Assessment of the impact of agriculture and industry on the changing geochemical regimes, macro invertebrate communities and wetland areas: A case study of Sezela estuary and wetland areas, KwaZulu-Natal

By

Suheil Malek Hoosen (21051819),

Submitted in partial fulfillment of the academic requirements for the degree of Master of Science in Environmental Science, in the School of Environmental Science, Department of Geography, Faculty of Science and Agriculture

University of KwaZulu-Natal
South Africa

Supervisors: Dr S. Pillay and Dr K. Naidoo

2017

PREFACE

The experimental work described in this dissertation was carried out in the School of Geography and Environmental Sciences, University of KwaZulu-Natal, Westville campus, from March 2016 to December 2017, under the supervision of Dr Srinivasan Pillay and Dr Kuben Naidoo.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text

ACKNOWLEDGEMENTS

I would like to take the time to thank my supervisor **Dr Srinivasan Pillay and Dr Kuben Naidoo**, for his valuable insight and constant monitoring of my progress, throughout the duration of the study. He has been a massive help and inspiration in putting the whole project together and I appreciate all the work he put in it.

I would like to thank the Chemistry Department for their assistance in the chemical analysis of sediment and water samples for the study.

I would also like to thank my colleagues **Miss Shanice Mohanlal and Naeem Van Heeren** for their help with the laboratory analysis of my sediment sub-samples and on assisting me in my field work as well.

Finally, I would like to thank **Mr. Eddie Powys** for all the laboratory assistance in the process of my project.

DECLARATION – PLAGARISM

I, Mr Suheil Malek Hoosen declare that;

1. The research reported in this thesis, except where other indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from otherwise researchers. Where other written sources have been quoted, then:
    - Their words have been re-written but the general information attributed to them has been referenced;
    - Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.
5. This thesis does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed:

As the candidate's supervisor I have/have not approved this dissertation/thesis for submission.

Signed: Name: Dr S. Pillay Date:

Signed: Name: Dr K. Naidoo Date:

ABSTRACT

The Sezela estuary and wetlands make up a vast area of the Sezela in which these environments impacted by anthropogenic activities. The Sezela area is located along the south coast of KwaZulu-Natal province of South Africa in which the predominant land uses are commercial dryland sugarcane plantation cultivation and the Sezela Sugar Mill.

Due to the anthropogenic activities in the area, several coastal environments have been degraded. The degradation of these environments can be detrimental to the organisms that are dependent on them for ecosystem services and even poverty-stricken people that require these environments for basic needs (Kotze *et al*., 2007). In addition, due to the water crisis currently in South Africa, further degrading these estuarine and wetland environments can rapidly increase the processes of drought. Therefore, assessing the quality of these environments is imperative to identify their functionality and need for rehabilitation (Macfarlane *et al*., 2007).

The identification of estuarine and wetland functionality are conducted through field, laboratory analysis and statistical analysis. The determination of the health of the Sezela estuary was conducted through a step-by-step method which involved sediment granulometric analysis, sediment and water quality (utilisation of ICP-OES) and macro invertebrate indicators in the sediment. The health status of wetlands were determined through the PES and ecological services provided by the wetland utilising tools such as WET-Health and WET-EcoServices. It was determined that the Sezela estuary contained relatively coarse material and lacked species composition and richness due to past pollution of the estuary by the mill. The Sezela wetland areas were degraded as a result of dryland sugarcane plantation in which two of the three wetlands were predominantly impacted drastically which were the channelled valley bottom wetlands and not the floodplain wetland.

It was necessary for the Sezela estuary and wetlands to be mitigated and rehabilitated in order to re-establish past conditions or conditions that will promote the return of organisms into the estuary and wetland environments. The measures that can be implemented are improve sediment and water quality, removal of alien invasive vegetation and re-vegetation with indigenous vegetation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AEV	Acute Effect Value
Al	Aluminium
C	Carbon
CC	Calcium Carbonate
Cd	Cadmium
CEV	Chronic Effect Value
Cu	Copper
CSIR	Council for Scientific and Industrial Research
CVB	Channelled Valley Bottom
DIN	Dissolved Inorganic Phosphate
DIP	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affair and Forestry
DWS	Department of water and sanitation
EC	Electrical Conductivity
EF	Enrichment Factor
F	Floodplain
Fe	Iron
GIS	Geographical Information System
GPS	Geographic Positioning System
Hg	Mercury
HGM	Hydrogeomorphic
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectroscopy
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff

Mn	Manganese
N	Nitrogen
NFEPA	National Freshwater Ecosystem Protected Area
NWA	National Water Act
OM	Organic Matter
P	Phosphorous
Pb	Lead
PES	Present Ecological State
POE	Permanently Open Estuaries
PSU	Practical Salinity Units
SANBI	South African National Biodiversity Institute
SI	Syteme Internationale
TDS	Total Dissolved Solids
TOCE	Temporarily Open/Closed Estuaries
TWQR	Target Water Quality Range
USEPA	United States Environmental Protection Agency
YSI	Yellow Springs Instrument
Zn	Zinc

1. INTRODUCTION

1.1. Estuaries and their importance

An estuary can be defined as a region where freshwater from rivers and salt water from the ocean mix to form brackish conditions. However, isolation of the estuary from the sea can occur when there is little or no fluvial input due to the formation of a sandbar. This can cause the estuary to become hypersaline or fresh (Potter *et al*., 2010). Although an estuary can be broadly classified, no estuary has similar characteristics. The characteristics of South African estuaries vary due to climatic and biogeographic zone differences. Furthermore, there are also distinct differences in physico-chemical features which determine the biota and structure of estuaries (Elliot and Whitfield, 2011).

Estuaries are extremely productive ecosystems that play an imperative function in the supply of nutrients, organisms and sediment to the coastal environment (Barbier *et al*., 2011). Estuaries supply fundamental ecological services such as nurseries for many different species of marine fish and invertebrates. In addition, estuaries provide feeding and roosting areas for many different species of birds, either migratory or resident. Many estuaries have important economic functions including tourism, recreational activities such as fishing and use of jet-skies, and even as a source of income for the seafood industry (Barbier *et al*., 2011). Certain estuaries also contain extensive tracts of salt marsh or mangrove habitats which protect neighbouring lands and human settlements from storm surges which occur due to coastal storms. This littoral vegetation has the ability to capture contaminants in runoff and therefore can possibly lower the intensity of pollution (Przybysz *et al*., 2014).

There are many important organisms that reside in estuaries. Particularly important organisms are the macro invertebrates which refer to those organisms that are living on the surface of sediments or objects (epifauna) or within the sediment (infauna) (Teske and Woolridge, 2003). Macro invertebrate's species abundance, composition and distribution of these communities may vary generally both spatially and temporally. The changes in variation of these species occur due to ordinary fluctuations in mortality, reproduction and recruitment and also due to some sort of anthropogenic introduction into the system that can cause fluctuations in chemical and physical conditions of the environment (Teske and Woolridge, 2003). Estuarine systems that are healthy and unpolluted generally have a higher biomass of macro invertebrates, lower biomass usually exists when water quality is poor due to an absence of oxygen (Rosenberg *et al*., 2004).

