ANTHROPOCENTRIC IMPACTS ON THE ECOLOGY AND BIODIVERSITY OF THE NATALSPRUIT WATERCOURSE AND ITS ASSOCIATED WETLANDS

by

ELMARIE KRÜGER-FRANCK

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Supervisor: Prof. Tracey McKay

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ABSTRACT

Information regarding the ecological wellbeing of the Natalspruit and its adjoining wetlands is essential if the river is being managed using sound ecological management principles. Despite this, little is known about this river, with little documentation at the regional or municipal level. This study partially addresses this knowledge gap by evaluating the impacts of human activity on a section of the Natalspruit and its adjoining wetlands. It reports on pollution concentrations found at selected sample sites and compares the results to Rand Water data and the National Standards and Guidelines of South Africa for physicochemical parameters and contaminated soils. Water samples were collected at five chosen sample sites during May and July 2018. Soil samples were taken during July 2018. The study found that water at all five sample sites is not suitable for drinking, the health of livestock and recreational use due to the present and high Total Coliform levels (ranging from 450 CFU/100ml to 100 000 CFU/100ml), as well as Turbidity, Total Hardness, TDS, Mg, NO_2, SO_4, and BOD which also exceeded the guidelines. Only site SS1 (May) exceeded the $CaCO_3$ concentrations regarding livestock health. No guidelines were available for DO levels on the health of livestock. Cl levels in the Natalspruit was suitable for drinking. PO_4 concentration at all the sites were all within the guidelines of acceptable levels for aquatic ecosystems. In terms of heavy metals, Cr levels significantly exceeded the guidelines at all five sample sites with the exception of ecosystem health. This is of great concern due to the toxicity of Cr. Cu concentrations exceeded the guidelines for both all land-uses protective of water resources and ecosystem health, at SS1, SS2, SS3 and SS5. Ni concentrations exceeded the guidelines for all land-uses protective of the water resources at SS5. Pb and Zn concentrations exceeded the guidelines for the land-uses protective of the water resources at all the sites with the exception of SS4 for Pb and SS2 and SS4. SS1 and SS5 reported Zn concentrations higher than the guideline for the protection of ecosystem health. SASS 5, PES and EIS assessments indicated moderate to severe modifications of the river. Thus, mining, industrial activities, surface runoff from densely populated informal settlements and wastewater treatment plants have negatively impacted upon the river. Decades of environmental neglect and effluent discharge have degraded the ecosystem, thus necessitating rehabilitation. However, as the study was limited in both time and scope, so additional research should be undertaken.

Keywords: Environmental impacts, wetlands, fauna and flora, mining, industrial, informal settlements, environmental degradation, development, sustainable use, Natalspruit

DECLARATION

Name: Elmarie Krüger-Franck

Student number: 43891306

Anthropocentric Impacts on the Ecology and Biodiversity of the Natalspruit Watercourse and its Associated Wetlands

I declare that the above dissertation/thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

Signature	11 July 2019 **Date**

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ABBREVIATIONS, ACRONYMS AND SYMBOLS

AMD	Acid Mine Drainage
ANZMEC	Australian and New Zealand Minerals and Energy Council
As	Arsenic
ASPT	Average Score Per Taxon
BOD	Biochemical Oxygen Demand
Ca	Calcium
$CaCO_3$	Calcium Carbonate
Cd	Cadmium
CFU	Colony Forming Units
Cl	Chloride
Cr	Chromium
CSIR	Council for Scientific and Industrial Research
Cu	Copper
DDT	Dichlorodiphenyltrichloroethane
DEA	Department of Environmental Affairs
DEADP	Department of Environmental Affairs and Development Planning
°C	Degrees Celsius
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
DRDLR	Department of Rural Development and Land Reform
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EKW	East Kolkata Wetlands
EPA	Environmental Protection Agency
ERWAT	The East Rand Water Care Company
Fe_2O_3	Iron Oxide
$FeCr_2O_4$	Chromite
GPS	Global Positioning System
H_2SO_4	Sulphuric Acid
Hg	Mercury

IC	Ion Chromatography
ICP-OES	Inductively Coupled Plasma Atomic Emission Spectroscopy
K	Potassium
MF	Membrane Filters
Mg	Magnesium
mg/kg	Milligram per Kilogram
mg/L	Milligram per Litre
ml	Millilitre
mm	Millimetre
MWEU	Ministry of Water and Environment Uganda
N	Nitrogen
Na	Sodium
NEMA	National Environmental Management Act
Ni	Nickel
nm	Nanometre
NO_3	Nitrates
NO_2	Nitrites
NTU	Nephelometric Turbidity Unit
O_2	Oxygen
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
Pb	Lead
PES	Present Ecological State
PO_4	Orthophosphate
REMP	River Eco-status Monitoring Programme
SANAS	South African National Accreditation System
SANBI	South African National Biodiversity Institute
SASS 5	South African Scoring System Version 5
SAWS	South African National Weather Service
SIC	Stones in Current
SO_4	Sulphate

SOOC	Stones out of Current
TDS	Total Dissolved Solids
UN	United Nations
UNISA	University of South Africa
UOM	Unit of Measure
USA	United States of America
WMA	Water Management Area
WRC	Water Research Commission
WWAP	United Nations World Water Assessment Programme
Zn	Zinc
μL	Microliter

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Water resources in South Africa are used for a variety of undertakings including mining, agriculture, forestry, irrigation, industry, hydroelectricity and household use. The steady increase in the number of these activities has resulted in additional pressure exerted on the water sources and wetlands of South Africa. This pressure does not only pertain to increased water usage but also encompasses the salinization, pollution and eutrophication of South Africa's water sources. Although wetlands and river systems can tolerate some pollution from anthropocentric activities such as mining, agriculture and industrial practices, they will, over time, become degraded (Dudgeon, *et al.*, 2006). The watercourses of the East Rand are no exception to this phenomenon with various pollutants being visibly evident in the water bodies. Sustainable water use in South Africa is of significant importance to people, the economy and the environment. Most river systems and wetlands have already reached their threshold with regards the filtering of pollution (phytoremediation) but still, they continue to be inundated with Acid Mine Drainage (AMD), fertilizer runoff and inadequately treated water discharged from wastewater treatment plants, to name but a few (Arnold & Gibbons, 1996).

This study documents the overall ecological state of the Natalspruit and its associated wetlands (see Figure 1.1), focusing on the impact of anthropocentric activities. To date, and despite the area's ecological importance, limited work has been done to document the ecological state of the Natalspruit and its adjoining wetlands (Van Eeden & Schoonbee, 1996). This was evident due to the lack of physicochemical parameter data from Rand Water and the lack of criteria available from the National Guidelines pertaining to water quality. Knowledge of the ecological condition of the Natalspruit and its adjoining wetlands is essential to the informed formulation of effective ecological management action plans and principles at municipal level. Thus, this research work aimed to provide a detailed record of the ecological state of the area in addition to documenting the cumulative impacts of anthropogenic degradation. Additionally, the study will offer some recommendations as to the management and remediation of this important natural resource.

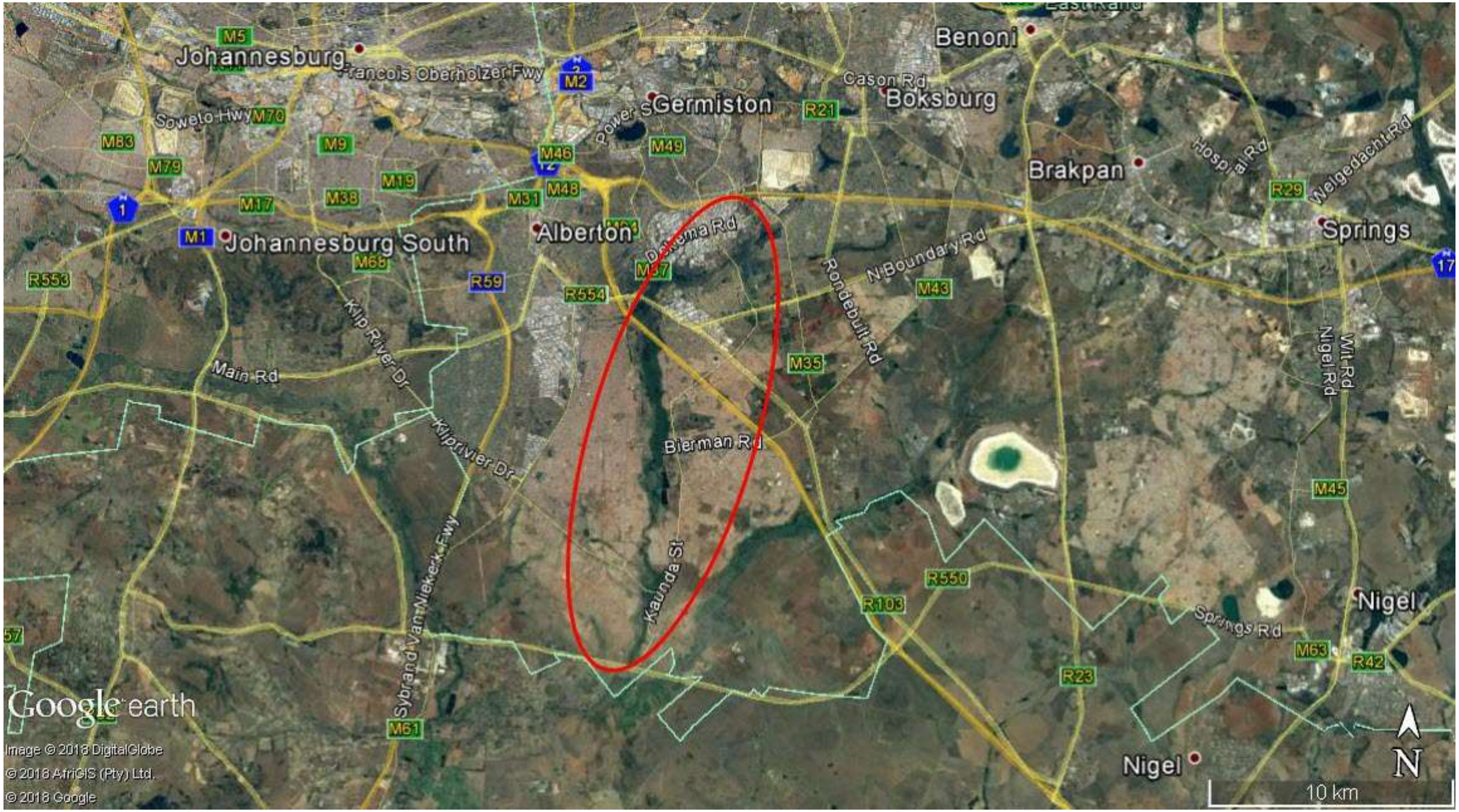


Figure 1.1: An aerial overview of the location of the Natalspruit and its associated wetlands (Source: Google Earth Pro, 2017).

1.2 Background of the Study

In recent times there has been increased recognition as to the importance of wetlands along with the acknowledgement that it is imperative that the ecology and biodiversity of these areas are conserved and well managed (Dudgeon, *et al.*, 2006; Strydom & King, 2009).

For instance, it is well documented that wetland areas act as natural sponges that filter contaminated water (phytoremediation), thus improving water quality and preserving aquatic ecology (Arnold & Gibbons, 1996). However, for a considerable period of time, the quality of rivers and wetlands in South Africa have been steadily declining mainly due to mining activities, industrial operations, wastewater treatment discharge and informal settlements (Durgapersad, 2005). Both mining and industrial activities produce large quantities of industrial runoff. Mine seepage from mine tailings and AMD contain multiple contaminants, including heavy metals. This is of concern as many wetlands and watercourses play host to endangered avifauna, flora and other living organisms (Arnold & Gibbons, 1996). Sadly, many wetlands and watercourses in South Africa do not enjoy sufficient environmental protection and continue to be degraded.

The maladministration and ruin of wetlands and watercourses in South Africa have, thus, resulted in the loss of aquatic animals and avifaunal species (DEADP, 2007). However, there are various projects and programmes in South Africa that aim to conserve the biodiversity and ecology of wetlands. In recent years projects, such as the River Eco-status Monitoring Programme (REMP)[1], have focused on monitoring the ecological conditions of river and wetland ecosystems to thus establish system change drivers and biological responses, both instream and riparian (DWS, 2016). A *system driver* refers to a natural, or any human action, which directly or indirectly results in change(s) in an ecosystem. Examples include *indirect drivers* such as population growth, science and technology as well as *economic* and *socio-political drivers* like decision-making. Direct drivers include the addition of synthetic fertilisers containing high volumes of nitrogen (N) that results in excessive nutrient loading of freshwater ecosystems (Nelson, 2006). The *biological responses* of species and organisms refer to their susceptibility and sensitivity to changes in an ecosystem and how these changes affect them – both positively and/or negatively (Peterson *et al*., 1993).

[1] Previously named the River Health Programme (RHP)

Recent studies on the degradation of freshwater systems in Gauteng include research undertaken at the Wonderfonteinspruit and the Klip River water systems. Both of these systems have been impacted by relentless residential development (formal and informal), industrial development, wastewater treatment discharge and mining activities (especially AMD) (Van Eeden, 2008; Durand, 2012). AMD is initiated by the discharge of water with an acidic pH, usually from mines which have been abandoned (Manahan, 2011). Geochemical processes are responsible for the formation of AMD where iron oxide (Fe_2O_3) in the gold ore is exposed to oxygen (O_2), or oxygenated water, to produce sulphuric acid (H_2SO_4) (Bartram & Ballance, 1996; Manahan, 2011). AMD has become especially significant in the past decade as it heavily affects water quality and aquatic health, not only locally, but also regionally and globally. AMD affects a community's livelihood and health as the only known organism to survive in such an acidic environment is extremophile bacteria (Krige, 2006). Harmony Gold (Krugersdorp) has taken steps to mitigate the impacts of AMD in the Wonderfonteinspruit by adding limestone to the river (Krige, 2006).

1.3 Problem Statement

Gold mining, industrial and agriculture activities, as well as informal settlements, have long affected the Natalspruit and its adjoining wetlands. Mining, once the backbone of the South African economy, has had significant negative impacts on the country's biophysical environment. Mine tailings, or mine dumps, are visible and often surrounded by relatively new property developments (Scott, 1995). A large percentage of the water present in the Natalspruit originates from effluent discharge, seepage and surface runoff originating from old mines, slime dams, ash heaps, chemical industrial plants and sewage treatment plants (Van Eeden & Schoonbee, 1996). Farming has also taken its toll. Located in close proximity to the banks of the Natalspruit, on the eastern side of the river, are agricultural activities that produce fertiliser runoff that, in turn, results in elevated NO_3 levels in the water. Diverted water from the Natalspruit is used to irrigate crops, for rural domestic activities and, to a lesser extent, provide water for livestock (Conrad, *et al.*, 1999). The Van Eeden and Schoonbee (1996) study documented the negative impacts of industrial activities and mining discharge on the Natalspruit and its avifauna species including the *Fulica cristaia* (Red-knobbed Coot), *Phalacrocorax africanus* (Reed Cormorant) and *Threskiornis aethiopicus* (African Sacred Ibis). Abnormally high levels of heavy metals, including cadmium (Cd), copper (Cu), nickel (Ni) and lead (Pb), were discovered in the liver, kidneys, skeletons and blood of these three bird species.

Since 1996, the Natalspruit and its associated wetlands have been subjected to a great deal of additional ecological pressure in the form of densely populated informal settlements and the activities of sewage treatment plants. Townhouse complexes and informal housing are often found within a few meters of the wetland and floodplain areas of the Natalspruit. These structures, and the people who reside in them, are vulnerable to possible flooding in the event of above-average rainfall (Durgapersad, 2005). Commercial inorganic fertilizers, which contain nitrates (NO_3), nitrites (NO_2), sulphates (SO_4) and orthophosphates (PO_4), cause eutrophication in the Natalspruit promoting dense algal growth. This is a further indication of how agricultural activities, which produce fertiliser run-off, if present in high concentrations, can negatively affect human, animal and aquatic life (Durgapersad, 2005). The 2005 study by Durgapersad that recorded a significant decline in the number of invertebrate species such as snails, river crabs, worms and insect larvae.

In addition, observations by the author of this study are that the two water treatment plants situated along the Natalspruit, and surrounding wetlands, produce poorly treated wastewater, which discharges into the river system. Illegal dumping of litter and rubble in open spaces on the fringes of the Natalspruit is prevalent, as is erosion with collapsing banks and the sediment transport observed in some areas. The deterioration of the Natalspruit has had serious negative impacts on the water quality of the Vaal River, as the Natalspruit is a tributary thereof (Durgapersad, 2005). The Natalspruit and its adjoining wetlands are heavily contaminated with no perceivable action are being taken or planned, to address this issue in the near future. Further noted by the author is the presence of alien invasive plants, such as: the Red river gum (*Eucalyptus camaldulensis*); Common Mulberry (*Morus alba*); Black Wattle (*Acacia mearnsii*); Indian Shot (*Cannas indica*); Castor Oil Plant (*Ricinus communis*); White-flowered Mexican Poppy (*Argemone ochroleuca*); Yellow-flowered Mexican Poppy (*Argemone mexicana*); Pompom Weed (*Campuloclinium macrocephalum*). All of these are present at various sites, more so in the northern section of the Natalspruit, and pose an immense threat to the environment, biodiversity and human health (Wilson, Panetta & Lindgren, 2017).

1.4 Aim and Objectives

This study sought to document mining, industrial and other human-related activities that impact on the ecological state and biodiversity of the Natalspruit and its adjoining wetlands.

The intention of the study was to:

a) Identify the biological significance of the Natalspruit and its adjoining wetlands through taxonomic classification and identification of the fauna, flora and other living organisms found in the system.
b) Document the impacts of the mining and industrial activities, as well as the adjacent human settlements, on the freshwater ecology of the Natalspruit and its adjoining wetlands.
c) Determine whether the fauna and riparian vegetation of the Natalspruit and its adjoining wetlands are under ecological pressure.
d) Provide recommendations for the remediation and mitigation of the Natalspruit and its adjoining wetlands.

1.5 Research Questions

1. What importance does the Natalspruit and its adjoining wetlands hold for the various fauna, flora and other living organisms present within it?
2. What are the impacts of mining activities, industrial actions and rural settlements on the freshwater ecology of the Natalspruit and adjoining wetlands?
3. Are the fauna and riparian vegetation of the Natalspruit and its adjoining wetlands under ecological pressure?
4. What recommendations could be made for the remediation and mitigation of the Natalspruit and its adjoining wetlands?

1.6 Research Design

This section presents the research design selected for this study. An in-depth case study design was adopted in order to address each of the research questions, aims and objectives of the study (Johansson, 2007; Yin, 2012). Case study methodology is widely used in environmental studies and involves the integration of knowledge and data from a variety of sources that is then used to inform certain decisions (Scholz & Tietje, 2002).

1.6.1 Methodology: An overview

The approach adopted in this study was predominantly that of *quantitative research*. This approach involved the collection of data on a set of defined variables, to provide evidence of the impacts of anthropocentric activities on the ecology and biodiversity of the Natalspruit and its associated wetlands (Gauri, 2005).

Water sampling, sediment sampling and macro-invertebrate sampling were done to determine the water quality of the Natalspruit. Water and sediment samples were collected and analysed by an accredited laboratory for physicochemical parameters. The macro-invertebrate collection and identification for the presence of different taxa were done using SASS 5 methodology to further assist in determining the *health* of the Natalspruit. Ecological Importance and Sensitivity (EIS) and Present Ecological State (PES) assessments were also conducted to assess the anthropocentric impacts on the watercourse and its associated wetlands.

1.7 Consistency Matrix

Research Question 1: *What importance does the Natalspruit and its adjoining wetlands hold for the various fauna, flora and other living organisms present within it?*

Data was collected through observations, field note taking and photographs. The fauna, flora and other living organisms present at the sample sites were recorded to determine the level of species diversity present. An EIS assessment and wetland classification was conducted together with fauna and flora taxonomic classification and identification that was done in order to determine the value and importance of the Natalspruit and its adjoining wetlands.

Research Question 2: *What are the impacts of mining activities, industrial actions and rural settlements on the freshwater ecology of the Natalspruit and adjoining wetlands?*

The determination of contaminant levels was achieved by the collection and analysis of water and soil samples which were collected for analysis by an accredited laboratory. Water samples were collected in High-Density Polyethylene containers and X Lab soil jars were used for the collection of the soil samples. Also, a SASS 5 (macro-invertebrate) assessment was conducted. A SASS 5 equipment kit, notebook, stationery and photographs were used to identify the diversity of macro-invertebrates present in the Natalspruit. Furthermore, the description and water sample analysis included the analysis of Microbiological Determinands, Physical and Aesthetic Determinands, Chemical Determinants (Macro-Determinants) (Dissolved

Elemental), Anions and Chemical Determinants (Micro-Determinants). Sediment samples analysis included the analysis of Chemical Determinants (Macro-Determinants) by means of Elemental Analysis by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES)/MS (X-Lab Earth Science, pers comm, 18/09/2017). The results were then compared to those collected by Rand Water and the accepted water quality standards of aquatic ecosystems. Ecoclassification was also employed to deduce the drivers and responses of the Natalspruit and its associated wetlands (Macfarlane *et al.*, 2008; Kleynhans, Louw & Graham, 2009).

Research Question 3: *Are the fauna and riparian vegetation of the Natalspruit and its adjoining wetlands under ecological pressure?*

A desktop survey was conducted which included Google Maps, aerial photographs, EIS and PES assessments and cartographic maps to further determine the extent of anthropogenic activities on the Natalspruit and adjoining wetlands. Evidence of alien vegetation was recorded and photographed which was introduced to the area and wetland descriptors. Description and sample analysis included observations and interpretation of the fauna and riparian vegetation of the Natalspruit and its adjoining wetlands.

Research Question 4: *What recommendations could be made for the remediation and mitigation of the Natalspruit and its adjoining wetlands?*

Contaminated water remediation and mitigation methods such as wetland restoration, community engagement, awareness creation, bank restoration as well as contaminated soil remediation methods such as dredging, excavation, and monitoring would largely be dependent on the level of contaminants present and which method is to be used (Alter, 2012). Remediation and mitigation measures serve to alter the conditions affecting the living organisms of the Natalspruit and adjoining wetlands. Water analysis comparison of sample test results to that of Rand Water's recent results and the Department of Water and Sanitation water quality guidelines together with the comparison with previous studies and its findings were done of the Natalspruit region to determine the most adequate remediation and mitigation methods applicable.

1.8 Chapter Layout

Chapter 1: The introductory chapter presents the introduction *to* and the background *of* the Natalspruit and its associated wetland area. The rationale behind the study is explained and the importance of an ecological and biodiversity impact assessment of the area is highlighted. The problem statement provides a concise description of the negative impacts on the Natalspruit and its surrounding wetland area.

Chapter 2: This chapter presents a detailed description of the study area. The boundaries and location of the area are defined and a detailed description of the background of both the study and area is provided.

Chapter 3: The literature review has presented this chapter. Current research and knowledge regarding the impacts of mining as well as industrial and human settlement activities on the aquatic and terrestrial ecology are presented along with an explanation as to the importance of wetlands. This chapter also explains the different methodologies used to contribute to ecological and biodiversity impact assessments internationally, regionally and locally.

Chapter 4: This chapter presents the research design and methodology in terms of the theoretical analysis of the approaches applied in the study of the Natalspruit. The chapter also elucidates the data collection methods. The data analysis and ensuing information are discussions towards conceptualising possible answers to the research questions and support for decision-making.

Chapter 5: This chapter delivers the outcomes of the water analysis, as analysed by a SANAS certified laboratory.

Chapter 6: This chapter presents the outcomes of the sediment (soil) analysis and testing.

Chapter 7: This chapter delivers the outcomes of the SASS 5 macro-invertebrate assessment, EIS and PES assessments.

Chapter 8: This chapter presents a discussion regarding the data analysis and the identification of impacts on the Natalspruit from mining, industrial and human settlement activities.

Chapter 9: The last chapter delivers recommendations and a conclusion as to possible ways in which to reduce the risk of the identified impacts such as AMD, informal settlement activities, sewage contamination and industrial runoff on the Natalspruit.

1.9 Conclusion

This chapter established the importance of South Africa's watercourses and wetlands and identified the environmental difficulties experienced by, and the negative anthropocentric impacts on the Natalspruit. Impacts from mining, industrial activities, informal settlements and agricultural practices are noted as the main contributors to the deterioration of the Natalspruit, its associated wetlands, and the living organisms associated with the study area. The description of the study area and the background of the Natalspruit in Chapter 2 will address the aims and objectives described in this chapter. Consequent chapters will assist in addressing these aims and objectives through data collection, data analysis, discussions and recommendations.

CHAPTER 2: DESCRIPTION OF THE STUDY AREA

2.1 Introduction

This chapter describes the location, topography, climate, geohydrology and socio-economic characteristics of the Natalspruit and its associated wetlands. The potential environmental impacts, which stem from human activities such as mining, industrial activities, informal settlements and urban development, are also discussed.

2.2 Location

The Natalspruit and its adjoining wetlands are situated in a heavily industrialised part of the East Rand, in eastern Gauteng. This densely settled area includes Southern Alberton, Katlehong and Vosloorus and is located in map quadrant 2628AC (as per Figure 2.1) of the 1:50 000 map series of South Africa. The Natalspruit is a substantial tributary of the Rietspruit which confluences with the Klip River at Vereeniging Road. As such, it forms part of the upper section of the Vaal Water Management Area.

The Natalspruit and its adjoining wetlands stretch roughly 26 km in length from its source, south of Boksburg, to its confluence with the Elsburgspruit, which lies at the junction of the N17 and M53 motorways. The Natalspruit extends to the south of Vosloorus where the Tsietsi Phase 5 informal settlement is located directly to it's the west and Magagula Heights to its east. Here the Natalspruit culminates and converges with the Rietspruit at the R550 bridge.

Figure 2.1: An adapted quadrant map of South Africa indicating the location of the Natalspruit and its associated wetlands in quadrant 2628, with respect to its latitude and longitude (Source: (Pieter, pers comm, 10/03/2018).

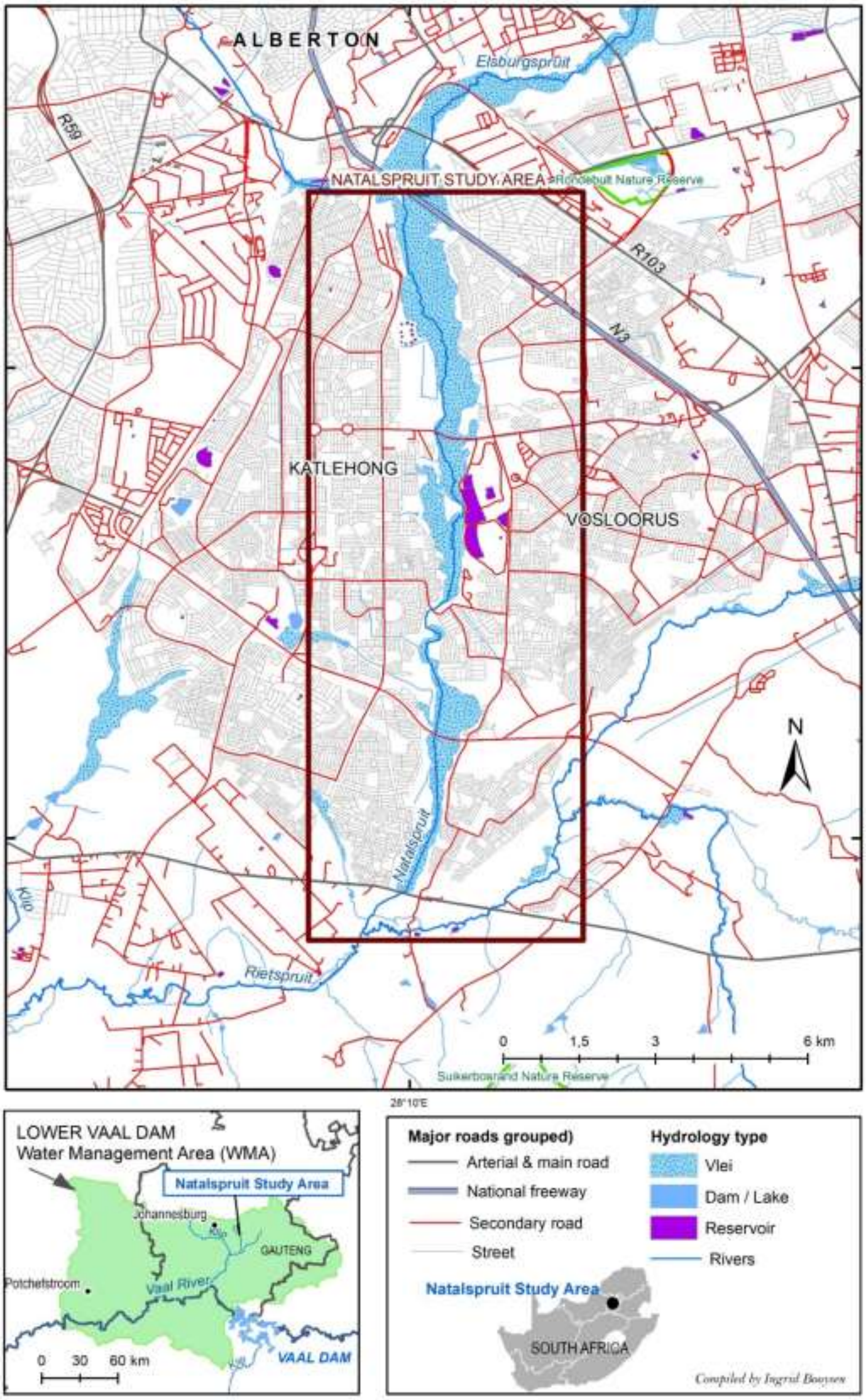


Figure 2.2: A topographical map of the Natalspruit and its associated wetlands showing its location within the Lower Vaal Dam Water Management Area (Source: DWA, 2012; DRDLR, 2017; DEA, 2018).

The catchment area of the Natalspruit encompasses areas on the East Rand such as Alberton, Boksburg and Germiston. The Natalspruit wetland region is bordered by the M2 motorway in the north, the N3 motorway to the east, the N12 motorway to the south and the M1 motorway to the west. The Natalspruit wetland is easily accessible from various roads which link the mentioned motorways. The study covers most of the 230 km^2 area between Elsburgspruit, in the north, and its convergence with the Rietspruit, in the south. Figure 2.2 indicates the major river systems of the Lower Vaal Dam Water Management Area (WMA) of which the Natalspruit is a tributary of the Rietspruit and the larger Vaal River (Booysen, pers comm, 16/06/2018).

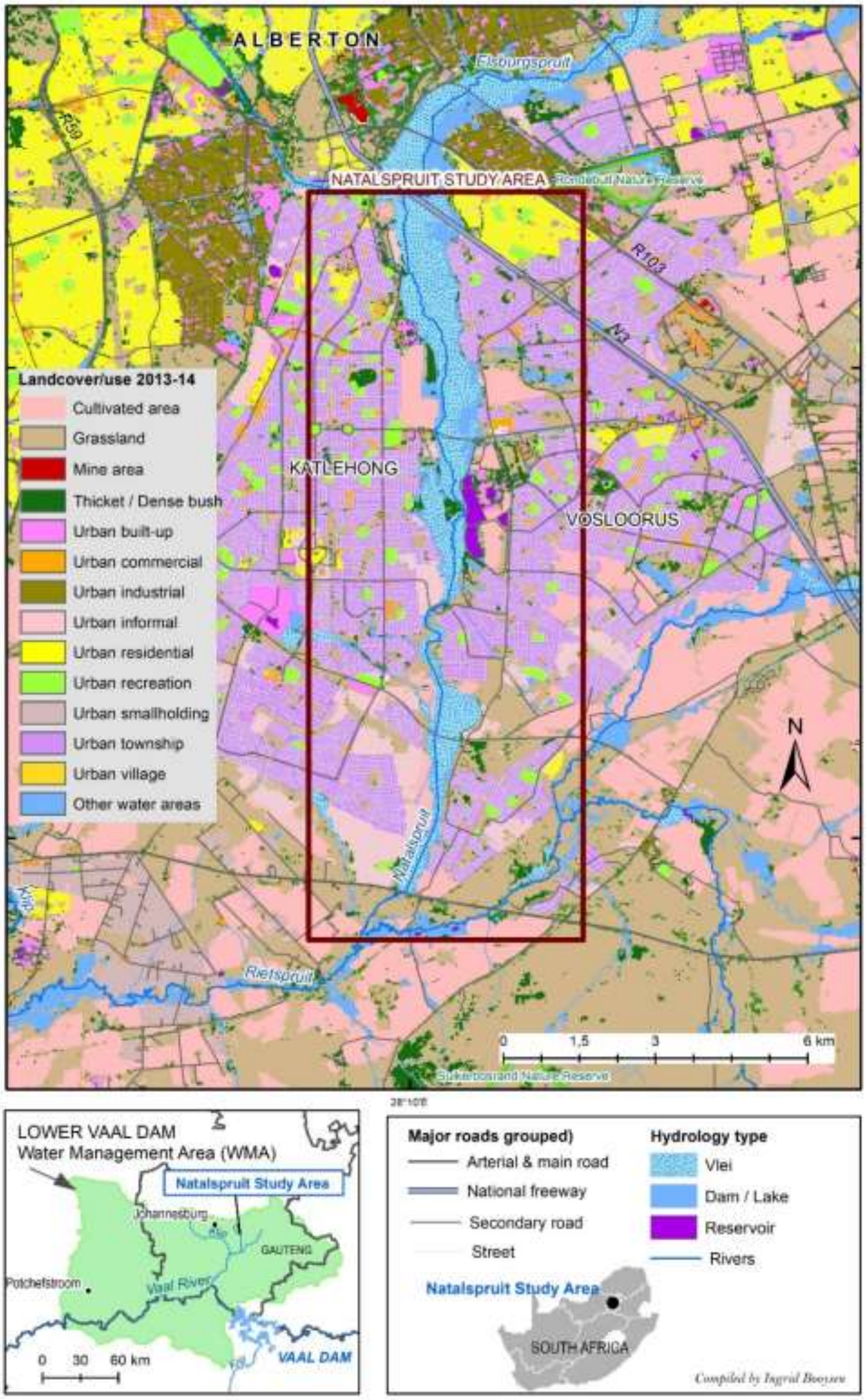


Figure 2.3: Land cover and land use in and around the study area of the Natalspruit and its associated wetlands (Source: DWA, 2012; DEA, 2018; DRDLR, 2017).

Agricultural activities south of the Elsburg mine tailings complex are visible between the M35 and the M53. Urban industrial activities along the eastern border of the Natalspruit and its adjoining wetlands include factories such as Beleric Recycling, Custom Moulders, Multiply Packaging, Reef Tankers and an old scrapyard in Bevan Road. Further south, urban residential areas, such as Spruitview, border the eastern area of the Natalspruit and its adjoining wetlands. Urban informal settlements, townships and smallholdings are located in the Vlakplaats area between the M53 and the Natalspruit and its adjoining wetlands. As seen in Figure 2.3, the large urban townships (category indicated in light purple) of Katlehong and Vosloorus and the urban informal settlements (category indicated in light pink) in the south surround the Natalspruit and its associated wetlands. To the north of the Natalspruit lies the urban residential area of Alberton (DWA, 2012; DEA, 2018; DRDLR, 2017).

The area has been impacted on by industrial and mining zones, such as Afrox in Wadeville. The Elsburg mine tailings complex is north of the N17 and east of the Natalspruit. The densely inhabited urban residential area of Katlehong is west of the Natalspruit and its associated wetlands. The suburbs of AP Khumalo, Ramakonopi East, Mosoleke East, Palime, Motsamai, Motloung, Tshwongeni and Tsietsie Phase 5, all form part of the eastern sections of Katlehong and border the Natalspruit and its adjoining wetlands. The western wetland border of the Natalspruit is dominated by informal settlements.

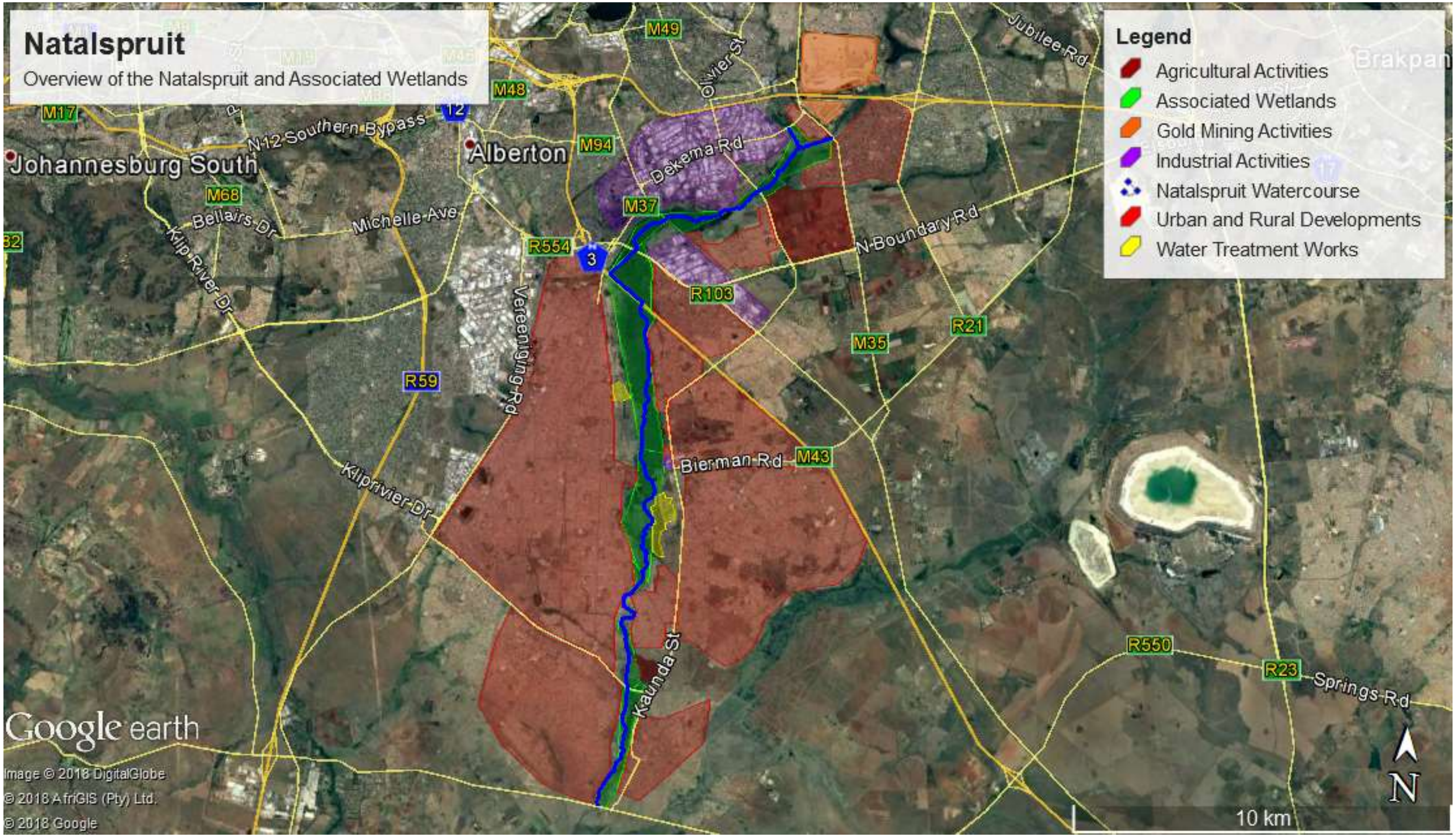


Figure 2.4: Anthropocentric activities located around the Natalspruit and its associated wetland areas (Source: Google Earth Pro, 2017).

The East Rand Water Care Company (ERWAT) wastewater treatment plant, which discharges treated sewage water into the Natalspruit, is south of Vlakplaats. Moleleki and Rietfontein, situated north of the R550, conclude the urban and rural settlements bordering the eastern section of the Natalspruit and adjoining wetlands. Large expanses of the surrounding Natalspruit wetland is occupied by old mine dumps, railway lines next to the watercourse in some sectors and large power line pylons (NTC Environmental Services, 2016). As Figure 2.4 indicates, mining activities, agricultural areas, water treatment works, urban and rural developments and industrial activities all affect the Natalspruit and its associated wetlands.

2.3 Geomorphology

The Natalspruit area has been shaped by a variety of geomorphological processes including climate, weather, organisms and leaching regimes such as neoformation, or the forming of clay particles (Hugget, 2007). Furthermore, the overall river morphology and fluvial geomorphology of the Natalspruit is best described as a channelled valley bottom river, which receives surface and sub-surface water input. The quality of the water is generally regarded as fair to poor (Ollis *et al*., 2015).

The Natalspruit and its associated wetlands are located 1603m above sea level. Topographically, the eastern half of the watercourse is visibly more elevated than the western half. Topographical features in the area include undulating plains with seasonal pans, canalised river areas and ridges (Environomics, 2007). Locally, the northern parts of the Natalspruit wetlands are characterised by bank erosion and sedimentation from eroded soils. This is due to increased water run-off from road infrastructure and industrial development. The artificial nature of these structures gives rise to an increased channelling of surface run-off (NTC Environmental Services, 2016).

2.4 Geohydrology and Pedology

The Natalspruit wetland area consists of dolomitic formations with elevated areas dominated by Black Reef geological formations and a pre-Transvaal sequence of geological formations in the Johannesburg, Booysens and Turffontein sub-groups. These form part of the Dwyka group and the Karoo super-group (Kafri & Foster, 1989; NTC Environmental, 2016). The eastern and western divide is characterised by dolerite formations in the east and chert formation in the west and is regarded as an area of high permeability (Kafri & Foster, 1989).

Figure 2.5: Hutton clay/loam soil representation of the Natalspruit (Source: Brits, 2018).

The site-specific geology of the Natalspruit wetland consists of mineral deposits such as gold-bearing quartzite, conglomerate, shale and lutaceous arenite (NTC Environmental, 2016). The soil profile throughout the study area is mostly uniform. The predominantly observed and identified soil types found in the Natalspruit and its associated wetlands are, according to their colour and consistency: loam/clay Hutton soils underlain by rock, yellow/brownish Avalon soils (mine tailings) and sandy Mispah types (Soil Classification Working Group & Macvicar, 1991).

Table 2.1: Indicating the soil types of the Natalspruit and its associated wetlands **(**Source: adapted from Soil Classification Working Group and Macvicar, 1991).

SOIL	TOPSOIL HORIZON	GENERAL DESCRIPTION
Avalon	Orthic	Yellow-brown Apedal B
Hutton	Orthic	Red Apedal B
Mispah	Orthic	Hardpan

2.5 Climate

The Natalspruit wetland experiences a temperate Highveld climate (see Figure 2.6), characterised by warm and rainy conditions in the midsummer to autumn months and cool but dry weather conditions during the colder winter months (Hoare, Van der Merwe & Claasen, 2008).

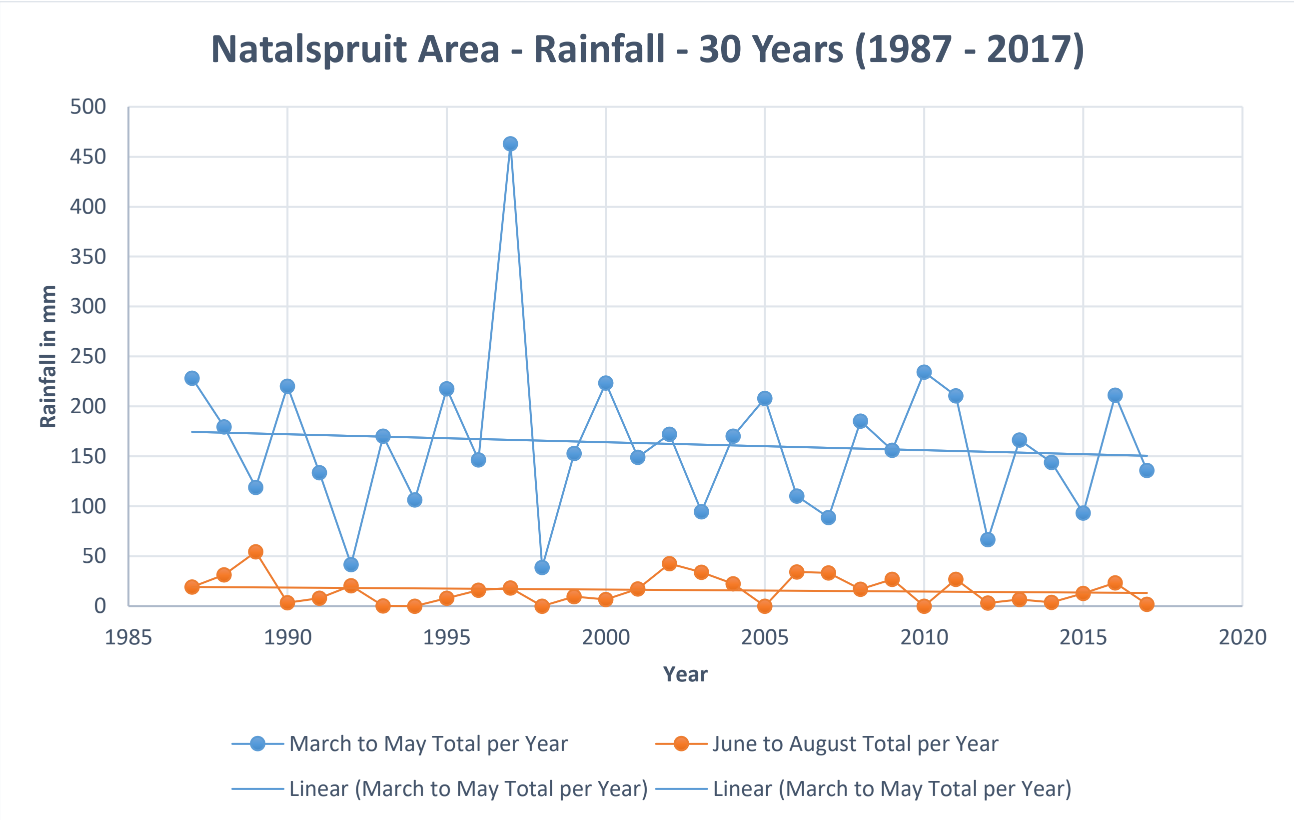


Figure 2.6: Rainfall data for the Natalspruit area for the period 1987 to 2017 (Source: data provided by SAWS, 2018).

According to Dlamini (pers comm, 05/05/2017), over a period of 30 years, the average rainfall in the Natalspruit area has been 744.30mm per annum, as measured by the South African National Weather Service. Also, the graph only presents rainfall data for the seasons under study and not the entire annual rainfall. The most precipitation occurs from October to March when thunderstorm activity is at its peak. Periodic hailstorms occur during this period, usually inflicting little to no damage in the area. However, in recent years, two damaging hailstorms have been recorded every five years (Hoare, Van der Merwe & Claasen, 2008). During the winter (May to September), severe frost and black frost spells have been known to occur. These drop in temperatures cause plant cells to freeze and swell which, in turn, results in the rupturing of cell walls and damage and/or death of vegetation (Pearce, 2001).

2.6 Biodiversity

The Natalspruit area boasts a diversity of avifauna, flora, vertebrate and invertebrates species. Unfortunately, mining and industrial activities, as well as, the building of road infrastructure have heavily disturbed most of the wetland biodiversity. The Natalspruit and its associated wetlands have also experienced extensive ecological and biodiversity degradation of its fauna and flora due to invasions of alien floral species. For example, the Natalspruit is now dominated by *Phragmites australis* (Common Reed) and *Typha capensis* (Cattail), which has curtailed the growth of indigenous riparian vegetation and floral species diversity. The tree species found in the area consist mainly of alien invasive species including *Acacia mearnsii* and *Eucalyptus camaldulensis*. Both of these invaders are notorious for their consumption of large quantities of water (NTC Environmental Services, 2016).

Available literature also confirms that the most common herb present in the Natalspruit wetland (riparian region) is that of *Datura forex* (Large Thorne Apple) (NTC Environmental Services, 2016). Importantly, patches of the poorly conserved endangered Soweto Highveld grassland, which consists of short-medium tufted grasses with species such as *Themeda triandra* (Red Grass), also occur in the region (Thomas, 2015). Thus, any grassland areas such as this can be viewed as being of *high conservation importance* (Hoare, Van der Merwe & Claasen, 2008).

Diversity of avi-faunal species was documented such as *Threskiornis aethiopicus*, *Egretta garzetta* (Little Egret) and numerous others. Available literature also indicates the degradation of the avi-faunal species with large amounts of heavy metals having been found in the organs of the avi-fauna frequenting the Natalspruit and its associated wetlands (NTC Environmental Services, 2016).

2.6.1 Fauna and Flora

A number of different exotic plant and tree species have been introduced by human activities to the Natalspruit wetland area as per Figure 2.7.

Figure 2.7: *Typha capensis* along the banks of the Natalspruit (Source: Brits, 2018).

