	**5**	**25**	**64**
	12-Dec-13	**4.8**	**48**	**67**
	29-Jan-14	**6.7**	**80**	**69**
	31-Mar-14	**5.6**	**56**	**63**
	13-May-14	**6.5**	**84**	**69**
	07-Jul-14	**5.3**	**58**	**69**
	26-Aug-14	**5.7**	**63**	**69**
	29-Oct-14	**5.3**	**37**	**68**
	27-Nov-14	**9**	**42**	**65**
	23-Dec-14	**5**	**50**	**65**
	27-Mar-15	**5.5**	**66**	**69**
	19-Jun-15	**3.7**	**11**	**67**
	23-Oct-15	**4.3**	**34**	**68**
	29-Feb-16	**6.2**	**68**	**70**
	15-Jun-16	**4.3**	**30**	**68**
Average Score		**5.23**	**52.56**	**68.91**
RMD019 - Msunduzi at Motorcross	30-Apr-10	**4.4**	**44**	**74**
	21-May-10	**5.6**	**62**	**73**
	30-Jun-10	**3.6**	**18**	**73**
	28-Jul-10	**4**	**28**	**71**
	18-Aug-10	**4.5**	**27**	**67**
	28-Sep-10	**3.6**	**25**	**66**
	26-Oct-10	**3.8**	**23**	**64**
	17-Nov-10	**5.1**	**46**	**65**
	29-Dec-10	**4.7**	**42**	**70**
	20-Jan-11	**3.8**	**42**	**69**
	23-Feb-11	**6.3**	**75**	**71**
	07-Apr-11	**4.4**	**53**	**68**
	28-Apr-11	**5.2**	**68**	**66**
	23-May-11	**5.7**	**63**	**68**
	23-Jun-11	**5.4**	**43**	**65**
	20-Jul-11	**5.4**	**59**	**63**

	10-Aug-11	**4.9**	**49**	**66**
	27-Sep-11	**3.9**	**27**	**67**
	24-Oct-11	**3**	**21**	**75**
	17-Nov-11	**3.7**	**26**	**66**
	31-Jan-12	**5.2**	**57**	**66**
	29-Feb-12	**4.4**	**48**	**70**
	20-Mar-12	**4.9**	**49**	**71**
	30-Apr-12	**4.9**	**44**	**67**
	22-May-12	**5**	**45**	**64**
	29-Jun-12	**4.7**	**47**	**67**
	30-Jul-12	**3.9**	**35**	**70**
	29-Aug-12	**3.9**	**35**	**66**
	29-May-13	**5.1**	**46**	**70**
	11-Jul-13	**3.4**	**27**	**69**
	22-Aug-13	**3.9**	**27**	**72**
	05-Sep-13	**4.1**	**37**	**67**
	12-Dec-13	**4.6**	**46**	**67**
	29-Jan-14	**5.7**	**51**	**70**
	13-May-14	**5.5**	**44**	**69**
	07-Jul-14	**5.6**	**50**	**68**
	26-Aug-14	**4.3**	**39**	**73**
	23-Sep-14	**4.5**	**45**	**68**
	29-Oct-14	**5.3**	**32**	**67**
	23-Dec-14	**3.3**	**26**	**68**
	27-Mar-15	**3.9**	**27**	**68**
	19-Jun-15	**2.5**	**5**	**68**
	23-Oct-15	**3.3**	**20**	**69**
	29-Feb-16	**4.6**	**60**	**67**
	15-Jun-16	**5.5**	**39**	**68**
	28-Oct-16	**2.7**	**19**	**72**
	22-Jun-17	**3.2**	**16**	**76**
Average Score		**4.44**	**39.51**	**68.60**

RMD024 - Duzi at Eddy Hagan Dr	30-Mar-10	**6.3**	**126**	**74**
	20-May-10	**6.5**	**123**	**71**
	16-Aug-10	**7.1**	**106**	**64**
	19-Jan-11	**6.6**	**131**	**70**
	20-May-11	**6**	**138**	**72**
	01-Aug-11	**6.4**	**147**	**65**
	10-Jan-12	**7.6**	**99**	**74**
	17-May-12	**6.7**	**140**	**65**
	28-Aug-12	**6.2**	**105**	**76**
	30-Apr-13	**6.2**	**131**	**73**
	31-May-13	**6**	**127**	**71**
	20-Feb-14	**6.4**	**109**	**76**
	10-Apr-14	**6.5**	**117**	**74**
	09-May-14	**5.9**	**118**	**68**
	10-Jul-14	**7.1**	**106**	**67**
	07-Aug-14	**6.4**	**83**	**68**
	13-Oct-14	**6.3**	**138**	**65**
	12-Feb-15	**6.5**	**104**	**76**
	19-Jun-15	**6.1**	**79**	**67**
	23-Oct-15	**6.4**	**121**	**70**
	29-Feb-16	**6.6**	**92**	**72**
	15-Jun-16	**6.7**	**141**	**73**
	28-Oct-16	**6.1**	**177**	**75**
	22-Jun-17	**6**	**15**	**80**
Average Score		**6.44**	**115.54**	**71.08**