1.2. Wetlands and their importance

Wetlands can be described as an area of land flooded or saturated for long periods of time. Certain plants have adapted to wetland conditions such as growing in anaerobic soil (Ramachandra and Kumar, 2008). The spaces that exist between soil particles usually become filled with water due to the soil becoming increasingly wet. A typical characteristic of wetlands is their inability to drain water efficiently therefore becoming waterlogged. Anaerobic conditions usually occur in waterlogged wetland soils due to the rapid usage of oxygen by organisms and plant roots (Ramachandra *et al*., 2002).

Wetlands are an important ecosystem to human kind as they are directly and indirectly beneficial. Primarily, wetland function is to protect and regulate water resources (Ramachandra and Kumar, 2008). Wetlands are an imperative component for human society as it provides several services for life on earth. Some of these direct benefits are flood storage, drinking water, fodder, climate stabilizers, energy, recreation and protein production. Indirect benefits of wetlands include the reduction of flood damage by regulating water flow during floods, sustaining stream flow and controlling erosion (especially in shoreline areas where wave action occurs), recharging ground water sources, purifying water as they act as natural filters that trap heavy metals, sediments, disease causing pathogens and pollutants (Ramachandra *et al*., 2002).

1.3. Motivation of the study

One of the most recognised and important aspects of estuaries are their high productivity. The combination of the marine environment from the seaward side and freshwater environment from terrestrial catchment sand related chemical and physical processes, tend to produce environments that are rich in food characterised by energy subsidies which result in significant animal biomass and carrying capacities. Furthermore, this environment is created even though the environment becomes highly variable in nature due to parameters such as temperature and salinity (Harrison, 2004). The dynamic features of these estuaries have been used by humans for many different activities such as recreational fishing, human settlement and also by industries (Blaber, 2002; Davenport and Davenport, 2006).

The main reason for human settlement around estuaries is due to these systems offering humans more services for their well-being as compared to other systems which may also cover a larger area as compared to estuaries (Elliot and Whitefield, 2011). In addition, although these systems offer several services, estuarine habitats have come under degradation and swift environmental change. For instance, according to the Millenium Assessment Report (2005), approximately

35% of world mangrove areas have been converted or lost, a rough estimation of 20% coral reefs have been destroyed and degraded globally in the last few decades and approximately 20% wetlands in coastal areas have been lost in some countries.

The destruction and degradation of the marine and estuarine systems are due to human-induced activities and will therefore require appropriate maintenance and rehabilitation for these systems to function well (Elliot and Whitfield, 2011). These systems supply crucial cover, food, breeding and nursery grounds and migratory corridors for several marine and coastal organisms. They also provide an economic basis for humans such as viable seafood industries, coastal tourism and aesthetics that are far beyond just ecological functions. Estuaries and wetlands also play vital roles in reducing poor water quality, as well as coastal wetlands preventing flood events by storing excess water during these events. Furthermore, coastal storms are also buffered by ecosystems such as wetlands and barrier beaches, therefore protecting coastal human settlements (Ramachandra *et al*., 2002).

Therefore, coastal systems that are negatively impacted, whether in the sea, on land and in fresh and brackish water areas, will have massive negative aftermath for the productivity and health of other marine and terrestrial environments (Gonzalez-Ortegon *et al*., 2010). Due to an ever-increasing human population and pressure on these coastal areas from humans, the services that these ecosystems provide will continue to be strained and will affect humans that rely on these coastal environments negatively. Therefore, proper usage and rehabilitation should be a focus in these coastal areas in order to acquire the maximum services that they provide (Elliot and Whitfield, 2011).

1.4. Aims and Objectives

The aim is to investigate human induced changes that have impacted the ecological health status of the Sezela estuary and wetlands, KwaZulu-Natal.

The objectives of the study were to investigate the:

- Changes in geochemical regimes in the Sezela estuary;
- Changes in hydrology in the Sezela estuary and wetland areas;
- Use of a desktop study to determine applicable information affecting the greater catchment wetland area;
- Identify, delineate and classify the wetland areas;
- To determine the pollution status of the Sezela estuary adjacent to the Illovo Sugar Mill;

- Identifying macro invertebrate indicator organisms in the Sezela estuary.

1.5. Chapter Outline

Chapter one gives a brief explanation of estuaries and wetlands and their unique ability of adaptation to changes in their environment. It further explains the importance of these systems and how they have changed over time. Thereafter, the aims and objectives of the study are outlined briefly.

Chapter two encompasses the literature review which is inclusive of two main components which are estuary and wetland. Each component has various sub-sections e.g. hydrodynamics and sediment dynamics, direct and indirect benefits of wetlands and threats to wetlands. The literature in these sections comprehensively explains various aspects of each component of how they function, their benefits and how they have come under stress due to natural and human induced anthropogenic activities.

Chapter three explains different characteristics of the Sezela study area which are climate, slope and topography, hydrology, geology, National Freshwater Ecosystem Protected Areas (NFEPA) and vegetation.

Chapter four consists of two subsections which are estuary and wetland methodologies. The estuary methodology consists of subsections starting with data collection which explains how the primary data was collected and with what equipment. Thereafter, physical analysis, data analysis, laboratory analysis, granulometric analysis and statistical analysis is explained. Furthermore, water and sediment sample analysis is explained with regards to Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) and how it was used to acquire data. In addition, water quality guidelines are explained of how attained results will be compared to the South African Standards of water quality. The wetland methodology consists of a similar structure to the estuary methodology; however, it does differ with certain aspects. These aspects are the method of desktop delineation and field assessment, the tools used to assess the functionality of the wetland areas which are WET-EcoServices and WET-Health, and the determination of hectare equivalence of the wetlands.

Chapter five presents results of the estuary in which grain size composition is discussed, thereafter sediment statistical distribution such as mean, median, skewness, sorting and kurtosis is assessed. Sediment and water quality of the estuary is determined for physico-chemical parameters, faecal indicator bacteria, nutrients and metals. Furthermore, macro-invertebrates were assessed to determine point source pollution and functionality of estuarine environment. The results of the wetland study involved delineation of three wetlands systems in which two were channelled valley bottom wetlands and one was a floodplain wetland. The different hydrological zones were determined for these wetlands such as the permanent, seasonal and temporary zones and to determine if the wetlands were vulnerable or not. The functionality of the wetland was determined by using WET-EcoServices and WET-Health tools. Finally, hectare equivalence was conducted to determine the amount of healthy wetland and loss of wetland.

Chapters six and seven are the discussion and conclusion respectively. The discussion gives an explanation of the results obtained and how it can be related to the Sezela estuary and surrounding wetland environment. The conclusion sums up the entire study and provides management and mitigation recommendations to ensure these practices are known in order to preserve these unique ecosystems.