The northern section of the Natalspruit vegetation consists of mainly of *Phragmites* australis, various grass species and a plethora of alien invasive plant and tree species such as *Eucalyptus camaldulensis*, *Morus alba*, *Acacia mearnsii*, *Ipomoea indica* (Morning Glory), *Cannas indica*, *Mirabilis jalapa* (Four-o'clock) and *Cirsium vulgare* (Spear Thistle).

Figure 2.8: *Cirsium vulgare*, an alien invasive plant located in some regions of the wetland area (Source: Brits, 2018).

Avi-faunal species found in this area are: *Bostrychia hagedash* (Hadeda Ibis), *Euplectes orix* (Southern Red Bishop), *Bubulcus ibis* (Western Cattle Egret), *Acridotheres tristis* (Indian Myna), *Vidua macroura* (Pin-tailed Whydah), *Euplectes progne* (Long-tailed Widowbird), *Passer domesticus* (House Sparrow), *Ploceus velatus* (Southern Masked Weaver), *Passer melanurus* (Cape Sparrow), *Vanellus armatus* (Blacksmith Lapwing), *Urocolius indicus* (Red-faced Mousebird), *Streptopelia semitorquata* (Red-eyed Dove), *Streptopelia capicola* (Cape Turtle Dove) and *Spilopelia senegalensis* (Laughing Dove).

Figure 2.9: The section of the Natalspruit with grass and reed embankments (Source: Brits, 2018).

In the areas located in the northern parts between the urban and informal settlements of Katlehong and Vosloorus, the fauna and flora consist mainly of *Pennisetum clandestinum* (Kikuyu) grass and *Phragmites australis*. Avi-faunal species such as *Euplectes orix*, *Anas capensis* (Cape Teal) and *Plegadis falcinellus* (Glossy Ibis) are present.

Figure 2.10: Grassland/floodplain area hosting numerous birds with *Phragmites australis* and *Arundo donax* (Giant Reed) present in the background (Source: Brits, 2018).

Located in close proximity to the water treatment works, in a floodplain area, one can also find livestock such as sheep, goats and cattle. Dense patches of the *Phragmites australis* and *Arundo donax* are also present.

Unique vegetation includes *Nasturtium officinale* (Watercress), *Pennisetum setaceum* (Fountain Grass), *Panicum maximum* (Guinea Grass) and various species of fungi.

A variety of other avi-faunal species are also present such as *Bostrychia hagedash*, *Euplectes orix*, *Plegadis falcinellus*, *Threskiornis aethiopicus*, *Bubulcus ibis*, *Egretta garzetta*, *Ardea melanocephala* (Black-headed Heron), *Ploceus velatus*, *Plectropterus gambensis* (Spur-winged Goose), *Dendrocygna viduata* (White-faced Duck), *Gallinula chloropus* (Common Moorhen), *Fulica cristata*, *Vanellus armatus*, *Anhinga rufa* (African Darter) and *Ardeola ralloides* (Squacco Heron).

Figure 2.11: Natalspruit with little, to no, *Phragmites australis* but an abundance of grassland consisting of the various previously mentioned species (Source: Brits, 2018).

Further south of the Natalspruit, in close proximity to the southern suburbs of Katlehong and Vosloorus, livestock such as domestic pigs and chickens are prevalent. The predominant vegetation in this area includes a variety of the previously mentioned grasses on the banks of the watercourse and, to a lesser extent, *Phragmites australis* in some places.

Avi-faunal species were observed in this area such as *Bostrychia hagedash*, *Euplectes orix*, *Bubulcus ibis*, *Vanellus armatus*, *Anhinga rufa*, *Elanus caeruleus* (Black Shouldered Kite) and *Motacilla capensis* (Cape Wagtail). Alien invasive plant species were not as prevalent at this site, with the exception of *Salix babylonica* (Weeping Willow) and *Populus alba* (Poplar) trees.

Figure 2.12: *Themeda triandra* is abundant on both banks of the Natalspruit located close to the R550 (Source: Brits, 2018).

Cattle frequent the area close to the R550 and an abundance of *Themeda triandra*, a highly palatable and nutritious grass, was documented. *Themeda triandra*, a perennial tufted grass, is the most important grazing grass in Southern Africa (Van Oudtshoorn, 2004). It is abundant at high altitudes, such as Gauteng, and can be found in undisturbed open grasslands as part of the endangered Soweto Highveld Grassland, growing in mostly loam/clay soil (Van Oudtshoorn, 2004).

Avi-faunal species included *Bostrychia hagedash*, *Ardea melanocephala*, *Mirafra Africana* (Rufous-naped Lark), *Turdus smithii* (Karoo Thrush) and *Numida meleagris* (Helmeted Guineafowl).

2.7 Social Characteristics

The communities located along the banks of the Natalspruit and its adjoining wetlands are dependent on the watercourse to sustain their livelihoods. Some poverty-stricken communities rely on the Natalspruit for their basic needs such as water to cook, clean and bathe themselves on a daily basis (Miller & Spoolman, 2007). Maize crops were evident along the wetland edges on the outskirts of the Katlehong informal settlements. These communities depend on subsistence farming and the Natalspruit is vital to their daily nourishment and survival. The watercourse and its floodplain at provided ample grazing and water for livestock. The watercourse and floodplain also provided an area of recreation for the local children who frequently swim here on hot summer days.

Figure 2.13: Children from the local community frequent this section of the Natalspruit (Source: Brits, 2018).

Positive social impacts on the local community are the employment and revenue created by the operational mines in the area (Naidoo, 2017). However, due to poor management, these mining activities in the northern section of the Natalspruit could impact negatively on the health of all those who consume water from the Natalspruit. The effects of AMD, produced by mining activities, can result in the serious contamination of water that may lead to cancer or genetic diseases in the future (Murcott, 2012).

In addition, two water sewage treatment works are located next to the Natalspruit. Abandoned mine shafts in the area encourage people from the local communities to partake in illegal mining practices, exposing them to possible injury and even death (Naidoo, 2017).

2.8 Economic Characteristics

The consumption of items from the Natalspruit and its associated wetlands contributes to the local communities' well-being and welfare (Lee & George, 2000; Niemelä *et al*., 2011). Small-scale agricultural activities are located north of Vosloorus, in close proximity to the Natalspruit, which is used to irrigate farmlands. These agricultural practices create employment opportunities for some local people. The mining and industrial activities prevalent in the area also benefit the local economy and create employment opportunities (Lee & George, 2000; Niemelä *et al*., 2011).

One serious side effect of mining in the area is AMD. AMD is a by-product of the gold mining activities (from the East Rand mines and Elsburg tailing complex) and a key concern as regards water quality. To remedy the effects of AMD, water used by mines must be treated by adding limestone to address the acidic nature of the water. This process, however, adds large amounts of salt that results in the salinisation of soil, which in turn, negatively affects watercourses. Often, however, inadequate amounts of limestone are added which, in combination with high rainfall levels, results in ingression into the shafts. In this way, AMD polluted water can subsequently be decanted into river systems such as the Vaal river (Krige, 2006). AMD pollution has dire consequences for the environment. Thus, the balance between maintaining the mining sector (which is important for the economy) and maintaining water resources is an ongoing significant challenge (Naidoo, 2017). It is important to note that if the Vaal river becomes polluted with AMD, the water may be rendered unfit for human consumption, irrigation or agricultural and livestock use (Wood, Dixon & McCartney, 2013). Consumption of such water could lead to heavy metal poisoning and chronic diarrhoea. This condition, in vulnerable people, could be fatal, leading to dehydration and even death (Naidoo, 2017). In addition, flooding of water sources with AMD can erode human-made sedimentary structures, such as buildings, which could have monetary implications for the maintenance of infrastructure in Gauteng (Naidoo, 2017).

2.9 Conclusion

This chapter aimed to describe and identify the geomorphology, geohydrology and socio-economic characteristics of the Natalspruit and its associated wetlands. Evidence of a variety of anthropocentric activities, as presented in this chapter, points to the destruction of the Natalspruit and its ecological biodiversity (Durgapersad, 2005). The importance of the Natalspruit and its associated wetlands, globally, and in South Africa, follow in Chapter 3.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

Wetlands form in zones where surface water collection occurs and where sub-surface water flows towards the surface, via springs and/or seepage, resulting in, over a protracted period, an elevated moisture content level. Wetlands can comprise of tall reeds, lush vegetation and areas of open water. Differences in hydrology and geomorphology give rise to a variety of different types of wetlands as well as a diversity of vegetation species (Van Der Valk, 2006). Extensive developments by humans can negatively affect the value of wetlands (Mitsch & Gosselink, 2000). Seeing that wetlands act as natural sponges that, through the process of phytoremediation facilitate a more controlled method of wastewater treatment, these human impacts can be problematic. Phytoremediation also benefits an ecosystem by supporting services such as soil formation, nutrient cycling and water cycling (Vymazal, 2010; 2015).

Wetlands, through phytoremediation, thus fulfil an important ecological role by regulating carbon, N and phosphorus (P) levels. In so doing they contribute to denitrification and the reduction of floods, thus adding social and economic value (Hadjibiros, 2014). Globally, an average of between 54% and 57% of natural wetlands are lost and degraded because of anthropocentric activities. It is estimated, however, that total loss and degradation can possibly be as high as 87% (WWAP & UN-Water, 2018). The rate of wetland loss in Europe and the United State of America has decreased. In Asia, Africa and South America it has, however, increased, mainly as a result of anthropocentric activities which are impacting negatively on wetlands worldwide (WWAP & UN-Water, 2018).

Wetland degradation impacts negatively on human health as these degraded wetlands can no longer support humans with the necessary ecosystem services. Irrigation and drinking water becomes scarce or depleted, and food sources, such as fish, are poisoned. The reduction of food and water sources impacts negatively on the wellbeing of people. In addition, altered riparian vegetation structures can no longer support flood control and this results in increased soil erosion, eventually leading to the flooding of human settlements in close proximity to wetlands (Finlayson, Horwitz & Weinstein, 2015).

3.2 International Literature

3.2.1 Agricultural Impacts on Wetland Ecology and Biodiversity

Worldwide the agricultural sector has been responsible for much of the destruction of wetlands. It is important to note that riverine areas and wetlands are valuable ecosystems that encompass rich biodiversity and provide important facilities to society. Wetlands, for example, possess high agricultural latency due to their nutrient recycling potential. In addition, natural wetlands facilitate flood control, act as pollution filters, ensure erosion control and provide a balanced ecological habitat for plants and wildlife (Kracauer, Grozev & Rosenzweig, 1997).

In a recent study, Stoate *et al*. (2009) noted that the majority of land within the European Union is used for agriculture and that this has resulted in extensive changes to the nutrient cycle and carbon sequestration. Additionally, biosolids, such as N and P, are important to sustain plant growth but, if applied excessively, the accumulation of N in the soil can be harmful (Vymazel, 2010; 2015).

The condition of wetlands in the Netherlands has changed vastly over the course of the past 2000 years with many of these areas having been claimed for agriculture. Unfortunately, these wetlands, which cover more or less 16% of the country, are situated along the West-Palearctic bird migration route. This route constitutes an eco-zone and is considered vastly important for migrations undertaken by endangered avi-faunal species including *Puffins mauretanicus* (Balearic Shearwater), *Vanellus gregarious* (Sociable Lapwing), *Numenius tenuirostris* (Slender-billed Curlew) and *Geronticus eremita* (Northern Bald Ibis) (Van Roon, 2012; Lewis, 2016). Major instances of wetland reclamation along the Netherlands' coastal deltaic plain has taken place in an effort to supplement agricultural land. The high-level mineral content peat is fertile and thus considered suitable for agriculture. However, successes have been short-lived as the water retention characteristics of peat has resulted in the decline of farming activities (Vos, 2015).

In Brazil, a developing country, the complex and diverse Del Plata Basin biome has been subjected to rapid agricultural expansion. This has given rise to increased concern as to the impact of agricultural practices on ecology (Cavalcanti *et al*., 2015). The Pantanal, located in this biome, is a significant eco-region that, due to its vast water regulation capacity, plays an important role in the hydrological cycle of the area (Cavalcanti *et al*., 2015). The cultivation of land and resultant agricultural practices in the Pantanal do not justify the loss of the rich biodiversity in the area (Cavalcanti *et al*., 2015).

Another example taken from the developing world is the Palwal district in India, where 224 wetlands have been lost to agriculture. This expansion is affecting the rich diversity of bird species found in the neighbouring wetland areas (Sundar *et al*., 2015). Irrigation, along with the consequent establishment of canal works to pump groundwater to agricultural lands in the region, can potentially impact negatively on the wetlands in this region (Sundar *et al*., 2015).

3.2.2 Mining, Industrial and Human Settlement Activities

a) Mining Activities

Globally, mining operations, industrial activities and human settlements have had several adverse effects on riparian ecosystems. Mining operations are polluters of air, soil and water and produce large amounts of waste (Percival *et al*., 2017). According to Turner *et al*. (2000), many research studies have reported on the negative impacts of mining activities that produce heavy metal content. Inactive or abandoned mines can often be linked to heavy metal concentrations (in soil, water) which then adversely affect the ecosystems, people and economy of many countries. For example, AMD in Canada has proven to be the number one environmental problem in the mining industry. Therefore, to cover the costs of AMD in Canada, trust funds have been established. These funds are now a prerequisite to mining in this country (Naidoo, 2017).

Australia and New Zealand have attempted to limit the impacts of AMD through the implementation of a baseline framework that serves as an environmental standard for mine operations (Naidoo, 2017). These strategies include mine closure plans in an effort to predict any possible post-closure acid generation (Hargraves & Martin, 1993; ANZMEC, 1996). According to Naidoo (2017), these strategies allow for the assessment of long-term management options as regards AMD.

Lastly, in Zimbabwe, the Mupfure catchment area, situated in the Harare mining district, is also affecting the environment and the livelihoods of those individuals living in the vicinity (Derman & Manzungu, 2016). Water from the Mupfure river catchment area and the Marimba river and its associated impacts of AMD, south-west of Harare, is progressing at a slow rate. However, it still poses an environmental threat and health risk to the poverty-stricken communities that use the Mupfure water catchment area and Marimba river as water sources. AMD discharge is *not* viewed as a threat in Zimbabwe and, consequently, it receives little or no research attention. The unstable political climate and a weak economy have resulted in the Zimbabwean government focusing on more immediate and pressing issues (Ravengai *et al*., 2005).

b) Industrial Activities

Industrial stormwater runoff often contains heavy metals, toxins and residual chlorine. In the case of the Savanah River Site, situated in South Carolina USA, Cu, emanating from industrial sites, has entered the aquatic system. This process has resulted in the bioaccumulation of Cu in the wetland sediment (Edwards *et al.*, 2014). Thus, elevated Cu levels, which have serious impacts on life cycle duration, have been found in resident frogs (Rodgers *et al.*, 2001).

Additionally, a tar-like substance derived from the petroleum industries, namely bitumen, is currently responsible for the destruction of multiple wetlands in the province of Alberta, Canada (Timoney, 2015). The bitumen industry in this area is highly profitable but, unfortunately, it has a poor environmental record. There is limited scientific research as to its negative impact on the Alberta wetlands (Timoney, 2015). In Nigeria, aquatic ecosystems, such as wetlands, are being degraded and destroyed by aquatic pollution caused by increased human activities and industrialisation. Industrial effluents, such as oil, grease, phenol and cyanide (which includes DDT), dyes, mercury (Hg) and Cd originate from, amongst others, beverage and tobacco industries. These effluents have ultimately ended up in the wetlands through ruptured pipes or urban storm water runoff (Okonkwo, Kumar & Taylor, 2015). In Uganda, the wetlands of Lake Victoria are being negatively impacted by industrial activities that include a brewery, tanning operations, Cu smelters, battery assembly plants and a sewage treatment plant. Effluents, such as Cu, Pb, Ni, Zn and Co were present in high concentrations in soil samples taken from the wetlands of Lake Victoria (Muwanga & Barifaijo, 2006; Brebbia, 2014).

c) Human Settlement Activities

Urbanisation has had large-scale environmental consequences. All over the world, the dispersion of people has resulted in the introduction of animals and plants to regions that are not their indigenous or endemic habitat; this is especially true of wetland areas (Revollo-Fernández, 2015). Furthermore, present trends of urbanisation in wetland areas, especially in developing countries, has led to rapid population growth in cities and ever-increasing pressure on its wetlands. An example of this would be Mexico City in Mexico, which encompass the Xochimilco wetlands and Calcutta in India that hosts the East Kolkata Wetlands (EKW) (Goudie & Viles, 2003; Revollo-Fernández, 2015). Moreover, it is reported that the USA has lost roughly 54 % of its wetlands due to urbanisation. This includes parts of the Everglades in Florida (Goudie & Viles, 2003; Revollo-Fernández, 2015).

Human settlements adjacent to wetlands in Srinagar City, located in the Kashmir valley in India, have been responsible for the formation of channels and the dumping of waste, resulting in degradation and the loss of biodiversity within the wetlands (Mushtaq & Pandey, 2014). Lastly, residents from settlements adjacent to the wetland used the Manguo wetland in Kenya as a dumping ground. The local inhabitants also burnt waste and used a houseboat to slaughter livestock, dumping the waste into the wetland (Joseph, 2017).

3.2.3 Ecological Degradation of Fauna and Flora in Wetlands

Globally, the exploitation of natural resources has had dire cumulative impacts on the biodiversity of wetlands. Polluted water, soil and landscape degradation and ecological disturbances have led to the destruction of fauna and flora present in wetlands. Singh (2013) states that in Faridabad, a city located on the Yamuna river and wetlands in India, mining and industrial activities have inhibited plants from photosynthesising due to the deposits of mine and industrial dust on the leaf foliage. This has resulted in the elimination of plant species diversity in the river and wetland area. In the Eastern areas of North America (New York State), developments and mining practices have given rise to the decline of the Cerulean Warblers (*Setophaga cerulea*) in the Montezuma Wetland Complex due to habitat and vegetation loss (Buehler, Welton & Beachy, 2006). The Nyando Wetland is located in the Lake Victoria basin in Kenya, Africa. It has been negatively impacted by biological degradation. This degradation in wetlands encompasses the alteration of biological communities, through the removal of fauna and flora and the introduction of alien invasive species, because of human activities (Latawiec & Agol, 2015).

Internationally, wetlands located in Alberta, Canada, also face biological degradation. These wetlands, which host avi-faunal species including the Yellow Rail, Horned Grebe and the Rusty Blackbird, are currently at risk from bitumen production. Additionally, roughly 400 flora species, which are listed as rare or endangered, are located in the Alberta wetlands. These flora species cannot tolerate or adapt to the high levels of bitumen pollution that will lead to their disappearance from the wetlands (Timoney, 2015).

3.2.4 Urban and Industrial Development

Half of the earth's population reside in cities and other urban areas (Randolf, 2012). The management of the natural environment in order to protect urban ecosystems has thus led to the conception of development frameworks governed by sustainable environmental management principles. These include the implementation of urban and industrial development policies, especially to regulate developments in close proximity to wetland areas (Randolf, 2012). Unfortunately, wetland areas that contain floodplains appear to be an easy target for urban development as opposed to areas with hills. The flood risk posed for communities living in such urban developments and informal settlements, however, is high.

China's Jiangsu province has experienced extreme wetland loss due to urban and industrial development. The reclamation of the Pearl River Estuary, having reached 622.24 km^2 within 40 years, prompted the creation of China's 1989 Environmental Protection Law to improve the environment and define urban planning (Randolf, 2012). In an effort to reduce the destruction of wetlands in the Jiangsu province, a Strategic Environmental Assessment was included in the Jiangsu Coastal Development Plan to assess the impacts of development on the estuary and wetlands in the area and to support long-term integrated ecosystem management (Li *et al.*, 2014). In contrast to the Jiangsu Coastal Development Plan, the Kampala Urban Development Plan, which was developed in Uganda in 1972, allocated wetlands for industrial developments, including Mukwano Industries, City Abattoir and Peacock Paints (MWEU, 2015). These industrial developments led to an increase in wetland infilling with murram (clay substance) and the subsequent loss of Kampala wetlands' fauna and flora (MWEU, 2015).

3.2.5 Fragmentation and Habitat Loss of Wetlands

Incorrect land use and inappropriate management principles occur worldwide. The removal of riparian vegetation from river courses and wetlands, for agriculture, results in the loss of ecological reliability. Furthermore, riparian vegetation in wetlands facilitates river channel stability, ecosystem process regulation (such as climate regulation and leaf fall matter forming part of nutrient cycling), food for aquatic organisms in the river and flood control (Vymazel, 2010; 2015).

According to Scott, Frail-Gauthier and Mudie (2014), in the coastal areas of North America, the loss of wetland areas is thought to be a result of human activities including wetland reclamation, accelerated global warming and the emancipation of pollutants. Further incidences of human intervention include upstream damming, affecting the natural processes pertaining to hydrology. The changes brought about through the destabilisation of wetland areas negatively impacts natural mechanisms that were driven by natural progression (Scott, Frail-Gauthier & Mudie, 2014). Natural processes, such as a rise in sea level, have also contributed to wetland habitat loss in the coastal areas of Louisiana where the formation of coastal deltas have influenced the natural flow of river water to the ocean (Scott, Frail-Gauthier & Mudie, 2014).

Only 60% of northeastern Switzerland's wetlands and watercourses are in a near natural state and are only fragmented by artificial barriers in order to avoid overflows and flooding of urban areas (OECD, 2017). The regulation of water levels in these wetland areas has led to the shrinking of water sources and has further resulted in higher concentrations of nutrients (OECD, 2017). The majority of the wetlands in northeastern Switzerland have undergone land usage changes with rapid urban development giving rise to widespread wetland fragmentation (OECD, 2017).

3.3 South African Literature Review

3.3.1 Agricultural Impacts on Wetland Ecology and Biodiversity

South Africa's wetlands are highly threatened with dramatic changes that have occurred since 2000. Southern African wetlands are diverse in size and their different geographical locations and controls have resulted in rich biodiversity (Knight & Grab, 2016). The very *richness* in biodiversity is a cause for great concern as each wetland is sensitive to external forces in its own unique way (Knight & Grab, 2016).

The Mfolozi wetlands and floodplain, located in KwaZulu-Natal, have suffered several agricultural impacts, including commercial sugar production. This has ultimately resulted in the modification of the natural flow of the Mfolozi River. Modifications to the watercourse and wetlands have also resulted in *decreased* connectivity of the main stream with the floodplain. The *increased* connectivity with downstream systems has necessitated the draining of the back-swamp to make it more suitable for farming. In recent times, the area has mostly been utilised for subsistence farming, thus small fields that produce a variety of crops for consumption by local people (Perissinotto, Stretch & Taylor, 2013). Similarly, a recent study conducted by Matavire (2015) indicated that sugarcane farming on the KwaDukuza wetlands (situated in the Northern coastal region of KwaZulu-Natal) has resulted in the gradual decline of wetland quality due to the addition of fertilisers which has given rise to elevated levels of N, phosphorus (P) and potassium (K). In addition, the Blesbokspruit wetland, located southeast of Johannesburg in Gauteng, has been degraded through agricultural processes. The spruit is utilised for the irrigation of crops and the tending of livestock. This has resulted in overgrazing and the trampling of vegetation in the wetland (Ambani & Annegarn, 2015).

3.3.2 Mining, Industrial, and Human Settlement Activities

a) Mining Activities

Mining operations, industry and other human activities in close proximity to wetlands have all been responsible for the degradation of the ecology and biodiversity of wetlands. Likewise, the Blesbokspruit, which integrates with the Marievale Bird Sanctuary (a listed Ramsar site) on the East Rand in Gauteng, has been visibly and negatively impacted (Ambani & Annegarn, 2015). The City of Johannesburg's monitoring programme has listed the negative impacts of gold mine tailings on wetland areas (NTC Environmental Services, 2016).

The Blesbokspruit wetland, recognised as a Ramsar Wetland in the 1980s, has lost its Ramsar status due to the discharge of AMD and the presence of high quantities of Na (Sodium), Cl (Chlorine), Mg (Magnesium) and SO_4 (Sulphate). The pollution ultimately resulted in the spruit becoming increasingly saline and acidic, significantly affecting the resident avi-faunal species (Ambani & Annegarn, 2015).

Further afield, the Grootspruit river in the Mpumalanga province of South Africa is adjacent to a tributary of the Zaalklapspruit wetland which later joins the Wilge river. The Zaalklapspruit wetland has been heavily impacted by effluent from a coal mine in the area which has negatively impacted on the water quality. It was also ascertained that the wetland was functioning poorly and that a channel incision had resulted in the concentration of high pH levels, thus resulting in a highly acidic environment. Research was conducted by the WRC, in conjunction with SANBI and the Council for Scientific and Industrial Research (CSIR), to assist coal mining companies in understanding their impact on wetlands such as the Zaalklapspruit wetland. A rehabilitation plan was implemented and it has yielded positive results including an increase in species diversity in the Zaalklapspruit wetland area (Oberholster *et al*., 2016).

Pollution and the impact of mining activities have also led to the degradation of the Vaal River, effectively affecting the drinking water source of millions of people (Pheiffer *et al*., 2014). Chemical analysis of Vaal river sediment samples identified 15 different metals (Pheiffer *et al*., 2014). Analysis of the *Clarias gariepinus*, a Catfish species found in the Vaal River, revealed that it contained traces of 15 metals in its organs. This discovery indicates a possible threat to other species in the Vaal River and, ultimately, a potentially serious threat to the health of people in the area (Pheiffer *et al*., 2014).

b) Industrial Activities

Industrial activities that produce pollutants proven detrimental to wetlands in South Africa include pharmaceuticals, healthcare products, pesticide production and other industrial chemicals (DWA, 2018). Municipal wastewater, such as sewage and industrial effluents, is expensive to treat and is thus often not treated adequately (DWA, 2018). Additionally, in South Africa, phosphates are added to soaps and washing detergents destined for domestic use which, when combined with municipal water, result in the production of grey water which is used to water vegetation and finally finds its way to water sources. Furthermore, grey water is also used for urban applications such as the tending of sports fields, parks and golf courses. Such water then ends up in rivers and wetland systems (DWA, 2018). The City of Johannesburg's monitoring programme was therefore implemented in an effort to indicate the negative impacts of sewage infrastructure spillages and stormwater runoff from industrial activities in the area (NTC Environmental Services, 2016).

c) Human Settlement Activities

The wetlands of South Africa have been subjected to an immense number of changes over the past years. These have mainly been because of human activities, including the establishment of human settlements in these ecologically sensitive areas (DEA, n.d.; Barrett *et al*., 2016). Poorly planned developments, inappropriate use of and poor or *no* land management principles have all affected negatively on the ecology and biodiversity of wetlands (DEA, n.d.). The disregard for the wellbeing of wetlands seems ironic, considering that South Africa relies on ecosystems - such as wetlands - to provide essential life-support services to sustain the people located in these areas (Barrett *et al*., 2016). Human settlement activities near wetlands have led to the introduction of alien invasive vegetation species to the surroundings. An example of the before mentioned would be maize, which does not naturally grow in the area, to fields along the Natalspruit.

Furthermore, human settlement activities have resulted in the annual burning of riparian wetland vegetation during the dry winter months to ensure protection from fires, in the form of fire breaks (DEA, n.d.). Additionally, the draining of wetlands by local communities for domestic, or livestock use, increases the threat of flooding around communal wetlands. Relevant examples of this would be the small towns of Petrus Steyn and Heilbron in the Free State (Belle, Collins & Jordaan, 2018). In conclusion, another impact of human settlement observed in this area is overstocking of livestock that results in the overgrazing of the wetland areas, especially during the winter months (Belle, Collins & Jordaan, 2018). This, in turn, leads to the pollution of the area as waste disposal practices are insufficient and riparian vegetation from the Natalspruit wetland is harvested for possible medicinal use (DEA, n.d.).

3.3.3 Ecological Degradation of Fauna and Flora

Anthropogenic actions dominate the function of ecosystems in South Africa. Consequently, the transport of alien invasive plant species, in some cases accidentally through human activities, results in the loss of biodiversity within a terrestrial or aquatic area (Vymazel, 2010; 2015). The visible and significant increase of *Eichhornia crassipes* (Water hyacinth), an alien invasive water plant in the Hartbeespoort dam in the North West province, is because of water eutrophication. Water hyacinth causes the water to become O_2 deficient and serves as a breeding ground for mosquitoes that carry the *Plasmodium* parasite responsible for malaria in humans (Water Wise, 2005).

A faunal and floral wetland ecological assessment was conducted on the proposed water supply, via a pipeline, to the area situated in close proximity to the Duvha Power Station in Mpumalanga. The power station forms part of the wetland footprint and the area indicated signs of fauna and flora degradation. Many instances of transformation occurred. An example of this being the clearing of surrounding wetland vegetation, which included riparian vegetation, to facilitate maintenance activities. As a result, alien vegetation thrived due to soil disturbances and the overgrazing of livestock in the area. The fauna in the area also declined due to the establishment of the power station and the consequent degradation of the wetland area. Species affected include the Blesbok (*Damaliscus pygargus phillipsi*), Yellow Mongoose (*Cynictis penicillata*) and the African Monarch butterfly (*Danaus chrysippus*) (Iliso Consulting, 2016).

3.3.4 Urban and Industrial Development

Economic, political and ecological circumstances in South Africa dictate the use of resources. The development of urban land and the way in which areas are used to shape local economies is a case in point (Mujuru & Mutanga, 2016). The use of land in South Africa is also viewed in terms of exploiting resources for economic gains, such as large-scale gold mining which. This, in turn, places great strain on surrounding ecologies (DEA, 2011; Mujuru & Mutanga, 2016). Gauteng province contains many examples of this seeing that it has long been associated with gold mining. In recent times, however, gold mining in the province has declined (Marais, Nel & Donaldson, 2016).

The environmental impacts of urban and industrial development, as well as mining in Gauteng, include environmental modification, the loss of niches, food chain bioaccumulation, food source loss and the loss of prey species, purging of sensitive species and the decline of primary production (Knight & Grab, 2016). An example of this process is Robinson Lake on the West Rand that is bereft of aquatic life. The lake also contains degraded soil and vegetation masses that have been negatively impacted by AMD (Mujuru & Mutanga, 2016).

Lastly, increasing industrial development and urbanisation in South Africa is because of its rapid population growth with the country being home to an estimated population in excess of 52 million people. Urban and industrial development in Gauteng has increased exponentially over the last decade with more than 1.5 million people migrating to the province in search of improved employment prospects (Margui & Hedblom, 2017). The impact on the environment has been significant and wetlands, such as the Natalspruit, where high-density populations exist on the eastern (Vosloorus) and western (Katlehong) banks, have been severely negatively impacted.

3.3.5 Fragmentation and Habitat Loss

A significant cause of biodiversity loss in South Africa is the conversion of natural ecosystems for alternative uses. This has consequently resulted in aquatic organisms gradually losing their resilience to these environmental changes. Aquatic organisms are adaptable to variable water flows and water quality but cannot cope with significant environmental changes (King *et al*., 2005; Vymazel, 2010; 2015). An increase, or decrease, in water flow, alters flow patterns and can result in the loss of aquatic plant and organism biodiversity (King *et al*., 2005). Wetland fragmentation constitutes a particular problem in South Africa but, due to the lack of detailed national wetland records, the precise level of wetland fragmentation and habitat loss is unknown (Jogo & Hassan, 2010).

The case of the Ga-Mampa wetland in the Limpopo province, which provides roughly 400 households with water, is a case in point (Kotze, 2005). It is estimated that the local farmers have transformed most of the wetland area into croplands through the artificial drainage of water from the wetland (Sarron, 2005). In conclusion, the township of Sebokeng located in the Sedibeng District Municipality is situated next to the Rietspruit River. This settlement is heavily dependent on the wetland for its livelihood, a dependency that has ultimately resulted in the fragmentation of the wetland and habitat loss (Siyaya, 2015). Similar to Sebokeng, the intentional or unintentional alteration of the Natalspruit and its associated wetlands (by means of fragmentation leading to habitat loss) has led to complications because of pollution and the overexploitation of the fauna and flora of the area and its demand for water.

3.4 Conclusion

Urban planning, especially planning which impacts wetlands, faces momentous challenges in South Africa and worldwide (Randolf, 2012). Unfortunately, environmental legislation is only effective when it is implemented. Ecological sensitive areas are negatively impacted by the lack of enforcement by authoritative governing bodies, leading to the degradation of wetlands. Aquatic and wetland conservation will only be successful *if*, and *when*, environmental policies are effectively enforced by the relevant governing bodies and local communities are educated regarding the conservation and significance of these sensitive wetland systems.

The previous two chapters clearly indicated that the Natalspruit is visibly experiencing complications because of various anthropocentric impacts. This chapter explained how what is happening to the Natalspruit is similar to the experiences and difficulties faced by many other wetland regions throughout the world. Chapter 4 will provide the methodology towards scientifically researching the impacts of anthropocentric activities on the Natalspruit in order to determine the extent of degradation of the watercourse and its associated wetlands.

CHAPTER 4: METHODOLOGY

4.1 Introduction

This chapter outlines the research design, which consists of a case study approach, and research methodology used to answer the research aims, objectives and research questions. The chapter further describes the geographical study area and selected sample sites as identified by Global Positioning System (GPS) coordinates. In addition, it describes the methods used that include: field observations, water and soil sample collection, SASS 5 data collection together with the WET-Health method for ground truthing. Furthermore, this chapter elucidates the methods used for analysing the collected samples, the ethical considerations which are taken into account as well as a description as to the limitations of the study.

4.2. Research Design

A predominantly quantitative approach, which included a case study design, was employed in this study. A case study approach allows for the collection of information related to a phenomenon and allows the researcher to draw certain conclusion/s after considering all available information and following the interpretation and calculation of the relationship between properties (Swanborn, 2010; Yin, 2018).

4.3. Methodology

Research methodology is the process adopted to guide the collection of information, such as data, in order to make informed decisions with regards to solving a problem or answering a question (Kumar, 2014). The methodology, based on a case study design, incorporated reports of past studies to provide a holistic and in-depth understanding of the research conducted. This led to a contextual analysis of the conditions in the real-life context (Zainal, 2007).

4.4. Sample sites

Five sample sites were strategically identified using Google Earth Pro. These selected sites displayed impacts associated with human activities and point source pollution. Water samples were collected at sample sites 1, 2, 3, 4 and 5 in May 2018 and again in July 2018, as illustrated in Figure 4.1 and recorded on field sample sheets (see Appendix 1, 2 and 3). Furthermore, soil samples were collected at sample sites 1, 2, 3, 4 and 5 in July 2018 and recorded on field sample sheets (see Appendix 4). SASS 5 (macro-invertebrate) sampling took place in July 2018 at sample sites 1, 2, 3, 4 and 5 and recorded on a SASS 5 score sheet (see Appendix 5). The sample sites chosen are representative of the Natalspruit. The sample sites are not located at any point of direct discharge, as this might have affected the analyses results (Bartram & Ballance, 1996). However, accessibility to the Natalspruit and safety of the researcher were also taken into consideration when identifying sample sites.

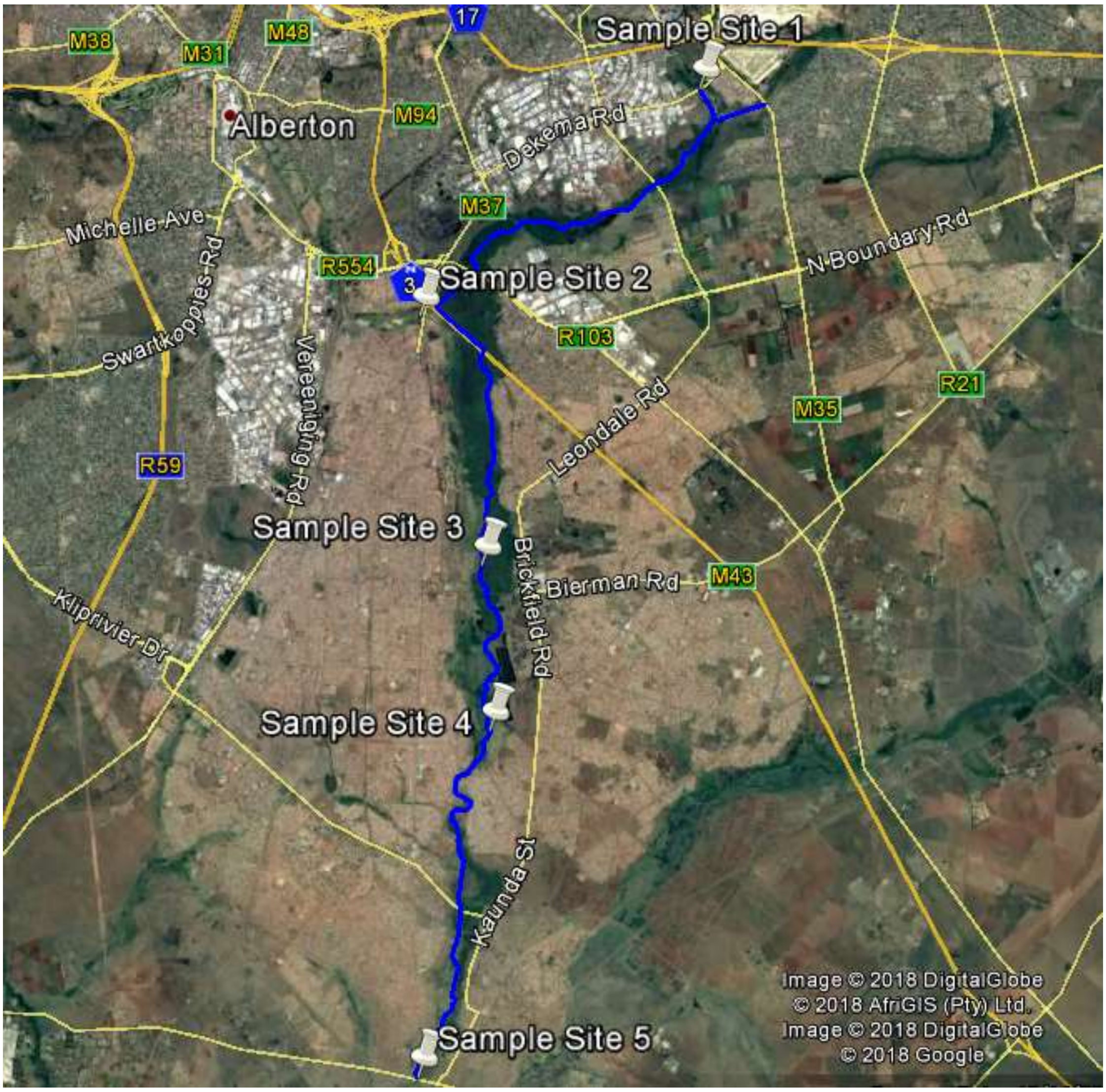


Figure 4.1: Map of the study area that indicates the chosen sample sites along the Natalspruit (Source: Google Earth Pro, 2017).

Identification of the sampling points was achieved through a desktop survey. Aerial photographs, maps, GPS, compass and Google Earth were used to determine the five sample sites and to provide a clear picture of the location and catchment area of the Natalspruit. Initially, eight sample sites were identified, but due to access constraints, such as overgrown vegetation, only five viable sample sites where used for the consequent collection of data**.** Water and soil samples were collected for analysis at all five the sample sites (as per Figure 4.1) by means of collection methods as described later in this chapter.

The coordinates for the sample sites are as follow:

SS1: 26°15'35.99"S and 28°12'34.99"E
SS2: 26°18'0.35"S and 28° 9'32.95"E
SS3: 26°20'29.34"S and 28°10'21.54"E
SS4: 26°22'7.89"S and 28°10'31.46"E
SS5: 26°25'33.95"S and 28° 9'53.80"E

4.4.1 Description of SS1

The land, surrounding *SS1*, is primarily used for urban and industrial functions with signs of mining activities as well. A bridge, in Sarel Hattingh Street, crosses over the Natalspruit. The soil is comprised of a mixture of loam and clay in the area. Mine tailings are located immediately behind the urban housing on the western side of the Natalspruit and wetland (Figure 4.2). The Natalspruit is a singular, but relatively strong flowing, stream at this site.

Figure 4.2: Recent townhouse developments on the eastern side of the wetland in close proximity to the Natalspruit. The wetland, with a mine tailings dump, is located directly behind the building development (Source: Brits, 2018).

During July, one of the driest winter months, it was evident that the area surrounding the Natalspruit and associated wetland area had been burnt, as illustrated in Figure 4.3. It is highly unlikely that the burning of the Natalspruit wetland had been planned as veld fires are a common occurrence in the Highveld during the winter months. The negative effects of the regular burning of a wetland area include exposing the soil to further erosion and solar radiation as well as stripping the soil of nutrients (Kotze, 2013).

Figure 4.3: In stark contrast to Figure 4.2, this photo shows SS1 after the grass had burnt during July 2018. Most of the vegetation has been destroyed (Source: Brits, 2018).

At this site, the Natalspruit follows a channelled valley bottom with the wetland boundaries reaching from urban housing, on the western side, to townhouses, on the eastern side. In this area, the Natalspruit flows from north to south (Figures 4.2 and Figure 4.4).

Figure 4.4: Elevated view from the bridge in Sarel Hattingh Street with a dead *Eucalyptus camaldulensis* (Red River Gum) on the Western Bank of the Natalspruit (Source: Brits, 2018).

4.4.2 Description of SS2

SS2 is situated on the fringes of Katlehong bordering Masakhane Street (Figure 4.5). This section of the Natalspruit flows from west to east. The soil in this area can be described as darkish loam/sandy. The wetland is characterised by *Pennisetum clandestinum* and *Phragmites australis* in patches.

The watercourse at this site is shallow when compared to SS1, with less alien invasive vegetation. Signs of sediment deposits are visible east of the bridge on both sides of the Natalspruit. Efforts to curb soil erosion and preventative measures to stop the erosion of the cement structure were implemented by the strategical placement of gabions on the western side of the bridge (Figure 4.5).

Figure 4.5: Degraded gabions erected to prevent this section of the Natalspruit from creating a second stream (especially during periods of heavy rainfall) which would undermine a road bridge (in Masakhane Street, Katlehong). Cattails are growing between the broken gabions (Source: Brits, 2018).

The further degradation of the wetland at SS2, due to bulldozer activity, has resulted in what is known as the *"Cobra Effect"*[2]. Extensive excavation activities (as per Figure 4.6) were done at

[2] The "Cobra Effect" according to the Oxford Dictionary (2010), is when an intended solution results in the worsening of the original problem.

SS2 to eliminate stagnant water pools. These excavations have not only changed the site completely but have also resulted in the creation of deeper areas where pools of stagnant water will once again form during the rainy season. Furthermore, the soil and sediment layers were disturbed and, in some cases, removed. Some areas were now exposed to erosion due to the lack of vegetation (Morgan, 2005).

Figure 4.6: Further degradation of the wetland was observed in July after bulldozers had bulldozed large parts of the site in order to eliminate the accumulation of stagnant water (Source: Brits, 2018).

A large blue pipe runs through this section of the site. The boundaries of the wetland, at SS2, are defined by urban housing north of the Natalspruit and a dilapidated athletics stadium/sports centre and tarred parking area to the south of the watercourse and wetland. This small watercourse joins the larger section of the Natalspruit and its adjoining wetlands roughly 500 meters east of the bridge.

Figure 4.7: Downstream from the mentioned gabions, as per Figure 4.5, with the bridge in Masakhane Street, Katlehong, visible in the background (Source: Brits, 2018).

4.4.3 Description of SS3

SS3 is located roughly 700 meters from sewage water treatment works. The treated water is discharged into the Natalspruit just south of the treatment plant. The land surrounding this area also provides grazing for domestic livestock such as sheep, goats and cattle. In close proximity to the Natalspruit, dark loam soil is present and wetland, with lighter sandy soil, is located on the floodplain. The area which possibly serves as a buffer zone between the wetland/floodplain and the informal/urban settlements on the western side of the watercourse is possibly (inadvertently) present in the event of the Natalspruit River flooding during the rainy season. In places, concrete fencing prohibits the building of settlements in this area.

Figure 4.8: The slow flowing section of the watercourse consists of a large number of *Nasturtium officinale* (Source: Brits, 2018).

The watercourse splits into individual streams between the dense growths of *Phragmites australis* and *Arundo donax*. Unique vegetation, unlike that found at other sample sites, includes *Nasturtium officinale* as well as *Pennisetum clandestinum*, *Pennisetum setaceum* and *Panicum maximum*, as per Figure 4.8. Unlike SS1 and SS2, no other alien invasive plants or grasses were observed. Disturbances included overgrazing of domestic livestock, human foot traffic creating a network of paths throughout the floodplain (as per Figure 4.9), litter, illegal dumping of building material and car tracks which can be mainly attributed to the local municipality's patrol vehicles.

Figure 4.9: Livestock, such as sheep and goats, on the floodplain area at SS3. This section of the Natalspruit would possibly provide drinking water as well (Source: Brits, 2018).

4.4.4 Description of SS4

SS4 is located south of the second sewage water treatment works. Treated water is discharged 400 meters upstream from this site. The surrounding land is used for subsistence farming with small crops, such as maize, and livestock, such as pigs and chickens. East and west of the watercourse are a multitude of informal settlements. The soil consists mainly of loam and sand. The surrounding informal settlements are located in close proximity to the wetland on both sides of the Natalspruit. On the eastern side of the watercourse, there are signs (dry at the time of research) that the Natalspruit overflows its banks, thus creating temporary shallow channels.

Figure 4.10: Picture of the meandering Natalspruit at SS4 with mainly grassland and little, to no *Phragmites australis* (Source: Brits, 2018).

The predominant vegetation is a variety of grasses on the banks of the watercourse and, to a lesser extent, *Phragmites australis* in some places, as per Figure 4.10. Disturbances at the site included old dilapidated and abandoned structures. *Salix babylonica* and *Populus alba* were dispersed intermittently along the watercourse. There was no obvious presence of alien invasive plant species at this site with the exception of *Salix babylonica* trees and *Populus alba*. The local children frequently play and swim in this section of the Natalspruit. The water is full of small pieces of debris with turbidity visually present, as per Figure 4.11. Overall, this area is in a better condition compared to the previous three sites.

Figure 4.11: This picture was taken with a dome and GoPro camera to indicate the fast flowing motion of the watercourse as well as its turbidity (Source: Brits, 2018).

4.4.5 Description of SS5

SS5 is located next to the R550. The surrounding land is dotted with a small number of informal settlements.

Figure 4.12: The Natalspruit, at SS5, is slow flowing and quite wide when compared to the previous four sample sites (Source: Brits, 2018).

In this section, no reeds nor alien invasive vegetation species were observed. In addition, no obvious instances of pollution or litter were present at SS5. Observations also indicated that there were no obvious floodplains and/or buffer zones. The watercourse, at SS5, consists of a wide channelled valley bottom and was observed to be slow flowing (Figure 4.12). It is reasonable to believe that local inhabitants use this section of the Natalspruit for drinking water, cooking, bathing and for watering livestock since the area seems to have no access to municipal water.

Figure 4.13: More riverbank erosion exposing different layers of soil (Source: Brits, 2018).

Cattle were seen 300 meters from the site, thus suggesting that the grasslands are used for grazing. This assumption is further supported by the abundance of *Themeda triandra*, a highly palatable and nutritious grass. The area possesses a few scattered broken-down rocky outcrops with multi-coloured soil layers on the banks of the Natalspruit, as per Figure 4.13.

4.5 Sample collection

One water sample and one sediment sample were collected at each sample site. X-Lab Earth (Johannesburg) provided sterile water sampling bottles. The lid of the container was carefully removed and the sample bottle was then submerged to collect the required amount of water. For each sample, the date, time and temperature of the water were recorded. The water samples were stored in a cooler box on ice and then delivered to the laboratory the next day. The water quality was tested by X-Lab Earth laboratory (Johannesburg, South Africa) in order to determine physicochemical parameters such as the pH, turbidity, SO_4, phosphate, chloride (Cl), coliform bacteria, hardness, colour, temperature, NO_3, NO_2, DO and Biochemical Oxygen

Demand (BOD). Photographs were taken, where necessary, to further substantiate and assist in the documentation of findings.

A sediment corer was used to collect soil samples. The corer was lowered into the substrate to the desired depth of roughly 15 cm, slowly lifted to the surface, and then transferred to an X-Lab soil jar provided by the laboratory. Care was taken to not contaminate the sample. The soil samples were stored in a cooler box on ice and delivered to the laboratory the next day. The dates and times of sample collections were recorded. Where necessary, photographs were taken to further substantiate and assist in the documentation of findings.

The collection of macro-invertebrates, during July, included the use of a SASS 5 net at the sample points to collect and trap visible living macro-invertebrates by moving the net through the different biotopes in various areas at each sample site. SASS 5 is a biological index utilised to ascertain *river health* by focusing on macro-invertebrates (Dallas, 2007). A special net, tray, gloves, magnifying lens, tweezers, pipettes, sample containers, stationery and waders were used. When the water ran clear and the samples settled at the bottom of the net, the net was emptied into the sample tray and then submerged in water. Debris was carefully removed from the tray. Organisms were identified, photographed and recorded using a SASS 5 scoring sheet. Relevant literature and field guides related to this study were used to assist in the identification of macro-invertebrates, riparian vegetation, avi-fauna, other flora and mammals and noted in their appropriate lists (see Appendix 6).