2. LITERATURE REVIEW

2.1. South Africa as a water scarce country

The Earth's surface is covered with approximately 70% of water in which all life on earth is dependent on it for survival Life on earth is dependent on water which covers approximately 70% of its surface (Olaniran *et al.,* 2012). The distribution of freshwater resources on the earth is uneven and constitutes only 2.5% of the water on earth and less than 0.3% of all freshwater can be found in rivers, lakes and in the atmosphere. Freshwater constitutes only 2.5% of total water resources on earth and is found mainly in rivers, lakes and in the atmosphere (Roux & Nel, 2013). South Africa is considered water scarce due to the limited extent of freshwater resources and the availability of freshwater to each person per annum barely exceeds 1200m^3 for a population of approximately 50 million people (Kamika & Momba, 2013). South Africa is a semi-arid country and experiences poor rainfall throughout the year (Olaniran *et al.,* 2012; Kusangaya *et al.,* 2014). The water resources in South Africa are under immense pressure in recent years due to rapid demographic changes, industrialization, urbanization, mismanagement of water treatment plants, poorly maintained infrastructure as well as the establishment of human settlements which lack proper sanitary infrastructure (Kamika & Momba, 2013; Singh & Lin, 2015). This has resulted in a drastic increase in the amount of pollution entering water systems such as marine and estuarine environments (Kamika & Momba, 2013). Numerous countries around the world are also prone to water scarcity and the debilitating effects thereof (Qlarniran *et al*., 2012).

2.2. Types of Estuaries in South Africa

The South African coastline consists of 600 km^2 of total estuarine area in which two main types are found. These are Permanently Open Estuaries (POE) and Temporarily Open/Closed Estuaries (TOCE) (Turpie *et al*., 2002). The estuarine classification system used in South Africa is highly dependent on several factors such as topography, geology of catchment, climate variation and marine-estuarine interaction. Furthermore, the classification allows for sub-classes of POE's and TOCE's (known to be estuarine bays, lakes and river mouths) which are dependent on hydrodynamic variations (Whitfield and Bate, 2007).

2.2.1. Permanently Open Estuaries (POEs)

Permanently Open Estuaries are becoming a rare entity as a direct result of the increase of drought conditions in South Africa. However, it is noted that approximately 25% of South Africa’s estuaries are known to be POEs which are connected to the ocean (Whitfield, 1998). The three categories that these POE’s fall into are naturally open estuaries, human inducted estuarine bays and river mouths. Permanently Open Estuaries characteristically have large catchments with relatively high runoff during the year. Furthermore, tidal flows play a pivotal role in sustaining open mouth conditions, together with situations where sediment input is lacking or if estuarine mouths are protected from wave energy like estuarine bays (Whitfield and Bate, 2007).

2.2.2. Temporarily Open/Closed Estuaries (TOCEs)

The vast majority of the estuaries in South Africa (approximately 75% of estuarine environments) are known to be TOCEs. The main characteristics of a TOCE is the isolation from the marine environment for short or long periods of time by a sand berm as a result of periods of no or low river inflow (Whitfield, 1998). TOCE’s are predominantly closed during the year and fill their basins to a point of breach by natural forces such as increase river flow or water levels that are high or anthropogenic forces such as unnatural breaching through excavation. The natural or anthropogenic breaching of the mouth eliminates a substantial amount of sediment from the berm but the mouth of the estuary can rapidly close as a result of low flow from the river and infilling of fluvial and marine sediment (Whitfield and Bate, 2007). In this study, the Sezela estuary is known to be a TOCE that breaches naturally throughout the year when high fluvial flow occurs (Begg, 1978).

2.3. Hydrodynamics of TOCE’s

2.3.1. Catchment size and river flow

Catchment size does not play a pivotal role in determining whether an estuary will be a POE or TOCE. This is largely due to the semi-arid nature of the South African climate which in some instances impacts run-off in catchment areas (Whitfield, 1992). However, the main driver in determining the type of estuary is the river flow which is indirectly linked to catchment size. Hence, POEs usually have larger catchments than TOCEs and have significant river flow throughout the year as compared to TOCEs which are characterised by strong seasonal runoff variations. Furthermore, extreme rain events can cause mouth opening of a TOCE as a result of rapid inflow of water from catchment areas (Whitfield and Bate, 2007).

2.3.2. Mouth Status

The mouth status of a TOCE can be closed or open at any given time. During the open mouth status, the estuarine and sea environment is connected and serves several functions such as the influx of nutrients and a corridor for fish to migrate. During low river flows, TOCEs become disconnected from the sea and the estuarine mouth is recognised as closed during normal tide and spring high tide cycles. The closure of the mouth is often a result of high wave energy beaches, storm events, marine overwash and prevailing drought conditions (Whitfield and Bate, 2007).

According to van Nierkerk, (2005); van Nierkerk *et al*., (2002) and Huizinga *et al*, (2001), apart from open and closed states, a third semi-closed state, may exist in small estuarine systems. This state is characteristic of the mouth being nearly closed, with a narrow and shallow opening which allows water to trickle to the sea. One of the main reasons for this state is the perched estuarine environment (bed above mean sea level) precluding tidal exchange. These estuaries are known to be brackish in nature as a result of marine overwash occurring during high spring tides.

2.3.3. Size of estuary and tidal flow

Size and tidal flow are imperative characteristics which play a pivotal role in the mouth status of estuaries. Large estuaries (>150Ha) are usually predominantly open and can maintain open mouth status even when flow is low and catchment run-off decreases (Whitfield and Bate, 2007). Medium sized estuaries (<150Ha) and small (<100Ha) can sustain open mouth status during spring tides but are predominantly closed during neap tides. Furthermore, if river flow is low within these estuaries the mouth status becomes closed as there is inadequate ebb tidal flow to sustain open mouth status prior to closure (Whitfield and Bate, 2007).

2.3.4. Inflow of river

The inflow of rivers (baseflow) plays an imperative role in sustaining the open mouth status of South African TOCEs. Larger estuaries sustain open mouth status through tidal flow but for medium to smaller TOCEs, river inflow is the only driving force to sustain open mouth status (Whitfield and Bate, 2007).

South African coastal estuaries require flow regime to sustain open mouth status but is strongly dependent on factors such as wave conditions and sediment availability. Flow regimes on different energy beaches differ as high energy beaches in KwaZulu-Natal require a velocity flow ranging between 5-10 m^3s^{-1}, whereas a low energy beach with the Western Cape region requires a velocity flow ranging between 1-2 m^3s^{-1} to maintain open mouth status (Huizinga *et al*., 2001). Furthermore, semi-closed mouth state estuaries require a river inflow that significantly low around 0.05-1 m^3s^{-1} to maintain the mouth status that it occupies (Huizinga *et al*., 2001).

Beach sediment must also be compensated for when considering the river inflow within an estuary. This is due to the fact that water from the estuarine environment can be lost through seepage in berms (sandbar between the sea and estuary environment) (DWAF 2002 and 2003b). Coarser sediment will cause a higher volume of water to seep through, hence, a higher river inflow will be required to sustain an open mouth state. The aforementioned scenario is characteristic of TOCEs in South Africa, whereas, POEs are not sensitive to river inflow reduction as a direct result of tidal flow and/or run-off events produce enough flow regime to sustain open mouth status conditions yearly (DWAF 2002 and 2003b).