Binoculars and a digital camera were used to record visual observations and determine signs of obvious degradation. Eco-classification (WET-Health Method, PES and EIS) was also used (Macfarlane *et al.*, 2008; Kleynhans, Louw & Graham, 2009). The WET-Health method is a technique that facilitates the rapid assessment of wetland health (Macfarlane *et al.*, 2008). The focus of the WET-Health method is on analysing and defining the functional variables, biotic variables (such as vegetation, aquatic macro-invertebrates and birds) and physical variables (such as soil composition, water source type, geomorphic setting and location) of a site. It uses numerical data to explain and provide evidence of impacts (Gauri, 2005). The emphasis of this study was to ascertain the ecology and biodiversity of the Natalspruit, and adjoining wetland, and how it is affected by anthropocentric activities.

In addition, rainfall and discharge data were acquired from the South African Weather Service, the Department of Water Affairs and the Ekurhuleni Metropolitan Municipality. Rand Water water quality data was used for comparative purposes.

4.6. Data collection, field techniques and laboratory analysis for water collection samples

Sterile sampling bottles were collected from X-Lab Earth, a SANAS accredited laboratory, and used to gather water samples for the analysis of microbiological, physical, aesthetic and chemical determinants (both macro- and micro-determinants). Sterile X-Lab soil jars were also used for the collection of soil sediment samples in order to analyse the chemical determinants (macro-determinants). All samples were kept and transported in a cooler box with packets of ice which ensured that a constant temperature was maintained.

The sample collection and analytical methods are described in the following sections:

Water analysis of microbiological determinants such as total coliforms (Bacteria E-Coli, Coli) required the collection of 10 samples. Analysis of physical and aesthetic determinants, such as turbidity and pH analysis (25 °C), required the collection of 10 samples each. Testing of chemical determinants (macro-determinants), which include dissolved elemental by ICP-OES/MS and hardness calculations such as calcium (Ca), TDS, hardness and Mg required the collection of 10 samples in total. Testing of anions by ion chromatography (IC) such as NO_3, NO_4, sulphate and Cl required the collection of 10 samples in total. Testing of chemical determinants (micro-determinants) such as PO_4, Dissolved Oxygen (DO) and BOD required the collection of 10 samples each.

Sediment analysis of chemical determinants (macro-determinants) by means of elemental analysis by ICP-OES/MS tested for determinants such as Hg, Cd, Pb, Ni, Cr (chromium), Cu and arsenic (As). This required the collection of five samples in total, one sample at each sample site.

A statistician made use of statistical software to analyse the data and Microsoft Excel software was used for database creation. A comparison of the water analysis results was made with the results of each physicochemical parameter, at each sample site, and then compared to the recent results from Rand Water and the water guidelines, as stipulated by the Department of Water Affairs. Data obtained from the soil analysis and its chemical determinants were compared with one another at each sample site and with the National norms and standards for the remediation of Contaminated Land and Soil Quality in South Africa as stipulated by NEMA (National Environmental Management: Waste Act, Act No. 59 of 2008) (Molewa, 2012).

4.6.1 Microbiological determinants: total coliforms

Total coliform bacteria are often used to determine water quality (DWAF, 1996a). Total coliform bacteria mainly consists of a group of bacteria that include *Escherichia, Citrobacter, Enterobacter, Klebsiella, Serratia* and *Rahnella* (DWAF, 1996a). Coliform bacteria are present in the intestines of animals and in the soil. Total coliform bacteria is an indication of the presence of faecal matter which has entered a river or stream originating from humans, animal, storm runoff and agriculture.

i) Sampling

Care was taken to ensure that the sample bottle was not contaminated before the water sample was collected at the sample site. Sample collection took place on non-windy and non-rainy days to avoid contamination. The lid was carefully removed and the sample bottle was submerged to collect 100 ml water, as indicated by a line on the sample bottle. The date and time were noted on a label on the sample bottle and then documented on the sample checklist. Same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

Incubator set at 35 °C
Stereoscopic microscope
Microscope lamp
Glass pipets
Membrane filtration units
Membrane Filters (MF)
Sterile phosphate-buffered dilution water
Sterile petri dishes
Sterile 47mm diameter absorbent pads

iii) Laboratory analysis method

A cellulose membrane filter was used to filter the water sample. This membrane retains the bacteria present in the water sample. The filter was placed on an absorbent saturated pad and then incubated at 35 °C for 24 hours. Colonies of bacteria, which propagate on the pad, are examined for the existence, after breakdown, of a bluish colour (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.2 Physical and aesthetic determinants: pH at 25 °C

The pH value measures hydrogen ion activity in the water sample. Pure water contains no solutes, so the water is electrochemically neutral. An increase in hydrogen ions results in a decrease in pH as the solution becomes more acidic. On the other hand, a decrease in the hydrogen ions results in an increase in the pH as the solution becomes more alkaline (DWAF, 1996a).

i) Sampling

To test the pH of the water of the Natalspruit, water samples were collected at the identified sample sites. A sterile high-density polyethylene container was used at each sample site to collect a 50 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box. Same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

pH-meter
Thermo Scientific Gallery Plus Discrete Analyser
Buffers
Deionized water
Glass beaker
Magnetic stirrer
Stir bar
Graduated cylinder

iii) Laboratory analysis method

This method is used to determine the pH of drinking, ground, surface, wastewater and leachates. It is based on standard methods to examine water and wastewater namely Method 4500-H pH value and the Thermo Scientific D09065 insert. The instrumentation used for this technique was a Thermo Scientific Gallery Plus Discrete Analyser. The pH was measured at 25 ℃ by using a two-electrode galvanic cell consisting of an indicator pH electrode and a reference electrode (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.3 Chemical determinants - macro-determinants (dissolved elemental) Ca, Mg, hardness, TDS

Water hardness refers to the quantity of Mg and Ca present in the water (Somerset Educational, 2015). Excessive hardness can cause problems with scaling in pipes and hot water appliances, also resulting in corrosion problems. Scaling is the accumulation of undissolved carbonate and SO_4 salts, Mg and calcium carbonate ($CaCO_3$) (DWAF, 1996c, DWAF, 1996d). Total dissolved solids (TDS) consist of inorganic salts and organic materials in water with elements consisting of Mg and Ca. TDS originates from natural sources, industrial runoff, agricultural runoff and agricultural activities (Razowska-Jaworek, 2014).

i) Sampling

To ascertain the amount of TDS, Ca, Mg and hardness in the Natalspruit, water samples were collected at the identified sample sites. All constituents were tested individually from the water samples. A sterile high-density polyethylene container was used at each sample site to collect a 500 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

Conductivity probe

iii) Laboratory analysis method

The technique is centred on measuring the conductivity level, using a conductivity probe, which determines the presence of ions in the water samples. The presence of ions is then converted to TDS values (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.4 Anions by ion chromatography:

Nitrates and Nitrites

NO_3 and NO_2 are chemical nutrients that could contribute to water quality problems. They often enter a river system through sewage discharge or fertiliser runoff from farmlands. This process can lead to excessive algae, or above average aquatic plant growth (Somerset Educational, 2015).

i) Sampling

Water samples for testing NO_3 and NO_2 levels in the Natalspruit were collected at the five identified sample sites. A sterile high-density polyethylene container was used at each sample site to collect a 200 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

4.6.5 Sulphate (SO_4)

Sulphates, which are highly soluble in water, naturally occur in several minerals used in the production of fertilisers, textiles and insecticides. SO_4 are also used in mining, sewage treatment and the metal industries (Vymazal, 2016).

i) Sampling

A water sample to test the SO_4 content in the Natalspruit was collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect a 50 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

4.6.6 Chloride (Cl)

Sewage water treatment plants use of Cl to regulate microbiological safety and treat water before discharge. Untreated sewage water contains pathogenic microorganisms and may increase the risk of microbiological infection. If Cl levels are too high, it could cause irritation of the mucous membranes of aquatic animals such as fish. A reading of between 0 and 0.2ppm is considered acceptable in aquatic systems (Somerset Educational, 2015).

i) Sampling

Water samples to test for the Cl content of the Natalspruit were collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect a 100 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was stored at a temperature of 4 °C in a cooler box. Same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used for anions NO_3 (Section D), NO_2 (Section D), SO_4 (Section E) and Cl (Section F)

Ion chromatograph
Pre-column
Analytical column
Conductivity suppressor
Conductivity detector
1 ml Syringe
Chromeleon software (version 6.80)
Pipettes
Beakers

iii) Laboratory analysis method for anions NO_3 (Section D), NO_2 (Section D), SO_4 (Section E) and Cl (Section F)

This method is based on the Environmental Protection Agency (EPA) method 300.1 which determines the presence of non-living anions in water sampling by means of IC, 4110B for waters and solids (soluble) and NIOSH 7903, NIOSH 6013, Radiello F1, Radiello J1 and Radiello K1 (X-Lab Earth Science, pers comm, 18/09/2017).

The mediums tested with this technique include drinking and surface water, varied industrial and urban wastewaters, groundwater, solids, leachates without the use of acetic acid, and solid phase absorbents associated with Radiello methods and NIOSH method. The analysis is performed on a Dionex ion chromatograph, using a 25 µL sample loop, an AG14 guard column, AS14 anion separator analytical column, a conductivity detector, and/or a variable wavelength photometer (X-Lab Earth Science, pers comm, 18/09/2017).

During IC, a pump delivers a mobile-phase eluent at a uniform rate and pressure that typically ranges between 500 to 5000psi. Furthermore, IC involves the addition of a minor quantity of fluid sample into a flowing stream of fluid, thus called the mobile phase. The fluid then moves through a column filled with a cross-linked polymer resin, the so-called motionless phase. The splitting/separation of the mixture into its constituents is done in accordance with the varying points of retention of each constituent in the column. The level at which the constituent remains in the column relates to its partitioning coefficient as per the fluid mobile phase and the inactive phases. Chromeleon software (version 6.80) was used to analyse the data.

4.6.7 Orthophosphate as PO_4

Chemical determinants - micro-determinants

Natural processes produce PO_4. Possible sources include partially treated sewage discharge, agricultural runoff and fertilisers (Somerset Educational, 2015).

i) Sampling

Water samples to test PO_4 levels in the Natalspruit were collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect each of the 100 ml water samples which were labelled accordingly and listed on the checklist. To preserve the samples, they were kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

Analytical balance
Beakers
Pipettes
Sampler
Multichannel pump
Manifold
Colourimetric detector
Data recording device

iii) Laboratory analysis method

The method was developed to determine the phosphate content of the water sample and based on three sources:

SO_4 in Waters, Solids and Effluents 1988 (Procedures for the Investigation of Waters and Related Materials). Customary approaches for the investigation of water and wastewater (Method 4500 P-E); and EPA Method 365.1 Phosphorous (all forms), colourimetric, automatic, ascorbic acid and Thermo scientific D06729_03 insert environmental phosphate.

The PO_4 anion responds to ammonium molybdate and antimony potassium tartrate, which is a catalyst, under acidic circumstances to form a 12-molybdophosphoric acid complex. It is then condensed with ascorbic acid to produce a bluish heteropoly complex. The absorbance of this compound is measured spectrophotometrically at an 880nm wavelength and is associated with the phosphate anion assembly by way of a calibration curve. The unit of measure (UOM) is mg/l (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.8 Dissolved Oxygen (DO)

Atmospheric O_2 disbands in water. River plants that photosynthesise produce O_2 and introduce it into the water (DWAF, 1996e) form it. DO and percentage saturation is an important indicator and measurement for water quality. Cold water holds more O_2 than warmer water. Bacteria and decaying plant material can cause a decrease in the percentage of DO (Somerset Educational, 2015).

i) Sampling

A water sample to test the DO content of the Natalspruit was collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect a 300 ml water sample, ensuring that there were no additional air bubbles that might affect the DO levels. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

Pipettes
Beaker
Probe
Titrator

iii) Laboratory analysis method

The Winkler Method with Azide Modification is used to test for DO in water samples. In the analysis, manganous ions react with the DO in the alkaline solution to form a manganese oxide hydroxide floc. Azide is added to subdue intrusion from NO_2. The solution is then acidified and the manganese floc is reduced by iodide to form free iodine as I3 – in proportion to the O_2 concentration in the sample. The liberated iodine is then titrated to the starch-iodide endpoint (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.9 Biochemical Oxygen Demand (BOD)

BOD is the quantity of O_2 that dissolves in water and is used or consumed, by organisms found in the water (DWAF, 1996c). BOD, organic nitrogen concentrations and temperature influence DO levels in water (DWAF, 1996c). When aquatic plants die, bacteria feed on the decomposing plant material and this process depletes O_2. The measure of the quantity of DO used is called BOD (Somerset Educational, 2015).

i) Sampling

Water samples to test the BOD content in the Natalspruit were collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect a 1000 ml water sample, ensuring that there were no additional air bubbles that might affect the BOD levels. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment Used

Incubator set at 20 °C
Graduated cylinder
Erlenmeyer flask
Titrator

iii) Laboratory Analysis Method

The BOD samples are diluted 30 times with water. The water sample is then incubated and kept at 20 °C for a period of five days. After five days, reagents such as manganese sulphate (2 ml) and alkali-iodide-azide (2 ml) are added to the test sample. If O_2 is present, a brown-orange discolouration of the sample will occur. Concentrated H_2SO_4 (2 ml) is added to the sample that is succeeded by the Titration process when added to an Erlenmeyer flask. The volume of sodium thiosulphate solution consequently added is an indication of the DO in mg/L present in the sample (X-Lab Earth Science, pers comm, 18/09/2017).

4.6.10 Turbidity

The turbidity of water determines its level of clarity or muddiness. Turbidity indicates the presence of suspended solid matter in the water which could be caused by soil erosion, AMD and urban runoff (Somerset Educational, 2015). High water turbidity could result in the clogging fish gills, the smothering of aquatic insects and hatched insect larvae dying. Turbidity is an indicator as to the extent of water pollution in water bodies (Somerset Educational, 2015).

i) Sampling

Water samples to test the turbidity content in the Natalspruit were collected at the five identified sample sites. A sterile high-density polyethylene container was used to collect a 200 ml water sample. It was labelled accordingly and listed on the checklist. To preserve the sample, it was kept at a temperature of 4 °C in a cooler box and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

EUTECH Turbidimeter TN-100
Tungsten lamp
Glass sample cells
Distilled water

iii) Laboratory analysis method

This method is appropriate for aqueous samples with turbidity ranging from 0 to 800 NTU (Nephelometric Turbidity Unit). It may not be applicable to samples with solids that settle quickly. The turbidity of the water sample is measured using a EUTECH Turbidimeter TN-100. The formazin polymer is used as the turbidity standardisation suspension for water seeing that it is more consistent and reproducible for calibration than materials previously used to test for turbidity. The detection limit for this method is 0.05 NTU. The formazin polymer is utilised as the primary standard reference suspension. It is derived from standard approaches for the investigation of water and wastewater, Method 2130B: Turbidity Nephelometric method.

4.6.11 Temperature

Temperature changes in water sources determine biodiversity, or the number of animals and aquatic organisms that live in the water as well as their distribution (Somerset Educational, 2015; DWAF, 1996a). Temperature is imperative to the quality of water of an aquatic source as it influences the quantity of DO present in water, the photosynthesis frequency of water plants and the sensitivity of river entities to the toxicity of waste material (Somerset Educational, 2015).

i) Sampling, (ii) Equipment used and (iii) Laboratory analysis method

A calibrated thermometer was held 10 cm below the surface of the water for 2 minutes. The thermometer was then removed and a reading was recorded as degrees Celsius.

4.7 Data collection and field techniques for sediment sample collection methods: chemical determinants - macro-determinants (*Elemental Analysis by ICP-OES/MS)*

Sediment in a river, or stream, is often caused by anthropocentric actions that function as a basin and indicate deviations in a river column (Pandey & Singh, 2017).

i) Sampling

A sediment corer with a one-way valve was used to collect core sediment samples that provided a more representative vertical profile. The corer was lined with a new core liner in-between sampling to avoid contamination. The corer was slowly lowered to the substrate and allowed to penetrate the substrate to the desired depth of fifteen to twenty centimetres. It was then slowly extracted to the surface and the sediment sample was transferred to a 1-litre X-Lab soil jar, taking care not to contaminate the sample. The soil jar was labelled and documented accordingly. One soil sample per site was sufficient to test the presence of heavy metals (Hg, Cr, Cu, Pb, Ni, Cd and As). The samples were kept in a cooler box at 4 °C and same day delivery of samples to the laboratory took place for analysis.

ii) Equipment used

FPXRF spectrometer
Sealed radioisotope sources
X-Ray tubes
Niton XL2 device
Drying oven
Mortar and pestle

iii) Laboratory analysis method

X-ray fluorescence spectrometry, especially the Niton XL2 device, was used to analyse the bottom sediments of the Natalspruit. Non-representative debris was removed to ensure a smooth soil surface with moisture saturation of less than 20%. The sample was homogenized/dried and milled to pass through a 60 mesh-sieve (250 microns), placed in a 31.0 mm polyethylene sample cup and covered with a 2.5µm Mylar film for analysis (X-Lab Earth Science, pers comm, 18/09/2017). This method provided reliable information concerning anthropogenic impacts on the Natalspruit (Valentukeviciene, Ignatavicius & Valskys, 2014).

4.8 SASS 5 methodology

A visual assessment of the study area was made to ascertain obvious impacts on the study area, especially in relation to activities upstream of the Natalspruit and any other activities in the immediate vicinity. Digital photographs were taken at every sample site and these provided a pictorial representation of the Natalspruit and its associated wetlands. This process included a visual and pictorial account of the morphology, riparian vegetation, erosion and anthropocentric activities. Eco-classification (WET-Health method) took place and was calculated for each sample site to assess the drivers and responses at each of the sample sites (Macfarlane *et al*., 2008; Kleynhans, Louw & Graham, 2009).

The SASS 5 sample methodology and collection of macro-invertebrates are described in section 4.3. Research outcomes of the biological monitoring of the Natalspruit mainly depended on the interpretation of conditions related to each sample site (Kleynhans, Louw & Graham, 2009). The physiochemical parameters and sediment sample analyses further assisted in forming an understanding of the responses of macro-invertebrates to the biochemical composites that were present in the Natalspruit (Kleynhans, Louw & Graham, 2009).

4.9 Ethical considerations

Ethical considerations were imperative in this research project. Ethics are rules of conduct and moral principles that distinguish between correct and incorrect conduct (Stevenson, 2010). Ethical research clearance was obtained from the University of South Africa, ERC Reference #: 2017/CAES/155 on 4 December 2018 (as per Appendix 7). The adherence to ethical standards within this research project prevented the falsification of data and promoted the veracity of knowledge (Armstrong, 2000). The purpose of this study was to contribute information that could be used towards the improvement of the Natalspruit and its associated wetlands. It was essential that ethical environmental research was conducted to prevent further degradation of the study area. Ethical considerations applicable to this research project ensured that data collection in the field adhered to appropriate controls to ensure minimum environmental impact/s. It was important not to neglect any controls pointed out by other researchers. Appropriate sample sizes were collected at strategically selected sites to ensure that quality data were produced. Selecting the most relevant sites enabled effective environmental observations.

Best practices and existing scientific formulas were used in the study to ensure validity and objectivity (Zyphur & Pierides, 2017). The laboratory stored the soil samples for a period of six months until they had enough volumes to constitute the destruction thereof. Budget Waste, a waste management company, performs classification of the waste and disposes of it accordingly, based on their assessment. The waste management company then supplied a safe disposal certificate to the laboratory. No permission was required to access any of the five sample sites seeing that the sites were not confined to private property.

The responsible and ethical handling of macro-invertebrates in the SASS 5 sampling and identification procedure was conducted with sensitivity and according to the ethical guidelines, as outlined by UNISA's Research Ethics Policy. The "3-R" principles of Replacement, Reduction and Refinement were applied (UNISA, 2012).

The collection and use of the macro-invertebrates were justified, the health and care of the organism were retained, and a representative sample size of the population was observed and identified to ensure minimal impact and distress of the macro-invertebrates sample at each sample site. The sample macro-invertebrates at each sample site was kept submerged in water from the Natalspruit to ensure their longevity and was returned unharmed to their original location at each sample site. Consent to use the photographs, which were taken by a professional photographer for this study, was provided by means of a letter included in Appendix 8.

4.10 Validity and reliability of the study

Firstly, the rationale of the study was to address the gap in literature regarding the Natalspruit, by offering a perspective on the state of the Natalspruit and its adjacent wetland/s. The research intended to supply adequate answers to the research questions by using suitable methods. To ensure reliability, great care was taken to ensure accuracy and consistency throughout the research project.

A work plan and checklist were compiled to help facilitate the sampling and testing activities within the allotted timeframe. This ensured that the tasks followed each other in a controlled manner and that all the necessary equipment was present.

Validity and reliability are imperative in research as they ensure the truthfulness of a quantitative research approach. Taylor (2013) defines reliability as the method to obtain consistent results over a period of time that can be consistently reproduced. Validity determines the truthfulness of the research results (Taylor, 2013).

The water, soil and SASS 5 sampling were collected in a consistent manner over a period of time, which ensured that the data were comparable. All samples and data collected were from the applicable populations in the study area within a specified timeframe. Statistical data analysis of the samples was used to ensure, as far as possible, the desired accuracy of the tests.

SANAS and SASS 5 standards and procedures were followed which ensured that reliable and valid results were obtained from the water, soil and macro-invertebrate samples. The equipment used was calibrated and sterilised to ensure further accuracy of the analysis results. Samples were collected and analysed correctly to ensure a high-quality standard was achieved and monitored efficiently (Bartram & Ballance, 1996).

4.11 Budget

The research project started in March 2018 with completion at the end of February 2019. A quote for the tests was received from X-Lab Earth, a SANAS accredited testing laboratory Sample collection from the specified sites, and testing of the samples, took place twice in 2018, once in May and once in July. The budget was divided into three sections with the first section including operating expenses such as travel, electronic equipment, and research materials and data collection equipment. The SASS 5 equipment quote was received from GroundTruth, a consulting company that focuses on business with regards to environmental resources, biodiversity and engineering (environmental). The second section included the cost of the water analyses of the water samples collected from the Natalspruit. The third section included the sediment analyses costs of the Natalspruit and its associated wetlands. The total cost for the water and sediment/soil analysis was R23 312.50 and the total budget for the project was R43 882.17 (see Appendix 9).

4.12 Limitations of the study

Despite the research having addressed its aims, there were inevitable limitations. Firstly, due to time and financial constraints, the time between the collections of water samples collected during May and July was short (only two months separating the two time periods). However, care was taken when the samples were collected for analysis. The number of sample collection sites were reduced from eight sample sites to five samples sites due to the inaccessibility of sections of the Natalspruit with excessive reed overgrowth, and safety considerations. Due to financial constraints, only one water and one sediment sample were collected per site during the respective chosen time periods, inhibiting the ability to allow for population variation calculation. The collection of sediment at some of the sample sites was hampered due to exposed bedrock but care was taken to collect the remaining available sediment for analysis.

4.13 Conclusion

This chapter described a suitable research methodology and case study design. The data collection of water and sediment samples were explained together with the methods of laboratory analysis thereof. The budget for the study was presented and limitations to the study were discussed. The data collected in this chapter provides a foundation for Chapter 5 in which the water sample results will be discussed.

CHAPTER 5: WATER RESULTS

5.1 Introduction

This chapter presents results obtained of the water quality analysis. As stated in Chapter 1, the objective of this study was to determine and document the impacts of anthropocentric activities on the Natalspruit. This chapter, therefore, presents the results of specific physicochemical parameters for the months of May and July 2018. The results are, where possible, compared to Rand Water results as well as the South African Water Quality Guidelines. The results then inform the discussion presented in Chapter 8. No rainfall was recorded for the study area during the month of July but in May 21.5 mm was recorded (Dlamini, pers comm, 06/02/2019). The average daily temperature was 19 °C in May and 12 °C in July. The Natalspruit water samples for May and July were analysed to determine the presence and/or levels of Turbidity, dissolved ICP-OES metals in water such as $CaCO_3$, Mg and Total Hardness, Anions such as Cl, NO_2, NO_3, SO_4, PO_4, DO, pH, BOD and Total Coliforms.

5.2. Results obtained from the May and July sample sites

5.2.1 pH at 25 °C

Low pH levels (<5.5) in water sources can result in the death of aquatic organisms. The optimum pH level to sustain aquatic systems ranges between 5.5 and 8.0 (Abowei, 2010).

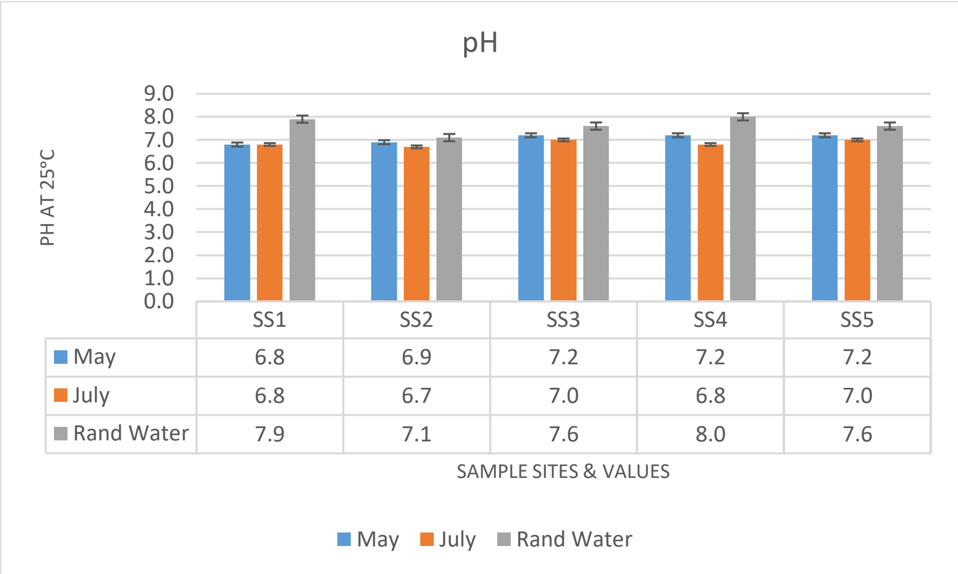
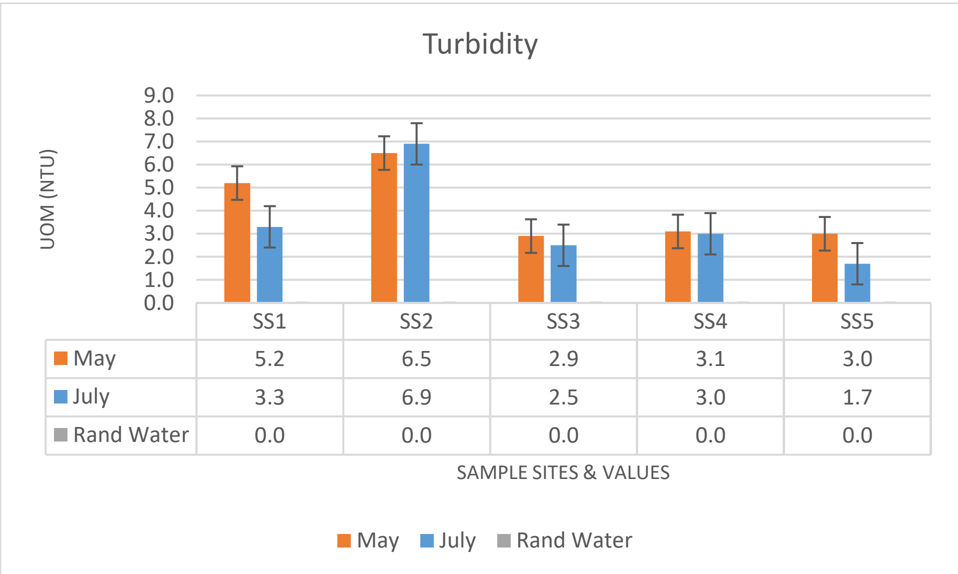


Figure 5.1: pH levels for each sample site measured during May and July 2018.

The pH levels of all five sample sites showed little variation for May and July. Results were between 5.5 and 8.0, an indication of almost neutral to slightly alkaline levels. The pH for site SS1 was 6.8 for both May and July, lower than Rand Water's recorded level of 7.9. The pH levels for site SS2 were 6.9 and 6.7, for May and July respectively. Both fractionally lower than the level of 7.1 recorded by Rand Water for the site. The pH level for site SS3 was 7.2 and 7.0, for May and July respectively. This deviates from the level of 7.6 reported by Rand Water for this site. The recorded pH levels for site SS4 were 7.2 and 6.8 for May and July, respectively, compared to a pH of 8.0 recorded by Rand Water. The pH levels for site SS5 was 7.2 for May and 7.0 for July, compared with 7.6 recorded by Rand Water. According to DWAF (1996a), the South African water quality guidelines for pH indicate that levels between 5.0 and 9.7 are deemed suitable for drinking purposes. There are no guidelines available as to the effect of pH on the health of livestock.

5.2.2 Turbidity

Turbidity is a term used to measure suspended particles and, thus, watercourse clarity. It is an indicator of environmental hazards (as described in Chapter 4, section 4.6.10) and possible public health hazards. This parameter is used to monitor water quality for compliance with the national norms and standards of South Africa (AWWA, 2010).



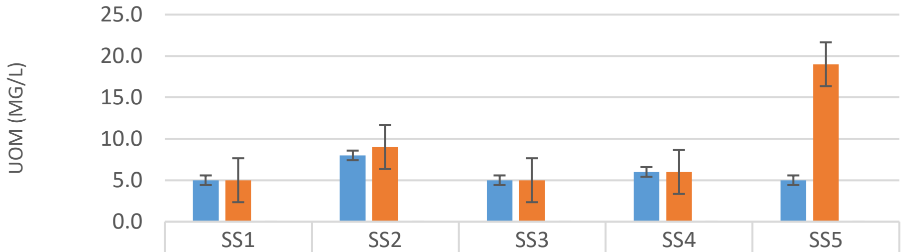
	SS1	SS2	SS3	SS4	SS5
May	5.2	6.5	2.9	3.1	3.0
July	3.3	6.9	2.5	3.0	1.7
Rand Water	0.0	0.0	0.0	0.0	0.0

Figure 5.2: Turbidity levels for each sample site during May and July 2018.

According to the South African National Standard (SANS 241:2011) turbidity levels may not exceed ≤1.0 NTU for operational compliance and ≤5.0 NTU for aesthetic compliance (DWA, 2013). Turbidity results varied across all sample sites during both May and July. In May, the turbidity levels were generally higher across all the sample sites compared to July (see Figure 5.2). These results are within the guidelines. Site SS2 was an exception, with a result of 6.9 NTU recorded during July compared to 6.5 NTU for May. Thus, turbidity levels at SS2 exceeded the guidelines. Rand Water had no turbidity results for any of the sample sites. There are no guidelines available as to the impact of turbidity on the health of livestock.

5.2.3 Biochemical Oxygen Demand (BOD)

BOD refers to the amount of O_2 dissolved in a water source. This O_2 can be utilised by micro-organisms, such as bacteria, during the decomposition of organic matter. BOD effectively measures the rate at which DO is needed during the process of decomposition of organic matter by micro-organisms (Naiman & Bilby, 1998).



	SS1	SS2	SS3	SS4	SS5
May	5.0	8.0	5.0	6.0	5.0
July	5.0	9.0	5.0	6.0	19.0
Rand Water	0	0	0	0	0

Figure 5.3: BOD levels for each sample site measured during May and July 2018.

The overall BOD levels for all sample sites varied with site SS1 recorded at 5.0 mg/L in May and <5.0 mg/L in July. BOD concentrations for site SS2 for May and July differed slightly at 8.0 mg/L for May and 9.0 mg/L for July. The BOD levels recorded at site SS3 were lower compared to site SS2 with <5.0 mg/L recorded for May and 5.0 mg/L recorded for July.

BOD levels for site SS4 were slightly higher at 6.0 mg/L for both May and July. The BOD levels for site SS5 were 5.0 mg/L in May and, in stark contrast to the other sample sites, 19.0 mg/L in July. Rand Water did not report BOD levels for any of the five sample sites. According to DWAF (1996a), the South African guidelines indicate acceptable BOD levels for drinking water are between 0 – 3.0 mg/L. There are no guidelines available as to the impact of BOD on the health of livestock.

5.2.4 Dissolved Oxygen (DO)

DO is vital to the survival of aquatic organisms in aquatic ecosystems. In polluted water sources (sewage) the DO levels significantly drop (<5.0 mg/L), suppressing respiratory function and resulting in the death of fish and other aquatic organisms (Abowei, 2010).

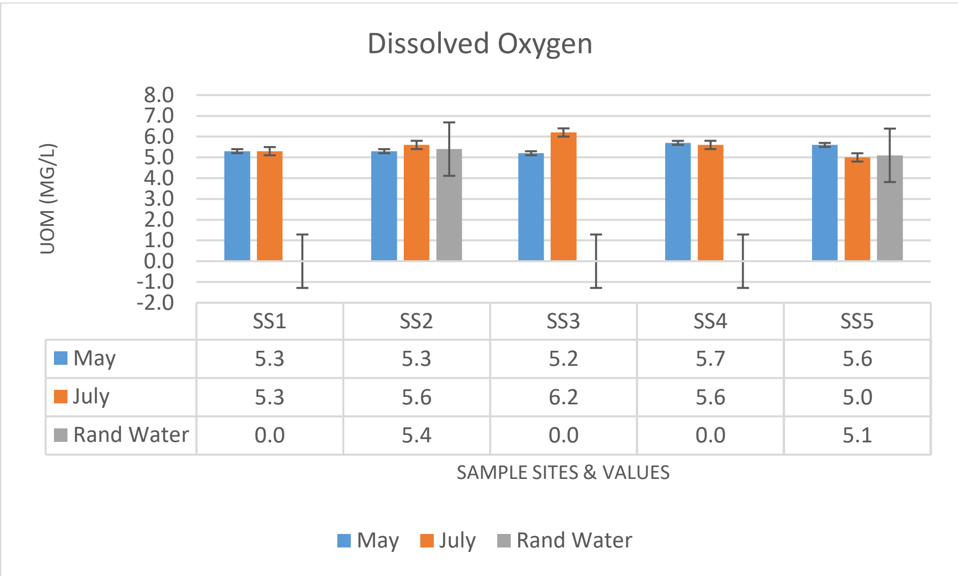


Figure 5.4: DO levels for each sample site measured during May and July 2018.

The differences in recorded DO levels at the Natalspruit sample sites in May and July are limited, indicating a consistent level of DO concentration. DO levels recorded for site SS1 for May and July were the same at 5.3 mg/L, with no data available from Rand Water for the sample site. DO concentrations for site SS2 indicated almost no difference in May and July with levels recorded at 5.3 mg/L and 5.6 mg/L, respectively. The recorded DO level by Rand Water for this site was 5.4 mg/L, thus similar to the study's results. Site SS3 yielded the greatest difference between May and July, with 5.2 mg/L and 6.2 mg/L, respectively.

Rand Water did not record DO levels for this site. For site SS4, there was almost no variation between May and July with readings of 5.7 mg/L and 5.6 mg/L, respectively. Rand Water did not record DO levels for this site. A minor difference in DO levels was detected at site SS5 with the May and July recordings being 5.6 mg/L and 5.0 mg/L, respectively. Rand Water recorded DO levels at 5.1 mg/L for this site. Lastly, there are no guidelines available as to the impact of DO levels on the health of livestock.

5.2.5 Total Dissolved Solids (TDS)

TDS is used as an indicator of water quality as it translates into the total amount of solids (mg/L) which remains after an evaporated water sample. These solids often originate from industrial, mining and agricultural activities (Fetter, 2018).

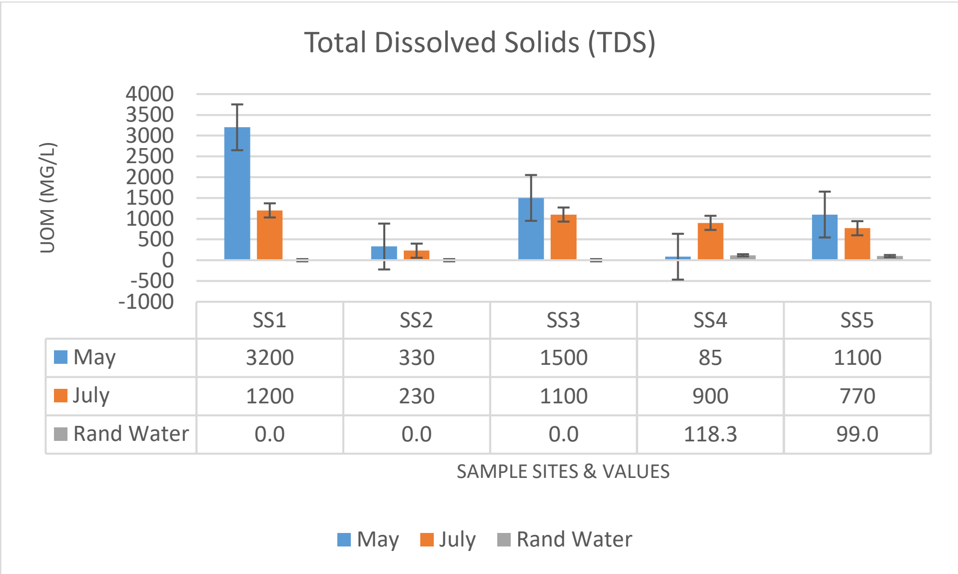


Figure 5.5: TDS levels for each sample site measured during May and July 2018.

The recorded TDS levels varied across all sample sites. All sites had higher TDS levels for July with the exception of site SS4. The TDS level recorded at site SS1 for May was 3 200 mg/L and for July 1 200 mg/L. No TDS levels were recorded by Rand Water for this site. TDS concentrations for site SS2 were lower compared to site SS1, which was 330 mg/L in May and 230 mg/L in July. No TDS levels were recorded by Rand Water for this site. TDS concentrations reported for site SS3 were higher compared to site SS2, with 1 500 mg/L recorded during May and 1 100 mg/L during July. No TDS levels were recorded by Rand Water for this site. TDS concentrations for site SS4 were at 85 mg/L for May and 900 mg/L for July, with Rand Water reporting levels of 118.3 mg/L.

TDS concentrations for site SS5 were 1 100 mg/L for May and 770 mg/L for July. Rand Water reported TDS levels for this site at 99 mg/L. According to DWAF (1996a), the South African guidelines indicate acceptable levels to be between 0 – 1 200 mg/L. Lastly, with regards to TDS and the health of livestock, the guidelines stipulate a target water quality range of 0 – 1 000 mg/L (DWAF, 1996c).

5.2.6 Total Hardness

Total hardness of water also referred to as "hard waters" coincides with the presence of $CaCO_3$, and Mg. High concentrations. Total hardness in water affects aquatic organisms such as fish (limiting growth), industrial operations and people utilising the water for domestic use through "scaling" which is the build-up of a powdery residue in household appliances and pipes (Boyd, 2000; Weiner, 2008).

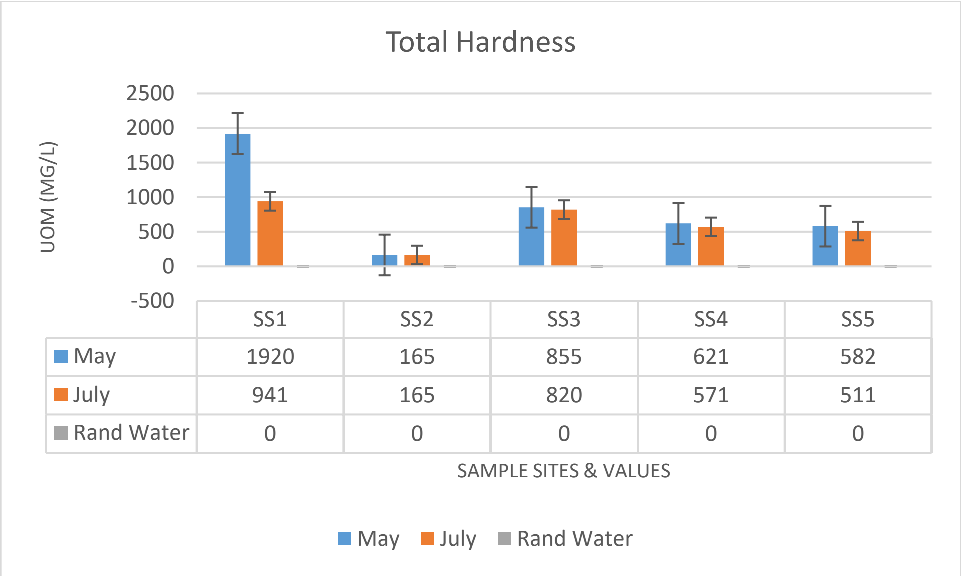


Figure 5.6: Total Hardness levels for each sample site measured during May and July 2018.

All of the sample sites recorded had higher TDS levels during May with the exception of site SS2 with the same total hardness levels for May and July. Total hardness levels for site SS1 (May) was recorded at 1920 mg/L and 941 mg/L during July. Site SS2 was reported to be the same at 165 mg/L for both sites. Total hardness levels were higher at site SS3 with recordings of 855 mg/L (May) and 820 mg/L during July. Sites SS4 recorded lower levels compared to site SS3 with 621 mg/L for May and 571 mg/L for July. Total hardness levels recorded for site SS5 were lower compared to site SS4 at 582 mg/L (May) and 511 mg/L and 511 mg/L (July).

5.2.7 Calcium Carbonate (Hardness) as $CaCO_3$

Water hardness is a physical parameter of a watercourse and is affected by measuring ions containing dissolved Mg and Ca in a said watercourse. Such minerals often derive from the surrounding soils and rock formations. These minerals, for example, contribute to the scaling of pipes in water treatment plants but are not considered hazardous to human health (Spellman, 2008).

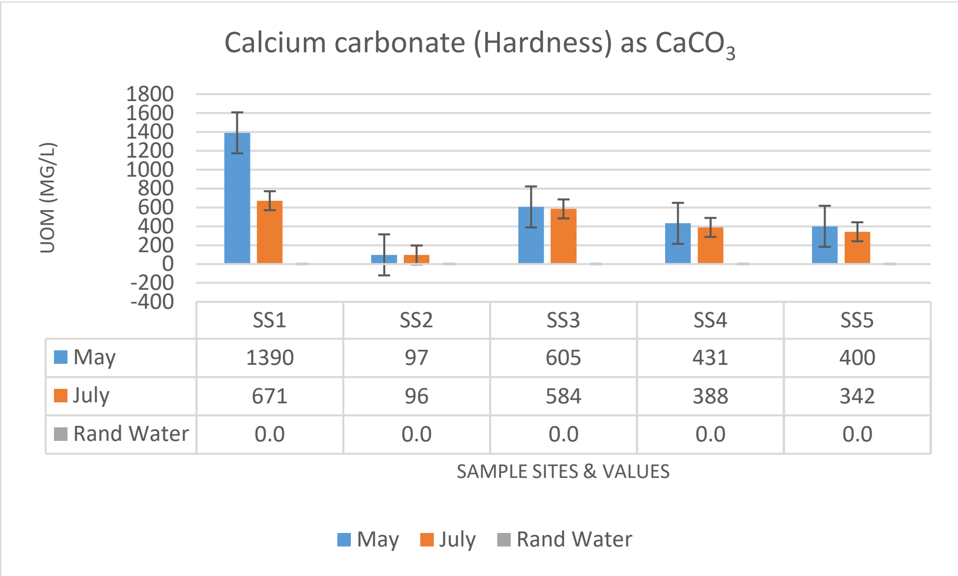


Figure 5.7: $CaCO_3$ levels for each sample site measured during May and July 2018.

May and July water hardness levels, recorded at sites SS2, SS3, SS4 and SS5 were similar. At site SS1 a considerable difference was noted between the May (1390 mg/L) and July water hardness levels (at 671 mg/L). No data regarding $CaCO_3$ was available from Rand Water for the five sample sites. There are also no recorded SANS 241:2011 standards with regards to the 2014 Blue Drop Limits. According to DWAF (1996c), livestock health guidelines stipulate a target water quality range of 0 – 1 000 mg/L.

5.2.8 Magnesium (Mg)

In conjunction with $CaCO_3$, Mg is a natural constituent of surface water which contributes to water hardness. The concentrations of Mg in a watercourse are influenced, just as $CaCO_3$, by various factors including the geology of the area, wetland catchment and surface runoff (Nazir & Deka, 2016).

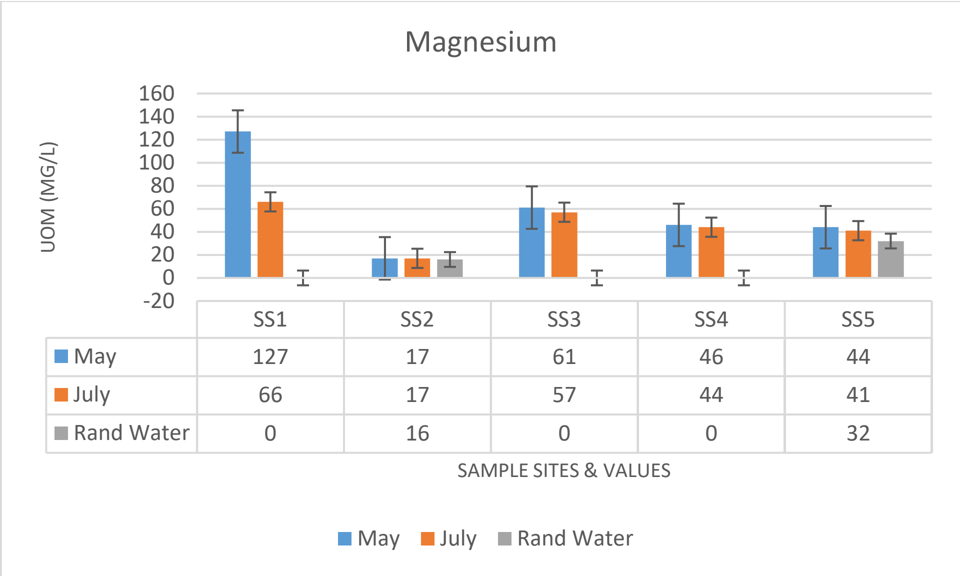


Figure 5.8: Mg levels for each sample site measured during May and July 2018.

The recorded Mg levels differed between the sample sites for both May and July. July's highest Mg levels were recorded at site SS1 with 66 mg/L and the lowest at site SS2 with 17 mg/L. In stark contrast, the highest Mg concentration recorded during May was 127 mg/L at site SS1. The Mg concentrations at sites SS3 and SS4 remained constant for May and July. Concentrations at SS3 were 61 mg/L (May) and 57 mg/L (July) and at site SS4 46 mg/L (May) and 44 mg/L (July). Sample results from Rand Water were only recorded for sites SS2 at 16 mg/L and SS5 at 32 mg/L. Site SS5 recorded results for May at 44 mg/L and for July at 41 mg/L. According to DWAF (1996a, 1996c), the acceptable levels of Mg for aquatic systems is between 0 – 0.18 mg/L, and 0 – 500 mg/L for the health of livestock. Thus, all sample sites exceeded the guideline for aquatic systems.

5.2.9 Chloride (Cl)

It is common practice for wastewater treatments plants to use Cl in the purification process before the water is discharged into a wetland or water source. The addition of Cl eliminates foul smelling odours, disinfects water and eliminates pathogenic micro-organisms (Spellman, 2009). Cl concentrations were present at all sample sites with levels at site SS1 at 85 mg/L during May (the highest recorded) and (considerably lower) during July at 56 mg/L. The recorded levels of Cl by Rand Water for SS1 is 57 mg/L, closely matching the July recording.

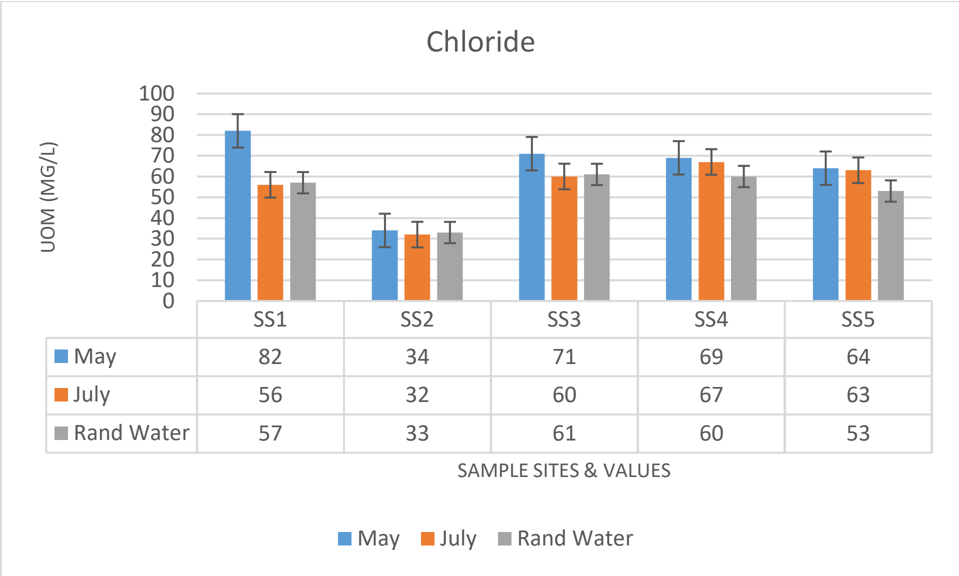


Figure 5.9: Cl levels for each sample site measured during May and July 2018.

The results differed slightly for sites SS1, SS3, SS4 and SS5 in May and July in comparison to the low Cl concentrations recorded at site SS2 with 32 mg/L (July) and 34 mg/L (May). Site SS1 concentrations were recorded at 82 mg/L (May) and 56 mg/L (July). Recorded concentrations for this site were recorded at 57 mg/L by Rand Water. The recorded Cl concentrations by Rand Water for site SS2 at 33 mg/L closely resembles the results recorded in this research study for May (34 mg/L) and July (32 mg/L). The Cl levels recorded at site SS3 were 60 mg/L (July) and 71 mg/L (May). The Cl levels at site SS4 were 67 mg/L (July) and 69 mg/L (May), respectively. The recorded Cl levels by Rand Water closely resembles recordings made by this research study with 61 mg/L for site SS3 and 60 mg/L for site SS4. Cl levels at site SS5 were recorded at 63 mg/L (July) and 64 mg/L (May) with the results from Rand Water at 53 mg/L. According to DWAF (1996a), there are no guidelines with regards to Cl levels in aquatic systems in South Africa, however, the guidelines for Cl levels in water used for drinking are 0 – 250 mg/L (DWA, 2013). Lastly, all the sample sites were well within the guidelines for the health of livestock which is 0 – 1 500 mg/L (DWAF, 1996c).

5.2.10 Nitrite (NO_2) and Nitrate (NO_3)

NO_2 and NO_3 occur naturally in the environment but, in excessive amounts, they can cause eutrophication of aquatic environments, such as rivers. This can, in turn, result in excessive growth of algal which depletes the O_2 in the water source, thus impacting negatively on aquatic life such as fish and macro-organisms (Liptak, 2003). Elevated levels can be attributed in part to sewage discharge.

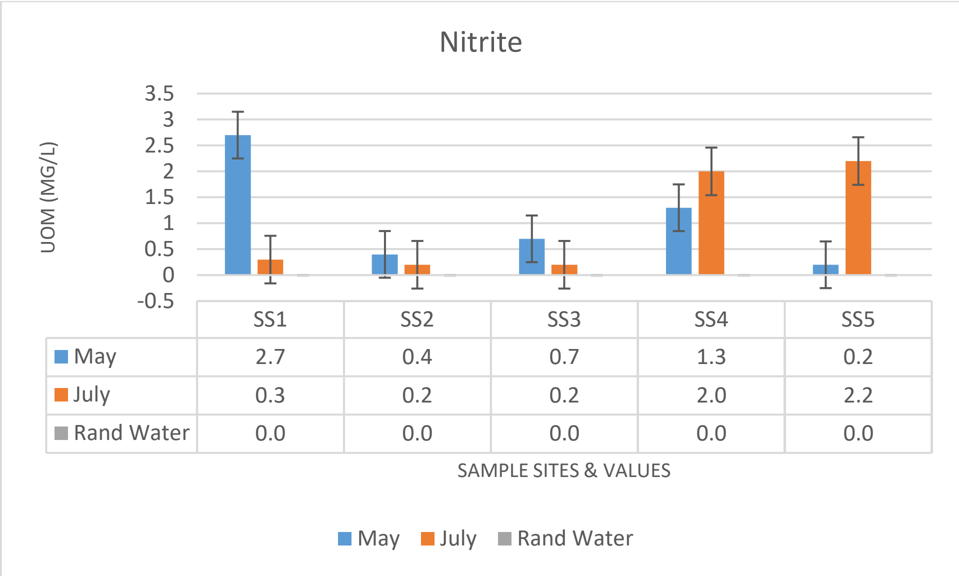


Figure 5.10: NO_2 levels for each sample site measured during May and July 2018.

In May, the NO_2 and NO_3 concentrations follow a similar trend, as per Figures 5.10 and 5.11. With regard to NO_2, as illustrated in Figure 5.9, the highest concentration was at site SS1 at 2.7 mg/L in May. A level of 0.3 mg/L was recorded for July. NO_2 concentrations at site SS2 were low, 0.4 mg/L for May and 0.2 mg/L for July. The NO_2 concentration at site SS3 (0.7 mg/L) and site SS4 (1.3 mg/L) increased slightly during May compared to site SS2. During July, site SS3's concentration was low at <0.2 mg/L and site SS4's level was at 1.3 mg/L for May. Recorded NO_2 concentrations at site SS5 during May was <0.2 mg/L in stark contrast to 2.2 mg/L for July. No recorded results were available for this sample site by Rand Water. There are no recorded guidelines with regards to the concentrations of NO_2 for aquatic systems. However, the DWA (2013) guidelines stipulate a NO_2 concentration of 0 – 0.9 mg/L for drinking water.

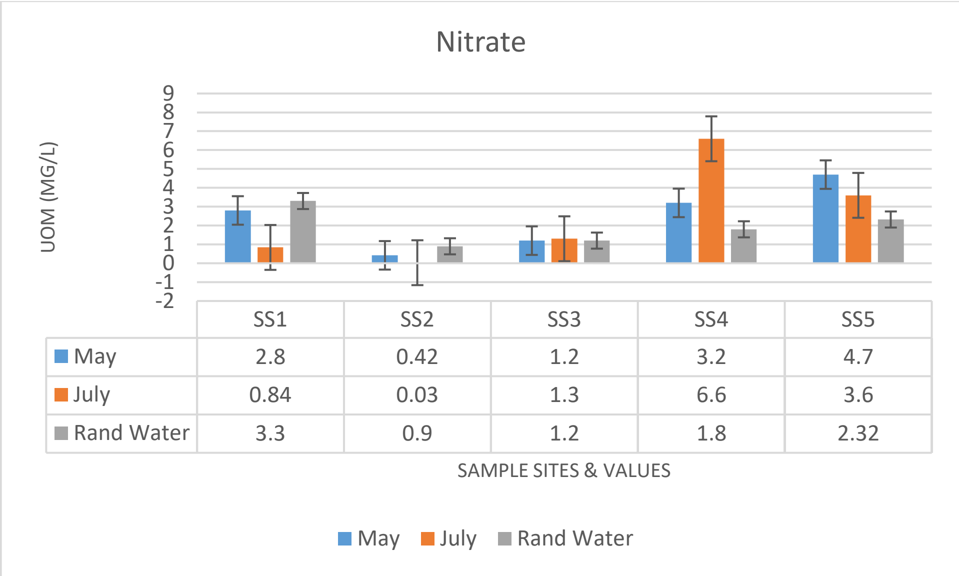


Figure 5.11: NO_3 levels for each sample site measured during May and July 2018.

NO_3 concentrations recorded at the sample sites for May and July varied. NO_3 levels recorded for site SS1 during May were 2.8 mg/L and during July 0.84 mg/L. The recorded NO_3 levels as supplied by Rand Water indicates a higher concentration of 3.3 mg/L. Likewise, site SS2 recorded the lowest NO_3 concentrations during May (0.42 mg/L) and July (0.03 mg/L). The recorded levels by Rand Water was 0.9 mg/L for site SS2. A slight increase in NO_3 concentrations was recorded at site SS3 compared to site SS2, with a fractional difference between May (1.2 mg/L) and July (1.3 mg/L). The NO_3 concentration recorded by Rand Water was 1.2 mg/L. NO_3 levels recorded at site SS4 during May (3.2 mg/L) and July (6.6 mg/L) were seemingly higher compared to the above-mentioned sample sites. Rand Water recorded NO_3 concentrations at 1.8 mg/L for this site. The recorded NO_3 concentrations for site SS5 for May was 4.7 mg/L and 3.6 mg/L for July. Rand Water recorded the NO_3 levels at 2.32 mg/L for this sample site. All of the sample sites recorded amounts well below the guidelines for the health of livestock (0 – 100 mg/L) (DWAF, 1996c). According to DWAF (1996a), there are no guidelines as to the concentration of NO_3 in aquatic systems in South Africa but the guidelines regarding NO_3 levels in drinking water recommend between 0 – 11 mg/L.

5.2.11 Sulphates (SO_4)

Water from mining activities, including AMD, contains SO_4. SO_4 are also present in the production of fertilisers as well as a by-product of industrial activities and sewage treatment plants. All of these activities can result in river pollution (Goel, 2006).

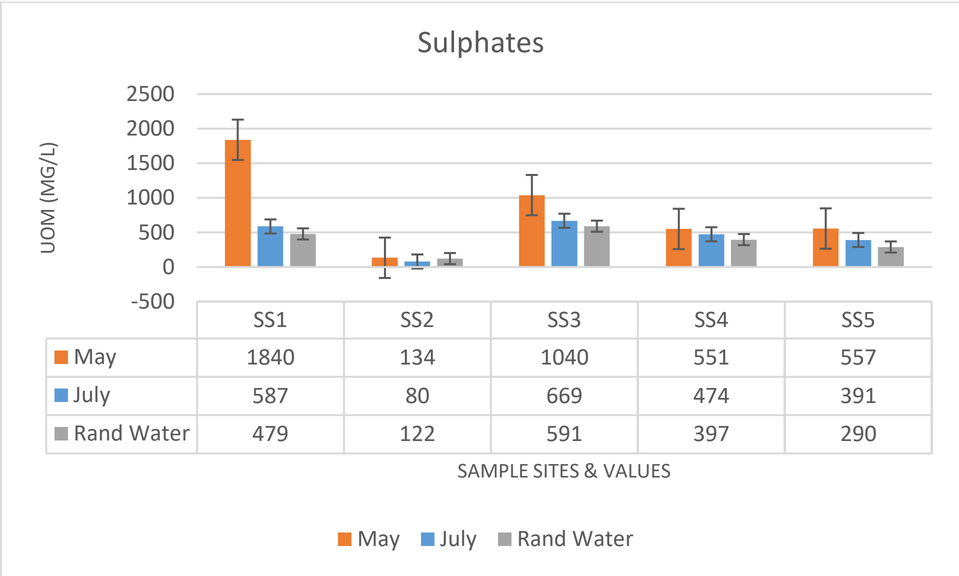


Figure 5.12: SO_4 levels for each sample site measured during May and July 2018.

SO_4 levels recorded for July were significantly higher than those for May at all sample sites. The SO_4 concentration for site SS1 was recorded at 1 840 mg/L (May) and at 587 mg/L (July). Rand Water recorded the SO_4 concentrations at 479 mg/L for site SS1. The lowest SO_4 concentrations were recorded at site SS2 with May recorded at 134 mg/L and July recorded at 80 mg/L. Rand Water recorded the SO_4 concentration at 122 mg/L. Sites SS3 and SS4, indicated high levels of SO_4 with concentrations recorded at site SS3 of 1040 mg/L (May) and 669 mg/L (July). SO_4 concentrations recorded at site SS4 were 474 mg/L for July and 551 mg/L for May. The SO_4 concentration documented by Rand Water for site SS3 was recorded at 591 mg/L and for site SS4 at 397 mg/L, respectively. SO_4 levels for site SS5 were recorded at 557 mg/L (May) and 391 mg/L (July). Rand Water recorded 290 mg/L of NO_3 for this site. According to DWAF (1996a), there are no guidelines regarding NO_3 concentrations in aquatic systems. However, according to DWA (2013), the guidelines dictate that SO_4 levels should be between 0 – 600 mg/L for drinking water. According to DWAF (1996c), a target water quality range of 0 – 1000 mg/L is advisable to maintain the health of livestock.

5.2.12 Orthophosphate (PO_4)

PO_4 occurs naturally in the environment but additional sources include sewage (domestic), pesticides, modern detergents and fertilisers which promote algal growth, eutrophication and O_2 depletion in water sources (Li & Liu, 2018).

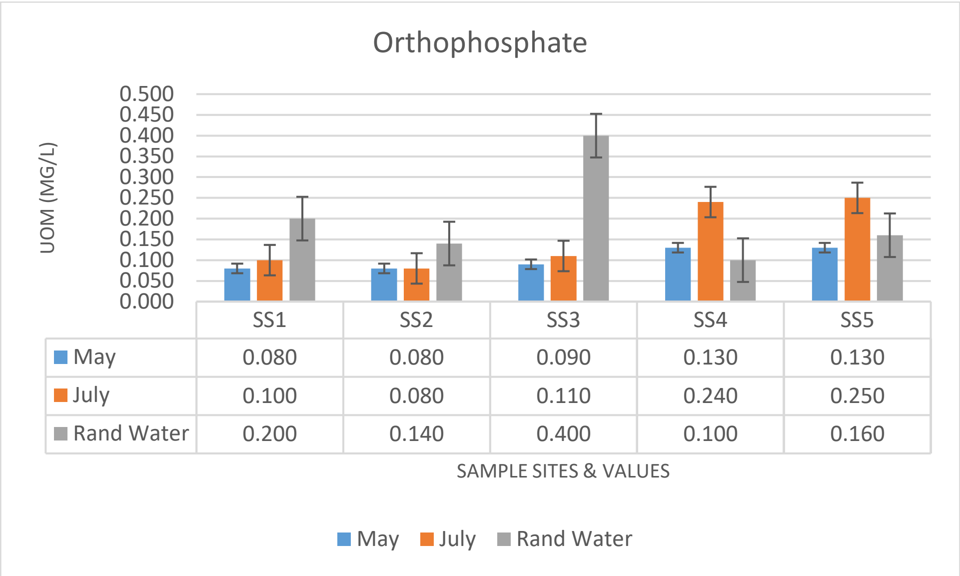
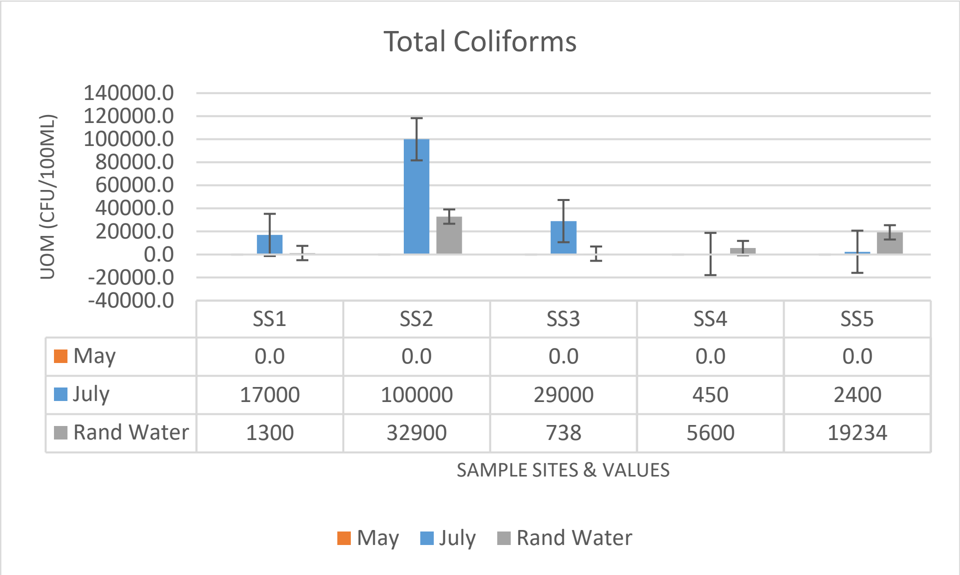


Figure 5.13: PO_4 levels for each sample site measured during May and July 2018.

The PO_4 concentrations vary across the sites for both May and July. The PO_4 concentrations for site SS1 during May was 0.08 mg/L and 0.1 for July, whilst the recorded PO_4 concentrations from Rand Water was roughly double (at 0.2 mg/L). The PO_4 concentrations for site SS2 were the same for May and July (at 0.08 mg/L). A slight increase in PO_4 concentration was recorded at site SS3 with 0.09 mg/L (May) and 0.11 mg/L (July). Rand Water recording this site at 0.4 mg/L. At site SS4, the PO_4 concentration in May was 0.13 mg/L and 0.24 mg/L during July. Rand Water reported PO_4 levels at 0.1 mg/L for this site. The PO_4 concentration for site SS5 was 0.13 mg/L for May and 0.25 mg/L for July. Rand Water recorded concentrations of 0.16 mg/L for this site. According to DWAF (1996a), the national guidelines indicate a level of 0 – 0.5 mg/L as acceptable for aquatic systems. There are no available PO_4 guidelines as to the health of livestock.

5.2.13 Total Coliforms

Total coliform bacteria occur naturally in soil but is also found in the intestines of animals and humans. It is often used as an indicator of water quality highlighting the presence of faecal matter in a water source (DWAF, 1996a).



	SS1	SS2	SS3	SS4	SS5
May	0.0	0.0	0.0	0.0	0.0
July	17000	100000	29000	450	2400
Rand Water	1300	32900	738	5600	19234

Figure 5.14: Total Coliform levels for each sample site measured during May and July 2018.

All samples taken during May had insufficient coliforms detected for analysis. However, total coliform concentrations were noted for July, with site SS1 recorded at 17 000 CFU/100 ml. Rand Water recorded a total coliform concentration of 1 300 CFU/100 ml for the site. The total coliform level at site SS2 was recorded at 100 000 CFU/100 ml. Rand Water recorded a total coliform level of 32 900 CFU/100 ml for the site. The recorded total coliform level at site SS3 was recorded at 29 000 CFU/100 ml with Rand Water indicating 738 CFU/100 ml. The reported total coliforms at site SS4 were 450 CFU/100 ml, the lowest compared to all of the other sites sampled in July. The recorded concentrations from Rand Water at this site was higher at 5 600 CFU/100 ml. Total coliform concentration for site SS5 was recorded at 2 400 CFU/100 ml with Rand Water reporting a total coliform level of 19 234 CFU/100 ml. According to DWAF (1996a), South African guidelines indicate that total coliform concentrations should be at 0 CFU/100 ml for drinking water. The guidelines pertaining to the health of livestock stipulate a target water quality range of 0 – 200 mg/L (DWAF, 1996c).

5.3 Conclusion

In this research study, the physicochemical parameters of collected water samples from the Natalspruit were analysed. The results were tabulated and presented to facilitate the comparison of sample sites to one another, as well as to the National Guidelines as set out by the Department of Water Affairs and the former Department of Water Affairs and Forestry. The detailed data are presented in Appendix 10 and 11. The following chapter, Chapter 6 will report on the results of the soil/sediment as analysed by an accredited laboratory.

CHAPTER 6: SOIL RESULTS

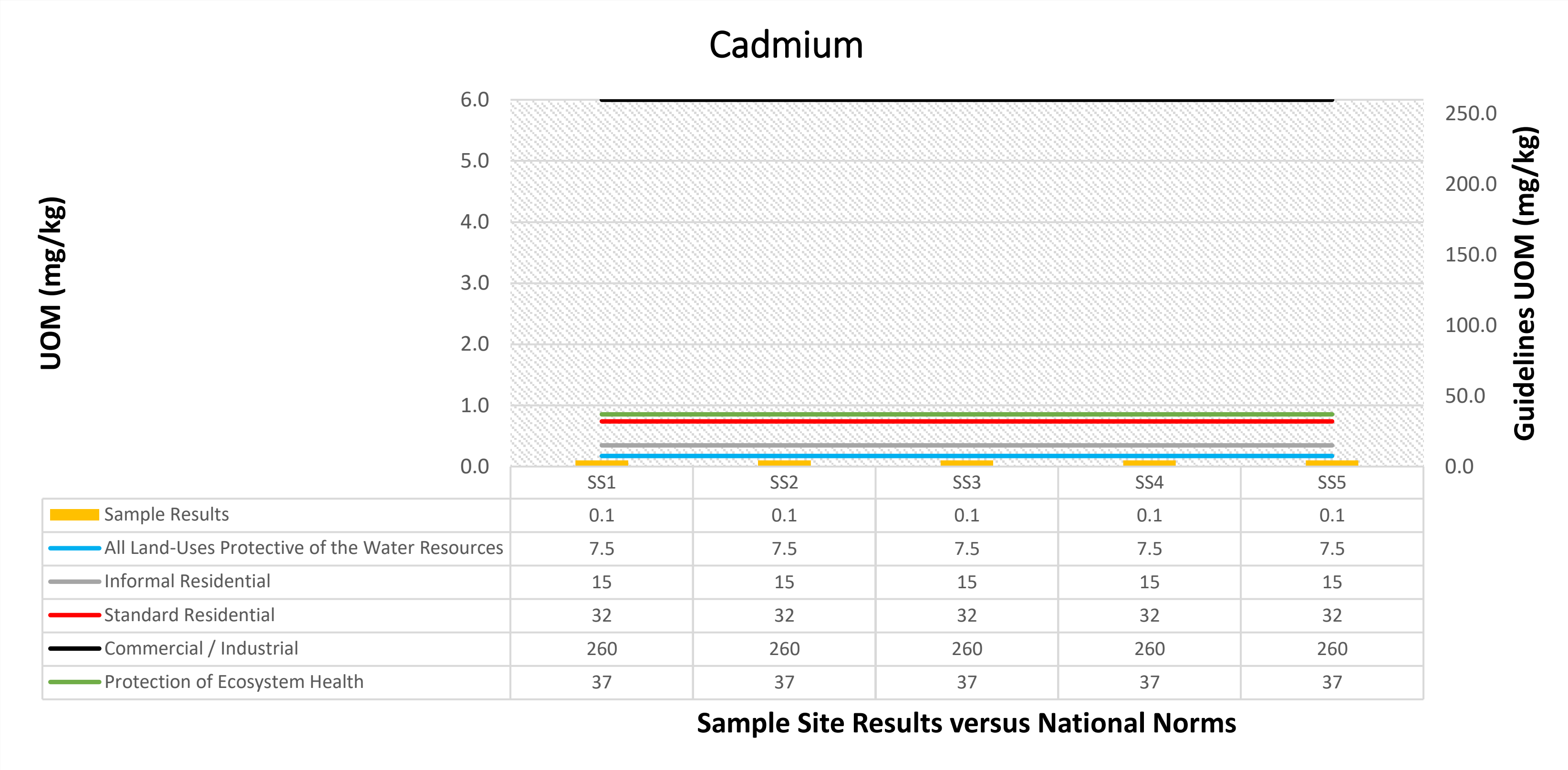
6.1 Introduction

This chapter presents the analysis results of soil sample samples collected at the end of July 2018. No rainfall was recorded for the study area during July 2018 and the average daily temperature for this month was 12 °C. The soil samples, collected in July, were analysed to determine the presence and levels of Cd, Cr, Cu, Ni, Pb, Zn and Hg. The results were tabulated in charts and comparisons were made between the results yielded by the different sample sites. These results were also compared to the National Norms and Standards for the Remediation of Contaminated Land and Soil Quality in South Africa (DEA, 2013).

6.1.1 Cadmium (Cd)

Cd occurs naturally in soil, its levels and presence depending on the geological composition of an area. However, anthropocentric activity (including agriculture, fertilisers and sewage) is generally considered a more common way through which Cd is introduced into the soil. Cd is absorbed by plants and has an accumulative effect if these plants are consumed as agricultural crops. Such consumption should, therefore, be avoided. Cd can affect a wide range of biota if present in a wetland system. It is considered toxic to humans and livestock as it damages the renal system (Singh & McLaughlin, 1999).

The Cd concentration for all sample sites was recorded as <0.1 mg/kg. This is considered well below the national norms and guidelines of 7.5 mg/kg for all land uses protective of water, 15 mg/kg for informal residential use, 32 mg/kg for standard residential use, 260 mg/kg for commercial and industrial use and 37 mg/kg for the protection of ecosystem health (DEA, 2013). As illustrated in Figure 6.1, the recorded values for SS1, SS2, SS3, SS4 and SS5, therefore, suggest that the presence of Cd does not pose health risks to either humans and/or the environment.



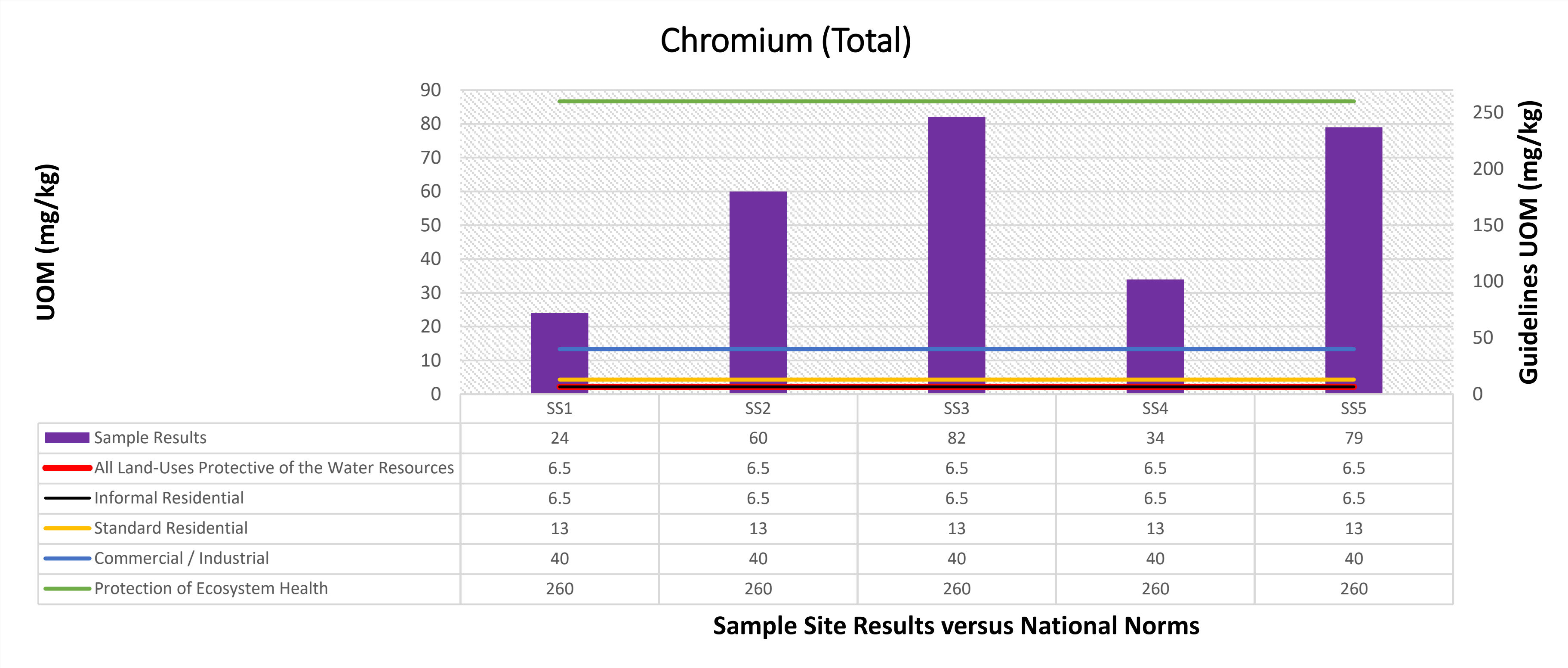
	SS1	SS2	SS3	SS4	SS5
Sample Results	0.1	0.1	0.1	0.1	0.1
All Land-Uses Protective of the Water Resources	7.5	7.5	7.5	7.5	7.5
Informal Residential	15	15	15	15	15
Standard Residential	32	32	32	32	32
Commercial / Industrial	260	260	260	260	260
Protection of Ecosystem Health	37	37	37	37	37

Figure 6.1: Cd concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.2 Chromium (Cr) (Total)

Cr occurs naturally in the environment as chromite ($FeCr_2O_4$) which is easily soluble and dependent on specific pH conditions. It is commonly used by industries for plating, tanning and the production of textile dyes. In recent years, its widespread use has contributed to increased environmental pollution. Cr is introduced to watercourses and/or rivers via direct discharge from industrial activities, leaching of soil and atmospheric deposition from solid wastes and other activities that generate Cr by-products. Cr levels in soil or sediment vary according to the composition of the sediment or soil and are increased through anthropocentric actions. This can be detrimental to aquatic ecosystems as Cr is effortlessly absorbed and stored by plants. It can also easily leach into deeper sediment or soil layers that could subsequently pollute groundwater. Over time, Cr transforms (oxidation, sorption, dissolution and reduction) as it enters sediment or soil. Furthermore, the accumulation of Cr in plants leads to stunted growth, genotoxicity and phytotoxicity which results in contamination of the food chain that, in turn, poses health risks to aquatic life, livestock and humans. The most common exposure is orally through food (the meat of animals, vegetables and fruit) and water. Negative impacts on the health of humans and animals include increased instances of stomach cancer, liver cancer, lung cancer (atmospheric exposure), kidney cancer, gastrointestinal complications, living cell death (cytotoxicity), tumour formation (carcinogenicity) and DNA damage (mutagenicity). Cr is, thus, considered extremely toxic when consumed orally (Oliveira, 2012; Sun, Brocato & Costa, 2015; Guertin, Avakian & Jacobs, 2016).

The Cr concentrations recorded at all sample sites varied but were all higher than the levels suggested by the national norms and guidelines, as per Figure 6.2. The Cr level for SS1 (at 24 mg/kg) was the lowest of all the sample sites but higher than the guidelines for all land-uses protective of water resources (6.5 mg/kg), informal residential (6.5 mg/kg) and standard residential use (13 mg/kg). The Cr level recorded at SS2 was the third highest of all the sample sites with a value of 60 mg/kg and thus higher than the levels suggested in the guidelines with the exception of those relating to the protection of ecosystem health (260 mg/kg). The Cr concentration for SS3 was the highest of all the sample sites at 82 mg/kg. This site exceeded all the guideline levels with the exception of the protection of ecosystem health. The Cr level reported for SS4 was the second lowest of all the sample sites, at 34 mg/kg, still exceeding the levels suggested in the guidelines for all land-uses protective of water resources (6.5 mg/kg), informal residential (6.5 mg/kg) and standard residential use (13 mg/kg). The Cr concentration for SS5 was 79 mg/kg, the second highest level when compared to other sample sites that exceeded the guidelines with the exception of guidelines for the protection of ecosystem health (260 mg/kg).



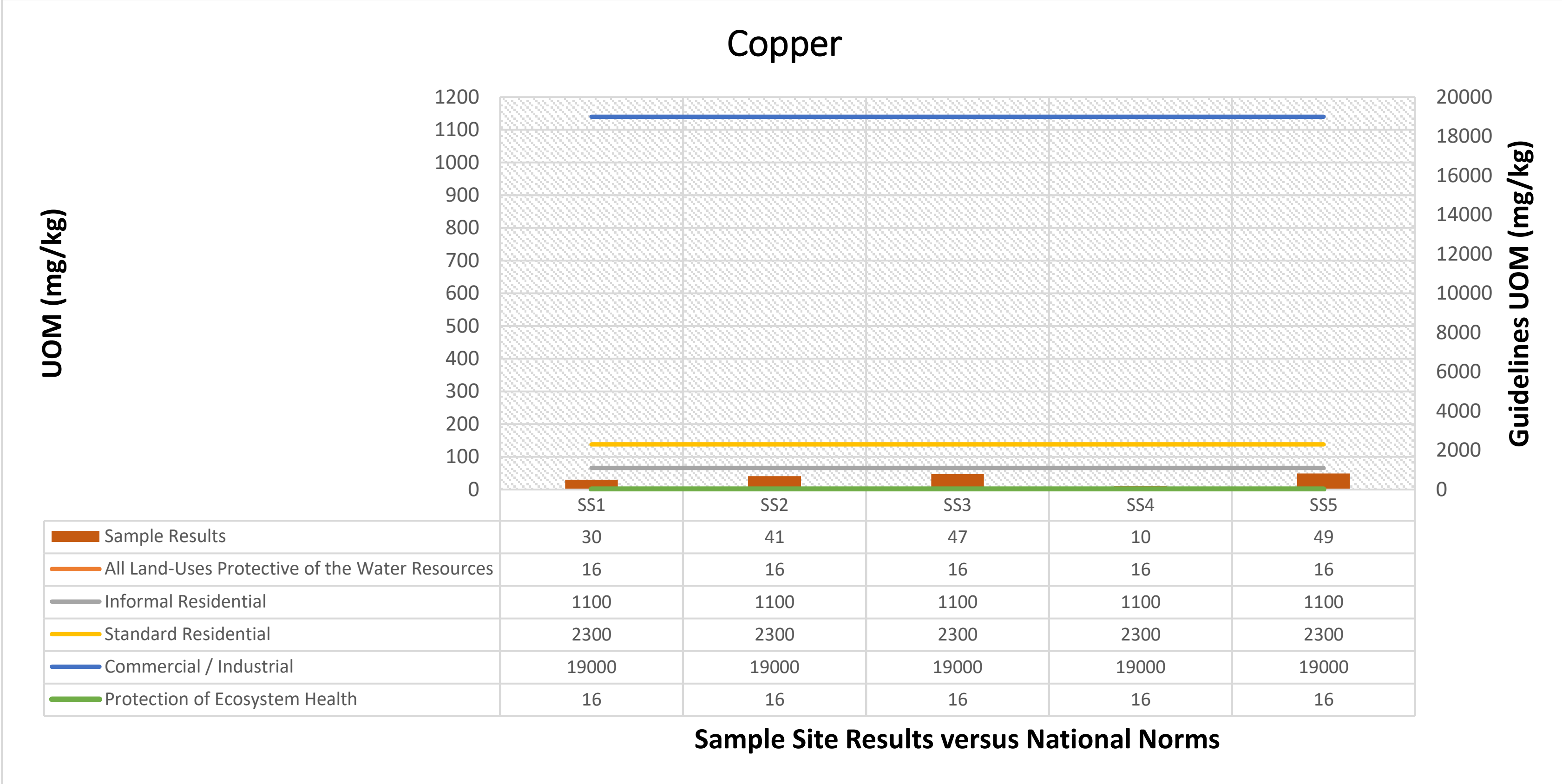
	SS1	SS2	SS3	SS4	SS5
Sample Results	24	60	82	34	79
All Land-Uses Protective of the Water Resources	6.5	6.5	6.5	6.5	6.5
Informal Residential	6.5	6.5	6.5	6.5	6.5
Standard Residential	13	13	13	13	13
Commercial / Industrial	40	40	40	40	40
Protection of Ecosystem Health	260	260	260	260	260

Figure 6.2: Cr concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.3 Copper (Cu)

A limited concentration of Cu is essential to plant growth and a lack thereof could result in lower crop yields. However, the excessive use of fertilisers containing high quantities of Cu in agricultural practices has led to the contamination of soil. The Cu present in fertilisers is highly mobile, when one compares it to naturally occurring Cu, as it usually leaches into the deeper layers of soil, depending on the texture and type of present. Ultimately, excessive Cu accumulation from agricultural practices, such as the excessive use of fertilisers, contaminates both surface and groundwater, posing health risks to both humans and animals when it enters the food chain (Stanislawska-Glubiak & Korzeniowska, 2018).

Recorded Cu concentrations for the five sample sites were varied but within the national norms and guidelines with the exception of the land-use protective of the water (16 mg/kg) and the protection of ecosystem health (16 mg/kg) as per Figure 6.3. The Cu concentration for SS1 was recorded at 30 mg/kg, the third lowest when compared to the other sample sites but exceeding all land-use protective of the water (16 mg/kg) and the protection of ecosystem health at 16 mg/kg. The Cu concentration for SS2 was 41 mg/kg, higher than both SS1 and SS4. This site also exceeded the all land-use protective of the water guidelines (16 mg/kg) and the protection of ecosystem health (16 mg/kg). The Cu concentration for SS3 was recorded at 47 mg/kg, the second highest of all the sample sites and also exceeding the all land-use protective of the water guidelines (16 mg/kg) and the protection of ecosystem health guidelines (16 mg/kg). The Cu concentration for SS4 was recorded at 10 mg/kg, the lowest compared to the other sample sites as well as the national norms and guidelines. The Cu concentration at SS5 was established at 49 mg/kg, the highest when compared to all the other sample sites but still lower than the national norms and guidelines with the exception of all land-use protective of the water guidelines and the protection of ecosystem health guidelines.



	SS1	SS2	SS3	SS4	SS5
Sample Results	30	41	47	10	49
All Land-Uses Protective of the Water Resources	16	16	16	16	16
Informal Residential	1100	1100	1100	1100	1100
Standard Residential	2300	2300	2300	2300	2300
Commercial / Industrial	19000	19000	19000	19000	19000
Protection of Ecosystem Health	16	16	16	16	16

Figure 6.3: Cu concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.4 Nickel (Ni)

Ni possesses carcinogenic properties and is toxic if it enters the food chain. Ni is also detrimental to biological systems, stunting the growth of animals, humans and plants (Hambley, 1996; Guo *et al*., 2018). Ni is a by-product of various industrial activities including smelting and mine water discharge. It is usually present in higher concentrations in water during periods of high rainfall because of the elevated surface runoff.

The Ni concentrations recorded at the sample sites were varied. The Ni concentration at SS1 was the lowest of all the sample sites at 30 mg/kg and thus within the national norms and guidelines (see Figure 6.4). The Ni concentration for SS2 was 49 mg/kg, the third highest of all the sites, but still in compliance with the national norms and guidelines. The Ni concentration for SS3 was 91 mg/kg, the second highest of all the sites, within the national norms and guidelines but equal to the guideline for all land-uses protective of water (91 mg/kg). The Ni concentration reported for SS4 was 31 mg/kg, the second lowest level when compared to the other sample sites but still within the national norms and guidelines. The Ni concentration for SS5 was recorded at 148 mg/kg, the highest of all the sites but within the national norms and guidelines with the exception of all land-uses protective of water (91 mg/kg).

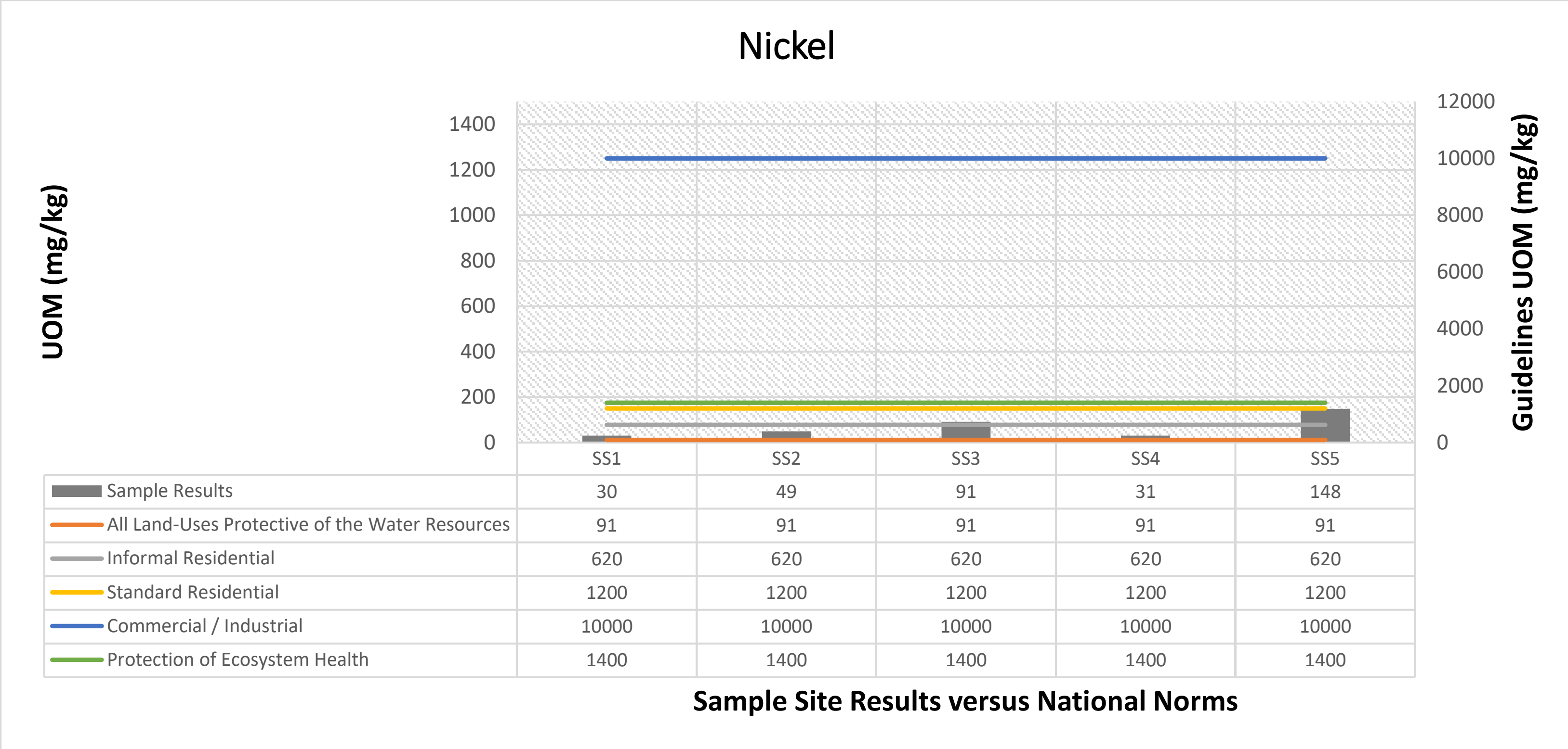
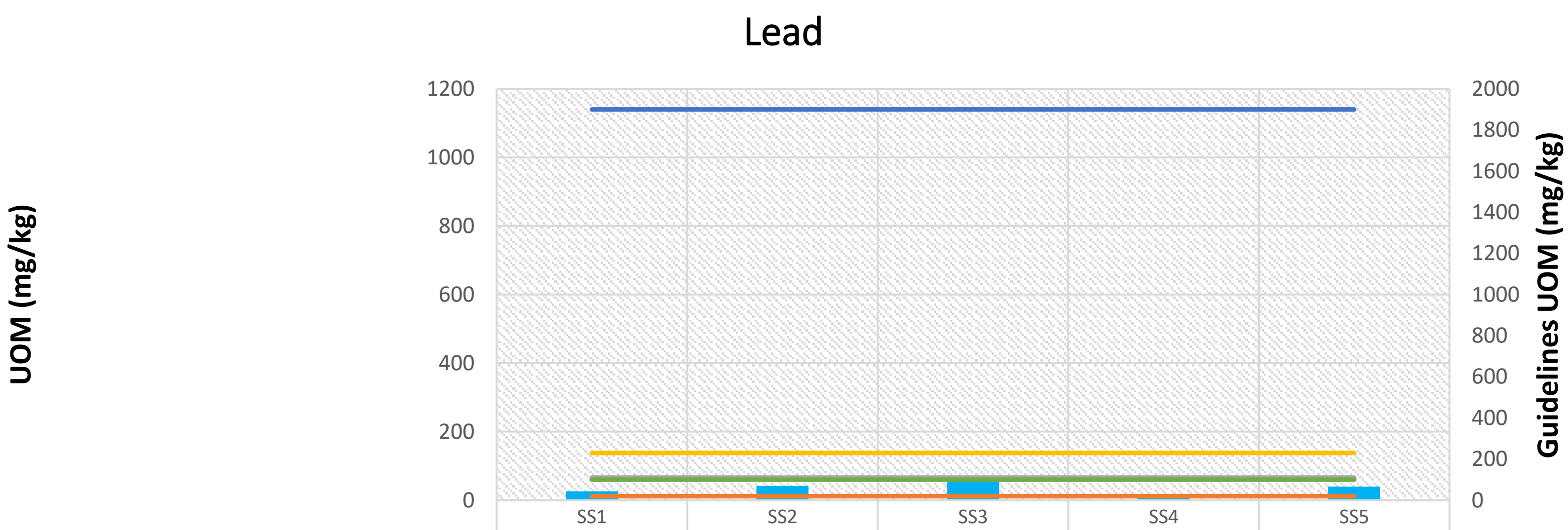


Figure 6.4: Ni concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.5 Lead (Pb)

Humans have for millennia used Pb. It is regarded as an ancient metal that plays an important role in industrial practices. Pb accumulation in soil results in the pollution of surface waters and contamination of plants. Anthropocentric activities such as smelters, manufacturing plants (stack emissions), mining and disposal processes contribute to increased Pb concentrations in the environment. At high doses, over a prolonged period, Pb is toxic to humans, animals and plants as it inhibits seed generation. The consumption of plants, such as vegetables, which grow in highly contaminated areas results in the entry of Pb into the food chain. High Pb concentrations can paralyse the gizzards of avi-faunal species, resulting in starvation and ultimately death. The effect of high Pb levels on humans include anaemia, renal failure, delirium, miscarriage and stillbirth (Yu, Landis & Sofield, 1998).

Pb concentrations varied across all the sample sites with SS1 at 26 mg/kg, the second lowest of all the sites (see Figure 6.5). Compared to the national norms and guidelines, SS1 was within all the guidelines with the exception of the all land-uses protective of water guideline (20 mg/kg). The Pb concentration at SS2 was 42 mg/kg, the second highest of all the sites. This result exceeds the all land-uses protective of water guideline (20 mg/kg). The Pb concentration for SS3 was 55 mg/kg, the highest recorded at any of the sample sites and exceeding the all land-uses protective of water guideline (20 mg/kg). The Pb concentration for SS4 was recorded at 6.7 mg/kg, the lowest of all the other sample sites and within all the national norms and guidelines. The Pb concentration for SS5 was recorded at 40 mg/kg, the third highest compared to the other sample sites, exceeding the all land-uses protective of water guideline (20 mg/kg).



	SS1	SS2	SS3	SS4	SS5
Sample Results	26	42	55	6.7	40
All Land-Uses Protective of the Water Resources	20	20	20	20	20
Informal Residential	110	110	110	110	110
Standard Residential	230	230	230	230	230
Commercial / Industrial	1900	1900	1900	1900	1900
Protection of Ecosystem Health	100	100	100	100	100

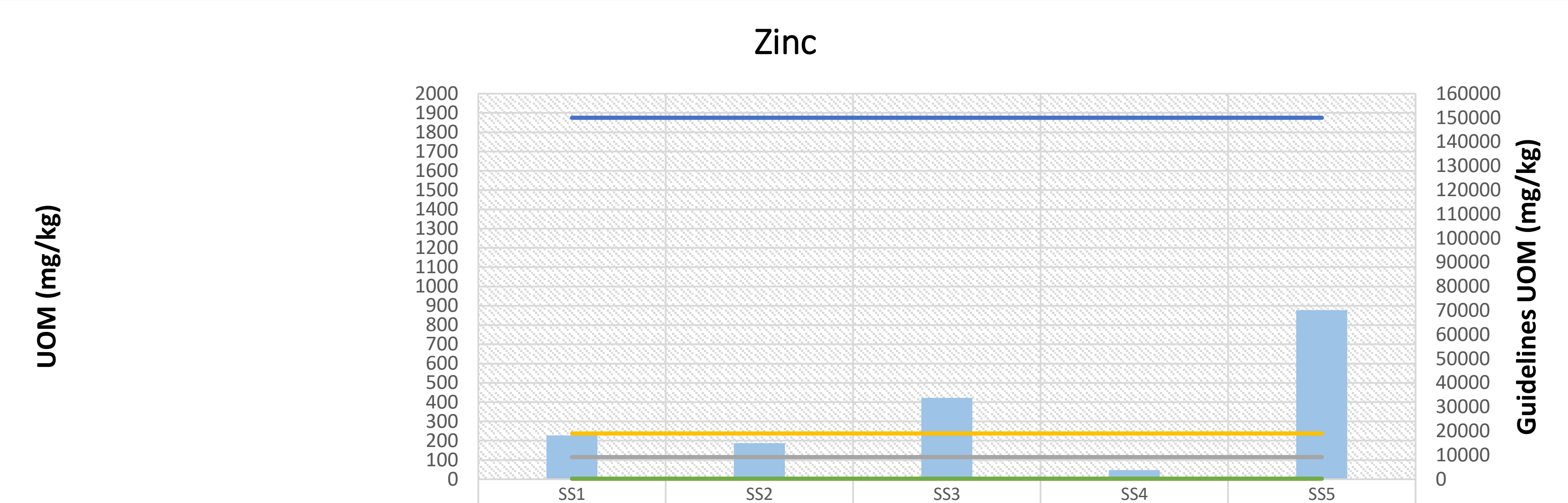
Sample Site Results versus National Norms

Figure 6.5: Pb concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.6 Zinc (Zn)

Zn is one of the most mobile of heavy metals. Its presence in soil can exercise a phytotoxic effect on plants and crops. High Zn concentrations inhibit plant growth and affect the metabolism of micro-organisms present in the soil. Zn accumulates in plants and animals, such as fish, which, when consumed by humans, interfere with the body's ability to metabolise Cu, thus resulting in gastrointestinal effects and immunotoxicity (Hung *et al*., 2016; Baran *et al*., 2018). High concentrations of Zn over extended periods thus impacts negatively on the health of humans and animals. The soil pH and organic matter also play an important role in the bioavailability of Pb in soil. Zn may also be introduced to the environment as a by-product of anthropocentric activities such as mining, landfilling and waste treatment. Zn leaches out of landfills into groundwater and rivers.

Zn concentrations varied across all the sample sites. SS1 recorded 228 mg/kg (as Figure 6.6), the third highest of all the sites but still within the limits set out by the national norms and standards. The Zn concentration for SS2 was 188 mg/kg, the second lowest of all the sites, but within the limits of the national norms and guidelines. The Zn concentration for SS3 was 423 mg/kg, the second highest of all the sites. This level exceeds the limit set out by all land uses protective of the water guidelines (240 mg/kg) as well as the protection of ecosystem health guidelines (240 mg/kg). The Zn concentration for SS4 was the lowest for all sites and within the limits of the national norms and standards. Lastly, the Zn concentration for SS5 was the highest of all the sites at 878 mg/kg. This level exceeds the limits of all land uses protective of the water guidelines (240 mg/kg) as well as the protection of ecosystem health guidelines (240 mg/kg).