2.3.5. Salinity

Salinity in POEs and TOCEs is an important variable in the functioning of the estuary environment. In TOCEs, salinity varies during high and low river flow periods. During high river flow salinity levels with the estuary are lowered as a result of increased dilution and reduced penetration from the marine environment at the estuary mouth, hence, the system is river dominated during high flow periods. Alternatively, during low river flow periods, penetration from the marine environment increases into the estuary as a result a distinct horizontal and/or longitudinal water column. Under these conditions, the head of the estuary will experience more fresh water conditions whereas the mouth will experience close to seawater saline conditions (Whitfield and Bate, 2007). During the closed mouth state, a TOCE can become gradually more saline or fresher due to certain factors. Factors such as reduced penetration through the berm from marine influences brings about more freshwater conditions, whereas, high volumes of evaporation bring about more saline estuarine conditions. Therefore, as long as evaporation and seepage is less than river inflow, freshwater conditions will be more prevalent until rising waters cause breaching of the berm and release seawater into the estuary which will change salinity levels (van Niekerk *et al*., 2005).

2.3.6. Water column stratification

The stratification in water column of estuaries is highly dependent on factors such as salinity mix and difference of water temperatures. The salinity levels in seawater is approximately 35

PSU (Practical Salinity Units), whereas, freshwater has a salinity level of ~0 PSU. Furthermore, temperatures between seawater and freshwater differ. Hence, the density of water mass is a direct result of the combination of salinity and temperature differences. In South African TOCEs, as a result of limited river inflow, estuaries predominantly have a full salinity gradient which is from 0-35 PSU and water temperatures which range between 5-30^{0}C (Whitfield and Bate, 2007).

2.3.7. Ebb-and flood tidal flow channels

The effects of inertia can often develop important and different ebb-and flood flow channels. During the flood tide (high flow rate), large amounts of water flow directly into the estuary. Hence, the flood tidal channel is the main channel straight into the estuary. Furthermore, as a result of the incoming tide into the estuary, large volumes of sediment is transported just inside the inlet, in which the flood tidal sand bank is situated (Huizinga *et al*., 2001).

The ebb-tidal flow velocity is of a much lower intensity as a direct result of the longer period of water outflow from the estuary. The ebb and flood tide channels are imperative in the estuary functioning as their degree of interaction plays a pivotal role on the time period of open mouth state. Furthermore, ebb channels that are well protected by the berm contributes drastically in extending the open mouth condition (Huizinga *et al*., 2001).

2.4. Sediment Dynamics

2.4.1. Littoral sediment transport and wave effects

Marine sediments are available in vast amounts and there are a number of processes that transport sediments into estuarine environments (mouths). Processes such as longshore current transports marine sediment in close proximity to the mouth of estuaries which are then transported into the estuary by predominantly tidal flows and in some instances in combination with wave action (Whitfield and Bate, 2007). Tidal flow is the most decisive process of marine sediment input into the estuary, however, other processes such as wind action and marine wave overwash are also contributors of marine sediment in estuarine environments (Theron, 2004b).

2.4.2. Rivers as a source of marine sediment

Rivers play a pivotal role in acting as a source of sediment input into the marine environment when high river inflows transport sediment from the estuarine environment into the marine environment (Theron, 2004b). The nature of the sediment size is highly dependent on catchment activities and certain factors such as farming practices, rainfall, size, slope and vegetation and most importantly the type of sediment sources. Therefore, if sediment from certain sources in which they are eroded easily are fined grained in nature such as mudstone and shale the bulk of the sediment discharged into the sea will be of a fine to medium grained size. Rivers drain rocks that are resilient to erosion and are coarse grained in texture, generally discharge lower sediment volumes to the sea. These sediments are generally of a medium to coarse grained size. The sand supplied by the river to the marine environment is predominantly from the bed load of the river, whereas the contribution of the suspended load is minimal and disperses out to deeper water in the sea (Theron 2000 and 2004b).

In some instances, storms that resulting in flood events cause rivers to transport excessive amounts of sediment by force to the mouth of the estuary and then into the marine environment (Whitfield and Bate, 2007). This scenario is intermittent and usually occurs in smaller estuaries. Increases and decreases in sediment contribution from the river environment to the estuarine environment have also been affected by human induced anthropogenic activities such as dams and bridges at the mouth of estuaries (Theron 2000 and 2004b). As the estuarine sediment is deposited into the marine environment, these sediments are subject to several coastal processes and hence become marine sediment (Theron 2004b).

2.4.3. Effects of flood, tidal transport and sediment balance over a long-term

River flow is known to be one of the main drivers for sediment transportation and water distribution, however, tidal transport is also a pivotal hydraulic driver in the estuary. The transportation of sediment by the tidal forces on the coastline is a combination of currents and wave processes which are of utmost importance in the mouth area of the estuary (Theron 2004a). Furthermore, wave action within estuary is rapidly reduced and current-wave collaboration further complicates forecasting sediment transportation and deposition. Nevertheless, the estimation of transportation of sediment within the estuary uses traditional river equations as a result of wave action generally being reduced within estuarine environment (Theron, 2004a).

Spring and neap tides determine velocity and transportation of sediment within the estuary. During a spring tide, velocity and transportation of sediment increase within an estuary whereas, a neap tide generates low velocity and low sediment transportation (Whitfield and Bate, 2007; Theron, 2004a). Floods play a pivotal role in eroding and transporting sediment out of the estuarine environment as mentioned previously (Theron, 2004a). Flood events can occur with a return period of 1 in 2-year or even periods of 1 in 50-years. These flood events that occur within rivers and into estuaries have the ability to remove large volumes of sediment from within the estuary to the marine environment. Hence, the equilibrium between erosion and sedimentation is highly dependent on flood events (Beck *et al*., 2004; Theron, 2004a).

2.4.4. Physical Properties of Sediments

Sediment can be placed into two categories which are cohesive and non-cohesive. Sediment that are cohesive are generally resistant to erosion which is also dependent on the cohesive bond that holds particle bonds together. Additionally, the cohesion of sediment particles always takes priority over the influence sediment particles physical properties, although cohesion is also a physical property (Simons and Senturk, 1992). Although cohesive bonds in sediment are relatively strong, processes such as erosion and transportation will render a cohesive sediment less cohesive to non-cohesive. Another influence on the modification of sediment particles is chemical and physical reactions (Morgan, 1995). In comparison to cohesive sediment, non-cohesive sediment are characteristically detachable and encompass larger particles (Theron, 2004a and b).

One of the most imperative physical properties of sediment is sediment size. Sediment size is an imperative parameter due to its correlation and dependence of other parameters such as gravity and shape on sediment particle size (Theron, 2004a and b). Factors such as sieve size, fall velocity, weight diameter and volume define sediment particle size. Furthermore, sediment size definitions are usually affected by other factors such as density and shape of sediment particles, however, volume is not affect by those factors (Schnurrenberger *et al*., 2003).