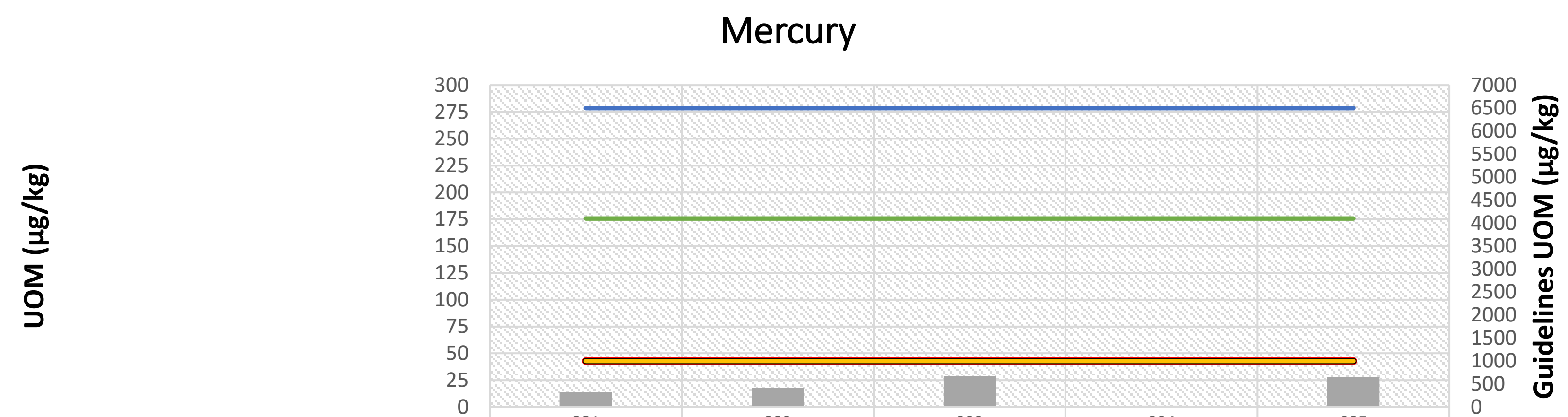
	SS1	SS2	SS3	SS4	SS5
Sample Results	228	188	423	48	878
All Land-Uses Protective of the Water Resources	240	240	240	240	240
Informal Residential	9200	9200	9200	9200	9200
Standard Residential	19000	19000	19000	19000	19000
Commercial / Industrial	150000	150000	150000	150000	150000
Protection of Ecosystem Health	240	240	240	240	240

Figure 6.6: Zn concentrations in the soil samples compared to the National Norms and Guidelines.

6.1.7 Mercury (Hg)

Hg is a product of mining activities and is utilised in several industrial production activities. It leaches into the ground and surface water during periods of high rainfall. Hg is toxic and can cause brain and liver damage when ingested. Plants absorb Hg, are known to store, and, thus, accumulate this heavy metal. Thereby Hg can find its way into the food chain. When consumed by humans and animals, it results in harmful effects on the central nervous system (Jiménez, Cabañas & Lefebvre, 2014).

Hg concentrations varied across the sample sites. At SS1 it was 14 µg/kg, the second lowest of all the sites and within the limits of the national norms and standards (see Figure 6.7). The Hg concentration at SS2 was 18 µg/kg, the third highest of the sites but within the limits of the national norms and standards. The Hg concentration at SS3 was the highest at 29 µg/kg, although still within the limits of the national norms and standards. The Hg concentration at SS4 was 1.3 µg/kg, within the limits of the national norms and standards. The Hg concentration for SS5 was the second highest of all the sites, at 28 µg/kg, but still within the limits of the national norms and standards.



	SS1	SS2	SS3	SS4	SS5
Sample Results	14	18	29	1.3	28
All Land-Uses Protective of the Water Resources	1000	1000	1000	1000	1000
Informal Residential	1000	1000	1000	1000	1000
Standard Residential	1000	1000	1000	1000	1000
Commercial / Industrial	6500	6500	6500	6500	6500
Protection of Ecosystem Health	4100	4100	4100	4100	4100

Figure 6.7: Hg concentrations in the soil samples compared to the National Norms and Guidelines.

6.2 Conclusion

The soil samples in this study were used to assess the recoverable metals in the soil, sludge and sediment of the Natalspruit. The results were tabulated and presented to facilitate a comparison amongst the sample sites as well as to the levels set out by the Department of Environmental Affairs (NEMA: Waste Act, 2008 [Act No. 59 of 2008]: National norms and standards for the remediation of contaminated land and soil quality). The detailed data are presented in Appendix 12. Chapter 7 will describe the SASS 5, EIS and PES assessment results of the Natalspruit and its associated wetlands.

CHAPTER 7: RESULTS AND DISCUSSION OF BIOMONITORING USING SASS 5

7.1 Introduction

The assessment of macro-invertebrates is one way to determine the overall state of health of rivers. This assessment method is considered reliable as macro-invertebrates are easily visible and sensitive to ecological change associated with anthropocentric activities such as mining as well as industrial and urban-residential activities. However, it is important to note that seasonal changes profoundly affect the distribution, presence and habitat preferences of macro-invertebrates in rivers (Rosenberg & Resh, 1993). For this research study, the assessment was conducted during July 2018. A well-known and widely recognised method of investigating river health in South Africa is to conduct a macro-invertebrates audit using the South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers (Dickens & Graham, 2002).

7.2 Reason and Background for Biomonitoring

The biomonitoring assessment was conducted in conjunction with an EIS assessment as well as a PES assessment. This was done to determine the overall state of health of the Natalspruit and its associated wetlands. As stipulated, the biomonitoring audit was conducted in accordance with the SASS 5 protocol. This chapter presents the results obtained in July 2018 and indicates the spatial variation of macro-invertebrates between the chosen sample sites taking into consideration:

- the overall water quality of the Natalspruit, and;
- the presence of aquatic organisms such as macro-invertebrates during the dry season**.**

7.2.1 The suitability of the chosen sites

These sites were chosen as they were easily accessible and safe. Care was taken to ensure that the chosen sites displayed biotope diversity. The chosen sites were judged to ably support a diversity of aquatic macro-invertebrates. Together with the analysis of the physicochemical parameters of the water quality and sediment analysis - to determine the overall condition of the Natalspruit – the sites were deemed suitable to establish the potential environmental impacts on the biological communities of the Natalspruit.

Table 7.1: Natalspruit bio-monitoring sites, July 2018**.**

Sample Site	Description	Latitude	Longitude
SS1	Situated beneath the bridge in Sarel Hattingh Street crossing over the Natalspruit	26°15'35.99"S	28°12'34.99"E
SS2	Situated on the outskirts of Katlehong located next to Masakhane Street	26°18'0.35"S	28° 9'32.95"E
SS3	Situated roughly 700 meters SE from ERWAT, a sewage water treatment plant	26°20'29.34"S	28°10'21.54"E
SS4	Situated south of the second sewage water treatment works located along the Natalspruit	26°22'7.89"S	28°10'31.46"E
SS5	Situated next to the R550, Heidelberg Road	26°25'33.95"S	28° 9'53.80"E

7.3 Eco classification: PES and EIS

A SASS 5 assessment on wetland health was conducted at each sample site using the indices of Macfarlane *et al.* (2009). The assessment was consequently interpreted within the context of ecological importance and sensitivity. These indices: (1) describe and indicate the integrity of wetlands; (2) supply impact scores and health categories associated with changes in hydrology; (2) summarise health scores associated with vegetation changes; (4) present impact scores associated with geomorphological changes; (5) afford insight into EIS ratings and, (6) facilitate a summary of present wetland health assessed for the Natalspruit as well as a health status of assessed sample sites.

7.3.1 SASS 5, Advantages and Disadvantages

SASS 5 (South African Scoring System Version 5) is a technique used for the rapid assessment of rivers in order to determine the general water quality. The SASS 5 biomonitoring assessment is regarded as a valuable tool for the management of aquatic water resources, especially as macro-invertebrates can be viewed with the naked eye (Dickens & Graham, 2002). SASS 5 is also good for assessing aquatic health and river condition as it is a measure that delivers consistent results across different biotopes (Dickens & Graham, 2002). The advantages of SASS 5 are that it is quick, able to assess potential problems, can set environmental objectives for rivers, can indicate, predict and assess developmental impacts on an ecosystem; and, lastly, it is viewed as an integral part to determining the Ecological Reserve. There are also some disadvantages. The researcher can encounter polluted water or other pollutants, researchers have to interact with the river and so there is the possibility of drowning. Sampling can only be performed when river flow is low. Lastly, dangerous animals, such as crocodiles do reside in some rivers and is a potential hazard.

7.4 SASS 5 Biomonitoring Results

7.4.1 Biotopes Sampled

At each of the sample sites, a variety of biotopes were collected to ensure diversity of macro-invertebrates.

Stone biotopes stones (stones out of current - or SOOC - and stones in current - or SIC) of varying sizes, ranging from 1 to 4 cm, as well as bedrock/large stones, exceeding 25 cm, in areas of fast (SIC) and slow flowing water (SOOC) were sampled by means of kick-sampling. This SIC sampling method was achieved by placing the net downstream and then kicking the riverbed (for roughly two minutes). The SOOC kick-sampling method (for roughly one minute) of the biotope dislodges macro-invertebrates ensuring their collection in the net by allowing the current to carry the loosened biota into the said net.

Larger stones and rocks were turned over by hand or dislodged by wader boots, thus freeing macro-invertebrates, which were then collected with the net that was strategically placed downstream. SIC and SOOC were combined into the “Stones” or “S” biotope on the scoring sheet (Dickens & Graham, 2002).

Vegetation biotopes, such as marginal vegetation, were sampled. Reeds, overhanging vegetation, including grasses and sedges, found at the river's edge in the fast flowing (in current) and slow flowing (out of current) water were sampled. This was achieved by sweeping the SASS 5 net vertically, just below the water's surface, through the vegetation. This back and forth sweeping motion through the vegetation was executed along a combined total length of two meters at the various sampling sites. Submerged vegetation (aquatic vegetation), such as algae and plant roots, was also sampled by dragging the net through and out of current sections at each sample site, totalling approximately one square metre. Samples in and out of current for marginal vegetation and aquatic vegetation were combined under "Vegetation" or "V" on the scoring sheet (Dickens & Graham, 2002).

Gravel, sand and *mud (GSM) biotopes* were sampled at all the sample sites in the fast (in current) and slow (out of current) flowing sections of the Natalspruit. The sampling method was similar to the sampling method used to extract small stone biotopes. The net was once again placed downstream but, instead of employing the kick-method, a shuffling or scraping of the substrate (sand, mud and gravel) with the feet, for roughly one minute, was used to dislodge macro-invertebrates ensuring their collection in the net whilst sweeping the net over the disturbed area.

The sand biotope (<2 mm) included sections of submerged sandbanks, of the watercourse and submerged sand located between larger rocks. The gravel biotope included small stones varying in size, but <2 cm, which was submerged in the moderate to faster flowing sections of the watercourse. The mud biotope consisted of fine sediment particles (<0.06 mm), located in the slower flowing sections of the watercourse. These collected samples were combined into a GSM biotope on the scoring sheet (Dickens & Graham, 2002).

Visual observations of the different biotopes were made during the sampling. In some cases, necessary organisms, which might have been missed by the net sampling, were collected by hand and added to the scoring sheet by resorting them under the most relevant and closely associated biotope (Dickens & Graham, 2002).

7.4.2 Macro-invertebrates sampled per Sample Site

The diversity of taxa sampled per sample site will now be discussed in detail. These discussions include references to water quality conditions and the habitat type in which the taxa were found. The data are consequently ordered from one to 15 in accordance with a broad range of sensitivity scores (see Table 7.2). This is done in an effort to determine macro-invertebrate tolerance to pollution in the contained taxa (Dickens & Graham, 2002).

Table 7.2: Sensitivity scores and sensitivity description as used in SASS 5 (Source: Dickens & Graham, 2002).

Sensitivity Score	Sensitivity Description
1 - 5	Highly tolerant to pollution
6 - 10	Moderately tolerant to pollution
11 - 15	Very low tolerance to pollution

7.4.2.1 SS1 (beneath the bridge in Sarel Hattingh Street)

A moderate to low diversity of taxa families and species were identified at SS1. Samples counted included: Oligochaeta (Annelida), Coenagrionidae (Odonata), Aeshnidae (Odonata), Gomphidae (Odonata), Notonectidae (Hemiptera), Elimidae/Dryopidae (Coleoptera), Chironomidae (Diptera) and Tipulidae (Diptera). Most of the taxa identified at SS1 displayed a sensitivity score of ≤ 6, thus indicating that they have a moderate to high tolerance of pollution.

Exceptions to this are taxa, such as Aeshnidae and Elimidae/Dryopidae, were also found at the site. These species only display a moderate tolerance for pollution. Aeshnidae were found in the stones and GSM biotope but also in the vegetation biotopes together with Elimidae/Dryopidae. Only one specimen of the latter was found in the vegetation biotope. Furthermore, these two taxa families tend to frequent areas where they can employ vegetation for emergence support whilst they transition from their larvae and nymph stages to adults (Laughlin *et al*., 2018). The moderate to low species diversity can be attributed to the industrial and mining activities located upstream from the site and surface run-off from artificial structures, such as roads and the bridge, as well as the fact that sampling of the macro-invertebrates was done during July.

7.4.2.2 SS2 (On the fringes of Katlehong located next to Masakhane Street)

No macro-invertebrate species were found at SS2. The only taxon identified at this site was a low count of Chironomidae (Midges), belonging to the Diptera (flies) order (see Figure 7.1). Chironomidae are considered indicators of low water quality as they possess a sensitivity score of ≤2 and are often found at degraded sites. It is well documented that Chironomidae is able to tolerate watercourses containing low concentrations of O_2 (Serra *et al*., 2017). The low species diversity can be partially attributed to the fact that the sampling of macro-invertebrates was executed during July and cannot be wholly ascribed to the anthropocentric activities and physicochemical parameters of the stream quality. The watercourse mainly contains stones covered in sewage algae which deprives the water of O_2 due to the high levels of total Coliforms present, as described in Chapter 5.

Figure 7.1: A photo of Chironomidae sampled and photographed at SS2 (Source: Brits, 2018).

7.4.2.3 SS3 (Roughly 700m from an ERWAT sewage water treatment plant)

SS3 yielded only two taxa macro-invertebrates, namely Oligochaeta (aquatic earthworms) (see Figure 7.2) from the order Annelida and Chironomidae (midges) belonging to the Diptera (flies) order. This site is located a few hundred metres south of a sewage treatment plant with surrounding roads increasing surface run-off. The Oligochaeta taxon was sampled in the GSM biotope, which yielded fewer than 10 individuals, resulting in an estimate abundance of (**A**) (2-10 taxa) (see Figure 7.7). In addition, the Chironomidae taxon was found in the vegetation and GSM biotopes. This amounted to an estimate abundance of (**A**) and was thus, noted on the SASS 5 scoring sheet.

As mentioned, Chironomidae are indicators of poor water quality and a degraded area. Oligochaeta is prominent in sediment that has an abundance of aquatic plants (which was evident at site 3 and consisting largely of Watercress), in slow flowing water or stagnant pools and in watercourses which exhibit higher water temperatures (sample temperature 9.5 ^{o}C) (Lobe, Filser & Otomo, 2018). In addition, Oligochaeta possesses a sensitivity score of 1 on the SASS 5 scoring sheet, thus indicating a high tolerance towards polluted water courses and the presence of heavy metals. This is a clear indicator of the degradation of the Natalspruit at SS3 (Olomukoro & Dirisu, 2014). Lastly, the low species diversity can also be attributed to the sampling of macro-invertebrates during July and not only to the anthropocentric activities and physicochemical parameters of the stream quality at this sample site.

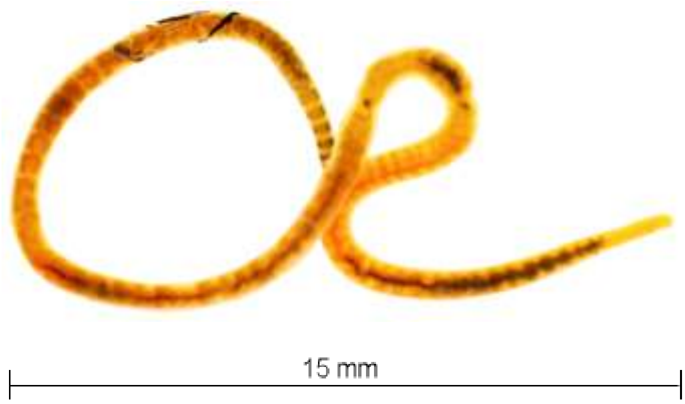


Figure 7.2: A photo of Oligochaeta sampled and photographed at SS3 (Source: Brits, 2018).

In addition, an alien invasive fish species, possibly *Gambusia affinis* (Mosquito Fish) (see Figure 7.3) was also collected at SS3. *Gambusia affinis* is prominent in the Eastern and Western Cape (and indigenous to the Mississippi River, USA). The species was originally introduced to South Africa to help control mosquito populations in rivers (Invasive Species South Africa, 2018). It is, however, important to note that collecting fish is not part of the SASS 5 assessment and that the section, which follows merely, serves as an indication of possible alien invasive fish species frequenting Gauteng rivers. The following observations indicate that it could indeed be *Gambusia affinis:* (1) the presence of a long slender caudal peduncle, (2) a few dusky spots on the fins, (3) large eyes and (4) an upturned mouth. Without conducting a scales and fin count, however, the identity of the fish as a *Gambusia affinis*, could not be confirmed. Professor Richard Greenfield of the Department of Zoology, University of Johannesburg, indicated that although *Gambusia affinis* are rare to Gauteng rivers, the species does occur periodically (pers comm, 21/11/2018). These invasive fish have also been reported in other Gauteng rivers such as the Apies and Wilge (De Klerk, 2011; Lombard, Chimimba & Zengeya, 2018). As they are readily available in Gauteng pet shops, it is possible that this species was introduced to the Natalspruit. Further studies are recommended to determine whether *Gambusia affinis* is indeed present in the Natalspruit.

Figure 7.3: A photo of *Gambusia affinis* sampled and photographed at SS3 (Source: Brits, 2018).

7.4.2.4 SS4 (South of the second sewage water treatment works)

Low diversity of taxa families and species was identified at SS4 (SIC and SOOC). These included: Oligochaeta (Annelida), Chironomidae (Diptera), one Corixidae (Hemiptera) and one Culicidae larvae (Mosquitoes). The low taxa diversity can possibly be attributed to the impact of the second water sewage treatment plant. This second sewage plant is located upstream of SS4. There are also many informal settlements in close proximity of the Natalspruit. All of the taxa identified at SS4 displayed a sensitivity score of ≤3 with a moderate to high tolerance to pollution, indicating degradation of the site.

Furthermore, macro-invertebrates, such as Oligochaeta, were sampled in the stones and the GSM biotope (estimated abundance of **A**, 2-10 taxa[3]**)** (see Figure 7.7) as well as Corixidae (one individual) (see Figure 7.4). Corixidae was only present in the GSM biotope which is usually found in close proximity to vegetation, with Chironomidae (estimated abundance of **A**) being

[3] SASS 5 guidelines were used to determine the abundance of the different taxa, for example, a single organism is scored as “1” from 2 to 10 which was then allocated an alphabetical letter such as “A”, from 10 to a 100 the letter “B” was assigned, from 100 to 1000 the letter “C” was assigned and if there were more than 1 000 organisms present, the letter “D” was assigned.

present in all three of the biotopes at this site. Only one individual Culicidae larvae (see Figure 7.4) was sampled in the vegetation biotope.

Both Corixidae (sensitivity score of 3) and Culicidae (sensitivity score of 1) possess a high tolerance to pollution (similar to Oligochaeta and Chironomidae), thus indicating that the watercourse is degraded (Singh, Yadav & Yadava, 2016). The low species diversity may also be due to the sampling of macro-invertebrates during July.

Figure 7.4: Photos of Culicidae larvae and Corixidae sampled and photographed at SS4 (Source: Brits, 2018).

7.4.2.5 SS5 (situated next to the R550, Heidelberg Road)

The highest diversity of taxa families and species were identified at SS5 (SIC and SOOC). These included: Oligochaeta (Annelida), Beatidae (Ephemeroptera), Ceanidae (Ephemeroptera), Coenagrionidae (Odonata), Hydropsychidae (Trichoptera), Gyrinidae (Coleoptera), Chironomidae (Diptera), Simuliidae (Diptera) and Sphaeriidae (Pelecypoda).

The moderate level of diversity can be attributed to all the anthropocentric activities located upstream from the site. There is, however, an improvement in water quality when compared to the other sites, despite the site being in close proximity to houses and the R550 bridge. Most of the taxa identified at SS5 have a sensitivity score of ≤6, indicating a moderate to high tolerance to pollution.

Macro-invertebrates such as Oligochaeta were sampled in the stones and GSM biotopes. This indicated an estimated abundance of **A** with the count being between 2 and 10. One species of Beatidae (see Figure 7.5) was sampled in the vegetation and GSM biotopes with an estimated abundance of **A**. One individual of Ceanidae was sampled in the vegetation biotope, also with Coenagrionidae (see Figure 7.5), with an estimated abundance of **A.** One individual of Hydropsychidae was found in the GSM biotope. Gyrinidae was present in all three biotopes (stone, vegetation and GSM) with an estimated abundance of **A**. Chironomidae was found in the stones and GSM biotopes with an estimated abundance of **A**. Lastly, one individual of Simuliidae was found in the stones biotope, together with Sphaeriidae, with an estimated abundance of **A**.

Figure 7.5: Photos of Beatidae and Coenagrionidae sampled and photographed at SS5 (Source: Brits, 2018).

In addition, a juvenile *Tilapia sparrmanii* (Banded Tilapia) illustrated in Figure 7.6 was found at SS5. *Tilapia sparrmanii* is the most widespread fish species found in slow-flowing rivers in South Africa. It prefers areas with aquatic vegetation, as is the case at SS5, with large amounts of green algae strands (Ellender & Weyl, 2014).

Figure 7.6: A photo of a juvenile *Tilapia sparrmanii* sampled and photographed at SS5 (Source: Brits, 2018).

7.4.3 SASS 5 Scoring and Results Calculation

As illustrated in Figure 7.7, the SASS 5 scores per sample site were consolidated to present the presence of macro-invertebrates and taxa diversity during the winter (July), as present in the Natalspruit.

The macro-invertebrates were identified and listed at a family level on the SASS 5 score sheet (see Figure 7.7), with each taxon allocated a quality score dependent on its resistance to river contamination and pollution. The highest scores were allocated to taxa vulnerable to contamination whilst the lowest scores were allocated to taxa resistant to water quality change and/or pollution. Identification of the taxa was done for 15 minutes per biotope and in the event where no new taxon was seen for 5 minutes, the identification process was halted.

The identified taxa were noted on the SASS 5 scoring sheet (as seen in Figure 7.7) in association with its appropriate biotope before collating the three columns into a single column, thus producing a total. SASS 5 guidelines were used to determine the abundance of the different taxa. For example, a single organism is scored as “1” from 2 to 10 which was then allocated an alphabetical letter such as “A”, from 10 to a 100 the letter “B” was assigned, from 100 to 1000 the letter “C” was assigned and if there were more than 1 000 organisms present, the letter “D” was assigned. After the scoring process, the sample was returned to the river but could also have been preserved to be sent to a laboratory.

Furthermore, the biotope diversity section on the SASS 5 scoring sheet, as per Figure 7.7, was allocated with values from 1 (low diversity) to 5 (high diversity). Thus, for example, marginal vegetation with low diversity consisted of only one species but high diversity marginal vegetation consisted of a variety of plant and/or grass species.

Lastly, the calculation was completed by the addition of the total column that then provided the final “SASS Score”. The different numbers of taxa found were also counted which then provided the “No. of Taxa”. Finally, the “SASS Score” was divided by the “No. of Taxa” which provided an ASPT (Average Score per Taxon). Also, note, the Beatidae and Hydropsychidae taxa were counted as one taxon (only one species of each were sampled) in accordance with the SASS 5 guidelines (Dickens & Graham, 2002). Finally, the classification of the ASPT and SASS 5 scores were determined.

7.4.3a SASS 5 Score Sheet, SASS Score, No. of Taxa and ASPT

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

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

Taxon	QV	S	Veg	GSM	TOT
DIPTERA (Flies)					
Athericidae (Snipe flies)	10				
Blephariceridae (Mountain midges)	15				
Ceratopogonidae (Biting midges)	5				
Chironomidae (Midges)	2	A	A	A	B
Culicidae* (Mosquitoes)	1		1		1
Dixidae* (Dixid midge)	10				
Empididae (Dance flies)	6				
Ephydridae (Shore flies)	3				
Muscidae (House flies, Stable flies)	1				
Psychodidae (Moth flies)	1				
Simuliidae (Blackflies)	5	1			1
Syrphidae* (Rat tailed maggots)	1				
Tabanidae (Horse flies)	5				
Tipulidae (Crane flies)	5	1			1
GASTROPODA (Snails)					
Ancylidae (Limpets)	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae* (Pond snails)	3				
Physidae* (Pouch snails)	3				
Planorbinae* (Orb snails)	3				
Thiaridae* (=Melanidae)	3				
Viviparidae* ST	5				
PELECYPODA (Bivalvies)					
Corbiculidae (Clams)	5				
Sphaeriidae (Pill clams)	3	A			A
Unionidae (Perly mussels)	6				
SASS Score		35	39	33	68
No. of Taxa		8	9	8	16
ASPT		[illegible]	[illegible]	[illegible]	[illegible]
Other biota:					
Comments/Observations:					

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

Figure 7.7: Consolidated SASS 5 Score sheet depicting macro-invertebrate abundance (July) of the Natalspruit (Source: adapted from Dickens & Graham, 2002).

Calculation of the SASS 5 and ASPT scores for the Natalspruit indicate a moderate diversity of taxa and the moderate modification of the watercourse, thus belonging to the **C** Class (see Figure 7.7 and Table 7.3) with a total SASS score of 68 and ASPT of 4.2.

Table 7.3: Classification of the Natalspruit according to its SASS 5 and ASPT scores (Source: adapted from Dickens & Graham, 2002).

CLASS	DESCRIPTION	SASS 5 SCORE %	ASPT
A	Unimpaired. High taxa diversity, including sensitive taxa.	90 – 100	Variable >90
B	Slightly impaired. High diversity of taxa but with fewer sensitive taxa.	80 - 90	<75 >90 76 - 90
C	Moderately impaired. Moderate diversity of taxa.	60 – 79	<60 >75 60 - 75
D	Largely impaired. Mostly tolerant taxa present.	40 - 59	<60 Variable
E	Severely impaired. Only tolerant taxa present.	20 - 39	Variable
F	Critically impaired. Very few tolerant taxa present.	0 - 19	Variable

The biological band for the Natalspruit was categorised as the Highveld (Upper) ecoregion, as per Figure 6.8. The SASS and ASPT scores are plotted in Figure 7.8 to illustrate the ecological category of the Natalspruit. The ecological category indicated that the Natalspruit is heavily to critically modified (**E / F**), as per Table 7.4.

Table 7.4: Biological Bands for the interpretation of SASS 5 data (Source: Dallas, 2007).

Ecological Category	Description
A	Natural/Unmodified
B	Good. Largely natural and unmodified
C	Fair. Moderately modified
D	Poor. Largely modified
E	Seriously modified
F	Critically or extremely modified

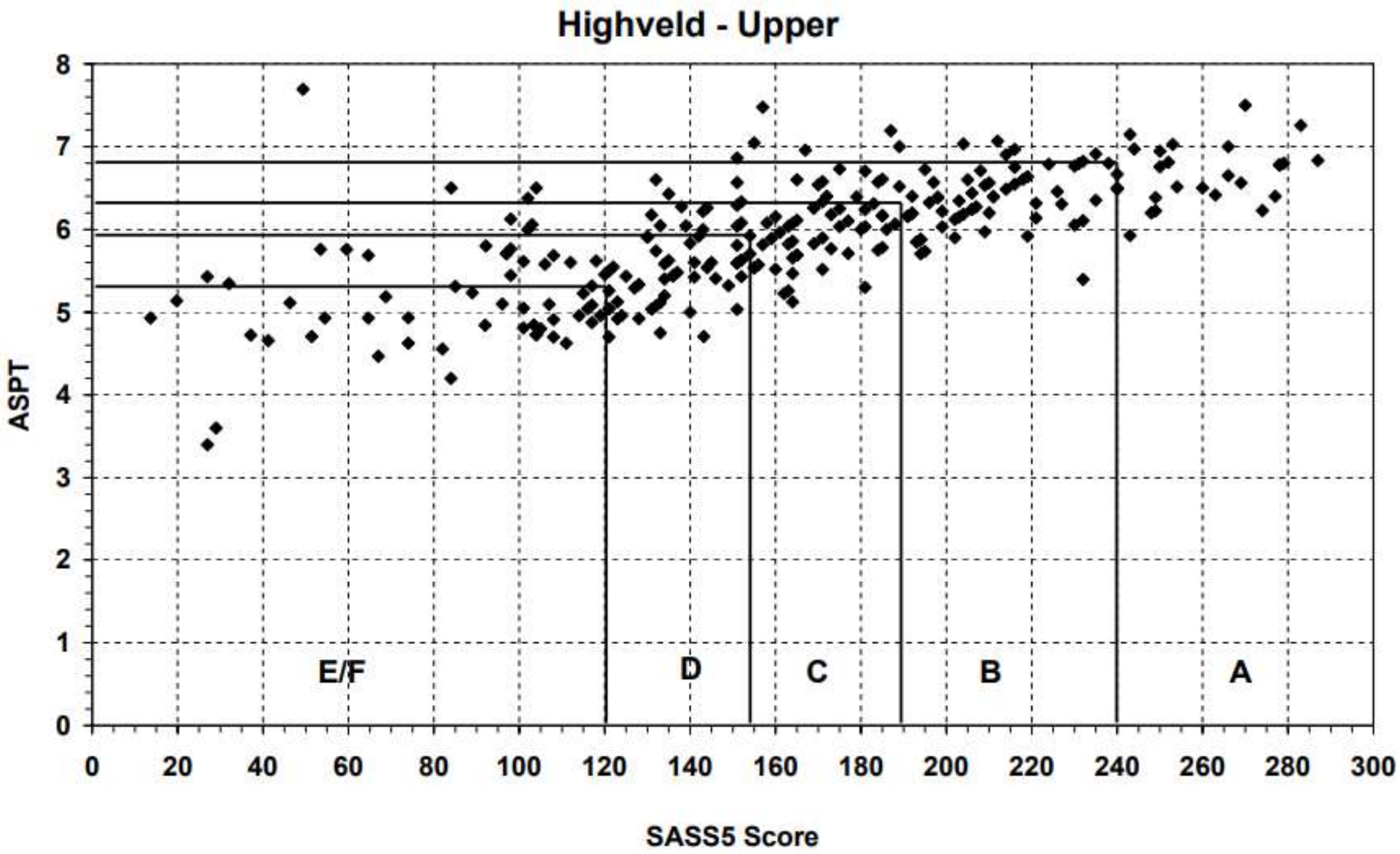


Figure 7.8: Biological bands for the Highveld (Upper), calculated from percentiles (Source: Dallas, 2007).

7.5 Eco classification: PES and EIS Results

7.5.1 Description of the Wetland Health Assessment (PES)

A scoring system is out of ten and contains six categories aligning the scores to corresponding observations made at each of the sample sites. It was then used to indicate the integrity of the Natalspruit wetlands. The scores range from zero (Category A), indicating *no modification*, to ten (Category F), indicating *severe modification*. The impact scores and health categories associated with changes in the Natalspruit hydrology were also executed in accordance with a scoring system out of ten, together with six categories, with the impact category ranging from *none* to *critical* scored out of ten. Zero, in this case, indicates *no modification* and ten indicates *severe modification*. The corresponding scores, together with observations made at each sample site, determined the hydrological health category that is indicated from A to F.

The summary of the health scores, associated with the change in vegetation assessment, was based on observations made at each sample site and included a scoring system calculated out of ten. Zero indicates natural vegetation with no modification and ten indicates severe vegetation modification. This scoring system was used to determine the score and associated health category for each sample site. The impact scores associated with geomorphological changes were calculated in accordance with observations made at the sample sites. This was done in an effort to determine possible threats, associated with the geomorphology of the area, to the integrity of the Natalspruit wetland area. A summary of the present wetland health, as assessed for the Natalspruit, was then tabulated.

7.5.2 Wetland Health Assessment Overall PES Scores

Table 7.5 presents a method used to assess the overall health of a wetland area in terms of its hydrology, geomorphology and vegetation. This method focuses on anthropocentric impacts on the wetland, thus rendering it ecologically meaningful in attempting to determine the wetland’s condition with visible indicators to assess its present state (Macfarlane *et al*., 2009).

Table 7.5: Health categories used by WET-Health for describing the integrity of wetlands (Source: Macfarlane *et al*., 2009).

HEALTH CATEGORY	DESCRIPTION	SCORE
A	Unmodified, natural.	0 – 0.9 (90% – 100%)
B	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1 – 1.9 (80% - 90%)
C	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact.	2 – 3.9 (60% - 80%)
D	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota and has occurred.	4 – 5.9 (40% - 60%)
E	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6 – 7.9 (20% - 40%)
F	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8 – 10 (0% - 20%)

Table 7.6 presents impact scores and health categories associated with changes in the hydrology of a wetland. These changes are assessed separately based on the assumption that, as regards hydrological impacts, different wetlands are most likely affected in different ways. This method is used to evaluate and elucidate changes related to water input into the wetland and to assess the effect/s of these changes on wetland health (Macfarlane *et al*., 2009).

Table 7.6: Impact scores and health category associated with changes in hydrology (Source: Macfarlane *et al*., 2009).

IMPACT CATEGORY	DESCRIPTION	SCORE	HYDROLOGICAL HEALTH CATEGORY
None	No discernible modification or the modification is such that it has no impact on hydrological integrity.	0 – 0.9	A
Small	Although identifiable, the impact of this modification on hydrological integrity is small.	1 – 1.9	B
Moderate	The impact of this modification on hydrological integrity is clearly identifiable but limited.	2 – 3.9	C
Large	The modification has a clearly detrimental impact on hydrological integrity. Approximately 50% of hydrological integrity has been lost.	4 – 5.9	D
Serious	The modification has a clearly adverse effect on hydrological integrity. Well in excess of 50% of the hydrological integrity has been lost.	6 – 7.9	E
Critical	The modification is so great that the ecosystem processes of this component of hydrological health are drastically altered. 80% or more of the hydrological integrity has been lost.	8 – 10	F

Table 7.7 presents an assessment of vegetation changes within wetlands. Vegetation provides important habitats to a variety of avi-faunal species in South Africa. Wetland vegetation also provides important economic benefits to local communities who utilise the reeds to weave goods, such as baskets, which they then sell (Macfarlane *et al*., 2009).

Table 7.7: Summary of the health scores associated with vegetation changes (Source: Macfarlane *et al*., 2009).

DESCRIPTION	SCORE	HEALTH CATEGORY
Vegetation composition appears natural.	0 – 0.9	A
A minor change to vegetation composition is evident at the site.	1 – 1.9	B
Compositional changes are evident, but the site still contains mostly species expected in the reference state. Vegetation composition has been clearly altered but still contains a large proportion of natural species expected in the reference state.	2 – 3.9	C
Vegetation composition has been largely altered and introduced, alien species are abundant but most characteristic wetland species are usually still present.	4 – 5.9	D
Vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien species.	6 – 7.9	E
Vegetation composition has been totally or almost totally altered, and if any characteristic species still remain, their extent is very low.	8 – 10	F

Table 7.8 presents an assessment of associated changes to wetland geomorphology, specifically as regards the accumulation and storage of sediment. Sedimentation may lead to the formation of features such as sandbars (visible at low flows), point bars (visible at low or normal flow) and banks or alluvial ridges, visible along the entire length of a channel when compared to the surrounding wetland. The method is also important in determining erosional head-cuts that have significant relevance to the rehabilitation and management of wetlands in South Africa (Macfarlane *et al*., 2009).

Table 7.8: Impact scores associated with geomorphological changes (Source: Macfarlane *et al*., 2009).

THREAT CATEGORY	DESCRIPTION	SCORE	HEALTH CATEGORY
None	No discernible threat or the threat is such that no impact on wetland geomorphic integrity could be expected.	0 – 0.9	A
Small	Although identifiable, the threat posed could only be expected to have a small impact on wetland integrity.	1 – 1.9	B
Moderate	The threat posed could be expected to have an identifiable, but limited impact on wetland integrity.	2 – 3.9	C
Large	The threat posed could be expected to reduce wetland integrity by approximately 50%.	4 – 5.9	D
Serious	The threat posed could be expected to reduce wetland integrity in excess of 50%.	6 – 7.9	E
Critical	The threat posed could be expected to destroy ecosystem processes.	8 – 10	F

The overall wetland health score was calculated using the following formula:

Overall health rating = [(Hydrology) + (Geomorphology) + (Vegetation)] / 3

The overall score provides an indication of wetland health (Macfarlane *et al*., 2009).

Table 7.9: SS1 Results**:**

Wetland	Hydrology	Geomorphology	Vegetation	PES Category
Natalspruit	6.5	6.1	6.9	6.5 (E)

The scores obtained for SS1 indicated that water inputs, from the catchment area, into the Natalspruit hydrological unit are being seriously altered. This site was described as a channelled valley bottom with well-defined steep banks but lacking the characteristics of a floodplain (Macfarlane *et al*, 2009). Most of the wetland area at this site has been altered by the construction of formal housing, roads, mine tailings and small agricultural land areas located in the immediate catchment area. This development has altered the dynamics of the surrounding surface water run-off into the Natalspruit and its associated wetland. The artificial surfaces (roads, large industrial yards, mine tailings) and conversion to agricultural land have resulted in rainwater run-off collecting impurities from these sources (heavy metals, fertilisers, industrial and household plastic pollution), all of which eventually find their way into the Natalspruit and associated wetlands.

Collectively, the loss of large natural wetland areas has occurred because of the ever-increasing urban sprawl, the proliferation of a large number of alien vegetation species, the dumping of building rubble and urban refuse, as well as, frequent fires. In turn, this has resulted in an excessively high run-off, introducing major bank erosion and resulting in the further incising of the Natalspruit with the creation of a deeper channelled valley bottom over time. The PES score, as per Table 7.9, is thus 6.5 (E). The anthropocentric activities at SS1 have resulted in a seriously modified wetland system.

Table 7.10: SS2 Results**:**

Wetland	Hydrology	Geomorphology	Vegetation	PES Category
Natalspruit	7.9	7.9	6.5	7.4 (E)

SS2 was delineated as a floodplain, containing a channelled-valley bottom with a well-defined stream channel possessing gentle slopes with the banks flooding during the rainy season (Macfarlane *et al*, 2009). This site has been classified as severely modified with the loss of the natural wetland habitat and a lack of basic ecosystem functioning. Extensive changes to the hydrology and geomorphology were observed at this site with the alteration of the wetland during the winter months because of infilling and excavation, by the local Ekurhuleni Metropolitan Municipality, in order to drain accumulated stagnant water. Thus, the wetland was radically altered compared to the first site visit in early 2018. Furthermore, the run-off and pollution from the road, urban housing and nearby athletics stadium further contributed to the degradation of this site.

Signs of sediment deposition were visible east of the bridge (Masakhane Street, Katlehong) on both sides of the Natalspruit. In an effort to curb soil erosion and prevent further erosion of the cement structure, gabions had been strategically placed on the western side of the bridge. Furthermore, the soil and sediment layers were disturbed and/or removed. Lack of vegetation cover leaves some sections are exposed to erosion (Morgan, 2005). A variety of alien vegetation species were present albeit less than what was found at SS1. Lastly, littering and dumping of garbage were evident at this site that, in addition to poor water quality, has resulted in the further degradation of the wetland. Because of the anthropocentric activities at SS2, the PES score indicated in Table 7.10 is 7.45 (E). This indicates a seriously modified wetland system.

Table 7.11: SS3 Results**:**

Wetland	Hydrology	Geomorphology	Vegetation	PES Category
Natalspruit	2.0	2.5	3.4	2.6 (C)

SS3 was delineated as a floodplain, containing a valley-bottom with oxbow features in places, the slopes of the riverbanks are gentle and there is flooding during the rainy season (Macfarlane *et al*, 2009). The hydrology of the site is being impacted upon by water treatment works (located roughly 700 meters above the sample site) as it is discharging treated sewage water into the Natalspruit. Furthermore, large amounts of sedimentation were evident at the site with the main watercourse becoming a braided channel. Animal dung was also present on the riverbanks.

The site is further altered by the presence of visible animal and human activity. These activities included grazing domestic livestock, foot traffic creating a network of walking paths throughout the floodplain, littering, and illegal dumping of building material and garbage as well as the local municipality's cars patrolling the area.

Collectively, the overall state and observations of the Natalspruit and its associated wetland at this site indicated disturbances of the floodplain and vegetation. Alien vegetation species were *Phragmites australis* and *Arundo donax* observed in the wetland adjacent to the Natalspruit. Thus, the overall PES score was calculated as 2.6 (C Category) as per Table 7.11.

Table 7.12: SS4 Results**:**

Wetland	Hydrology	Geomorphology	Vegetation	PES Category
Natalspruit	2.0	2.2	3.0	2.4 (C)

SS4 was delineated as a channelled valley bottom with defined banks but lacking the characteristics of a floodplain. The site was classified as moderately modified regarding changes in ecosystem processes with the wetland habitat and river remaining mostly intact (Macfarlane *et al*, 2009). Changes to the hydrology are constantly taking place with treated water (suspected to be only *partially* treated if one regards the water analysis results), being discharged by the water treatment plant located roughly 400m upstream of SS4. Alteration of the geomorphology and vegetation at this site was observed because of small scale subsistence farming (maize) and livestock (pigs and chickens). Most of the wetland at this site has been converted to residential land use in the form of informal housing, altering the run-off characteristics of water into the Natalspruit.

There was evidence of the Natalspruit overflowing its banks at times, thus creating temporary shallow channels and small amounts of bank erosion. Local children using this section of the Natalspruit to swim are aggravating these channels and erosion scars. Other anthropocentric impacts on the vegetation, such as abandoned ruins, were noted. Alien vegetation species such *Salix babylonica* trees and *Populus alba*, representative of a somewhat transformed habitat, have also invaded the watercourses and consume large amounts of water on a daily basis (Van Wyk & Van Wyk, 1997).

Collectively, the overall state of the Natalspruit and its associated wetland indicates disturbances to the hydrology, geomorphology and vegetation. Thus, the overall PES score was calculated to be 2.4 in the C Category as per Table 7.12.

Table 7.13: SS5 Results**:**

Wetland	Hydrology	Geomorphology	Vegetation	PES Category
Natalspruit	1.2	1.9	1.0	1.4 (B)

SS5 was delineated as a wide channelled-valley bottom with a well-defined stream channel possessing gentle slopes with well-defined banks (Macfarlane *et al*, 2009). This site has been classified as largely natural with few, or no, modifications to the watercourse with small, to no, loss of natural habitat (Macfarlane *et al*, 2009). Changes to the hydrology of the site were only evident in terms of the water analysis with no other impacts observed. Changes to the geomorphology of the site were only evident where cattle cross the river daily at a shallow point, resulting in some bank erosion.

Anthropocentric impacts included some informal settlements on the western bank of the Natalspruit with the suspected use of water from the river for bathing and as a water source for people and livestock. Furthermore, no alien vegetation species were observed at SS5.

Collectively, the overall state of the Natalspruit indicates little to no disturbances to the hydrology, geomorphology and vegetation. Thus, the overall PES score was calculated to be 1.4 in the B Category, as per Table 7.13.

Table 7.14: A summary of the PES scores for all 5 sample sites determining the overall PES Category for the Natalspruit and its associated Wetlands (Source: adapted from Macfarlane *et al*., 2009).

Natalspruit Wetland PES Summary		
	Sample Site	PES Category
	1	6.5 (E)
	2	7.4 (E)
	3	2.6 (C)
	4	2.4 (C)
	5	1.4 (B)
Overall PES Category		4.1 (D)

The overall PES state of the Natalspruit and its associated wetlands were calculated to be 4.1 in the D Category (see Table 7.14), indicating a large modification and change in ecosystem processes, including the loss of biota and natural habitat as categorised in Table 7.5.

7.5.3 Description of EIS

The EIS ratings is a scoring system that indicates the importance and sensitivity of habitat/s to modification/s, regardless of scale and determines the significance of the quantity and quality of river water (Macfarlane *et al*., 2009). To determine the EIS, a scoring method was used which consists of four categories. This ranges from *very high* to *low/marginal* with the range of the associated EIS score between zero and four. Zero, in this case, would indicate *no ecological importance* and four would indicate *high ecological importance*. This process is done through observations made in the study area. A summary of the health status of the assessed sample sites was tabulated and then calculated to determine the overall EIS of the Natalspruit and its associated wetland. EIS assessments are used to determine the value of ecosystem functions to benefit people as well as the ecological value of a water source to meet basic human needs, especially those of subsistence users. The degradation of wetlands and water sources through anthropocentric impacts results in them no longer functioning effectively and thus not benefitting humans and/or the environment (Kotze, 2010).

In order to determine the EIS of the Natalspruit, *primary* and *modifying* determinants were used. Primary determinants are further divided into two groups, namely indigenous wetlands species and floodplain habitats. Indigenous wetland species are assessed based on their characteristics such as being home to rare and endangered species, unique species and species richness.

Floodplain habitats are assessed in accordance with characteristics such as habitat or feature diversity, migration/feeding/ breeding site for wetland species, sensitivity to change, sensitivity to water quality, water storage, energy dissipation and chemical element removal. Modifying determinants are seen as additional characteristics that may influence the primary determinants.

The modifying determinants include characteristics such as its protected status (or lack thereof) and ecological integrity (Malan & Day, 2012). The EIS score was determined by adding together the scores of different characteristics and then comparing them to the scores presented in Table 7.15 to thus determine the range of EIS score and recommended ecological management class.

Table 7.15: EIS rating table (Source: Macfarlane *et al*., 2009).

ECOLOGICAL IMPORTANCE AND SENSITIVITY CATEGORIES	RANGE OF EIS SCORE	Recommended Ecological Management Class
Very high: Wetlands that are considered ecologically important and sensitive on a national or even international level. The biodiversity of these systems is usually very sensitive to flow and habitat modifications. They play a major role in moderating the quantity and quality of water in major rivers.	>3 and <=4	A
High: Wetlands that are considered ecologically important and sensitive. The biodiversity of these systems may be sensitive to flow and habitat modifications. They play a role in moderating the quantity and quality of water in major rivers.	>2 and <=3	B
Moderate: Wetlands that are considered ecologically important and sensitive on a provincial or local scale. The biodiversity of these systems is not usually sensitive to flow and habitat modifications. They play a small role in moderating the quantity and quality of water in major rivers.	>1 and <=2	C
Low/marginal: Wetlands that are not ecologically important and sensitive at any scale. The biodiversity of these systems is ubiquitous and not sensitive to flow and habitat modifications. They play an insignificant role in moderating the quantity and quality of water in major rivers.	>0 and <=1	D

The following results for the Natalspruit and its associated wetlands are tabulated in Table 7.16.

Table 7.16: Determining the EIS (floodplain and wetlands) of the Natalspruit and its associated wetlands (Source: adapted from Malan & Day, 2012).

PRIMARY DETERMINANTS			
Rare & Endangered Wetland Species			
Rating Guidelines	Rating	Description	Natalspruit Score
Very High	4	One or more species endangered on a National scale.	0
High	3	One or more species rare/endangered on Provincial scale.	
Moderate	2	More than one species rare/endangered on Provincial scale.	
Marginal	1	One species rare/endangered at local scale.	
None	0	No rare/endangered species at any scale.	
Populations of Unique Species			
Very High	4	One or more unique on National scale.	2
High	3	One or more populations on Provincial scale.	
Moderate	2	More than one population unique on local scale.	
Marginal	1	One population unique at local scale.	
None	0	No population unique at any scale.	
Species / Taxon Richness			
Very High	4	Rated on National scale.	2
High	3	Rated on Provincial scale.	
Moderate	2	Rated on local scale.	
Marginal	1	Not significant at any scale.	
Diversity of Habitat Types / Features			
Very High	4	High diversity of vegetation / geomorphological structure & interspersion.	1
High	3	High diversity of vegetation / geomorphological structure & low interspersion.	
Moderate	2	Low diversity of vegetation / geomorphological structure & high interspersion.	
Marginal	1	Low diversity of vegetation / geomorphological structure & low interspersion.	