Grain size distribution which is another parameter of sediment is influenced by several factors which are transportation, parent material, weathering history of particles and most importantly the sediment deposition environment on whether it is low or high energy environment (Theron, 2004a and b).

Grain size is an imperative parameter which is either measured in (phi or mm) as seen in Figure 2.1 in which certain size classes represent different categories which are known as Wentworth size class (Mitsch and Gosselin, 1993).

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	
	64		-6.0	Pebble	
	4		-2.0	Granule	
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	
1/2	0.50	500	1.0	Medium sand	
1/4	0.25	250	2.0	Fine sand	
1/8	0.125	125	3.0	Very fine sand	
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	
1/64	0.0156	15.6	6.0	Fine silt	
1/128	0.0078	7.8	7.0	Very fine silt	
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

Figure 2.1: Sediment grain size parameters and their classification.

(Wentworth, 1922).

Sediment size can be measured by several different methodologies which are calipers, photographic or optical method or by the sieving method which was used in this study. In sedimentation studies, sediment size does not play a pivotal role but has its importance. The most important parameter in sedimentation studies is sediment distribution with focus on river banks and bed formation by sediment or even the effects of dams on sedimentation (Tucker, 1998).

Parameters such as sorting, skewness and kurtosis are all measures of dispersion which are frequently used to determine sediment distribution within a fluvial system (Morgan, 1995).

The measure of dispersion sorting refers to the spread of grain size distribution, hence, it is directly related to the depositional mechanism and also a measure of standard deviation of sediment. As sediment is transported by different processes within the environment sorting of sediment increases with transportation distance (Morgan, 1995). The unit of measure used for sorting is usually phi but mm was used in this study. Furthermore, the different values obtained for sorting are representative of different sorting classes as seen in Table 2.1 below (Morgan, 1995).

Table 2.1: Sediments classification according to sorting.

Sorting class	Standard deviation (phi)	Standard deviation (mm)
Very well sorted	<0.35	1-0.5
Well sorted	0.35-0.5	1-0.5
Moderately well sorted	0.5-0.71	1-0.5
Moderately sorted	0.71-1.0	1-0.5
Poorly sorted	1-2	0.5-0.25
Very poorly sorted	>2	>0.25

(Folk and Ward, 1957)

The measure of symmetry of sediment size distribution is known as skewness, hence, no skew will exist whether sediment distribution is symmetrical. A positively skewed fluvial environment would be representative of surplus amounts of fine sediment, an example is a river environment in which clay and silt is surrounded between sediment clasts that are larger (Theron, 2004a and b). Alternatively, a negatively skewed fluvial environment will contain surplus amounts of coarser sediment, an example is within the marine environment in which coarser sediment is more difficult to be carried by continuous wave action and other transportation mechanisms as compared to finer sediment (Theron, 2004a and b).

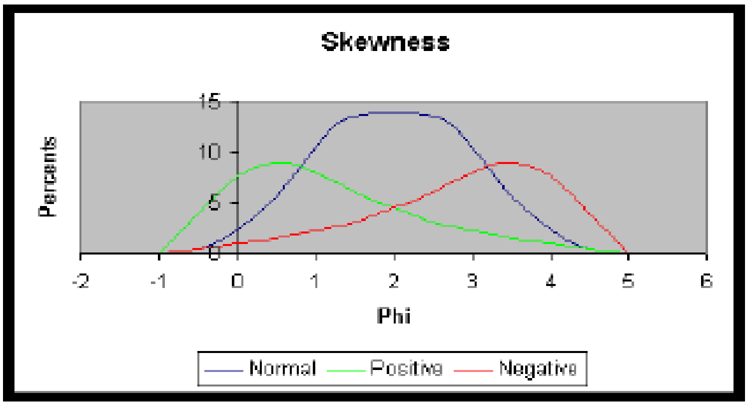


Figure 2.2: Classification of sediments with regards to skewness.

(Folk and Ward, 1957).

Kurtosis is a measure to determine if data within a normal distribution of sediment is flat or peaked. Hence, Leptokurtic (K>0) kurtosis represents a high kurtosis which most probably contain a distinct peak near the mean, thereafter rapidly declines and has a heavy tail (Folk and Ward, 1957). Low kurtosis (Platykurtic K<0) datasets are inclined flat topper which does not contain a sharp peak and in close proximity to the mean. Mesokurtic (K=0) which is uniform distribution only occurs under extreme circumstances (Folk and Ward, 1957).

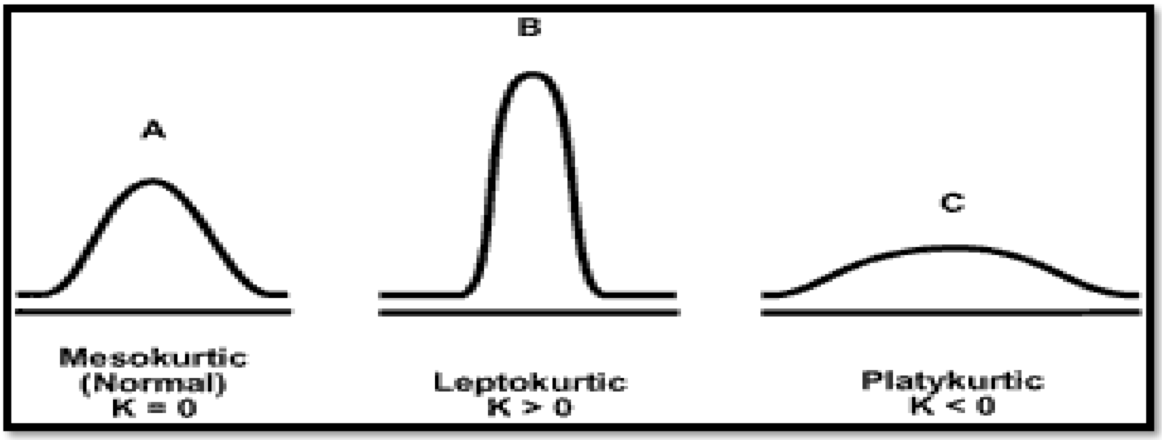


Figure 2.3: Illustrating distribution of Kurtosis.

(Folk and Ward, 1957).

2.5. Estuarine biological indicators

2.5.1. Microbial indicator of faecal pollution

Microbial communities including pathogenic micro-organisms are supported by surface water. These disease-causing micro-organisms are predominantly found in faecal material derived from human, livestock and wild animals. The faecal material enters the surface water *via* agriculture, sewage discharge, urban and storm water runoff (Hong *et al.,* 2010). Faecal pollution of surface water may cause microbial pathogens to enter the water system and can lead to waterborne illnesses. Most waterborne diseases are caused by enteric pathogens and since analysis of all pathogens is a time consuming and costly process, indicator organisms are used (Singh and Lin, 2015). Microbial quality uses indicator organisms such as faecal bacterial indictors. For the purpose of this study the microbial indicators used include total coliform bacteria, *Escherichia coli* (*E. coli*) and Enterococci (faecal *Streptococci*) (Olaniran *et al.,* 2012; Ganesh *et al.,* 2014).