Migration Route / Breeding / Feeding Site for Wetland Species			
Very High	4	Floodplain of International importance, sub-continentally critical breeding/feeding for wetland species survival.	1
High	3	Floodplain important breeding/feeding link for wetland species survival in sub-continent.	
Moderate	2	Floodplain moderately important breeding/feeding link for wetland species survival in SA.	
Marginal	1	Floodplain important for the survival of species in the catchment.	
Sensitivity to Changes in Natural Hydrological Regime			
Very High	4	Floodplain small with abundant habitat types with small regular floods, easily affected by anthropogenic changes.	3
High	3	Floodplain small with some habitat types supported with small regular floods, easily affected by anthropogenic changes.	
Moderate	2	Floodplain larger with some habitat types supported by large annual floods, less easily affected by anthropogenic changes.	
Marginal	1	Floodplain larger with habitat types supported by large infrequent floods, less easily affected by anthropogenic changes.	
Sensitivity to Water Quality Changes			
Very High	4	Floodplain small with abundant habitat types with small regular floods, easily affected by anthropogenic changes.	3
High	3	Floodplain small with some habitat types supported with small regular floods, easily affected by anthropogenic changes.	
Moderate	2	Floodplain larger with some habitat types supported by large annual floods, less easily affected by anthropogenic changes.	
Marginal	1	Floodplain larger with habitat types supported by large infrequent floods, less easily affected by anthropogenic changes.	
Flood Storage / Energy Dissipation / Element Removal			
Very High	4	Storage capacity, size of the floodplain and stream order all rated High.	1
High	3	Storage capacity, size of the floodplain and stream order – two rate High.	
Moderate	2	Storage capacity, size of the floodplain and stream order – one is rated High.	
Marginal	1	Storage capacity, size of the floodplain and stream order – none are rated High.	

MODIFYING DETERMINANTS			
Protected Status			
Very High	4	Floodplain is a Ramsar site or other category of protected status at International scale.	0
High	3	Floodplain in a National Park or other category of protected status at National scale.	
Moderate	2	Floodplain in a Provincial nature reserve or other category of protected status at Provincial scale.	
Marginal	1	Floodplain in Municipal nature reserve or other category of protected status at Provincial scale.	
None	0	Floodplain not in any category.	
Ecological Integrity			
Very High	4	The flood regime, water quality and floodplain habitat are unchanged from reference conditions.	2
High	3	The reference flood regime, water quality and floodplain habitat have been insignificantly affected by human activities.	
Moderate	2	The reference flood regime, water quality or floodplain habitat have been affected by human activities.	
Marginal	1	The reference flood regime, water quality or floodplain habitat have been significantly altered by human activities	
None	0	The reference flood regime, water quality or floodplain habitat have been almost completely altered by human activities.	

A summary of SASS 5 Score, ASPT, PES and EIS are provided in Table 7.17.

Table 7.17: Summary of the total scores of the SASS 5, ASPT, PES and EIS scores for the Natalspruit and associated wetlands**.**

ASSESSMENT	TOTAL
Biomonitoring	
Overall Ecological Category	E / F
Wetland Health Assessment	
Overall PES	D
Ecological Importance and Sensitivity	
Overall EIS	C

7.6 Summary

The overall ecological category (Biological Bands for the interpretation of SASS 5 data) for the Natalspruit and its associated wetlands is Ecological Category **E / F**. This indicates that the Natalspruit is seriously to critically modified. The overall PES category average (**D**) indicates the stream is modified to a large degree with a large change in ecosystem processes and loss of natural habitat and biota. The overall EIS median score was calculated to be 1.5 resulting in a Recommended Ecological Management Class of **C.** This indicates a moderate EIS score. Thus, the Natalspruit can be considered an ecologically important and sensitive stream at both a local and provincial level. The stream is sensitive to flow and habitat modifications. Lastly, the Natalspruit, and its associated wetlands, play a small role in moderating the quantity and quality of water of major rivers (Malan & Day, 2012).

7.7 Conclusion

The chapter outlined the collection and analysis of macro-invertebrates as well as EIS and PES data. This data was used to determine the overall state of the Natalspruit and its associated wetlands' health through the SASS 5 method, a wetland health assessment and the determination of the EIS of the Natalspruit and its associated wetlands. Chapter 8 will provide a platform of discussions regarding the water analysis, soil analysis, SASS 5, EIS and PES assessment results obtained from Chapter 5, Chapter 6 and Chapter 7.

CHAPTER 8: DISCUSSION

8.1 Introduction

Assessments of water, sediment and macro-invertebrates were conducted at certain specific sites along the Natalspruit. This was done to determine the presence (and levels) of pollution whilst comparing the results to the standard norms and guidelines for water and sediment pollution levels and the ecological bands for macro-invertebrates. This study made use of methods such as elemental analysis by ICP-OES/MS, an analysis of microbiological determinants, physical and aesthetic determinants, chemical macro-determinants, anions by IC, chemical micro-determinants, the turbidity Nephelometric method, the Winkler method with azide modification, EPA Method 365.1, EPA method 300.1, Paired-T test statistical analysis, EIS assessment, PES assessment and the SASS 5 method.

This chapter unfolds as follows. Firstly, the various study sites are compared to one another. Secondly, the different physicochemical parameters are discussed and compared between the five sampling points, as well as against the Water Quality Guidelines of South Africa, where possible, compared to the results from Rand Water. It is important to note that Rand Water does not possess a fully comprehensive database of some physicochemical parameters. Thus, data were not available for all physicochemical parameters for all the sample sites in this study. Additionally, there is no set of comprehensive National Water Guidelines for all physicochemical parameters. Lastly, the number of macro-invertebrate taxa reported for the sample site is discussed in terms of location, riparian vegetation, biotope diversity and pollution factors

8.2 Comparing results by study sites Statistical Analysis Discussion (Wet/May and July Comparison)

Analytical methods were employed to analyze the seasonal variations to provide a holistic representation of the physicochemical data for the Natalspruit. Comparing the scores between May and July for the physicochemical parameters, a Paired T-test was used to test for statistical significance seeing that it could only be conducted between paired values (May and July for each sample site). Effect size for paired samples was used to measure practical significance. Note that there are limitations regarding some of the assumptions of the Paired T-test such as normality, as there are only five data points. The relevant non-parametric statistical tests could, therefore, not be done, resulting in reporting only the Paired T-tests and effect sizes (Cohen, 1992; De Winter, 2013)[4].

The results are presented in the following pages.

[4] Effect Size: An effect size measures the strength of the relationship between two variables contained within a statistical population, or a sample-based estimate of that quantity (Cohen's d=0.2 for a small effect size, d = 0.5 for a medium effect size, d = 0.8 for a large effect size). A descriptive statistic expresses the assessed magnitude of a relationship without making any statement about whether the seeming relationship in the data mirrors a true affiliation in the population. Thus, an effect size is a method of enumerating the difference between two groups in terms of standard deviation units, thereby placing the extent of the difference into context (Cohen, 1992).

8.2.1 Difference: pH at 25 °C (May) and pH at 25 °C (July)

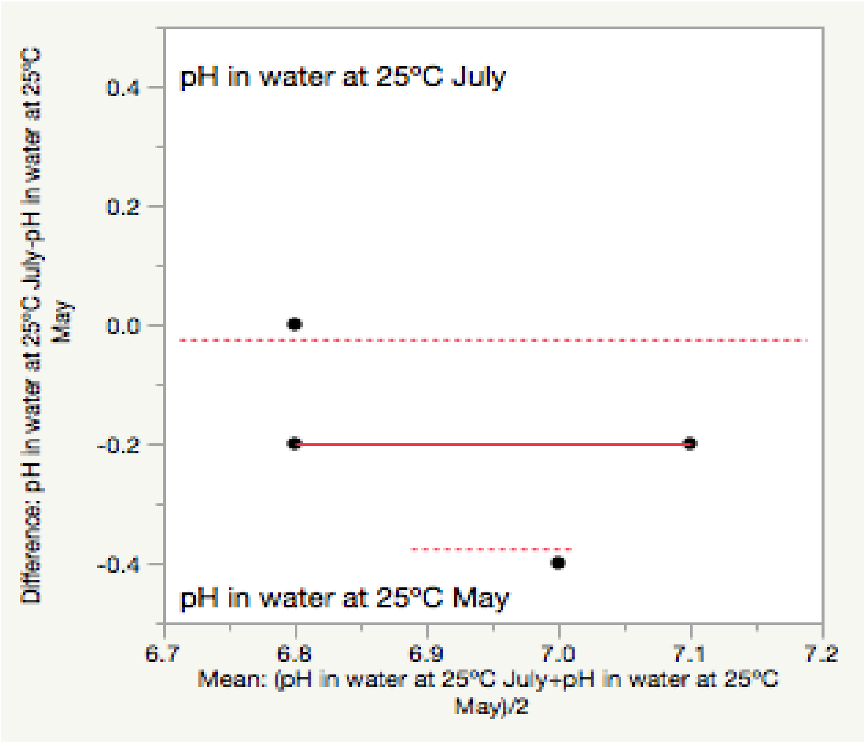


Figure 8.1: Statistical seasonal differences between May and July for pH 25 °C.

Comparing the mean scores between May and July for pH at 25 °C (July = 6.86 and May = 7.06), a decrease (mean difference) of 0.2 occurred. The p-value from the paired T-test is well below 0.05 (p=0.034), indicating a significant statistical difference. Note, however, the effect-size of 1.45 indicates a large effect size scoring in excess of d = 0.8.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
pH at 25 °C for July	6.86	5	-0.2	0.141	-3.16	0.034	1.45
pH at 25 °C for May	7.06						

Table 8.1: Table indicating data of paired T-tests for pH for May and July.

8.2.2 Difference: Turbidity (May) and Turbidity (July)

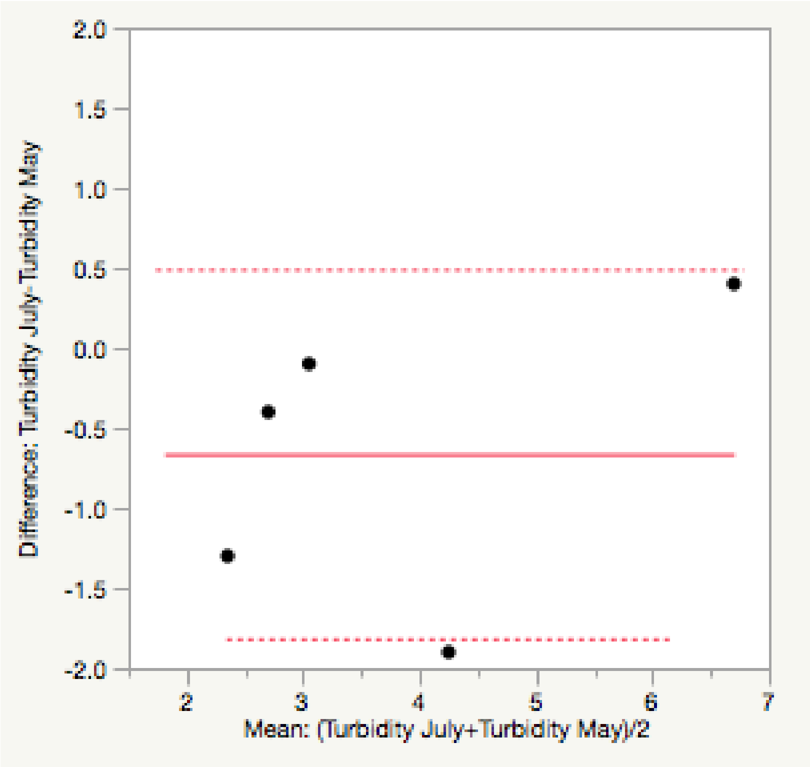


Figure 8.2: Statistical seasonal differences between May and July for Turbidity.

Comparing the mean scores between May and July Turbidity (July = 3.48 and May = 4.14), a decrease (mean difference) of 0.66 occurred. The p-value from the paired T-test is above 0.05 (p=0.187), so no statistically significant difference was detected. The effect-size of 0.71 indicates a medium effect size as it scores higher than d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Turbidity for July	3.48	5	-0.66	0.929	-1.58	0.187	0.71
Turbidity for May	4.14						

Table 8.2: Table indicating data of paired T-tests for Turbidity for May and July.

8.2.3 Difference: BOD (May) and BOD (July)

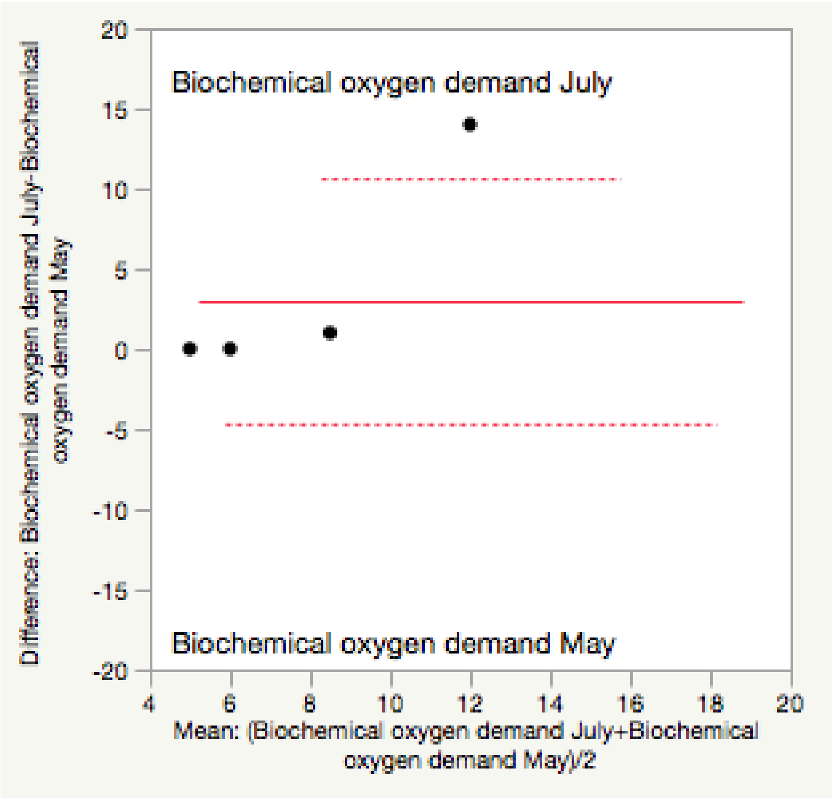


Figure 8.3: Statistical seasonal differences between May and July for BOD.

Comparing the mean scores between May and July for BOD (July = 8.8 and May = 5.8), a decrease (mean difference) of 3 occurred. The p-value from the paired T-test is above 0.05 (p=0.338), so no statistically significant difference was detected. The effect-size of 0.49 indicates a medium effect size as it scores higher than d = 0.2 but just below a medium effect size of d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
BOD for July	8.8	5	3	6.164	1.09	0.338	0.49
BOD for May	5.8						

Table 8.3: Table indicating data of paired T-tests for BOD for May and July.

8.2.4 Difference: DO as O_2 (May) and DO as O_2 (July)

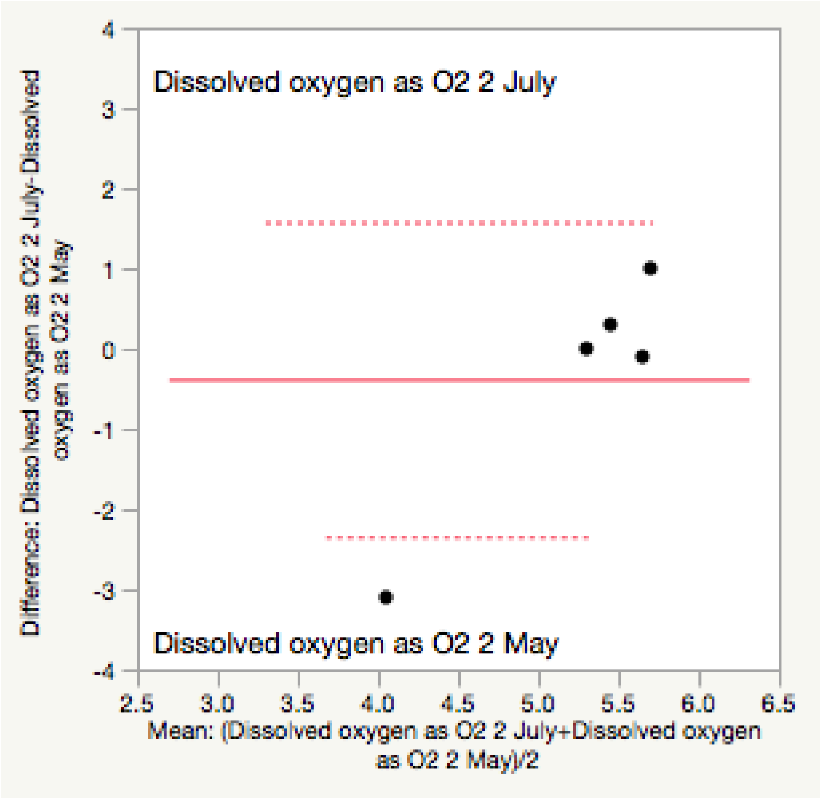


Figure 8.4: Statistical seasonal differences between May and July for DO.

Comparing the mean scores between May and July for DO as O_2 (July = 5.04 and May = 5.42), a decrease (mean difference) of 0.38 occurred. The p-value from the paired T-test is above 0.05 ($p=0.619$), so no statistically significant difference was detected. The effect-size of 0.24 indicates a small effect size as it scores higher than $d = 0.2$.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
DO as O_2 for July	5.04	5	-0.38	1.580	-0.54	0.619	0.24
DO as O_2 for May	5.42						

Table 8.4: Table indicating data of paired T-tests for DO for May and July.

8.2.5 Difference: TDS (May) and TDS (July)

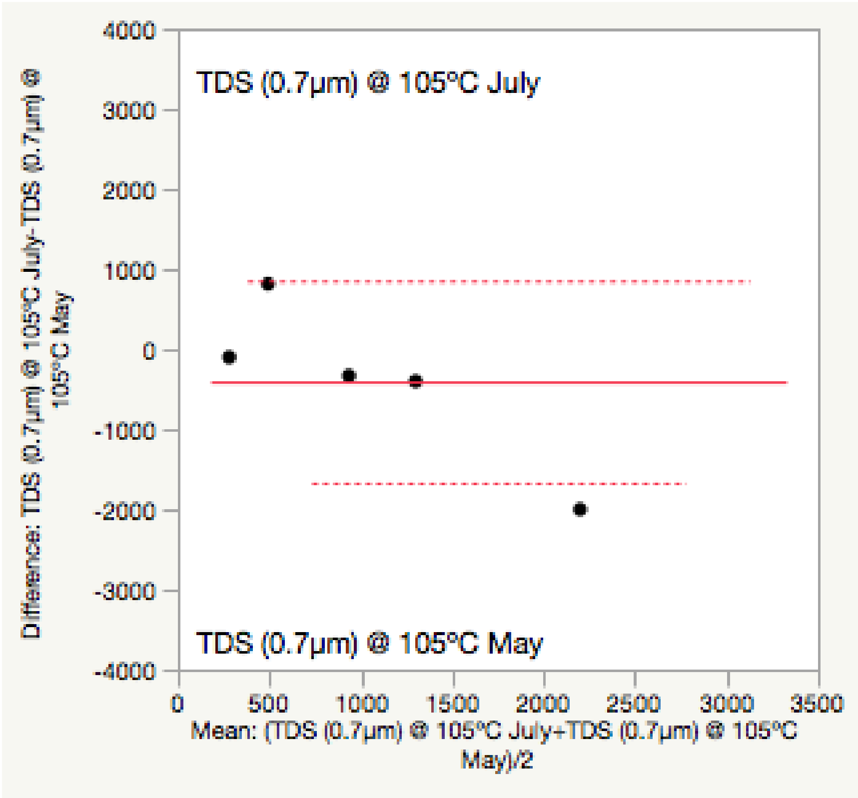


Figure 8.5: Statistical seasonal differences between May and July for TDS.

Comparing the mean scores between May and July for TDS (July = 840 and May = 1243), a decrease (mean difference) of -403 occurred. The p-value from the paired T-test is above 0.05 (p=0.425), so no statistically significant difference was detected. The effect-size of 0.40 indicates a medium effect size as it scores higher than d = 0.2 but just below a medium effect size of d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
TDS for July	840	5	-403	1016.253	-0.89	0.425	0.40
TDS for May	1243						

Table 8.5: Table indicating data of paired T-tests for TDS for May and July.

8.2.6 Difference: Total Hardness as $CaCO_3$ (May) and Total Hardness as $CaCO_3$ (July)

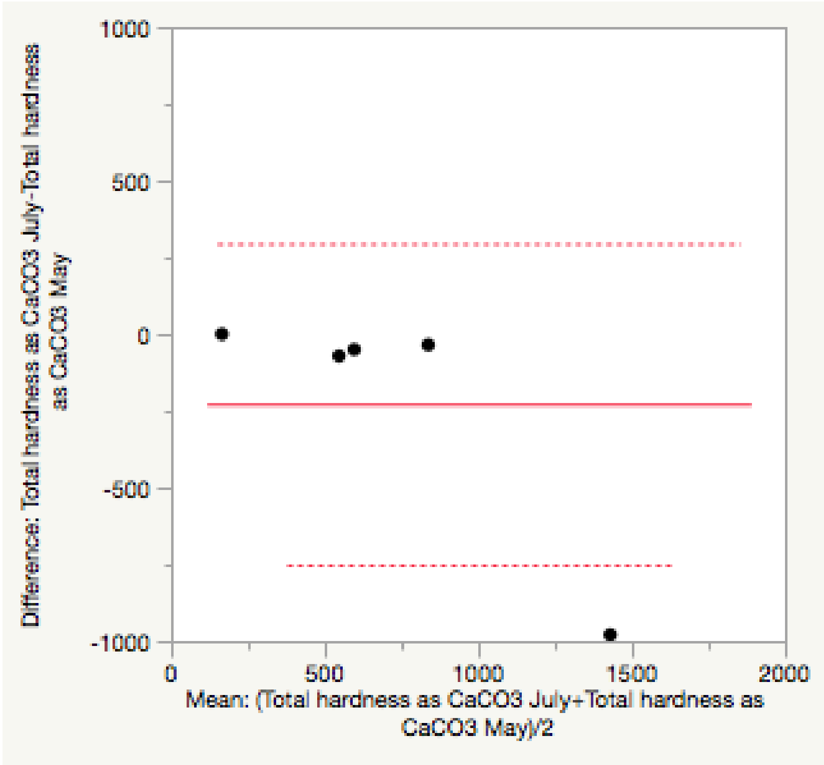


Figure 8.6: Statistical seasonal differences between May and July for Total Hardness as $CaCO_3$.

Comparing the mean scores between May and July for Total hardness as $CaCO_3$ (July = 601.6 and May = 828.6), a decrease (mean difference) of 227 occurred. The p-value from the paired T-test is above 0.05 (p=0.259), so no statistically significant difference was detected. The effect-size of 0.54 indicates a medium effect size as it scores higher than d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Total hardness as $CaCO_3$ for July	601.6	5	-227	58.842	-1.21	0.295	0.54
Total hardness as $CaCO_3$ for May	828.6						

Table 8.6: Table indicating data of paired T-tests for Total hardness as $CaCO_3$ for May and July.

8.2.7 Difference: Ca hardness as $CaCO_3$ (May) and Ca hardness as $CaCO_3$ (July)

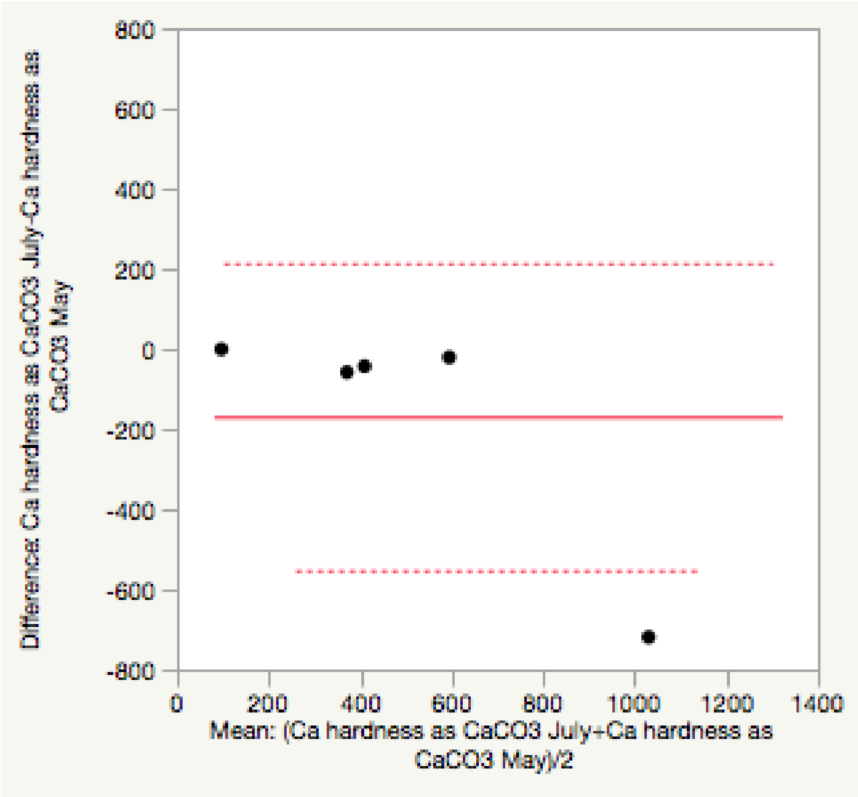


Figure 8.7: Statistical seasonal differences between May and July for Ca hardness as $CaCO_3$.

Comparing the mean scores between May and July for Ca hardness ($CaCO_3$ (July = 416.2 and May = 584.6), a decrease (mean difference) of 168.4 occurred. The p-value from the paired T-test is above 0.05 (p=0.29), so no statistically significant difference was detected. The effect-size of 0.55 indicates a medium effect size as it scores higher than d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Ca hardness as $CaCO_3$ for July	416.2	5	-168.4	308.55	-1.22	0.289	0.548
Ca hardness as $CaCO_3$ for May	584.6						

Table 8.7: Table indicating data of paired T-tests for Ca hardness as $CaCO_3$ for May and July.

8.2.8 Difference: Mg (May) and Mg (July)

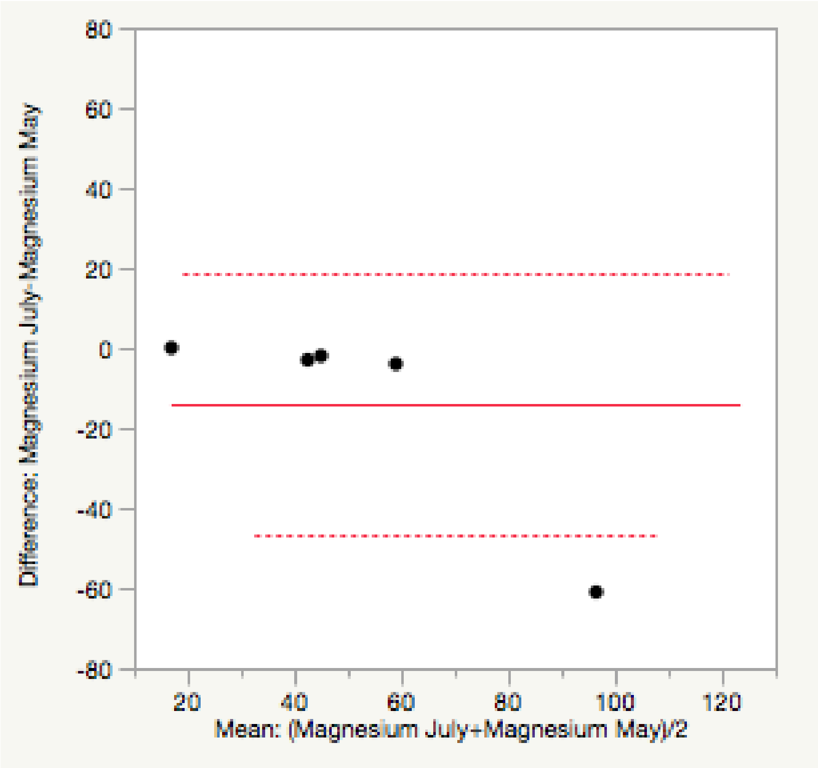


Figure 8.8: Statistical seasonal differences between May and July for Mg.

Comparing the mean scores between May and July for Mg (July = 45 and May = 59), a decrease (mean difference) of 14 occurred. The p-value from the paired T-test is above 0.05 (p=0.300), so no statistically significant difference was detected. The effect-size of 0.53 indicates a medium effect size as it scores higher than d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Mg for July	45	5	-14	26.315	-1.19	0.300	0.53
Mg for May	59						

Table 8.8: Table indicating data of paired T-tests for Mg for May and July.

8.2.9 Difference: Cl (May) and Cl (July)

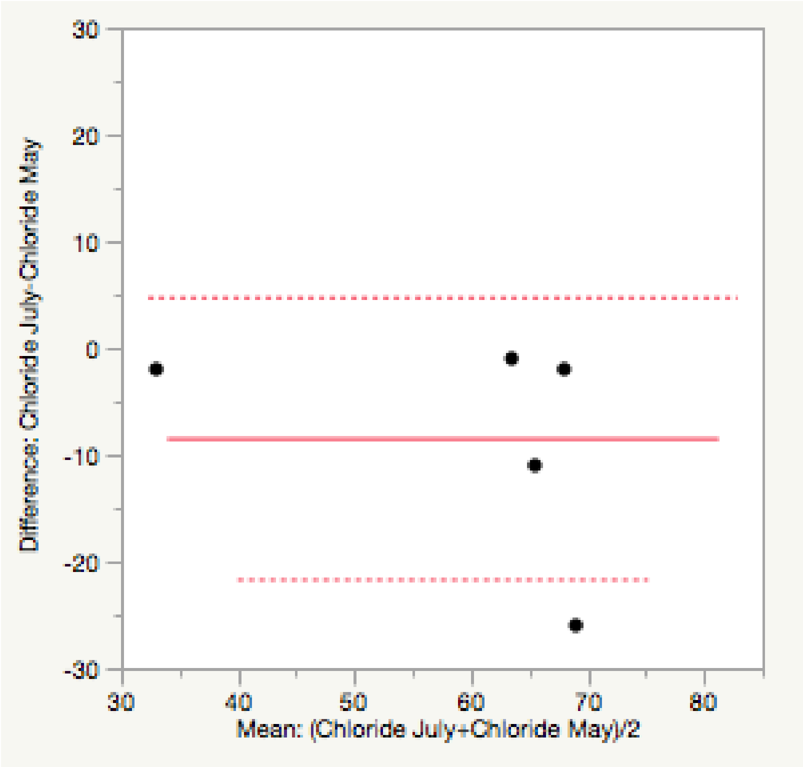


Figure 8.9: Statistical seasonal differences between May and July for Cl.

Comparing the mean scores between May and July for Cl (July = 55.6 and May = 64), a decrease (mean difference) of 8.4 occurred. The p-value from the paired T-test is above 0.05 (p=0.152), so no statistically significant difference is detected. The effect-size of 0.79 indicates a large effect size as it scores higher than d = 0.5 but just below a large effect size of d = 0.8.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Cl for July	55.6	5	-8.4	10.664	-1.76	0.152	0.79
Cl for May	64						

Table 8.9: Table indicating data of paired T-tests for Cl for May and July.

8.2.10 Difference: NO_2 (May) and NO_2 (July)

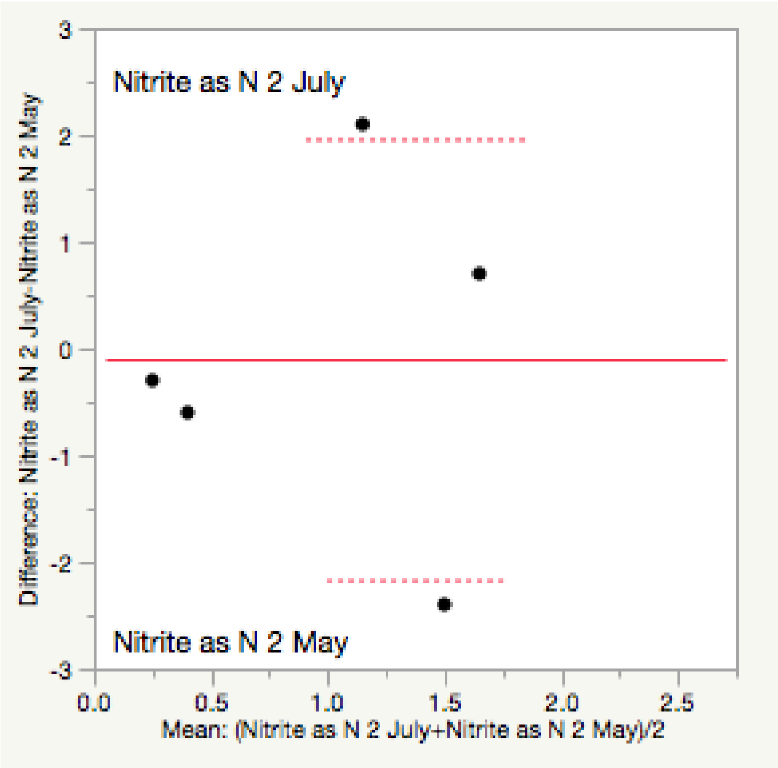


Figure 8.10: Statistical seasonal differences between May and July for NO_2.

Comparing the mean scores between May and July for NO_2 (July = 0.94 and May = 1.04), a decrease (mean difference) of 0.1 occurred. The p-value from the paired T-test is above 0.05 ($p=0.899$), so no statistically significant difference was detected. The effect-size of 0.06 indicates a small to very small effect size scoring below $d = 0.2$.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
NO_2 for July	0.94	5	-0.1	1.662	-0.13	0.899	0.06
NO_2 for May	1.04						

Table 8.10: Table indicating data of paired T-tests for NO_2 for May and July.

8.2.11 Difference: NO_3 (May) and NO_3 (July)

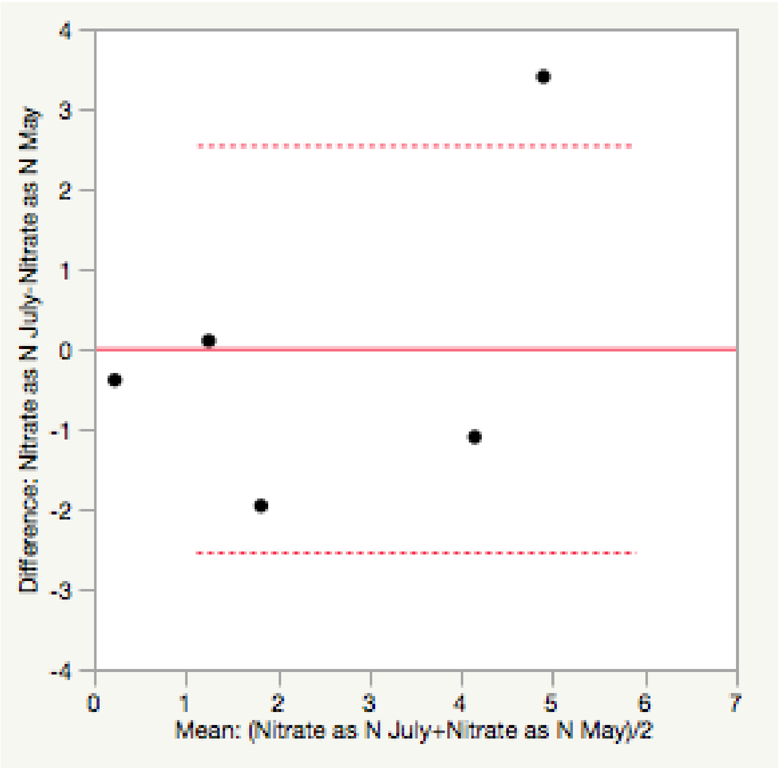


Figure 8.11: Statistical seasonal differences between May and July for NO_3.

Comparing the mean scores between May and July for NO_3 as N (July = 2.474 and May = 2.464), a decrease (mean difference) of 0.01 occurred. The p-value from the paired T-test is above 0.05 (p=0.991), so no statistically significant difference was detected. The effect-size of 0.005 indicates a very small effect size scoring below d = 0.2.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
NO_3 for July	2.474	5	0.01	2.048	0.01	0.991	0.005
NO_3 for May	2.464						

Table 8.11: Table indicating data of paired T-tests for NO_3 for May and July.

8.2.12 Difference: SO_4 (May) and SO_4 (July)

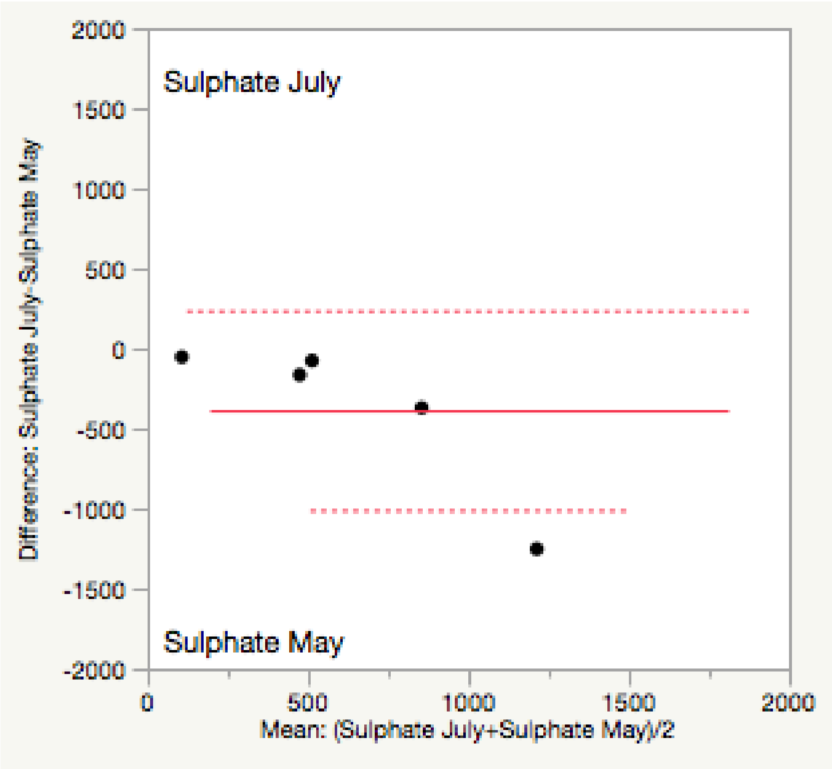


Figure 8.12: Statistical seasonal differences between May and July for SO_4.

Comparing the mean scores between May and July for SO_4 (July = 440.2 and May = 824.4), a decrease (mean difference) of 384.2 occurred. The p-value from the paired T-test is above 0.05 (p=0.161), so no statistically significant difference was detected. The effect-size of 0.77 indicates a large effect size as it scores higher than d = 0.5.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
SO_4 for July	440.2	5	-384.2	501.499	-1.71	0.161	0.77
SO_4 for May	824.4						

Table 8.12: Table indicating data of paired T-tests for SO_4 for May and July.

8.2.13 Difference: PO_4 (May) and PO_4 (July)

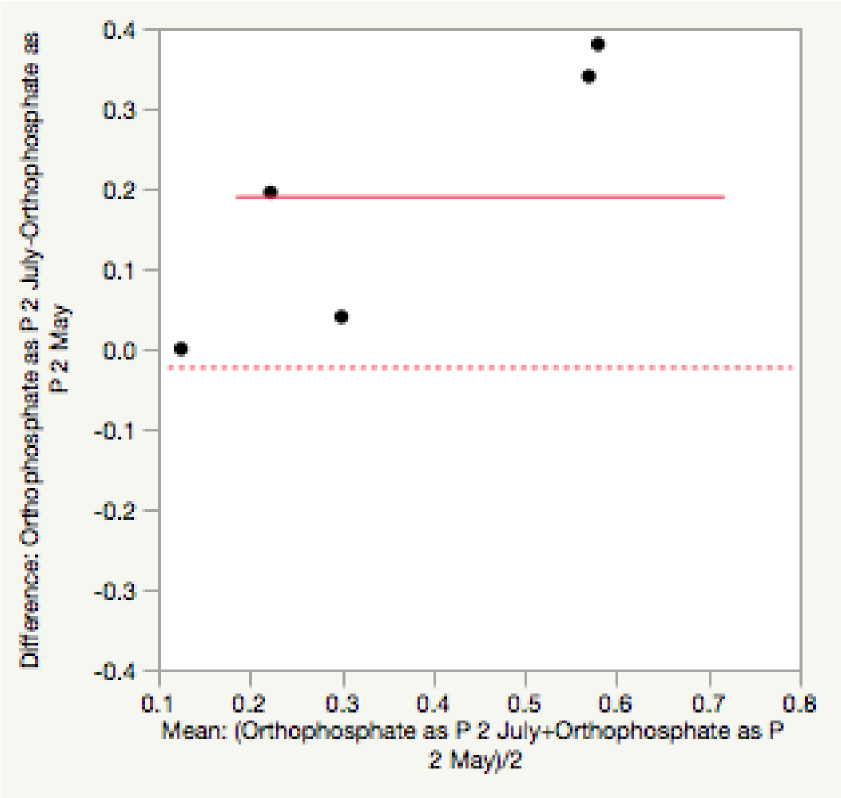


Figure 8.13: Statistical seasonal differences between May and July for PO_4.

Comparing the mean scores between May and July for PO_4 (July = 0.455 and May = 0.264), a decrease (mean difference) of 0.191 occurred. The p-value from the paired T-test is above 0.05 (p=0.067), so no statistically significant difference was detected. The effect-size of 1.16 indicates a large effect size scoring in excess of d = 0.8.

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
PO_4 for July	0.455	5	0.191	0.171	2.49	0.067	1.16
PO_4 for May	0.264						

Table 8.13: Table indicating data of paired T-tests for PO_4 for May and July.

8.2.14 Difference: Total Coliforms (May) and Total Coliforms (July)

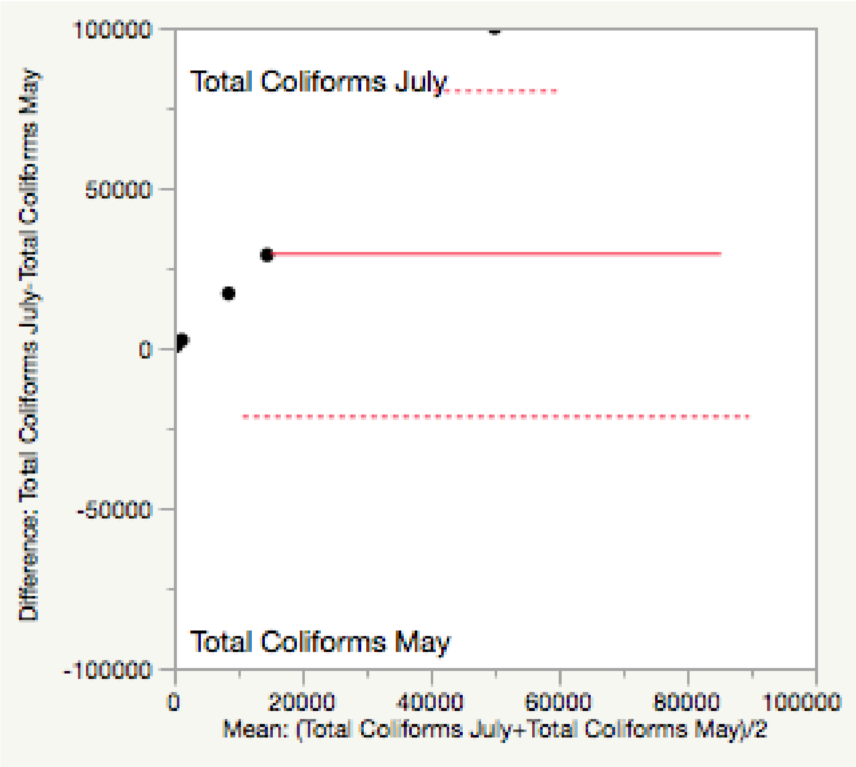


Figure 8.14: Statistical seasonal differences between May and July for Total Coliforms.

Comparing the mean scores between May and July for Total Coliforms (July = 29770 and May = 0), a decrease (mean difference) of 29770 occurred. Due to no presence of coliforms for May the seasonal comparison and analysis could not be done as seen in Figure 8.14[5].

Pair	Mean	n	Mean Difference	Std of Difference	t-ratio	P-value	Cohen's d Effect Size
Total Coliforms for July	29770	5	29770	40941.063	1.63	0.179	-
Total Coliforms for May	0						

Table 8.14: Table indicating data of paired T-tests for Total Coliforms for May and July.

[5] No readings during the laboratory analysis for total coliform levels were reported for May, possibly due to no wastewater discharge from the treatments plants during the sampling period together with intact sewer drains at the time.

8.2.15 Summary of Differences between May and July

With the exception of pH for May and July, none of the other physicochemical parameters between May and July was statistically different from each other. Thus, the river between the sample sites is relatively uniform in character. A statistical difference (of p=0.034 as per Table 8.15) was found between May and July for pH (with a strong effect size of d=1.45). However, the pH guidelines did not exceed the guidelines. That said, a variation in pH could be an indicator of a pollution event. No significant statistical difference existed for Turbidity. Comparing May and July for BOD resulted in a mean difference of three (with p=0.338), indicating no significant statistical difference (with a moderate effect size of d=0.49). Comparing DO between May and July indicated a mean difference of 0.38 (with p=0.619) indicating no significant statistical difference (low effect size of d-0.24). The mean difference recorded for TDS between May and July was -403 (with p=0.425) indicating no statistical difference (moderate effect size of d=0.40).

A mean difference of 227 occurred for Total hardness as $CaCO_3$ between May and July (with p=0.259) indicating no significant statistical difference (moderate effect size of d=0.54). A mean difference between May and July for Ca hardness, as $CaCO_3$ had a mean difference of 168.4 (with p=0.29) with no significant statistical difference detected (moderate effect size of d=0.55). A mean difference between May and July of 14 occurred for Mg (with p=0.300) indicating no significant statistical difference (moderate effect size of d=0.53). No significant statistical difference (mean difference of 8.4) was detected between May and July with regards to Cl (with p=0.152 and a strong effect size of d=0.79). Comparisons for May and July for NO_2 and NO_3 levels were similar with NO_2 indicating a mean difference of 0.1 (p= 0.899) and no significant statistical difference (very low effect size of d=0.06). Similarly, a mean difference between May and July for NO_3 of 0.01 occurred (with p=0.991) indicating no significant statistical difference (very low effect size of d=0.005).

A mean difference of 384.2 occurred between May and July for SO_4 (with p=0.161) indicating no significant statistical difference (strong effect size of d=0.77). Comparing May and July for PO_4 indicated a mean difference of 0.191 (with p=0.067) signifying no significant statistical difference (strong effect size of d=1.16). No seasonal comparison for Total Coliforms between May and July could be done due to no data available for May (see Table 8.15).

Pair	UOM	Mean Difference	P-value	Cohen's d Effect Size
pH at 25°C for May and July	pH	-0.2	0.034	1.45
Turbidity for May and July	NTU	-0.66	0.187	0.71
BOD for May and July	mg/l	3	0.338	0.49
DO as O_2 for May and July	mg/l	-0.38	0.619	0.24
TDS for May and July	mg/l	-403	0.425	0.40
Total hardness as $CaCO_3$ for May and July	mg/l	-227	0.295	0.54
Ca hardness as $CaCO_3$ for May and July	mg/l	-168.4	0.289	0.55
Magnesium for May and July	mg/l	-14	0.300	0.53
Chloride for May and July	mg/l	-8.4	0.152	0.79
Nitrite (NO_2) for May and July	mg/l	-0.1	0.899	0.06
Nitrate (NO_3) for May and July	mg/l	0.01	0.991	0.005
Sulphate (SO_4) for May and July	mg/l	-384.2	0.161	0.161
Orthophosphate as PO_4 for May and July	mg/l	0.191	0.067	1.16
Total Coliforms for July	CFU/100 ml	29770	0.179	n/a

Table 8.15: Table indicating a summary of differences of paired T-tests for the physicochemical parameters compared between May and July.

8.3 Physicochemical Parameter Concentrations of Water Samples

In this section, the different physicochemical parameters of each sampling point are analysed. The reported values for each of the parameters are also compared to the Water Quality Guidelines of South Africa and, where possible, compared to the results from Rand Water. The guidelines contain technical specifications as to acceptable levels for physicochemical parameters in order to safeguard freshwater ecosystems. However, these guidelines are not complete or static and require constant research endeavours that could result in the regular modification of the guidelines (DWAF, 1996a).

8.3.1 pH

Relatively normal pH levels were reported for the Natalspruit at all the sample sites for May and July were reported. Thus, there appears to be no evidence of AMD and other sources of pollution that may affect the pH levels (Abowei, 2010). However, Rand Water reported slightly higher pH values on average compared to the results reported during this study, however. Notably, the highest reported pH values were recorded at sites SS3, SS4 and SS5, all three at 7.2 during May compared to the lowest recorded pH value of 6.7 recorded at site SS2 during July. The fluctuating levels of pH between the sample sites for the Natalspruit can possibly be attributed to seasonal change (no precipitation was received during July) resulting in a slightly more acidic pH concentration at site SS2, opposed to precipitation received during May resulting in a more alkaline concentration. Furthermore, photosynthesis, decomposition of plant matter and respiration also contribute to fluctuating pH concentrations (DWAF, 1996a). Lastly, the pH concentrations were all within the guidelines as described in Chapter 5 (DWA, 2013).

8.3.2 Turbidity

The reported result at site SS2 (6.9 NTU) during July was the highest recording with regards to Turbidity compared to the lowest levels recorded at site SS5 (1.7 NTU) during July. The difference in turbidity levels suggests greater runoff volumes at site SS2 (throughout the year) due to a large number of artificial surfaces on the western side (Wadeville industrial area) together with the major disturbance of the area caused by bulldozers working at the site when water samples were collected in July (as described in Chapter 4, section 4.4.2). During May, the results suggested that the higher turbidity was caused by rainfall resulting in increased stream flow, which may have resulted in sediment deposits being disturbed and re-suspended or an indication of erosion upstream. In comparison with site SS2, at site SS5, there are no artificial surfaces located before the R550 bridge to contribute to increased turbidity levels (AWWA, 2010). Although there are no guidelines concerning the impact of turbidity levels on the health of livestock, site SS2 does exceed guidelines regarding aesthetic compliance (DWA, 2013). Lastly, according to DWAF (1996f), the guidelines for recreational use, that high turbidity levels (SS2) contributes to poor visibility such as dense algal growth resulting in concealed objects below the water surface, thus creating dangerous conditions for swimmers.

8.3.3 Biochemical Oxygen Demand (BOD)

The reported BOD levels for all five sample sites for both May and July varied with the lowest reported at 5 mg/L at sites SS1 and SS3 for both May and July (no algae was present at these sites) but the presence of total coliform bacteria may be linked to the BOD levels. The BOD levels at site SS2 could be attributed to the presence of algae (rocks in the river were completely covered by algae) and high levels of total coliform bacteria (as reported in Chapter 5, section 5.2.13). BOD levels increase when DO levels decrease due to the consumption of O_2 by bacteria (total coliforms). It is important to note that algae host bacteria. The general assumption then is that more algae present may indicate a higher presence of bacteria, resulting in a higher level of BOD (Naiman & Bilby, 1998; Abowei, 2010). BOD for site SS5 was recorded as the highest in comparison to the other sample sites for both May and July, at 19 mg/L during July. Like site SS2, copious amounts of algae were observed at site SS5. All of the sample sites, for both May and July, exceed the BOD levels with regards to the South African guidelines (as described in Chapter 5, section 5.2.3), rendering the water of all five the sample sites unsuitable for drinking (DWAF, 1996a).

8.3.4 Dissolved Oxygen (DO)

DO levels reported only slight variations between the different sample sites for May and July at just higher than the minimum DO level of 5 mg/L needed to support aquatic life (Abowei, 2010). The lowest recorded DO level was reported at site SS5 during July (5.0 mg/L) compared to the highest level reported at 6.2 mg/L (site SS3) during July. The relatively low levels of DO reported across all of the sites is a possible indicator of the presence of algal blooms (depleting the DO levels), as observed at SS2, SS3 and SS5 (DWAF, 1996b).

8.3.5 Total Dissolved Solids (TDS)

TDS levels at all the sample sites for the study indicated variations. All the sample sites reported considerably higher TDS levels during May with the exception of site SS4 at 900 mg/L (July). The highest TDS level was recorded at site SS1 (3 200 mg/L) during May in comparison to the lowest recording of 85 mg/L at site SS4 during May. Rand Water only reported TDS for sites SS4 and SS5 and these were both lower than recorded levels for this study with the exception of site SS4 at 118.3 mg/L. The levels of TDS for SS1 (May and July) and SS3 (May) both exceed the South African guidelines (aquatic systems) of acceptable TDS levels at 1 200 mg/L. The guidelines of 1 000 mg/L for the health of livestock is exceeded by sites SS1 (May and July), SS3 (May and July) and SS5 (May), rendering these sites unfit for consumption by livestock. The high levels of TDS are attributed to mining, industrial activities and wastewater treatment plants located along the sample sites of the Natalspruit. The flow increase in the Natalspruit due to precipitation received during May attributed to higher TDS levels.

8.3.6 Total Hardness

The total hardness of water at all of the sample sites for both May and July were varied but high, with the exception of site SS2 for both periods. The total hardness recorded as the same at 165 mg/L (lowest levels). Site SS1 would be expected to have high concentrations (914 mg/L recorded during July and 1 920 mg/L for May). The high total hardness levels recorded corresponds with the high levels of $CaCO_3$ and Mg at site SS1. This is attributed to the close proximity of the Elsburg Tailings Complex (containing limestone). The levels for July (820 mg/L) and May (855 mg/L) at site SS3 and 571 mg/L (July) and 621 mg/L (May) at site SS4 may be attributed to the sewage treatment plants located in close proximity to site SS3 and site SS4, discharging water treated with limestone (Liang, 2009). The recorded levels at site SS5 for May and July were analysed at 582 mg/L and 511 mg/L respectively, with some improvement compared to sites SS1, SS3 and SS4. Lastly, there are no recorded measurements for any of the sample sites by Rand Water and no guidelines set out by DWAF concerning acceptable levels of total hardness in an aquatic environment.

8.3.7 Calcium Carbonate (Hardness) as $CaCO_3$

$CaCO_3$ levels for all the sample sites varied along the Natalspruit. The highest reported level was recorded at site SS1 (May) compared to the lowest level at site SS2 (July). The higher levels of $CaCO_3$ at site SS1 for May and July could be attributable to the close proximity of the Elsburg Tailings Complex that would contain crushed rock strata such as limestone. Limestone is usually added during the gold mining process in an attempt to neutralise the effects of AMD. This accounts for the high level of $CaCO_3$ at site SS1 where a higher level of surface runoff from the tailings dam washes into the Elsburgspruit and ultimately into the Natalspruit (Spellman, 2008). According to DWAF (1996c), livestock health guidelines stipulate a target water quality range of 0 – 1 000 mg/L, resulting in the water at site SS1 unsuitable for consumption by livestock.

8.3.8 Magnesium (Mg)

Mg concentrations varied greatly among the sample sites along the Natalspruit. The highest Mg concentration was reported at site SS1 (127 mg/L) during May compared to the lowest Mg concentration at site SS2 (17 mg/L) for May and July. It is likely that the close proximity of SS1 to the Elsburg Tailings Complex resulted in the high Mg concentrations during May and July due to leaching and surface runoff into the Natalspruit. The lower Mg concentrations at SS2 may be attributed to a large amount of *Phragmites australis* and *Arundo donax* both of which act as a filter, lowering the Mg concentrations, unlike the absence of *Phragmites australis* and *Arundo donax* at SS1 (Potasznik & Szymczyk, 2015). Mg levels at SS3 and SS4 for May and July can be attributed to the discharge of treated wastewater (Mg is widely used to treat wastewater) from the sewage treatment plants located in close proximity to both the sample sites (Liang, 2009). All sample sites exceeded the guideline for aquatic systems concerning Mg (0.18 mg/L) with the exception of site SS2 with 17 mg/L (DWAF, 1996a). Lastly, all of the sample sites fall within the guidelines for the health of livestock (500 mg/L) (DWAF, 1996c). Mg results from Rand Water were available for sites SS2 at 16 mg/L and SS5 at 32 mg/L.

8.3.9 Chloride (Cl)

Cl concentrations recorded at each of the sample sites differed slightly and these recordings differed from Rand Water's data. The highest Cl concentration was reported at site SS1 (May) at 82 mg/L compared to the lowest Cl level of 32 mg/L at site SS2 (July). The higher concentrations of Cl at site SS1 (especially during May) could be attributed to the recovering/retreating of the Elsburg Tailings Complex (using Cl) over a period of 12 years (from 2007 until present) resulting in an influx of Cl levels through runoff into the Natalspruit during May (DRDGOLD, 2019). Low Cl concentrations recorded at site SS2 could possibly be due to the absence of mining activities and sewage treatments plants in the vicinity. Cl levels for site SS3 and site SS4 could be attributed to the two sewage/wastewater treatment plants located upstream from the two sites. It is standard practice for wastewater treatment plants to treat and purify wastewater with Cl before discharging the water into a watercourse (Spellman, 2009). Cl levels for all of the sample sites were well within limits for both human and animal consumption according to the guidelines for the health of livestock (1 500 mg/L) and drinking water guidelines (DWA, 2013; DWAF, 1996c).

8.3.10 Nitrite (NO_2)

The higher concentration at site SS1 during May could be attributed to the agricultural activities near site SS1 on the eastern side of the Natalspruit due to surface runoff, which transports fertilisers into the watercourse from irrigation. NO_2 concentrations at site SS2 indicated a low level of NO_2 compared to site SS1. The NO_2 concentration at site SS3 and site SS4 increased slightly during July in comparison to site SS2 because of no wastewater treatment plants or agricultural activities in close proximity to the site. NO_2 levels for sites SS4 and SS5 were higher than site SS3 and this could be ascribed to inadequately treated sewage discharge from the two wastewater treatment plants and raw sewage discharge from the tributary at site SS2 (see section 5.2.12). Recorded NO_2 concentrations at site SS5 during July, in stark contrast compared to concentrations in May 0.2 mg/L) could due to large herds cattle in this area (numerous points of cattle crossings were observed). No comparison could be made to results from Rand Water seeing that no data was available. No guidelines were available concerning the concentrations of NO_2 for aquatic health, however, sites SS1 (May), SS4 (May and July) and SS5 (July) exceeded the guideline for the suitability of drinking water exceeding 0.9 mg/L.

8.3.11 Nitrate (NO_3)

NO_3 levels for sites SS1 and SS2 during May and July could be attributed to agricultural activities. An increase in NO_3 concentrations between SS3 and SS4 could be due to sewage discharge. NO_3 levels recorded at site SS4 during July (6.6 mg/L) and May (3.2 mg/L) were seemingly higher compared to the before mentioned sample sites, indicating the presence of sewage water discharge from the wastewater treatment plants located upstream from the sample site. The lack of rainfall during July also means that the NO_3 concentrations were not diluted. The recorded NO_3 concentrations for site SS5 are due to cattle present at the site, as discussed previously. All of the sample sites recorded amounts well within the guidelines for the health of livestock (0 – 100 mg/L and within the guidelines for drinking water (0 – 11 mg/L) (DWAF, 1996a; DWAF, 1996c).

8.3.12 Sulphates (SO_4)

The highest SO_4 concentrations were recorded at site SS1 during May (1 840 mg/L) and the lowest SO_4 concentrations were at site SS2 during July (80 mg/L). The SO_4 concentrations for site SS1 (May and July) could be attributed to agricultural and mining activities upstream from the site (Goel, 2006). SO_4 concentrations at site SS2 were the lowest of all the sites. No agricultural or mining activities are located in close proximity to this site. High SO_4 levels were recorded at sites SS3 and SS4 during May. This may be due to two wastewater treatment plants discharging partially treated water into the Natalspruit. The reported SO_4 levels for these two sites were lower in July due to the lack of rainfall and runoff resulting in the lower SO_4 concentrations. The presence of SO_4 levels for site SS5 is possibly due to the presence of cattle faecal matter and remnants of partially treated wastewater, together with the lack of phytoremediation (very few to no reeds found at the site). According to DWAF (1996a), there are no guidelines regarding NO_3 concentrations in aquatic systems. Sites SS1 (May) and SS3 (May and July) both exceed the guidelines for drinking water (600 mg/L). Sites SS1 and SS3 (for May) both exceed the guidelines for maintaining the health of livestock (DWA, 2013).

8.3.13 Orthophosphate (PO_4)

The highest PO_4 concentrations were recorded at site SS5 during July at 0.250 mg/L compared to the lowest concentration at sites SS1 (May) and SS2 (May and July) at 0.08 mg/L. PO_4 concentrations at site SS3 indicate a slight increase perhaps due to its close proximity to a sewage treatment plant. Similarly, high PO_4 concentrations were also recorded at sites SS4 and SS5 are also located downstream of a sewage treatment plant. The recorded PO_4 levels from Rand Water varies compared to the results from this study where in some instances the levels were higher and in other instances were lower. All the sample sites were within the guidelines of 0 – 0.5 mg/L for aquatic health (DWAF, 1996a). There are no available PO_4 guidelines as to the health of livestock.

8.3.14 Total Coliforms

Total coliforms for May at all of the sample sites were not detected during analysis. It is possible that during the time of sample collection, the wastewater treatment plants did not discharge partially treated water into the Natalspruit. For July, the highest total coliform concentrations were recorded for site SS2 (100 000 CFU/100 ml) compared to the lowest at site SS4 (450 CFU/100 ml). Total coliform levels for site SS1 could be due to the agricultural activities near the site utilising animal manure to assist in fertilisation. The high total coliform levels at site SS2 could be due to raw sewage flowing from the Roseacre area, a tributary water source to the Natalspruit (see Chapter 5, section 5.2.13) (NTC Environmental Services, 2016). Total coliform concentrations reported for site SS4 were significantly lower than site SS3, but levels rose again at site SS5. The total coliform concentrations at site SS4 are of concern due to the children from the informal settlements frequenting this site, swimming and playing in the water. According to DWAF (1996f), the guidelines stipulating water quality for recreational use, the total coliform levels at this site pose a risk to the children swimming at this site. The risk (short and long term) of health impacts, such as ear and skin infections prevail if they ingest some of the water the children may also contract gastroenteric infectious diseases (DWAF, 1996f). Furthermore, concerning human safety, the total coliform concentrations would attribute to increased plant and algal growth. The total coliform concentrations for site SS5 are due to animal faecal matter at this site (large numbers of cattle). According to DWAF (1996a), South African guidelines indicate that total coliform concentrations should be at 0 CFU/100 ml for drinking water indicating that all of the sample sites exceed the set-out guidelines. The guidelines pertaining to the health of livestock stipulate a target water quality range of 0 – 200 mg/L indicating that water at none of the sample sites is adequate for the consumption by livestock seeing it exceeds the set-out guidelines (DWAF, 1996c).

8.3.15 Summary of Physicochemical Parameters and Comparison to the National Stand Guidelines of South Africa (Table 8.16).

For some indicators, the guidelines were not exceeded. Table 8.16 indicates that all pH concentrations for all of the sample sites were within the guidelines and thus be considered suitable for drinking purposes. All the sample sites were within the guidelines for Cl levels in water used for drinking and well within the guidelines for the health of livestock (DWA, 2013; DWAF, 1996c). None of the sample sites exceeded any of the guidelines concerning NO_3 levels. In terms of PO_4, none of the sample sites exceeded the national guidelines for aquatic systems (DWAF, 1996a).

However, for most, there are concerns, with guidelines exceeded. Turbidity levels for site SS2 exceeded the guidelines regarding aesthetic compliance and guidelines regarding the water quality for recreational use (DWAF, 1996f; DWA, 2013). All of the sample sites exceeded the BOD levels for drinking water (DWAF, 1996a). The levels of TDS for SS1 (May and July) and SS3 (May) both exceed the South African guidelines (aquatic systems) of acceptable TDS levels. The guidelines for the health of livestock was exceeded by sites SS1 (May and July), SS3 (May and July) and SS5 (May) (DWAF, 1996a; DWAF, 1996c). $CaCO_3$ concentrations at SS1 exceeded the guidelines for livestock (DWAF, 1996c). All the sample sites exceeded the guidelines for aquatic systems concerning Mg with the exception of site SS2, although none exceeded the Mg guidelines for the health of livestock (DWAF, 1996a; DWAF, 1996c). NO_2 concentrations exceeded the guidelines for drinking water at site SS1 (May), site SS4 (May) and (July) and lastly site SS5 (July) (DWA, 2013). With regards to SO_4 levels, sites SS1 (May) and SS3 (May and July) both exceed the guidelines for drinking water and guidelines for maintaining the health of livestock (DWAF, 1996a; DWA, 2013). Concerning Total Coliform concentrations, all of the sites exceeded the guidelines for drinking water, the health of livestock and recreational purposes (DWAF, 1996a; DWAF, 1996c; DWAF, 1996f).

	Turbidity		TDS		Ca as $CaCO_3$		Mg		Total Hardness		Cl		NO_2	
	May	July	May	July	May	July	May	July	May	July	May	July	May	July
SS1	5.2	3.3	3 200	1 200	1 390	671	127	66	1 920	941	82	56	2.7	0.3
SS2	6.5	6.9	330	230	97	96	17	17	165	165	34	32	0.4	<0.2
SS3	2.9	2.5	1 500	110	605	584	61	57	855	820	71	60	0.7	<0.2
SS4	3.1	3.0	85	900	431	388	46	44	621	571	69	67	1.3	2.0
SS5	3.0	1.7	1 100	770	400	342	44	41	582	511	64	63	<0.2	2.2

	NO_3		SO_4		PO_4		DO		pH		BOD		Total Coliforms	
	May	July	May	July	May	July	May	July	May	July	May	July	May	July
SS1	2.8	0.84	1 840	587	0.08	0.10	5.3	5.3	6.8	6.8	5.0	5.0	0.00	17 000
SS2	0.42	0.03	134	80	0.10	0.08	5.3	5.6	6.9	6.7	8.0	9.0	0.00	100 000
SS3	1.2	1.3	1 040	669	0.09	0.11	5.2	6.2	7.2	7.0	5.0	5.0	0.00	29 000
SS4	3.2	6.6	551	474	0.13	0.24	5.7	5.6	7.2	6.8	6.0	6.0	0.00	450
SS5	4.7	3.6	557	391	0.13	0.25	5.6	5.0	7.2	7.0	5.0	19.0	0.00	2 400

Unacceptable
Tolerable
Acceptable
No National Data

Table 8.16: The Physicochemical Parameters compared to the National Standard Guidelines of South Africa for drinking water, animal health and recreational use.

8.4 Heavy Metal Concentrations of Soil Samples

Cd concentrations for all the sample sites were recorded at <0.1 mg/kg, posing no health risks (human or environmental) according to the National Norms and Guidelines (DEA, 2013). Cr levels for all the sample sites varied with SS1 exceeding the guidelines for *all land-uses protective of water resources* (6.5 mg/kg), *informal residential* (6.5 mg/kg) and *standard residential use* (13 mg/kg). Site SS2, SS3 and SS5 exceeded all of the guidelines with the exception of the *protection of ecosystem health* guidelines (260 mg/kg). Site SS4 exceeded the guidelines for *all land-uses protective of water resources* (6.5 mg/kg), *informal residential* (6.5 mg/kg) and *standard residential use* (13 mg/kg). The high Cr levels at most of the sites, especially site SS2 (60 mg/kg), SS3 (82 mg/kg) and SS5 (79 mg/kg) most likely originate from Junction Hill (SCAW Metals), west (and between SS1 and SS2) of the Natalspruit. This industry is a great contributor of Cr (they produce large amounts of ash containing Cr). SCAW Metals have four stormwater dams (storm runoff and waste disposal) and during periods of high rainfall, the EIA report states that it overflows into the environment (Synergistics Environmental Services, 2014). Furthermore, the Cr concentrations originate from before the Natalspruit with research studies conducted on the Elsburgspruit and its catchment also indicating high levels of Cr in plant species such as *Typha capensis* and *Phragmites australis* (Ma, 2005). The Elsburgspruit catchment area is located north of the Natalspruit. This could be contributing to the high Cr levels at the sample sites. In comparison to the other heavy metals reported, Cr is possibly the most toxic and a great cause for concern with regards to human and animal health (see Chapter 6, Section 6.1.2).

Cu concentrations for the five sample sites indicated variation but were within the National Norms and Guidelines with the exception of the *all land-use protective of the water* (16 mg/kg) and the *protection of ecosystem health* of 16 mg/kg which was exceeded by all of the sample sites with the exception of SS5 (10 mg/kg). The Ni concentrations varied for all of the sample sites but not exceeding any of the National Norms and Guidelines with the exception of *all land-uses protective of water* (91 mg/kg).

Pb concentrations varied for all the sample sites but did not exceed any of the National Norms and Guidelines. Zn concentrations varied for all the sample sites with only SS3 (423 mg/kg) and SS5 (878 mg/kg) exceeding the limits of *all land-use protective of the water* guidelines (240 mg/kg) and *protective of ecosystem health* guidelines (240 mg/kg). Hg concentrations reported for all the sample sites varied but all sites reported within the limits as set out by the

National Norms and Standards (DEA, 2013). The presence of heavy metals in a wetland system such as the Natalspruit is most likely attributable to anthropocentric activities such as mining and industrial practices, negatively affecting the aquatic ecosystem and ultimately posing a health hazard to the local communities dependent on the Natalspruit for their subsistence farming practices and livelihood (Stanislawska-Glubiak & Korzeniowska, 2018).

8.5 SASS 5 Biomonitoring

The number of macro-invertebrate taxa reported for the five sample sites along the Natalspruit varied for each sample site dependent on location, riparian vegetation, biotope diversity and pollution factors. The greatest macro-invertebrate diversity was experienced at site SS5 due to its more natural state and distance from mining and industrial activities compared to site SS2 with the lowest recorded diversity due to the anthropocentric impacts at the site. The SASS 5 (68) and ASPT (4.2) scores were calculated which indicated a *moderate taxa diversity* and *moderate modification* of the watercourse which was then categorised as belonging to the **C** Class. The Natalspruit watercourse was then categorised as the Highveld (Upper) ecoregion (biological band). The SASS 5 and ASPT scores illustrate the ecological category of the Natalspruit watercourse. The ecological category indicated that the Natalspruit watercourse is *heavily modified* to *critically modified* (**E / F**).

8.6 PES and EIS

The PES assessment included an assessment of the Hydrology, Geomorphology and Vegetation, which ultimately determines the overall PES (Wetland Health Assessment) score, namely 4.1. This resulted in the Natalspruit being categorised in Category (**D**), which indicates the stream, is *modified* to a large degree with a *large change in ecosystem processes* and *loss of natural habitat and biota*. The EIS assessment was conducted by assigning a score between zero (*no ecological importance*) and four (*high ecological importance*). The overall EIS (Ecological Importance and Sensitivity) median score was calculated at 1.5 resulting in a Recommended Ecological Management Class of **C.** This indicated a moderate EIS score. Thus, the Natalspruit could be considered an *ecologically important and sensitive stream* at both a local and provincial level. The stream is *sensitive to flow and habitat modifications*. An ecologically important and sensitive stream, together with its sensitivity to flow and modifications to its habitat, refers to the ability of a watercourse or stream to maintain its ecological diversity and function at the local and provincial level. Lastly, the Natalspruit watercourse and its associated wetlands play a *small role in moderating the quantity and quality of water of major rivers*. This refers to the floodplain of the Natalspruit to be considered as important and sensitive only on a local and provincial level. However, is not sensitive to flow modifications, hence its classification, based on the views of Malan & Day (2012) which is that the river plays a small role in controlling the measure and value of water to major rivers.

8.7 Summary

The overall state of the Natalspruit indicates that it is polluted, with effluent discharge from mining and industrial activities and wastewater treatment plants. Of concern are the concentrations of heavy metals such as Cr and the total coliform counts. Other pollution sources such as informal settlements and agricultural activities are likely also contributing to the degradation of the Natalspruit based on the high levels of Mg, NO_2, BOD, DO and SO_4 levels found. There were, however, differences at various sample sites. This may be due to the dilution of concentrations as water in the watercourse flows away from the impact zone, with areas that are more capable of phytoremediation and low-flow rates.

8.8 Conclusion

The statistical analysis described in this chapter indicated the significant difference between the May and July results and the impact of seasonal variations. The discussion of the parameters of the water and soil samples indicated the extent of pollution present in the Natalspruit and the levels compared to the guidelines indicating the severity of its degradation. Biomonitoring, PES and EIS assessments discussed further emphasized the pollution levels of the Natalspruit providing a more holistic view regarding its degradation and the severity thereof. The presence of the reported high Cr levels is especially of great concern with regards to its impact on human, animal and plant life (see Chapter 6, section 6.1.2). The following and last chapter (Chapter 9) provides a conclusion and recommendations for remediation and mitigation measures.

CHAPTER 9: RECOMMENDATIONS AND CONCLUSION

9.1 Introduction

This study reveals the extent and severity of anthropocentric activities on the Natalspruit and its associated wetlands. Data, water and sediment/soil samples were collected to be used along with biomonitoring, PES and EIS assessments to thus determine the anthropocentric impacts on the river and its associated wetlands. Although small variations across all five sample sites were noted, the overall results indicate an ecosystem which has been subjected to moderate to severe wetland modification and which displays elevated pollution levels (Ollis *et al*., 2015). The presence of high Cr levels is of particular concern as this metal is exceptionally toxic and adversely affects the health of humans, animals and vegetation. Total coliform concentrations are also problematic. Recommendations for mitigating measures are provided in this chapter as a starting point from which to achieve the restoration of the ecology and biodiversity of the Natalspruit and its associated wetlands. The increasing trend of pollution from anthropocentric activities on the Natalspruit warrants adequate environmental planning and implementation of environmentally sound practices.

9.2 Objectives and Outcomes

The biological significance and ecological importance of, as well as the pressures exerted on the Natalspruit, and adjoining wetlands, were identified through EIS and PES assessments, biomonitoring and the taxonomic classification and identification of fauna, flora (terrestrial and riparian) and other living organisms as per Section 9.4. The impacts on the Natalspruit, and its adjoining wetlands, resulting from mining operations, industrial activities and human and informal settlements were documented through the testing and analysis of the chosen physicochemical parameters and sediment and soil analysis, as per Section 9.4. Recommendations for mitigation and remediation of the Natalspruit and its adjoining wetlands is provided (see Section 9.4).

9.3 An overview of the main results (Physicochemical Parameters, Sediment Analysis, SASS 5, EIS and PES)

The average temperature recorded for the Natalspruit and associated wetlands for May was 19 °C and for July 12 °C. At these temperatures, BOD and DO levels are not affected. Turbidity levels varied between the individual sample sites and between May and July, across all sample sites. All sites exceeded the SANS 241:2011 and DWA Guidelines of ≤1.0 NTU for *operational compliance* and SS1 and SS2 exceeded ≤5.0 NTU for *aesthetic compliance* (DWA, 2013). The pH levels for all five Natalspruit sample sites displayed limited variations for both seasons, thus indicating relatively normal pH levels between 5.5 and 8.0, thus neutral to slightly alkaline levels. BOD analysis indicated minor variations between each of the sample sites, both seasons with the exception of SS5. However, none of the sample sites conforms to the guideline parameters of 0 – 3.0 mg/L for BOD, and thus the water is not deemed suitable for drinking (DWAF, 1996a). The recorded TDS levels varied for all the sample sites with all of them indicating higher TDS levels for May due to rainfall and higher flow. The TDS recorded at SS1 (May and July) and SS3 (May) indicated that the water was unsuitable for drinking as it exceeded the guideline of 1 200 mg/L.

$CaCO_3$ varied greatly at SS1 (seasonal variation) with not much variation recorded at SS2, SS3, SS4 and SS5 for both seasons. There are no recorded SANS 241:2011 standards regarding $CaCO_3$. Mg levels varied (seasonally) significantly at SS1 compared to SS2, SS3, SS4 and SS5 and they differed from Rand Water data. Furthermore, all of the sample sites exceeded the guidelines for *aquatic ecosystems*, which stipulates acceptable Mg levels to be between 0 – 0.18 mg/L (DWAF, 1996a). Likewise, Total Hardness levels varied significantly between May and July for SS1 but remained mostly similar for SS2, SS3, SS4 and SS5. There were no recorded measurements for any of the sample sites by Rand Water and no guidelines set out by DWAF regarding acceptable levels of total hardness in an *aquatic environment*.

Results for Cl concentrations varied between May and July for all sample sites but were similar to each other, as well as aligned with data from Rand Water. Cl levels for all sites did not exceed the guideline of 0 – 250 mg/L (DWA, 2013). NO_2 and NO_3 levels varied between the sample sites for both seasons. NO_2 levels for SS1 (wet season), SS4 (both seasons) and SS5 (July) all exceeded the guideline of 0 – 0.9 mg/L for human consumption (DWA, 2013). NO_3 concentrations recorded at the sample sites for both seasons varied, but none exceeded guidelines regarding NO_3 levels for drinking water, which should be between 0 – 11 mg/L

(DWAF, 1996a). SO_4 levels recorded for May were significantly higher than those recorded for July for all sample sites with SS1 (May) and SS3 (May and July) exceeding the guideline of 0 – 600 mg/L for drinking water (DWA, 2013). The PO_4 concentrations varied between the sample sites for both May and July, but all sample sites were at an acceptable level of between 0 – 0.500 mg/L for *aquatic systems*.

Total coliform concentrations were only recorded in July (see Chapter 5). All sample sites were reported unsuitable for human and livestock consumption and recreational use due to the presence and high levels of total coliforms present in the Natalspruit (DWAF, 1996a; DWAF, 1996c; DWAF, 1996f). Pb concentrations at site SS3 (423 mg/kg) and SS5 (878 mg/kg) exceeded the limits of *all land-use protective of the water* guidelines (240 mg/kg) and *protective of ecosystem health* guidelines (240 mg/kg). Hg concentrations reported for all the sample sites varied, but all sites were within the limits set out by the National Norms and Standards (DEA, 2013). High Cr levels reported at four of the five sample sites exceeded the mentioned guidelines and, in comparison to the other heavy metal concentrations reported, Cr is the most concerning aspect of the sediment/soil analysis reported.

9.4 Research Questions

The study achieved the objective of answering all the research questions as summarised below:

Research Question 1: *What importance does the Natalspruit and its adjoining wetlands hold for the various fauna, flora and other living organisms present within it?*

The importance of the Natalspruit watercourse was determined by assessing and observing its EIS. The importance (for humans) and ecological value (fauna, flora and other living organisms) can be deemed as **moderate**, with an ecological management class of **C**. The Natalspruit watercourse and its associated wetlands are considered ecologically important.

Research Question 2: *What are the impacts of mining activities, industrial actions and rural settlements on the freshwater ecology of the Natalspruit and adjoining wetlands?*

Impacts from mining activities, industrial actions and rural settlements were indicated by the results of the physicochemical parameters and sediment/soil analysis. High levels of turbidity were reported at site SS2 (6.9 NTU) which were caused by high runoff from the Wadeville industrial area and bulldozing, an observed major disturbance of the area, of the site during July. BOD levels were high at all five sample sites due to the total coliform levels (100 000 NTU at SS2), most likely originating from two wastewater treatment plants and damaged sewer drains along the Natalspruit. There were also substantial algal growths observed along the Natalspruit (Durgapersad, 2005). High levels of TDS (SS1 reported 3 200 mg/L) are possibly due to upstream mining activities, industrial operations and wastewater treatment plants. The Elsburg Tailings Complex, which contains limestone, and wastewater treatment plants, which uses limestone, Mg and Cl to treat effluent, were reported as sources of high Total Hardness, Mg, Cl and $CaCO_3$ levels in the Natalspruit. Subsistence agriculture in the area may use animal manure as fertiliser that could result in high levels of NO_2, NO_3 and SO_4, although poor treatment of sewage may also be a contributing factor. High Cr levels, which negatively affect the health of humans, animals and vegetation, were recorded at all five sample sites. It is likely that these elevated levels are due to industrial activities from the upstream SCAW Metals plant. Macro-invertebrate populations sampled yielded only taxa that are tolerant of pollution levels, an indication of the low macroinvertebrate biodiversity in the Natalspruit.

Research Question 3: *Are the fauna and riparian vegetation of the Natalspruit and its adjoining wetlands under ecological pressure?*

The EIS ratings concluded that no rare or endangered wetland species were observed at any scale. Species richness was rated as ‘moderate’ on a local scale. Low diversity of vegetation and geomorphological structure, as well as low interspersion, were observed. The floodplain is important for the survival of some species. As the floodplain is small, some habitat types will be easily affected by anthropocentric changes. Storage capacity, floodplain size and stream order were not rated as high. Modifying determinants concluded that the present floodplain is not categorised as ‘protected’. Lastly, ecological integrity such as the flood regime, water quality and floodplain habitat have been affected by human activities which have resulted in the Natalspruit being heavily modified and no longer considered a stream in pristine condition.

A Wetland Health Assessment, indicating the overall PES scores, concluded that the Natalspruit watercourse, and its associated wetlands, were rated a **D** in the health category with a score of 4.1. This indicates that the study area is under ecological pressure and that it has been largely modified due to anthropogenic activities resulting in significant changes in its ecosystem processes that have, in turn, resulted in the loss of natural habitat and biota.

Research Question 4: *What recommendations could be made for the remediation and mitigation of the Natalspruit and its adjoining wetlands?*

Contaminated water remediation and mitigation methods such as wetland restoration, river bank restoration, soil remediation and community engagement and awareness creation are recommended for the Natalspruit watercourse and its adjoining wetlands. It is important to note that as it is very likely that the Natalspruit is influencing the pollution load in the Vaal River, thus, it is highly recommended that various measures are taken to rehabilitate the Natalspruit to mitigate the knock-on effect[6]. The above-mentioned sections will now be outlined in detail:

Wetland Restoration

Recommendations for creating, or restoring, the Natalspruit and its associated wetlands include:

- creating areas to allow for shallow water impoundments to support wetland avifauna;
- restoring the hydrology of the Natalspruit and associated wetlands through the use of gabions to plug drainage ditches;
- removing alien invasive plant species such as the Red River Gum (*Eucalyptus camaldulensis*); Common Mulberry (*Morus alba*); Black Wattle (*Acacia mearnsii*); Indian Shot (*Cannas indica*); Castor Oil Plant (*Ricinus communis*); White-flowered Mexican Poppy (*Argemone ochroleuca*); Yellow-flowered Mexican Poppy (*Argemone mexicana*) and Pompom Weed (*Campuloclinium macrocephalum*).
- preventing the occurrence of and removing illegally dumped waste;
- restoring and replacing existing damaged sewer drains to prevent further discharge of raw sewage;

[6] R240 million keeps Vaal River clean-up going, but project need R1.1 billion. https://www.timeslive.co.za/news/south-africa/2019-02-21-r240m-keeps-vaal-river-clean-up-going-but-project-needs-r11bn/ [Accessed 22 February 2018].

- introducing indigenous riparian vegetation and allowing passive colonisation (wind dispersal) or actively planting or sowing seeds at numerous sites along the Natalspruit and associated wetlands;
- formulating and enforcing policies and procedures which ensure that fully treated wastewater is discharged from the two sewage treatment plants located north of SS3 and SS4. This is a key task for the Department of Water Affairs and the local municipality; and
- reducing surface water run-off from agricultural, industrial and mining activities.

River Bank Restoration

Recommendations for river bank remediation of the Natalspruit and associated wetlands include:

- planting indigenous riparian vegetation which would root and then stabilise the bank, thus minimising erosion of the banks, especially during floods;
- implementing channel bank infrastructures such as gabions, concrete linings and ripraps;
- incorporating vegetation in hard structure designs to prevent increased flow velocity from hard structures to prevent, or limit, altering the geomorphological processes of the Natalspruit further; and
- limiting domestic cattle through a method of *elimination of direct stressors* by erecting fencing, thus preventing cattle from crossing the Natalspruit at multiple points along the bank (SS5) (see Florsheim, Mount & Chin, 2008).

Contaminated Soil Remediation (heavy metal contamination)

Recommendation for remediation of contaminated sediments of the Natalspruit and associated wetlands include:

- remediation of contaminated soil should be done in accordance with the National Environmental Management: Waste Act, 2008 in order to comply with the set-out conditions of a waste management license. It is further recommended that bioremediation should be used, where possible (Hasegawa, Rahman & Rahman, 2016).

Community Engagement and Awareness Creation

Community members play an important role as they provide input regarding decisions to be made and actions to be taken. As such, they should be awarded the opportunity to participate in the regulatory affairs of water sources and wetlands. Recommendations for community engagement and awareness creation include:

- informing the community members of all the facts and the current state of the Natalspruit and associated wetlands in order to create awareness. This includes information that the river is not safe to swim in and may be a hazard for their livestock;
- providing community members with the opportunity to raise concerns and voice their opinions regarding rehabilitation;
- involving NGOs (non-governmental organisations) in ongoing research projects in the area. The promotion of citizen science amongst community members (especially the children) will help to effectively foster an understanding of river and wetland ecology, thus highlighting the long-term benefits of a healthy and biodiverse river and wetland system;
- creating safe recreational parks along the course of the Natalspruit to help with the treatment of the water to remove total coliforms.

9.5 Study limitations

As budget constraints meant only ten water samples could be collected across all five sample sites, as well as only five sediment/soil samples (one at each sample site) in July and one SASS 5 sample at each of the five sample sites, it is recommended that a more comprehensive, long term investigation should be undertaken. There were also limitations regarding some of the assumptions of the Paired T-test, such as normality, given that there were only five data points. The relevant non-parametric statistical tests could not be done, resulting in reporting only the Paired T-tests and effect sizes (Cohen, 1992; De Winter, 2013). A macroinvertebrate assessment for all the sites was conducted in July only, which could have accounted for the lack of taxa biodiversity. It is recommended that biomonitoring should take place over a longer period. It is preferable to obtain more data for further research analysis, for example, three or more data points for each of the five sample sites. Other limitations included a lack of Rand Water data for all of the sample sites as well as the absence of some of the guidelines for all of the physicochemical parameters examined in this study. No data was available from the Department of Water Affairs at all. Due to the limitations and financial constraints of this study, it is recommended that further and detailed research of the Natalspruit and its associated wetlands be done to determine the exact interventions needed to ensure its future biological diversity and sustainability.

9.6 Conclusion

This study has shown that anthropocentric activities are a major threat to the Natalspruit and its associated wetlands. Mining, agricultural, industrial and other human activities in the catchment are polluting the Natalspruit. The surface run-off from the polluted catchment is transporting contaminants, nutrients and sediments (with heavy metals present) into the Natalspruit. It appears that the volumes of pollutants in the Natalspruit exceeds the ability of the river and its wetlands to cope with. The assessments conducted in this study indicate that the Natalspruit and its associated wetlands are no longer pristine due to the moderate to severe modification of the catchment and river itself. Additionally, biodiversity is limited, most likely due to these anthropocentric activities and alien species invasion. The study concluded that the water is unsafe for both human and animal consumption and recreation. Wetlands form an intricate part of the natural landscape, retaining water naturally, preventing floods and providing habitat to diverse fauna and flora. An estimation concluded that half of South Africa's natural wetlands have been lost to anthropocentric activities and development projects (Mitsch & Gosselink, 2000). Thus, the protection of wetlands, even less significant ones such as those which form part of the Natalspruit, is important.

REFERENCES

Abowei, J. F. N. 2010. Salinity, Dissolved Oxygen, pH and Surface Water Temperature Conditions in Nkoro River, Niger Delta, Nigeria. *Adv. J. Food Sci. Technol*, 2(1), pp.36-40 [online]. Available at: https://pdfs.semanticscholar.org/ba9c/9d96a61e520a05b9dc7b4dedba128e65e92c.pdf [Accessed 27 December 2018].

Alter, B. 2012. *Environmental Consulting Fundamentals: Investigation and Remediation*. London: CRC Press.

Ambani, A. E. & Annegarn, H. 2015. A Reduction in Mining and Industrial Effluents in the Blesbokspruit Ramsar Wetland, South Africa: Has the Quality of the Surface Water in the Wetland Improved? *Water SA*, 41 (5), pp.648-659.

American Water Works Association. 2010. *Principles and Practices of Water Supply Operations: Water Quality*. 4th Edition. USA: AWWA.

Armstrong, A. 2000. Ethical Considerations in Wetland Management. Physics and Chemistry of the Earth. *Part B: Hydrology, Oceans and Atmosphere*, 25 (7-8), pp.641-644.

Arnold, C. L. & Gibbons, C. J. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*, 62 (2), pp.243-258.

Australian and New Zealand Minerals and Energy Council (ANZMEC), 1996. Summary of Report: Baseline Environmental Guidelines for New and Existing Mines. *Australian Company Secretary*, 48 (3), pp.126-127.

Baran, A., Wieczorek, J., Mazurek, R., Urbański, K., & Klimkowicz-Pawlas, A. 2018. Potential Ecological Risk Assessment and Predicting Zinc Accumulation in Soils. *Environmental Geochemistry and Health*, 40 (1), pp.435-450 [online]. Available at: http://0-eds.a.ebscohost.com.oasis.unisa.ac.za/eds/pdfviewer/pdfviewer?vid=1&sid=31e715f0-99d9-43fd-a181-b9052d9f2cd2%40sdc-v-sessmgr01 [Accessed 11 February 2019].

Barrett, G., Brooks, S., Josefsson, J. & Zulu, 2016. *The Changing Face of Land and Conservation in Post-colonial Africa: Old Land, New Practices*? UK: Routledge.

Bartram, J. & Ballance, R. 1996. *Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*. London: CRC Press.

Belle, J. A., Collins, N., & Jordaan, A. 2018. Managing Wetlands for Disaster Risk Reduction: A Case Study of the Eastern Free State, South Africa. *Jàmbá: Journal of Disaster Risk Studies*, 10 (1), pp.1-10.

Boyd, C. E. 2000. *Water Quality: An Introduction*. Norwell: Kluwer Academic Publishers.

Brebbia, C. A. 2014. *Water Pollution XII*: *12th International Conference in the series of Modelling, Monitoring and Management of Water Pollution*. UK: WIT Press.

Brits, A. (Photographer). 2018. *Natalspruit and Associated Wetlands*. South Africa: Anja Brits Photography.

Buehler, D. A., Welton, M.J. & Beachy, T.A. 2006. Predicting Cerulean Warbler Habitat Use in the Cumberland Mountains of Tennessee. *Journal of Wildlife Management*, 70 (6), pp.1763–1769.

Cavalcanti, I. F. A., Carril, A. F., Penalba, O. C., Grimm, A. M., Menéndez, C. G., Sanchez, E. & Pántano, V. 2015. Precipitation Extremes Over La Plata Basin–Review and New Results from Observations and Climate Simulations. *Journal of Hydrology*, 523, pp.211-230 [online]. Available at: https://www.sciencedirect.com/science/article/pii/S0022169415000451 [Accessed 04 April 2018].

Cohen, J. 1992. A Power Primer. *Psychological Bulletin*, 112 (1), pp.155 [online]. Available at: http://www.personal.kent.edu/~marmey/quant2spring04/Cohen%20(1992)%20-%20PB.pdf [Accessed 15 January 2019].

Conrad, J. E., Colvin, C., Sililo, O., Görgens, A., Weaver, J & Reinhardt, C. 1999. *Assessment of the Impact of Agricultural Practices on the Quality of Groundwater in South Africa*. WRC Report No. 641/01. Pretoria: Water Research Commission.

Dallas, H. F. 2007. The Effect of Biotope-Specific Sampling for Aquatic Macroinvertebrates on Reference Site Classification and the Identification of Environmental Predictors in Mpumalanga, South Africa. *African Journal of Aquatic Science*, 32 (2), pp.165-173.

De Klerk, M. 2011. Wetland Sensitivity, Function and PES Assessment in the Vicinity of the Proposed Development of Klerksoord X25 & X26, Pretoria, Gauteng [online]. Available at: http://leapviro.co.za/Klerksoord/Annexure%20D2%20Wetlandreport.pdf [Accessed: 21 November 2018].

Department of Environmental Affairs (DEA), 2011. The National Strategy for Sustainable Development and Action Plan (NSSD1). Gauteng Provincial Government [online]. Available at: https://www.gov.za/sites/default/files/sustainabledevelopment_actionplan_strategy_0.pdf [Accessed 5 June 2017].

Department of Environmental Affairs (DEA). 2013. NEMA: Waste Act, 2008 (Act No. 59 of 2008): National Norms and Standards for the Remediation of Contaminated Land and Soil Quality [online]. Available at: https://cer.org.za/wp-content/uploads/2010/03/national-environmental-management-waste-act-59-2008-national-norms-and-standards-for-the-remediation-of-contaminated-land-and-soil-quality_20140502-GGN-37603-00331.pdf [Accessed 30 January 2018].

Department of Environmental Affairs (DEA), 2018. *Geospatial Data from the South Africa Protected and Conservation Areas Database* [online]. Available at: https://egis.environment.gov.za/ [Accessed 12 June 2018].

Department of Environmental Affairs, n.d., *World Wetlands Day: State of Wetlands in South Africa* [online]. Available at: http://soer.deat.gov.za/dm_documents/WWD_Final_2Feb20123_TQdyf.pdf [Accessed 13 May 2018].

Department of Environmental Affairs and Development Planning (DEADP), 2007. *Provincial Guideline on Biodiversity Offsets*. The Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town [online]. Available at: https://www.westerncape.gov.za/text/2007/3/pgwcoffsetsguidelinedraft_5march_07.pdf [Accessed 21 October 2017].

Department of Rural Development and Land Reform (DRDLR), 2017. Geospatial (vector) Data for the National 1:50 000 Scale Topographic Map Series 2628AC, National Geospatial Information (NGI) [online]. Available at: http://www.ngi.gov.za/ [Accessed 12 June 2018].

Department of Water Affairs (DWA), 2012. *GIS Data from Water Resources of South Africa, 2012* Study (WR2012) [online]. Available at: www.dwa.gov.za/iwqs/gis_data [Accessed 12 June 2018].

Department of Water Affairs (DWA), 2013. *Monitoring Requirements (SANS 241:2011) & Drinking Water Quality Compliance: Blue Drop Limit*s [online]. Available at: http://www.dwa.gov.za/Dir_WS/DWQR/subscr/ViewComDoc.asp?Docid=594 [Accessed 15 January 2019].

Department of Water Affairs (DWA), 2018. *National Water and Sanitation Master Plan: Ready for the Future and ahead of the Curve. Volume 1: Call to Action* [online]. Available at: http://www.dwa.gov.za/National%20Water%20and%20Sanitation%20Master%20Plan/Documents/NWSMP_Vol%201_Call%20to%20Action_Ver%208.2_20180112.pdf [Accessed 12 May 2018].

Department of Water Affairs and Forestry (DWAF), 1996a. *South African Water Quality Guidelines. 2nd Edition. Volume 7: Aquatic Ecosystems*. Department of Water Affairs and Forestry, Pretoria [online]. Available at: http://www.dwa.gov.za/iwqs/wq_guide/Pol_saWQguideFRESHAquaticecosystemsvol7.pdf [Accessed 11 September 2017].

Department of Water Affairs and Forestry (DWAF), 1996b. *South African Water Quality Guidelines: Agricultural Water Use: Aquaculture*. 2nd Edition. Volume 6 [online]. Available at: http://www.dwaf.gov.za/iwqs/wq_guide/agriaqua.pdf [Accessed 27 December 2018].

Department of Water Affairs and Forestry (DWAF), 1996c. *South African Water Quality Guidelines: Agricultural Use: Livestock Watering*. 2nd Edition. Volume 5 [online]. Available at: http://www.dwaf.gov.za/iwqs/wq_guide/Pol_saWQguideFRESH_vol5_Livestockwatering.pdf [Accessed 11 February 2019].

Department of Water Affairs and Forestry (DWAF), 1996d. *South African Water Quality Guidelines*. 2nd Edition. Volume 3: Industrial Use. Department of Water Affairs and Forestry, Pretoria [online]. http://www.dwa.gov.za/IWQS/wq_guide/edited/Pol_saWQguideFRESHIndustrialusevol3.pdf [Accessed 13 September 2017].

Department of Water Affairs and Forestry (DWAF), 1996e. *South African Water Quality Guidelines*. 1st Edition. Volume 8: Field Guide. Department of Water Affairs and Forestry, Pretoria [online]. Available at: http://www.dwa.gov.za/iwqs/wq_guide/Pol_saWQguideFRESHFieldguidevol8.pdf [Accessed 10 September 2017].

Department of Water Affairs and Forestry (DWAF), 1996f. *South African Water Quality Guidelines*. 2nd Edition. Volume 2: Recreational Use. Department of Water Affairs and Forestry, Pretoria [online]. Available at: http://www.dwa.gov.za/Documents/Other/RMP/RWUM/RWU_GP6.pdf [Accessed 18 February 2019].

Department of Water and Sanitation (DWS), 2016. *River Eco-status Monitoring Programme* (REMP) [online]. Available at: https://www.dwa.gov.za/iwqs/rhp/default.aspx [Accessed 5 October 2016].

Derman, B. & Manzungu, E. 2016. The Complex Politics of Water and Power in Zimbabwe: IWRM in the Catchment Councils of Manyame, Mazowe and Sanyati (1993-2001). *Water Alternatives*, 9 (3), pp.513.

De Winter, J. C. 2013. Using the Student's T-Test with Extremely Small Sample Sizes. *Practical Assessment, Research & Evaluation*, *18*(10), pp.2-8 [online]. Available at: https://pareonline.net/pdf/v18n10.pdf [Accessed 15 January 2019].

Dickens, C. W. & Graham, P. M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Science*, 27 (1), pp.1-10.

DRDGOLD LIMITED. 2019. Ergo [online]. Available at: http://www.drdgold.com/our-business/ergo [Accessed 27 December 2018].

Dudgeon, D., Arhington, A.H., Gessner, M. O., Kwabata, Z .I., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L. & Sullivan, C. A. 2006. Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. *Biological Reviews,* 81 (2), pp.163-182.

Durand, J. F. 2012. The Impact of Gold Mining on the Witwatersrand on the Rivers and Karst System of Gauteng and North West Province, South Africa. *Journal of African Earth Sciences*, 68, pp.24-43.