Total coliform bacteria are a practical indicator of the general hygienic quality of the water and it is primarily used in regular monitoring of drinking water supplies. In some cases, the presence of total coliform bacteria may be indicative of the presence of the host or carrier pathogens which are responsible for the transmission of infectious disease. This indicator organism includes bacteria of faecal origin and these organisms can cause diseases such as salmonellosis, gastroenteritis, dysentery, cholera and typhoid fever (DWAF, 1996a). Water quality degradation in relation to microbial pathogens is influenced by several environmental factors these include the surrounding land uses and occurrence of storm water runoff. The recreational Target Water Quality Range (TWQR) for total coliforms is 0-130 counts/100 ml (DWAF, 1996c).

Escherichia coli are a very specific indicator for faecal pollution derived from human and warm-blooded animals. This indicator is the most commonly used indicator for faecal pollution and *E. coli* comprises of about 97% of coliform bacteria in human faeces. These organisms are transported via the faecal or oral route by contaminated or water which has not been properly treated. *E. coli* may result in disease such as salmonellosis, gastroenteritis, dysentery, cholera and typhoid fever being contracted (DWAF, 1996a). According to Singh and Lin (2015), seasonal changes in addition to anthropogenic activities affect the water quality and the physio-chemical properties of the river system thus influencing the bacterial abundance. The recreational TWQR for *E. coli* is 0-130 counts/100 ml (DWAF, 1996c).

Enterococci (faecal *Streptococci*) bacteria are relatively specific indicators of faecal pollution. Faecal *Streptococci* live longer in aquatic environments than coliform bacteria (Teklehaimanot, 2013). Enterococci bacteria is a better indicator of and better predicator of human faecal pollution and the risks of contracting gastrointestinal illness from sewage contaminated waters (Teklehaimanot, 2013; Singh & Lin, 2015). Furthermore, the presence of faecal S*treptococci* in addition to total coliforms and *E. coli* aids in the confirmation of the incidence of faecal pollution as a result of warm blooded animals. The presence of the bacteria indicates very recent pollution as once the bacteria leaves the animal intestine, it has a short survival period and it is not capable of multiplying in the environment (Adelekan, 2010). The recreational TWQR is utilized as none exist for aquatic ecosystems. The TWQR is 0-30 counts/100 ml (DWAF, 1996c).

2.5.2. Zoobenthos

Zoobenthos are organisms that reside in soft sediment which are commonly buried in sediment majority of the time. The sediment contains macrobenthic and meiobenthic organisms which are determined through mesh size aperture in which sieving of sediment and organisms retained or allowed through mesh determines if organisms are macrobenthic or meiobenthic (Teske and Woolridge, 2001). According to Hanekom *et al* (1988) and Day (1981) past research on macrobenthic used sieve sizes of 1-4 mm in the intertidal environment. However, recent studies over the past ten years on subtidal macrobenthic research used small sieve sizes such as 500 microns which was used in this study. According to research there is a distinct difference between intertidal and subtidal macrobenthic organisms in which subtidal species composition and structure consists of high amounts of polychaete worms and peracarid crustaceans (Schlacher and Woolridge, 1996b; Teske and Woolridge, 2001).

The advantage of the usage of smaller mesh sizes is the direct result of obtaining a higher density estimate of organisms as compared to using a coarser mesh (approximately 1mm) which is more appropriate if the key focus is biomass estimates (Schlacher and Woolridge 1996b and c). Macrobenthic species richness and abundance in the subtidal environments of estuaries are recognised as rich communities which are inclusive of many small species and juveniles which require a mesh size of 5oo microns to retain organisms. It is of utmost importance to sampling replicates of three per site to warrant representation of organisms are maximised at each sampling site. In the final analysis, it is essential that rare species are identified and listed as these species are imperative for accurate bioassessment and community studies (Cao *et al*., 1998).

2.5.3. Macrobenthic organisms in soft sediment of estuaries

Crustaceans and polychaetes are commonly occurring organisms in soft sediment in TOCEs and POEs along the coastline of South Africa which undergo their entire life cycle within the estuary (Teske and Woolridge, 2001). Characteristics of the aforementioned organisms and their range of tolerance to salinity and specifically amphipods have the ability to tolerate and grow in freshwater. Furthermore, benthic invertebrates are known to be able to tolerate low salinity levels as recorded in Lake Sibayi study, which similar estuarine species were found in this freshwater environment. The species recorded in Lake Sibayi were polychaete worms such as *Ceratoneries keiskama* and the amphipods *Corophium triaenonyx and Grandidierella lignorum* (Cao *et al*., 1998; Teske and Woolridge, 2001).

An important factor in the diversity and abundance of macrobenthic organisms depends on the mouth status of an estuary. A permanently open estuary will have a higher species diversity and abundance (de Villiers *et al*., 1999). However, it must be noted that a POE that is dominated by freshwater, commonly has low macrobenthic diversity and abundance. Flushing and recurrent flood events in estuaries are processes that influence the macrobenthic distribution and abundance as only a few species can withstand the fluctuation of salinity during these processes (de Villiers *et al*., 1999). Although POEs are species rich and abundant as compared to TOCEs, their species richness and abundance drops drastically upstream of the estuary. Conversely, macrobenthic species in TOCEs are more consistently distributed throughout the estuarine environment (Schlacher and Woolridge, 1996a). The main reasons for the difference in distribution of macrobenthic organisms in POEs and TOCEs is a directly result of factors such as horizontal salinity gradient variability and persistent marine-estuarine interaction between POEs as compared to TOCEs which effect the dynamics of species in the estuarine environments (Teske and Woolridge, 2003).

The true macrobenthic organisms or euryhaline species community structure are commonly not affected by salinity changes and ranges in surrounding estuarine water, although larvae maybe more sensitive to salinity changes as compared to adult species. However, this true macrobenthic community structure is characterised by moderately low species numbers in comparison to freshwater and marine influenced macrobenthic species (McLusky and Elliot, 2004). Similarly, freshwater rich estuarine systems manifest a similar macrobenthic community structure as euryhaline conditions. Furthermore, TOCEs may occupy fewer species of macrobenthic species as compared to POEs but may have a higher density of species in comparison to POEs (Teske and Woolridge, 2001).

The type of sediment in estuaries is an essential component in the community structure of macrobenthic organisms. Although estuaries along the coastline of South African have different abiotic factors such as mouth state, distribution of salinity and interaction between marine-estuarine interface, according to Teske and Woolridge (2003 and 2004), macrobenthic community structure of euryhaline subtidal species were primarily influenced by the sediment type. The two sediment types that estuarine macrobenthic organisms reside in are sand and mud. Therefore, water salinity seemingly decreases away from the mouth of the estuary but becomes increasingly less saline at the head where freshwater influence dominates this part of the estuary (Teske and Woolridge, 2004). Besides salinity and sediment type, other factors like pollution may also play an essential role in the community structure of macrobenthic organisms (Teske and Woolridge, 2003).

2.6. Water Quality

The term water quality is used to define different characteristics of water such as aesthetic, biological, chemical and physical in which determination of water usages are found for various aspects including protection of aquatic (inclusive of semi-aquatic) environments (DWAF, 1996a). TOCEs along the coastline of South African are dynamic and no estuary is the same as the other although they might have similar attributes. Furthermore, these estuaries have three hydrodynamic states which are open, semi-closed and closed mouth states. These states are highly dependent on factors such as beach profile, estuary size and mouth protection in which estuaries can experience all three states or just two, namely the open and closed mouth states. The following section will discuss physical water parameters such as dissolved oxygen (DO), pH, salinity, temperature and nutrients associated with the different mouth states mentioned above (DWAF, 1996a).

2.6.1. Salinity

The parameter salinity and its distribution within the estuary and associated mouth states are provided below:

Open Mouth State: When open mouth state exists in an estuary, this is partnered with a longitudinal salinity gradient which allows the marine environment to interact with the estuarine environment. The halocline location is dependent on the degree of river inflow. If deeper waters exist in the middle and upper areas of the estuary, vertical stratification can occur in this state in some estuarine environments (Taljaard and Slinger, 1993; Taljaard *et al*., 1992).

Semi-open mouth state: This state is characteristic of low freshwater contribution, hence give rise to a strong longitudinal salinity gradient. Freshwater inflowing into the estuarine system is limited to the surface of the estuary, whereas saline water is found in deeper areas. The main reason freshwater limited to the surface of water column is a direct result of saline water higher water density. As time passes by, the estuary changes into a homogenous brackish water environment as a result of freshwater phasing into saline water at the bottom layer of the water column and inclusive of wind mixing forces (Taljaard and Slinger, 1993; Taljaard *et al*., 1992). The stratification conditions that occur is highly dependent on depth of the estuary, wind mixing force strength and river inflow. Saline conditions commonly persist in deeper areas near the mouth during periods of spring tides as seawater seeps through the berm and into the estuary. If semi-closed mouth state perseveres for a few months coupled with little to no marine overwash, salinity in the estuarine environment will drop as a result of freshwater phasing into saline water at the bottom of the water column or from wind mixing forces (Taljaard and Slinger, 1993; Taljaard *et al*., 1992).

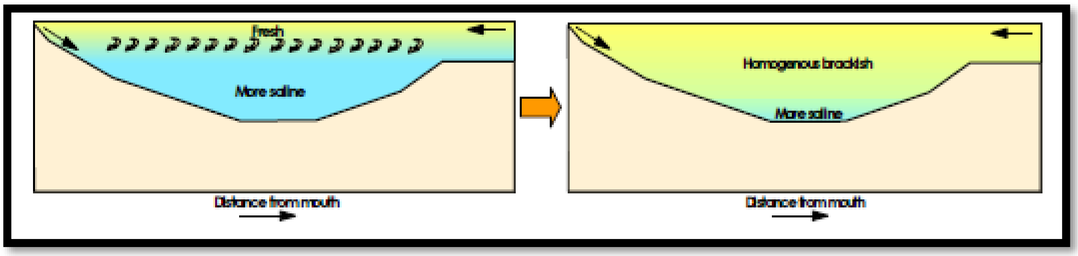


Figure 2.4: Salinity conditions in a TOCE when open mouth state (on the left of image) in present to seawater and river water.

(Whitfield and Bate, 2007)

Closed mouth state: The salinity throughout the estuarine water column during closed mouth state is commonly homogenous (Figure 2.5), while a small amount of longitudinal and vertical stratification maybe present instantly after mouth closure (Taljaard and Slinger, 1993; Taljaard *et al*., 1992). Marine overwash can still occur during the closed mouth state as a direct result of berm height and high energy waves. The change in the bottom water is dependent on factors such as the volume of seawater entering the estuary and the bathymetry of the estuary. The constant input of freshwater from river inflow results in estuarine environment becoming freshwater abundant, whereas, if river inflow is absent the system results in becoming more saline, or even, hypersaline if continuous evaporation occurs (Taljaard and Slinger, 1993; Taljaard *et al*., 1992).

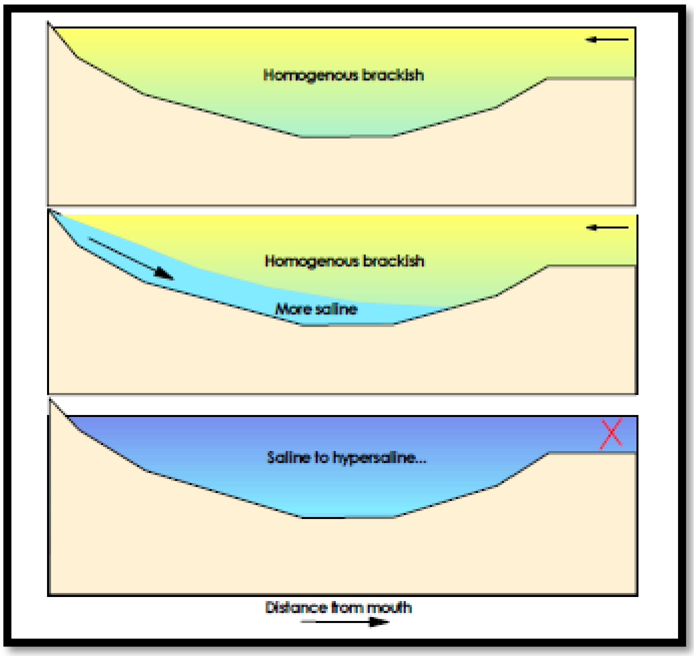


Figure 2.5: Homogenous water as a result of high amounts of river inflow, slight saline conditions as a result of marine overwash and hypersaline conditions due to lack of freshwater input (mouth on the left of image).

(Whitfield and Bate, 2007)

2.6.2. Temperature

Temperature in TOCEs are highly dependent on periodic trends in atmospheric temperature. Therefore, seasonal temperatures of estuarine waters during winter range between 15-20^{0}C and 20-25^{0}C in summer (Whitfield and Bate, 2007). Temperatures of water are also affected by prevailing sea conditions especially during open mouth state. Processes such as upwelling which predominantly occurs on the west coast of South Africa can affect temperatures of estuary waters in the mouth and middle reaches of the environment, as upwelling temperature range between 9^0-14^{0}C which commonly occur during spring/summer during off-shore wind processes (DWAF 1995; Monteiro and Largier, 1999).

2.6.3. pH

The pH in estuaries is highly dependent on sources flowing in and out of it, specifically, the river and sea. The pH of seawater ranges between 7.9-8.2 under natural conditions, whereas, river water pH is characteristic of activities that occur in the catchment area (DWAF, 1995). An example of catchment characteristics is Natal Group Sandstone which is commonly rich in humic acids from distinctive vegetation found in the soils which represent low pH levels of approximately 4. Nevertheless, due to marine-estuarine interaction and the input of seawater into estuarine environments, the pH levels within estuaries range between 7-8.5 (DWAF, 1995).