Durgapersad, K. 2005. *Effects of Wetlands on Water Quality and Invertebrate Biodiversity in the Klip River and Natalspruit in Gauteng, South Africa* [online]. Available at: https://repository.nwu.ac.za/handle/10394/531 [Accessed 7 October 2016].

Edwards, P. G., Gaines, K. F., Bryan, A. L., Novak, J. M. & Blas, S. A. 2014. Trophic Dynamics of U, Ni, Hg and Other Contaminants of Potential Concern on the Department of Energy's Savannah River Site. *Environmental Monitoring and Assessment*, 186 (1), pp.481-500.

Ellender, B. R & Weyl, O. L. 2014. A Review of Current Knowledge, Risk And Ecological Impacts Associated with Non-Native Freshwater Fish Introductions in South Africa. *Aquatic Invasions*, 9 (2), pp.117-132.

Environomics, 2007. Environmental Management Framework. Ekurhuleni Metropolitan Municipality, Ekurhuleni [online]. Available at: https://www.ekurhuleni.gov.za/469-environmental-managment-framework-2008/file [Accessed 2 June 2017].

Fetter, C. W. 2018. *Applied Hydrogeology*. 4th Edition. USA: Waveland Press, Inc.

Finlayson, C. M., Horwitz, H. & Weinstein, P. 2015. *Wetlands and Human Health*. New York: Springer.

Florsheim, J. L., Mount, J. F., & Chin, A. 2008. Bank Erosion as a Desirable Attribute of Rivers. *BioScience*, 58 (6), pp.519-529 [online]. Available at: https://academic.oup.com/bioscience/article/58/6/519/235969 [Accessed 12 February 2019].

Gauri, P. 2005. *Research Methods in Business Studies: A Practical Guide*. England: Prentice Hall.

Goel, P. K. 2006. *Water Pollution: Causes, Effects and Control*. New Delhi: New Age International Publishers.

Google Earth Pro, 2017. Natalspruit Sample Sites. Version 7.1.5.1557 [Software]. Available at: https://www.google.com/earth/download/gep/agree.html [Accessed 1 March 2018].

Google Earth Pro, 2017. Overview of the Natalspruit and its Associated Wetland Areas. Version 7.1.5.1557 [Software]. Available at: https://www.google.com/earth/download/gep/agree.html [Accessed 1 October 2017].

Goudie, A. & Viles, H. 2003. *The Earth Transformed: An Introduction to Human Impacts on the Environment*. 4th Edition. UK: Blackwell Publishers.

Guertin, J., Avakian, C. P. & Jacobs, J. A. 2016. *Chromium (VI) Handbook*. Florida: CRC press [online]. Available at: https://0-doi-org.oasis.unisa.ac.za/10.1201/9780203487969 [Accessed 11 February 2019].

Guo, Q. S., Su, M., Xiong, H. B., Mo, J. C., Li, X. F., Gao, Y. S. & Gao, Y. T. 2018. Deep Eutectic Solvent-Assisted Washing of Nickel from Polluted Mine Soil. *Ekoloji Dergisi*, 27 (106), pp.455-460 [online]. Available at: http://0-eds.a.ebscohost.com.oasis.unisa.ac.za/eds/pdfviewer/pdfviewer?vid=1&sid=e5851e33-dc68-4cca-9ef5-086f1c9af010%40sessionmgr4010 [Accessed 11 February 2019].

Hadjibiros, K. 2014. *Ecology and Applied Environmental Science*. London: CRC Press.

Hambley, A. G. 1996. *Removal of Nickel from Mine Water by a Natural Wetland in Northern Manitoba*. Natural Resources Institute, University of Manitoba, (Unpublished Master's Thesis), Winnipeg, Manitoba [online]. Available at: https://mspace.lib.umanitoba.ca/bitstream/handle/1993/23120/Hambley_Removal_of_nickel.pdf?sequence=1 [Accessed 11 February 2019].

Hargraves, A. J. & Martin, C. H. 1993. *Australasian Coal Mining Practice*. 2nd Edition. Australia: Western Print.

Hasegawa, H., Rahman, I. M. & Rahman, M. A. 2016. *Environmental Remediation Technologies for Metal-Contaminated Soils*. Tokyo: Springer.

Hoare, D., Van der Merwe, E. & Claasen, P. 2008. *Ekurhuleni Metropolitan Municipality: Biodiversity Report, 2008*. Ekurhuleni Metropolitan Municipality, Kempton Park [online]. Available at: https://www.ekurhuleni.gov.za/467-biodiversity-report-2008/file [Accessed 31 May 2017].

Hugget, R. J. 2007. *Fundamentals of Geomorphology: Routledge of Fundamentals of Physical Geography*. 2nd Edition. USA: Routledge.

Hung, Y. T., Wang, L. K., Wang, M. H. S., Shammas, N. K. & Chen, J. P. 2016. *Remediation of Heavy Metals in the Environment*. London: CRC Press.

Iliso Consulting, 2016. *Terrestrial Faunal, Floral and Wetland Ecological Assessment Update as part of the Environmental Impact Assessment Process for the Proposed Water Supply Pipeline Upgrade at the Duvha Power Station, Mpumalanga* [online] Available at: http://iliso.com/public_participation/Duvha_Pipeline/Terrestrial%20Faunal%20Floral%20and%20Wetland%20Ecological%20Assessment.pdf [Accessed 13 May 2018].

Invasive Species South Africa, 2018. *Gambusia affinis* (Mosquito Fish) [online]. Available at: http://www.invasives.org.za/legislation/item/831-mosquitofish-gambusia-affinis [Accessed 19 October 2018].

Jiménez, E., Cabañas, B. & Lefebvre, G. 2014. *Environment, Energy and Climate Change: Environmental Chemistry of Pollutants and Wastes*. London: Springer.

Jogo, W. & Hassan, R. 2010. Balancing the Use of Wetlands for Economic Well-Being and Ecological Security: The Case of the Limpopo Wetland in Southern Africa. *Ecological Economics*, 69 (7), pp.1569-1579.

Johansson, R. 2007. On Case Study Methodology. *Open House International*, 32 (3), pp.48-54 [online]. Available at: http://www.psyking.net/htmlobj-3839/case_study_methodology-_rolf_johansson_ver_2.pdf [Accessed 13 February 2018].

Joseph, W. 2017. *Effects of Human Settlements Activities on Wetlands: A Case Study of Manguo Wetland and Adjacent Human Settlements*. (Unpublished Master's Thesis) University of Nairobi, Kenya. [online]. http://urbanplanning.uonbi.ac.ke/sites/default/files/cae/artsdesign/urbanplanning/Joseph%20Wahome%20Research%202016.pdf [Accessed 20 April 2018].

Kafri, U. & Foster, M. B. J. 1989. Hydrogeology of the Malmani Dolomite in the Klip River and Natalspruit Basins, South Africa. *Environmental Geology*, 13 (2), pp.153-166.

King, N., Rosmarin, T., Friedmann, Y. & Reyers, B. 2005. *National State of the Environment Project: Biodiversity and Ecosystem Health*. *Background Research Paper Produced for the South Africa Environment Outlook Report on Behalf of the Department of Environmental Affairs and Tourism*. SRK Consulting [online]. Available at: http://soer.deat.gov.za/dm_documents/Biodiversity_-_Background_Paper_RWuoQ.pdf [Accessed 11 October 2017].

Kleynhans, C. J., Louw, D. & Graham, M. 2009. *River Ecoclassification Manual for Ecostatus Determination. Module G, Index of Habitat Integrity*. *Section 1, Technical Manual: Report to the Water Research Commission*. Water Research Commission. WRC Report 377. 09/TT.

Knight, J. & Grab, S. W. 2016. *Quaternary Environmental Change in Southern Africa: Physical and Human Dimensions*. UK: Cambridge University Press.

Kotze, D. 2010. *WET-Sustainable Use: A System for Assessing the Sustainability of Wetland Use*. Report No. TT 438/09: Water Research Commission. Pretoria, South Africa.

Kotze, D. C. 2005. *An Ecological Assessment of the Health of the Mohlapetsi Wetland Limpopo Province, South Africa* [online]. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/21610/21610.pdf?sequence=1&isAllowed=y [Accessed 10 July 2017].

Kotze, D. C. 2013. The Effects of Fire on Wetland Structure and Functioning. *African Journal of Aquatic Science*, 38 (3), pp.237-247.

Kracauer, E., Grozev, O. and Rosenzweig, C. 1997. Climate Change, Agriculture and Wetlands in Eastern Europe: Vulnerability, Adaptation and Policy. *Climatic Change*, 36 (1), pp.107-121.

Krige, W. G. 2006. *Hydrological/Chemical Aspects of the Tweelopie-/Riet-/Blaauwbankspruit, with Specific Reference to the Impact Water, Decanting from the Western Basin Mine Void, has on this System*. Environmental Impact Assessment for J. Fourie & Associates on behalf of Harmony GM Co Ltd [online]. Available at: https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwiBgefrr9bVAhVCDcAKHawODQsQFgg1MAI&url=http%3A%2F%2Fwww.miningweekly.com%2Fattachment.php%3Faa_id%3D5731&usg=AFQjCNG34_OZ7_aOMonMRZeAwjFKdy1MBQ [Accessed 15 November 2016].

Kumar, R. 2014. *Research Methodology: A Step-by-Step Guide for Beginners*. 4th Edition. California: Sage Publications.

Latawiec, A.E. & Agol, D. 2015. *Sustainability Indicators in Practice.* Berlin: De Gruyter Open.

Laughlin, M. M., Martin, J. G., Liesch, P. J & Olson, E. R. 2018. Dragonfly (Odonata: Corduliidae, Macromiidae, Gomphidae, Aeshnidae) and Damselfly (Odonata: Calopterygidae) Exuviae Observed at Record Heights in *Pinus strobus* and *Picea abies* Canopies. *The Great Lakes Entomologist*, 51 (1), pp.5.

Lee, N & George, C. 2000. *Environmental Assessment in Developing and Transitional Countries*. UK: John Wiley & Sons Ltd.

Lewis, M. 2016. AEWA at Twenty: An Appraisal of the African-Eurasian Waterbird Agreement and its Unique Place in International Environmental Law. *Journal of International Wildlife Law & Policy*, 19 (1), pp.22-61.

Li, D. & Liu, S. 2018. *Water Quality Monitoring and Management: Basis, Technology and Case Studies*. London: Academic Press.

Li, Y., Shi, Y., Zhu, X., Cao, H. & Yu, T. 2014. Coastal Wetland Loss and Environmental Change due to Rapid Urban Expansion in Lianyungang, Jiangsu, China. *Regional Environmental Change*, 14 (3), pp.1175-1188.

Liang, M. 2009. New Possibilities of Magnesium Utilization in Wastewater Treatment and Nutrients Recovery. *Land and Water Resources Engineering*, KTH, Stockholm (Unpublished Master's Thesis) Royal Institute of Technology, Stockholm, Sweden [online]. Available at: http://sjostad.ivl.se/download/18.71afa2f11269da2a40580007087/1350483757671/LWR_EX_09_29.pdf [Accessed 29 December 2018].

Liptak, B. G. 2003. *Instrument Engineers' Handbook, Volume One: Process Measurement and Analysis*. 5th Edition. London: CRC Press.

Lobe, P. D. D., Filser, J & Otomo, P. V. 2018. Avoidance Behaviour of Enchytraeus Albidus (Oligochaeta) After Exposure to AgNPs and AgNO 3 at Constant and Fluctuating Temperature. *European Journal of Soil Biology*, 87, pp.40-45 [online]. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1164556318300049 [Accessed 29 November 2018].

Lombard, R. J., Chimimba, C. T & Zengeya, T. A. 2018. Niche Complementarity between an Alien Predator and Native Omnivorous Fish in the Wilge River, South Africa. *Hydrobiologia*, 817(1), pp.329-340 [online]. Available at: https://0-link-springer-com.oasis.unisa.ac.za/content/pdf/10.1007%2Fs10750-017-3352-7.pdf [Accessed 21 November 2018].

Ma, Y. 2005. *Monitoring of Heavy Metals in the Bottelary River Using Typha Capensis and Phragmites Australis* (Unpublished Doctoral Dissertation), University of the Western Cape, South Africa [online]. Available at: https://core.ac.uk/download/pdf/58912915.pdf [Accessed 12 February 2019].

Macfarlane, D. M., Kotze, D. C., Ellery, W. N., Walters, D., Koopman, V., Goodman, P. & Coge, C. 2008. *WET-Health, Wetland Management Series: A Technique for Rapidly Assessing Wetland Health*. Wetlands Research Programme: Wetland Rehabilitation (WRC Project No. K5/1408). Pretoria: WRC.

Macfarlane, D.M., Kotze, D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P & Goge C. 2009. *WET-Health: A Technique for Rapidly Assessing Wetland Health*. Report No. TT 340/09: Water Research Commission. Pretoria, South Africa.

Malan, H. & Day, J. 2012. *Water Quality and Wetlands: Defining Ecological Categories and Links with Land Use*. Report No. TT 1921/1/12: Water Research Commission, Pretoria, South Africa.

Manahan, S. E. 2011. *Water Chemistry: Green Science and Technology of Nature's Most Renewable Resource.* London: CRC Press.

Marais, L., Nel, E. & Donaldson, R. 2016. *Secondary Cities and Development: Regions and Cities*. New York: Routledge.

Margui, E. & Hedblom, M. 2017. *Ecology and Conservation of Birds in Urban Environments*. Switzerland: Springer.

Matavire, M. M. 2015. *Impacts of Sugarcane Farming on Coastal Wetlands of the North Coast of Zululand, KwaDukuza, South Africa* (Unpublished Doctoral Dissertation, Stellenbosch University) [online]. Available at: https://www.google.co.za/search?q=Impacts+of+Sugarcane+Farming+on+Coastal+Wetlands+of+the+North+Coast+of+Zululand%2C+KwaDukuza%2C+South+Africa&rlz=1C1VFKB_enZA695ZA695&oq=Impacts+of+Sugarcane+Farming+on+Coastal+Wetlands+of+the+North+Coast+of+Zululand%2C+KwaDukuza%2C+South+Africa&aqs=chrome..69i57.612j0j7&sourceid=chrome&ie=UTF-8# [Accessed 29 October 2017].

Miller, G. T. & Spoolman, S. 2007. *Living in the Environment: Principles, Connections, and Solutions*. 15th Edition. Canada: Thompson Brooks/Cole.

Ministry of Water and Environment Uganda (MWEU), 2015. U*ganda Wetlands Atlas: Kampala City, Mukono and Wakiso Districts*, Volume 1. Uganda: Ministry of Water and Environment.

Mitsch, W. J. and Gosselink, J. G. 2000. The Value of Wetlands: Importance of Scale and Landscape Setting. *Ecological Economics*, 35(1), pp.25-33.

Molewa, B. E. E. 2012. National Environmental Management: Waste Act (59/2008): National Waste Management Strategy. South African National Department of Environmental Affairs, 563, 35306 [online]. Available at: https://www.environment.gov.za/sites/default/files/gazetted_notices/nemwa_soilquality_standards.pdf [Accessed 15 August 2018].

Morgan, R. P. C. 2005. *Soil Erosion and Conservation*. 3rd Edition. Oxford: Blackwell Publishing.

Mujuru, M. & Mutanga, S.S. 2016. *Management and Mitigation of Acid Mine Drainage in South Africa: Input of Mineral Beneficiation in Africa*. Pretoria: Africa Institute of South Africa.

Murcott, S. 2012. *Arsenic Contamination in the World. An International Sourcebook*. London: IWA.

Mushtaq, F., & Pandey, A. C. 2014. Assessment of Land Use/Land Cover Dynamics Vis-À-Vis Hydrometeorological Variability in Wular Lake Environs Kashmir Valley, India Using Multitemporal Satellite Data. *Arabian Journal of Geosciences*, 7 (11), pp.4707-4715.

Muwanga, A. & Barifaijo, E. 2006. Impact of Industrial Activities on Heavy Metal Loading and their Physico-Chemical Effects on Wetlands of Lake Victoria Basin (Uganda). *African Journal of Science and Technology*, 7 (1), pp.51-63.

Naidoo, S. 2017. *Acid Mine Drainage in South Africa: Development Actors, Policy Impacts, and Broader Implications*. Switzerland: Springer.

Naiman, R. J. & Bilby, R. E. 1998. *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*. New York: Springer-Verlag.

Nazir, S. & Deka, P. 2016. A Study on the Seasonal Trend of Physicochemical Parameters of Deepar Beel (Wetland) near to Khonajan, A Channel Connecting the River Brahmaputra. *International Journal of Chemical Studies*, 4 (4), pp.10-16 [online] Available at: http://www.chemijournal.com/archives/2016/vol4issue4/PartA/4-3-19-961.pdf [Accessed 12 January 2019].

Nelson, G. C., Bennett, E., Berhe, A.A., Cassman, K., DeFries, R., Dietz, T., & Zurek, M. 2006. Anthropogenic Drivers of Ecosystem Change: an Overview. *Ecology & Society*, 11 (2), pp.526-556.

Niemelä, J., Breuste, J. H., Elmqvist, T., Guntenspergen, G., James, P. & McIntyre, N. E. 2011. *Urban Ecology: Patterns, Processes, and Applications*. New York: Oxford University Press.

NTC Environmental Services, 2016. *Draft Basic Assessment Report for the Proposed Kyalami, Braamfonteinspruit, and Natalspruit Water Management Units Riverine and Eco-Parks Rehabilitation*, City of Johannesburg Metropolitan Municipality, Gauteng Province [online]. Available at: http://www.sahra.org.za/sahris/sites/default/files/additionaldocs/JCPZ%20Basic%20Assessment%20Report%2022%20August%202016%20.pdf [Accessed 15 November 2016].

Oberholster, P. J., De Klerk, A. R., Chamier, J., Cho, M., Crafford, J., De Klerk, L. P. & Schaefer, L. 2016. *Assessment of the Ecological Integrity of the Zaalklapspruit Wetland in Mpumalanga (South Africa) Before and After Rehabilitation: The Grootspruit Case Study*: Report to the Water Research Commission. Water Research Commission. *WRC Report No. 2230/2/16*. [online]. Available at: http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/2230%20Volume%202%20-%20Jo.pdf [Accessed 12 May 2018].

Oliveira, H. 2012. Chromium as an Environmental Pollutant: Insights on Induced Plant Toxicity. *Journal of Botany*, 2012(8), pp.1-8 [online]. Available at: http://dx.doi.org/10.1155/2012/375843 [Accessed 12 February 2019].

Ollis, D. J., Ewart-Smith, J. L., Day, J. A., Job, N. M., Macfarlane, D. M., Snaddon, C. D., Sieben, E. J. J., Dini, J. A. & Mbona, N. 2015. The Development of a Classification System for Inland Aquatic Ecosystems in South Africa. *Water SA*, 41 (5), pp.727-745.

Olomukoro, J. O & Dirisu, A. R. 2014. Macroinvertebrate Community and Pollution Tolerance Index in Edion and Omodo Rivers in Derived Savannah Wetlands in Southern Nigeria. *Jordan Journal of Biological Sciences*, 7 (1), pp.19-24 [online]. Available at: http://jjbs.hu.edu.jo/files/v7n1/Paper%20Number%204m.pdf [Accessed 29 November 2018].

Organisation for Economic Co-operation and Development (OECD), 2017. *Switzerland: OECD Environmental Performance Reviews*. Paris: OECD Publications.

Okonkwo, C. N. P., Kumar, L., & Taylor, S. 2015. The Niger Delta Wetland Ecosystem: What threatens it and why should we protect it? *African Journal of Environmental Science and Technology*, 9 (5), pp.451-463.

Oxford Dictionary. 2010. *Cobra Effect*. 3rd Edition. UK: Oxford University Press.

Pandey, J. & Singh, R. 2017. Heavy Metals in Sediments of Ganga River: Up-and Downstream Urban Influences. *Applied Water Science*, 7 (4), pp.1669-1678.

Pearce, R. S. 2001. Plant Freezing and Damage. *Annals of Botany*, 87 (4), pp.417-424.

Percival, R. V., Schroeder, C. H., Miller, A. S. & Leape, J. P. 2017. *Environmental Regulation: Law, Science, and Policy*. 8th Edition. New York: Wolters Kluwer.

Perissinotto, R., Stretch, D. D. & Taylor, R. H. 2013. *Ecology and Conservation of Estuarine Ecosystems: Lake St Lucia as a Global Model*. New York: Cambridge University Press.

Peterson, B. J., & Deegan, L. 1993. Biological Responses of a Tundra River to Fertilization. *Ecology*, 74 (3), pp.653.

Pheiffer, W., Pieters, R., Van Dyk, J. C., & Smit, N. J. 2014. Metal Contamination of Sediments and Fish from the Vaal River, South Africa. *African Journal of Aquatic Science*, 39 (1), pp.117-121.

Potasznik, A. & Szymczyk, S. 2015. Magnesium and Calcium Concentrations in the Surface Water and Bottom Deposits of A River-Lake System. *Journal of Elementology*, 20(3), pp.677-692 [online]. Available at: http://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-c1c5ee34-2058-4142-ad40-f6a84aa729e6 [Accessed 29 December 2018].

Randolf, J. 2012. *Environmental Land Use Planning and Management*. 2nd Edition. Washington: Island Press.

Ravengai, S., Love, D., Mabvira-Meck, M., Musiwa, K., & Moyce, W. 2005. Water Quality in an Abandoned Gold Mining Belt, Beatrice, Sanyati Valley, Zimbabwe. *Physics and Chemistry of the Earth*, 30 (11-16), pp.826-831.

Razowska-Jaworek, L. 2014. *Calcium and Magnesium in Groundwater: Occurrence and Significance for Human Health*. London: CRC Press.

Revollo-Fernández, D. A. 2015. Does Money Fly? The Economic Value of Migratory Bird Watching in Xochimilco, Mexico. *Modern Economy*, 6 (6), pp.643.

Rodgers, J. H., Lehman, R. W., Gladden, J. B., Bell, J. F. and Mooney, F. D. 2001. Wetlands for Industrial Wastewater Treatment at the Savannah River Site: a Case Study. *Proceedings of the Water Environment Federation*, 2001 (9), pp.55-72.

Rosenberg, D. M & Resh, V. H. 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. New York: Chapman and Hall.

Sarron, C. 2005. *Effects of Wetland Degradation on the Hydrological Regime of a Quaternary Catchment in the Mohlapitsi River Ga-Mampa Valley* (Doctoral dissertation, École Nationale Supérieure Agronomique de Rennes) [online]. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/21623/21623.pdf?sequence=1&isAllowed=y [Accessed 29 October 2017].

Scholz, R. W. & Tietje, O. 2002. *Embedded Case Study Methods*: *Integrating Quantitative and Qualitative Knowledge*. Thousand Oaks: Sage Publications.

Scott, D. B., Frail-Gauthier, J. F. & Mudie, P. J. 2014. *Coastal Wetlands of the World: Geology, Ecology, Distribution and Applications*. UK: Cambridge University Press.

Scott, R. 1995. *Flooding of Central and East Rand Gold Mines: An Investigation into Controls over the Inflow Rate, Water Quality and the Predicted Impacts of Flooded Mines*. WRC Report No. 486/1. Pretoria: Water Research Commission.

Serra, S. R., Graça, M. A., Doledec, S & Feio, M. J. 2017. Chironomidae Traits and Life History Strategies as Indicators of Anthropogenic Disturbance. *Environmental Monitoring and Assessment*, 189 (7), pp.326 [online]. Available at: https://www.researchgate.net/publication/317956700_Chironomidae_traits_and_life_history_strategies_as_indicators_of_anthropogenic_disturbance [Accessed 29 November 2018].

Singh, B. 2013. Impact of Mining on Flora and Fauna of Faridabad District in Haryana. *International Journal of Research in Science and Technology*, 2 (6), pp.5-6.

Singh B. R. & McLaughlin M. J. 1999. Cadmium in Soils and Plants. *Plant Science*, 161 (2), pp.371-373. Dordrecht: Springer [online] Available at: https://www.sciencedirect.com/science/article/pii/S0168945201003958 [Accessed 11 February 2019].

Singh, V. P., Yadav, S. & Yadava, R. N. 2016. *Environmental Pollution: Select Proceedings of ICWEES*. India: Springer.

Siyaya, J. S. 2015. *Review of Local Institutional Arrangement for Zone 3 Community Wetland in Sebokeng, Gauteng, South Africa* (Unpublished Masters Dissertation, University of South Africa) [online]. Available at: http://uir.unisa.ac.za/bitstream/handle/10500/19824/dissertation_siyaya_j.pdf?sequence=1&isAllowed=y [Accessed 14 May 2018].

Soil Classification Working Group & Macvicar, C. N. 1991. *Soil Classification: A Taxonomic System for South Africa*. 2nd Edition. Pretoria: Department of Agricultural Development.

Somerset Educational. 2015. *Micro-Life Water Quality Testing Kit Guide*. Cape Town: Somerset Educational Publishers.

Spellman, F. R. 2008. *The Science of Water: Concepts and Applications*. 2nd Edition. London: CRC Press.

Spellman, F. R. 2009. *Handbook of Water and Wastewater Treatment Plant Operations*. 2nd Edition. London: CRC Press.

Stanislawska-Glubiak, E. & Korzeniowska, J. 2018. Fate of Copper in Soils from Different Fertilizer Doses in Relation to Environmental Risk Assessment. *Polish Journal of Environmental Studies*, 27 (4), pp.1735-1741 [online]. Available at: http://0-eds.a.ebscohost.com.oasis.unisa.ac.za/eds/pdfviewer/pdfviewer?vid=1&sid=e6c9648b-efe6-46f6-ae8f-312ec0945215%40sessionmgr4009 [Accessed 11 February 2019].

Stoate, C., Báldi, A., Beja, P., Boatman, N. D., Herzon, I., Van Doorn, A., De Snoo, G. R., Rakosy, L. & Ramwell, C. 2009. Ecological Impacts of Early 21st Century Agricultural Change in Europe–a Review. *Journal of Environmental Management*, 91 (1), pp.22-46.

Stevenson, A. 2010. *Oxford Dictionary of English: Ethics*. 3rd Edition. UK: Oxford University Press.

Strydom, H. A. & King, N. D. 2009. *Environmental Management in South Africa*. 2nd Edition. Cape Town: JUTA.

Sun, H., Brocato, J. & Costa, M. 2015. Oral Chromium Exposure and Toxicity. *Current Environmental Health Reports*, 2 (3), pp.295-303 [online]. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4522702/pdf/nihms698984.pdf [Accessed 12 February 2019].

Sundar, K. G., Chauhan, A. S., Kittur, S. & Babu, S. 2015. Wetland Loss and Waterbird Use of Wetlands in Palwal District, Haryana, India: The Role of Agriculture, Urbanization and Conversion to Fish Ponds. *Wetlands*, 35(1), pp.115-125 [online]. Available at: https://0-link-springer-com.oasis.unisa.ac.za/content/pdf/10.1007%2Fs13157-014-0600-8.pdf [Accessed 20 April 2018].

Swanborn, P. G. 2010. *Case Study Research: What, Why and How?* London: Sage Publications.

Synergistics Environmental Services, 2014. *Waste Disposal Facility 5 at SCAW Metals, Germiston. Environmental Impact Report* [online]. Available at: https://sahris.sahra.org.za/sites/default/files/additionaldocs/Scaw%20Waste%20Disposal%20Facility%205_%20Final%20EIA_20140623.pdf [Accessed 12 February 2019].

Taylor, C. S. 2013. *Validity and Validation: Understanding Statistics*. New York: Oxford University Press.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment/Water Management area using GIS. *International Journal of Advanced Remote Sensing and GIS*, 4 (1), pp.828.

Timoney, K. P. 2015. *Impaired Wetlands in a Damaged Landscape: The Legacy of Bitumen Exploitation in Canada.* London: Springer International.

Turner, R. K., Van Den Bergh, J. C., Söderqvist, T., Barendregt, A., Van Der Straaten, J., Maltby, E. and Van Ierland, E. C. 2000. Ecological-economic Analysis of Wetlands: Scientific Integration for Management and Policy. *Ecological Economics*, 35 (1), pp.7-23.

University of South Africa (UNISA), 2012. Policy on Research Ethics [online] Available at: http://www.unisa.ac.za/static/corporate_web/Content/Colleges/CGS/documents/Policy-on-Research-Ethics-rev-appr-Council-20.09.2013.pdf [Accessed 2 October 2017].

United Nations World Water Assessment Programme (WWAP) & UN-Water, 2018. *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water*. Paris: UNESCO.

Valentukeviciene, M., Ignatavicius, G. & Valskys, V. 2014. Nitrogen and Organic Compounds Correlations in Groundwater from the Aquifer in a Semi-Island (Curonian Spit, Lithuania). *Ekologija*, 60 (1), pp.10-17.

Van Der Valk, A. G. 2006. *The Biodiversity of Freshwater Wetlands*: *Ecology, Evolution and Organisational Biology*. New York: Oxford University Press.

Van Eeden, E. S. 2008. Weaknesses in Environmental Action in South Africa: A Historical Glance on the West Rand (Gauteng Province). *International Journal of Water Resources Development*, 24 (3), pp.463-475.

Van Eeden, P. H. & Schoonbee, H. J. 1996. Metal Concentrations in Liver, Kidney, Bone and Blood of Three Species of Birds from a Metal-Polluted Wetland. *Water SA,* 22 (4), pp.351-358.

Van Oudtshoorn, F. 2004. *Guide to Grasses of Southern Africa*. 2nd Edition. Pretoria: Briza Publications.

Van Roon, M. R. 2012. Wetlands in the Netherlands and New Zealand: Optimising Biodiversity and Carbon Sequestration during Urbanisation. *Journal of Environmental Management*, 101, pp.143-150 [online]. Available at: https://www.sciencedirect.com/science/article/pii/S0301479712000709 [Accessed 18 February 2019].

Van Wyk, B & Van Wyk, P. 1997. *Field Guide to Trees of Southern Africa*. Cape Town: Struik Publishers.

Vos, P. 2015. *Origin of the Dutch Coastal Landscape*. Groningen: Barkhuis.

Vymazal, J. 2010. *Water and Nutrient Management in Natural and Constructed Wetlands*. Dordrecht: Springer.

Vymazal, J. 2015. *The Role of Natural and Constructed Wetlands in Nutrient Cycling and Retention on the Landscape*. Switzerland: Springer.

Vymazal, J. 2016. *Natural and Constructed Wetlands: Nutrients, Heavy Metals and Energy Cycling, and Flow*. Switzerland: Springer International Publishing.

Water Wise, 2005. *Alien Invasive Plants* [online]. Available at: http://www.waterwise.co.za/export/sites/water-wise/industry/alien-invasive/downloads/Water_Wise_Alien_Invasive_Plants.pdf [Accessed 12 July 2017].

Weiner, E. R. 2008. *Applications of Environmental Aquatic Chemistry: A Practical Guide*. 2nd Edition. London: CRC Press.

Wilson, J. R., Panetta, J. R & Lindgren, C. 2017. *Detecting and Responding to Alien Plant Incursions*. UK: Cambridge University Press.

Wood, A., Dixon, A. & McCartney, M. 2013. *Wetland Management and Sustainable Livelihoods in Africa*. Canada: Routledge.

Yin, R. K. 2012. *Applications of Case Study Research*. London: Sage Publications.

Yin, R. K. 2018. *Case Study Research and Applications: Design and Methods*. USA: Sage Publications.

Yu, M. H., Landis, W. & Sofield, R. 1998. *Introduction to Environmental Toxicology: Molecular Substructures to Ecological Landscapes*. 4th Edition. London: CRC Press.

Zainal, Z. 2007. Case Study as a Research Method. *Jurnal Kemanusiaan*, 5 (1), pp.1-6.

Zyphur, M. J. & Pierides, D. C. 2017. Is Quantitative Research Ethical? Tools for Ethically Practicing, Evaluating, and Using Quantitative Research. *Journal of Business Ethics*, 143 (1), pp.1-16.

APPENDICES

Appendix 1: Field Sheet for Water and Soil Sample Collection

Name: ___________________

Sampling Site Code:

Sampling Location GPS:

Bottle Marking: ____________________

Sampling Date: ____________________

Sampling Time: ____________________

Sampled by: ____________________

Sample No.

Temperature: ____________________°C

<table>
<tr><td>Grab Sample ☐

Container 2

Volume _________ml

Physical and Aesthetic Determinands, Chemical Determinands - Macro Determinands, Chemical Determinands - Micro Determinands</td></tr>
<tr><td>Comments:</td></tr>
<tr><td>Sample Bottles Required: Glass Water ☐ Plastic ☐ Glass Soil ☐

Tests Required: Turbidity, pH Analysis, Ca, Hardness, Mg, TDS, NO_3, NO_2, SO_4, Cl, and PO_4</td></tr>
</table>

APPENDIX 2

Appendix 2: Field Sheet for Water Sample Collection

Name: ___________________

Sampling Site Code:

Sampling Location GPS:

Bottle Marking: ____________________

Sampling Date: ____________________

Sampling Time: ____________________

Sampled by: ____________________

Sample No.

Temperature: ____________________°C

Grab Sample ☐ Container 3 Volume ____ml **Chemical Determinands - Micro Determinands**
Comments:
Sample Bottles Required: Glass Water ☐ Plastic Water ☐ Glass Soil ☐ **Tests Required**: DO, BOD

APPENDIX 3

Appendix 3: Field Sheet for Water Sample Collection

Name: ____________________

Sampling Site Code:

Sampling Location GPS:

Bottle Marking: ____________________

Sampling Date: ____________________

Sampling Time: ____________________

Sampled by: ____________________

Sample No.

Temperature: ____________________°C

Grab Sample ☐

Container 1

Volume __________ml

Microbiological Determinands

Comments:

Sample Bottles Required: Glass Water ☐ Plastic ☐ Glass Soil ☐

Tests Required: Total Coliforms (Bacteria E-Coli, Coli)

APPENDIX 4

Appendix 4: Field Sheet for Soil Sample Collection

Name: ____________________

Sampling Site Code:

Sampling Location GPS:

Bottle Marking: ____________________

Sampling Date: ____________________

Sampling Time: ____________________

Sampled by: ____________________

Sample No.

Temperature: ____________________°C

Grab Sample ☐

Container 4 (Soil)

Volume ____ml

Chemical Determinands - Macro Determinands (Soil)

Comments:

Sample Bottles Required: Glass Water ☐ Plastic Water ☐ Glass Soil ☐

Tests Required: Hg, Cd, Pb, Ni, Cr, Cu, As

Appendix 5: SASS 5 Field Sheet

SASS Version 5 Score Sheet

Version date: Sept 2005

Date (dd:mm:yr):					(dd.ddddd)
RHP Site Code:		Grid reference (dd mm ss.s) Lat:	S		
Collector/Sampler:		Long:	E		
River:		Datum (WGS84/Cape):			
Level 1 Ecoregion:		Altitude (m):			
Quaternary Catchment:		Zonation:			

Site Description:	Temp (°C):		Routine or Project? (circle one)	Flow:	
	pH:		Project Name:	Clarity (cm):	
	DO (mg/L):			Turbidity:	
	Cond (mS/m):			Colour:	
	Riparian Disturbance:				
	Instream Disturbance:				

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

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

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

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

Other biota:

Comments/Observations:

Procedure:

Kick SIC & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock for 1 min. Sweep marginal vegetation (IC & OOC) for 2m total and aquatic veg 1m². Stir & sweep gravel, sand, mud for 1 min total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found (by circling estimated abundance on score sheet). Score for 15 mins/biotope but stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone, rock & solid objects; Veg = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate each biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity) Rate turbidity: V low, Low, Medium, High, Very High

APPENDIX 6

Appendix 6: Species Lists

BIRDS	
COMMON NAME	**SCIENTIFIC NAME**
Hadeda Ibis	*Bostrychia hagedash*
Southern Red Bishop	*Euplectes orix*
Glossy Ibis	*Plegadis falcinellus*
African Sacred Ibis	*Threskiornis aethiopicus*
Western Cattle Egret	*Bubulcus ibis*
Little Egret	*Egretta garzetta*
Black-headed Heron	*Ardea melanocephala*
Indian Myna	*Acridotheres tristis*
White-throated Swallow	*Hirundo albigularis*
Pin-tailed Whydah	*Vidua macroura*
Long-tailed Widowbird	*Euplectes progne*
House Sparrow	*Passer domesticus*
Southern Masked Weaver	*Ploceus velatus*
Cape Sparrow	*Passer melanurus*
Spur-winged Goose	*Plectropterus gambensis*
White-faced Duck	*Dendrocygna viduata*
Yellow-billed Duck	*Anas undulate*
Red-billed Teal	*Anas erythrorhyncha*
Common Moorhen	*Gallinula chloropus*
Red-knobbed Coot	*Fulica cristata*
Rufous-naped Lark	*Mirafra Africana*
Karoo Thrush	*Turdus smithii*
Blacksmith Lapwing	*Vanellus armatus*
Red-faced Mousebird	*Urocolius indicus*
Crested Barbet	*Trachyphonus vaillantii*
Dark-capped Bulbul	*Pycnonotus tricolor*
African Darter	*Anhinga rufa*
Helmeted Guine**a**fowl	*Numida meleagris*
Black Shouldered Kite	*Elanus caeruleus*
Red-eyed Dove	*Streptopelia semitorquata*
Cape Turtle Dove	*Streptopelia capicola*
Laughing Dove	*Spilopelia senegalensis*
Squacco Heron	*Ardeola ralloides*
Cape Wagtail	*Motacilla capensis*
Cape Teal	*Anas capensis*

FISH	
COMMON NAME	**SCIENTIFIC NAME**
Mosquito Fish	*Affinis gambusia*
Banded Tilapia	*Tilapia sparrmanii*

TREES		
FAMILY	**COMMON NAME**	**SCIENTIFIC NAME**
SALICACEAE	Weeping Willow Tree	*Salix babylonica*
MYRTACEAE	Red river gum	*Eucalyptus camaldulensis*
MORACEAE	Common Mulberry	*Morus alba*
SALICACEAE	Poplar	*Populus alba*
SCROPHULARIACEAE	False Olive Tree	*Buddleja saligna*
FABACEAE	Black Wattle	*Acacia mearnsii*
	Honey Locust	*Gleditsia triacanthos*

COMMON NAME	SCIENTIFIC NAME
Karakul Sheep	*Ovis aries*
Domestic Goat	*Capra aegagrus hircus*
Jersey Cattle	*Bos taurus*
Domestic Chicken	*Gallus gallus*

PLANTS		
FAMILY	**COMMON NAME**	**SCIENTIFIC NAME**
CONVOLVULACEAE	Morning Glory	*Ipomoea indica*
CANNACEAE	Indian Shot	*Cannas indica*
BRASSICACEAE	Watercress	*Nasturtium officinale*
EUPHORBIACEAE	Castor Oil Plant	*Ricinus communis*
PAPAVERACEAE	White-flowered Mexican Poppy	*Argemone ochroleuca*
	Yellow-flowered Mexican Poppy	*Argemone mexicana*
NYCTAGINACEAE	Four-o’clock	*Mirabilis jalapa*
SOLANACEAE	Downy Thorn Apple/Malpitte	*Datura innoxia*
ASTERACEAE	Spear Thistle	*Cirsium vulgare*
	Pompom Weed	*Campuloclinium macrocephalum*

GRASSES		
FAMILY	**COMMON NAME**	**SCIENTIFIC NAME**
POACEAE	Common Reed	*Phragmites australis*
	Couch Grass	*Cynodon dactylon*
	Red Grass	*Themeda triandra*
	Common Finger Grass	*Digitaria eriantha*
	Three-awn Grass	*Aristida adscensionis*
	Kikuyu	*Pennisetum clandestinum*
	Guinea Grass	*Panicum maximum*
	South African Lovegrass	*Eragrotis planna*
	Cutgrass	*Leersia hexandra*
	Giant reed, Spanish reed	*Arundo donax*
	Fountain Grass	*Pennisetum setaceum*
	Pampas Grass	*Cortaderia selloana*
TYPHACEAE	Cattail	*Typha capensis*

MACRO-INVERTEBRATES		
ORDER	**COMMON NAME**	**FAMILY NAME**
ANNELIDA	Aquatic earthworms	*Oligochaeta*
ODONATA	Sprites & Blues	*Coenagrionidae*
	Hawkers & Emperors	*Aeshnidae*
	Clubtails	*Gomphidae*
HEMIPTERA	Backswimmers	*Notonectidae*
	Water boatmen	*Corixidae*
COLEOPTERA	Riffle beetles	*Elimidae/Dryopidae*
	Whirligig beetles	*Gyrinidae*
DIPTERA	Midges	*Chironomidae*
	Crane flies	*Tipulidae*
	Black flies	*Simuliidae*
	Mosquitoes	*Culicidae*
EPHEMEROPTERA	Mayflies	*Beatidae*
	Squaregills/Cainflies	*Ceanidae*
TRICHOPTERA	Caddisflies	*Hydropsychidae*
PELECYPODA	Pill clams	*Sphaeriidae*

APPENDIX 7

Appendix 7: Ethical Clearance

UNISA university of south africa

CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 04/12/2018

Dear Ms Kruger-Franck

Decision: Ethics Approval Renewal after First Review from 01/12/2018 to 30/11/2019

NHREC Registration # : REC-170616-051
REC Reference # : 2017/CAES/155
Name : Ms E Kruger-Franck
Student #: 43891306

Researcher(s): Ms E Kruger-Franck
elmariekrgr@yahoo.com

Supervisor (s): Dr TJM McKay
mckaytjm@unisa.ac.za; 011-670-9461

Working title of research:

Anthropocentric impacts on the ecology and biodiversity of the Natalspruit watercourse and its associated wetlands

Qualification: MSc Environmental Management

Thank you for the submission of your progress report to the CAES Health Research Ethics Committee as well as the CAES Animal Research Ethics Committee for the above mentioned research. Ethics approval is renewed for a one-year period. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 30 November 2019

Please note the following:

1. Permission is granted on the understanding that the execution of the SASS5 procedure will be supervised by a qualified person.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

The ***low risk application*** *was* ***reviewed*** *by the CAES General Research Ethics Review Committee on 02 November 2017 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

The reference number ***2017/CAES/155*** *should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

Prof EL Kempen

Chair of CAES Health REC

E-mail: kempeel@unisa.ac.za

Tel: (011) 471-2241

Prof MJ Linington

Executive Dean : CAES

E-mail: lininmj@unisa.ac.za

Tel: (011) 471-3806

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

APPENDIX 8

Appendix 8: Photographic Release and Permission Letter

anja brits photography

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Release and Permission to Use Photographic Image(s) And Waiver of Liability

21 August 2018

To: ELMARIE KRŪGER-FRANCK (MSc ENVIRONMENTAL MANAGEMENT)

Image(s): Pertaining to all images taken at Natalspruit throughout the year of 2018 with Elmarie Krüger-Franck for below mentioned project
License Type: Rights-managed
Type of Usage: Editorial
Intended Usage: Thesis
Project: Anthropocentric impacts on the ecology and biodiversity of the Natalspruit watercourse and its associated wetlands
Distribution area: Domestic use

By signing this release Anja Brits Photography agrees that Elmarie Krüger-Franck may use its name, likeness and/or photographic image(s) for official purposes.
Anja Brits Photography grants Elmarie Krüger-Franck the right to use the photograph(s) (whether digital or film) in her study and in publications, which may include, catalogues, videos, dissertations, essays, collages, etc. Anja Brits Photography furthermore grants Elmarie Krüger-Franck the right to crop and/or collage the image(s) with others.

Signing this form, releases and forever discharges Elmarie Krüger-Franck from any and all claims and demands arising out of or in connection with the use of said photograph(s), including but not limited to, any and all claims for invasion of privacy, defamation, or financial compensation.

Signature: [signature]

Printed Name: Anja Brits

Designation: Owner/Photographer

Date: 2018/08/21

Unit 35, Greenwood Estate
139 Linden Street
Sandown, Sandton
Gauteng
South Africa

c: 076 303 1536
e: info@anjabritsphotography.co.za
w: www.anjabritsphotography.co.za
h: @anjabritsphotography

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APPENDIX 9

Appendix 9: Research budget for water and sediment analyses, SASS 5 and other equipment

DESCRIPTION	UNIT OF MEASURE	TOTAL QTY 2018	TOTAL COST 2018
Travel			
Fuel Costs (Car)	12.00/l	–	0.00
Research Equipment			
Cellphone Airtime, 3G Internet Usage, Portable Hardrive, Digital Camera, Laptop Computer, Binoculars		–	0.00
SASS5 Sample Kit		1	3306.00
			3306.00
Additional			
Dissertation Binding		3	1328.67
Editor		1	5600.00
Cartographer		1	360.00
SASS5 Accredited Training Course	4 Day Course	1	9975.00
Statistician		–	0.00
			17263.67
Water and Soil Analysis			
Water			
MICROBIOLOGICAL DETERMINANDS			
Total Coliforms (Bacteria E-Coli, Coli)	CFU/100ml	10	1300.00
PHYSICAL AND AESTHETIC DETERMINANDS			
Turbidity	NTU	10	900.00
pH Analysis (25°C)	–	10	250.00
CHEMICAL DETERMINANDS - MACRO DETERMINANDS			
Dissolved Elemental by ICP-OES/MS including Hardness Calculations		10	3500.00
Calcium (Ca)	mg/l		
Hardness	mg/l		
Magnesium (Mg)	mg/l		
TDS	mg/l		
Anions by Ion Chromatography		10	2000.00
Nitrate (N)	mg/l		
Nitrite (N)	mg/l		
Sulphate (SO_4^{2-})	mg/l		
Chloride (Cl^-)	mg/l		
CHEMICAL DETERMINANDS - MICRO DETERMINANDS			
Orthophosphate (PO_4)	mg/l	10	1450.00
Dissloved Oxygen (DO)	mg/l	10	2500.00
Oxygen Demand Biochemical (BOD)	mg/l	10	4500.00
VAT 15%			**2362.50**
			18762.50
Soil			
CHEMICAL DETERMINANDS - MACRO DETERMINANDS			
Elemental Analysis by ICP-OES/MS		5	3500.00
Crushing, Splitting, Milling			
Mercury (Hg), Cadmium (Cd), Lead (Pb), Nickel (Ni), Chromium (Cr), Copper (Cu), Arsenic (As)	ug/kg & mg/kg		
VAT 15%			**1050.00**
			4550.00
			R 43 882.17

APPENDIX 10

Appendix 10: Raw analysed water sample data for May

		SS1	SS2	SS3	SS4	SS5
Turbidity	NTU	5.2	6.5	2.9	3.1	3.0
TDS (0.7µm) @ 105 ºC	mg/l	3200	330	1500	85	1100
Ca hardness as $CaCO_3$	mg/l	1390	97	605	431	400
Magnesium	mg/l	127	17	61	46	44
Total hardness as $CaCO_3$	mg/l	1920	165	855	621	582
Chloride	mg/l	82	34	71	69	64
Nitrite (NO_2)	mg/l	2.7	0.4	0.7	1.3	<0.2
Nitrate (NO_3)	mg/l	2.8	0.42	1.2	3.2	4.7
Sulphate	mg/l	1840	134	1040	551	557
Orthophosphate (PO_4)	mg/l	<0.25	<0.25	0.28	0.40	0.39
Dissolved oxygen as O_2	-	5.3	5.3	5.2	5.7	5.6
pH in water at 25 ºC	mg/l	6.8	6.9	7.2	7.2	7.2
Biochemical oxygen demand	mg/l as O_2	5.0	8.0	<5.0	6.0	5.0
Total Coliforms	CFU/100 ml	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected

APPENDIX 11

Appendix 11: Raw analysed water sample data for May

		SS1	SS2	SS3	SS4	SS5
Turbidity	NTU	3.3	6.9	2.5	3.0	1.7
TDS (0.7 µm) @ 105 ºC	mg/l	1200	230	1100	900	770
Ca hardness as $CaCO_3$	mg/l	671	96	584	388	342
Magnesium	mg/l	66	17	57	44	41
Total hardness as $CaCO_3$	mg/l	941	165	820	571	511
Chloride	mg/l	56	32	60	67	63
Nitrite (NO_2)	mg/l	0.3	<0.2	<0.2	2.0	2.2
Nitrate (NO_3)	mg/l	0.84	<0.03	1.3	1.5	3.6
Sulphate	mg/l	587	80	669	474	391
Orthophosphate (PO_4)	mg/l	0.32	<0.25	0.32	0.74	0.77
pH in water at 25 ºC	-	6.8	6.7	7.0	6.8	7.0
Dissolved oxygen as O_2	mg/l	5.3	5.6	6.2	5.6	<5.0
Biochemical oxygen demand	mg/l as O_2	<5.0	9.0	<5.0	6.0	19
Total Coliforms	CFU/100 ml	17000	100000	29000	450	2400

APPENDIX 12

Appendix 12: Raw analysed soil sample data for July

			SS1	SS2	SS3	SS4	SS5
Cadmium	mg/kg	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium (Total)	mg/kg	0.2	24	60	82	34	79
Copper	mg/kg	2	30	41	47	10	49
Nickel	mg/kg	0.5	30	49	91	31	148
Lead	mg/kg	1	26	42	55	6.7	40
Zinc	mg/kg	1	228	188	423	48	878
Mercury	µg/kg	0.1	14	18	29	1.3	28