2.6.4. Dissolved Oxygen (DO)

The amount of gaseous oxygen in water is known as DO. In TOCEs, organic material degradation as a result of bacterial activity reduces levels of DO within the estuarine environment (DWAF, 1995). The reduced levels of DO can be a result of natural processes such as rapid movement of volume of water, changes of temperature and nitrogen deposition from the atmosphere; and also through anthropogenic activities such as sewage treatment works discharge of waste water, application of fertilizers in catchment areas which wash into estuarine waters and high levels of nutrients in soil that are eroded and transported into estuarine environment (DWAF, 1995).

There are two types of DO levels that have adverse effects on organisms that reside in estuaries. The first and worst state is anoxia which is a direct result of no oxygen (0 $mg.L^{-1}$) and hypoxia which are oxygen levels ranging between 2-3 $mg.L^{-1}$ which can cause stress or death upon organisms that reside within the estuary, the latter usually occurs after eutrophication (Manickum *et al*., 2014). Any DO concentration above 3 $mg.L^{-1}$ does not usually cause death or stress upon organism in estuarine environments. The aforementioned characteristics of DO are different measures of DO that can occur at different mouth states in TOCEs (Singh and Lin, 2015).

Open mouth state: Due to the water exchange between the river inflow and tidal flushing in a TOCE during this state, DO concentrations are high and range between levels 5-6 $mg.L^{-1}$ (Singh and Lin, 2015).

Semi-closed mouth state: The semi-closed mouth state brings about strong vertical stratification which can cause lack of aeration in bottom waters coupled with organic loading which may cause bottom waters to have low DO concentrations of approximately <3 $mg.L^{-1}$. However, if waters are well-mixed as a result of wind mixing process and if vertical stratification in the water column is broken down, deeper waters maybe better oxygenated (as seen in Figure 2.6) (Manickum *et al*., 2014).

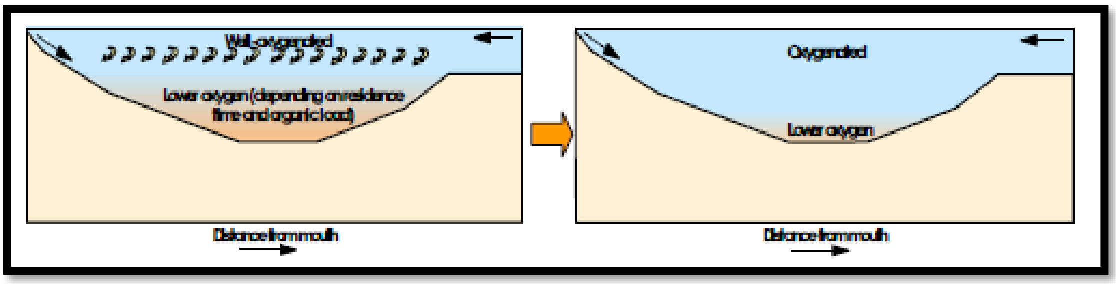


Figure 2.6: Illustration of DO change in TOCEs in the semi-closed mouth state.

<u>Closed mouth state</u>: The closed mouth state promotes a water column that is fairly homogenous and no vertical stratification occurring (DWAF, 1995). Therefore, the processes known as wind mixing will uphold aerated conditions through the water column. In some instances, low DO concentrations can occur in deeper stagnant pools of water coupled with organic loading. However, marine overwash can remedy the low DO levels found in these stagnant pools by introducing new seawater into the system, but it is highly dependent on the amount of seawater that enters the estuarine environment (DWAF, 1995).

2.6.5. Inorganic Nutrients

Inorganic nutrients, especially dissolved inorganic phosphate (DIP) and dissolved inorganic nitrogen (DIN). are considered the most important form of nutrient in estuaries. These inorganic forms of nutrients are introduced into estuarine waters by factors such as catchment characteristics, seawater intrusion through the berm of the estuary, biochemical processes such as nitrogen fixation remineralisation and groundwater seepage (Singh and Lin, 2015). Therefore, inorganic nutrient concentration in an estuary is directly related to sources of water input such groundwater, river and sea coupled with other biochemical processes and even physical processes such as evaporation. It is imperative to note that values of DIP and DIN in estuarine waters are not a precise quantity of the amount being processed at a given time (DWAF, 1995). The DIP and DIN behaviour differs under the three mouth states found in TOCEs.

<u>Open mouth state</u>: The concentrations of DIP and DIN during the open mouth state in a TOCE is largely dependent on factors such as seawater flushing in and river inflow. Primary production cannot occur during the open mouth state as swift water exchange does not permit adequate residence time in the water column for production to occur. This is typical of TOCEs in the South African coastline, especially smaller TOCEs (DWAF, 1995). Biochemical and physical processes coupled with groundwater input is known to be imperative for primary

production for benthic invertebrates and macrophytes which intake nutrients through their roots, however, although these processes play a pivotal role for certain organisms that reside within the estuary, they are not considered major sources of DIP and DIN in the overall water column (DWAF, 1995).

A linear relationship exists between DIP, DIN and salinity during the open mouth state as inorganics are usually higher at lower salinity values (DWAF, 1996a). This relationship assists with determining the destiny and distribution of DIP and DIN in an estuary as salinity exist in an extremely stable form. These inorganic nutrients experience higher concentrations with the inflow of rivers in comparison to seawater as a direct result of natural and anthropogenic catchment characteristics. Furthermore, upwelling events do not usually occur along the coastline of KwaZulu-Natal but is present along the Western and Eastern Cape coastline and plays a role in the nutrient loads in estuaries (DWAF, 1995).

<u>Semi-closed mouth state</u>: During the semi-closed mouth state, concentrations of DIP and DIN are largely dependent on river inflow and small amounts of seawater influence. Due to the longer residence time of water in this period, phytoplankton biomass is much higher which leads to a direct decrease of DIN and DIP concentrations (DWAF, 1996a). However, due to river inflow, DIP and DIN concentrations will be maintained to support a certain level of primary production in the water column. Biochemical processes and groundwater input will also be a source of DIP and DIN for primary production in TOCEs and, chlorophyll *a* and inorganic nutrients will have an inverse relationship in this mouth state (DWAF, 1995).

<u>Closed mouth state</u>: During this state, residence time of water will further increase and cause an increase in chlorophyll *a* and decrease in DIP and DIN for a short interval. Thereafter, the inorganic nutrients can become completely depleted which will result in a decrease in chlorophyll *a* in the water column (Taljaard and Slinger, 1993; Taljaard *et al*., 1992).

It is interest to note that processes such as remineralisation of organic matter in sediment and input of groundwater are imperative sources of DIP and DIN for macrophytes intaking these nutrients in their roots and for primary production of benthic microalga. These nutrients can become available in the water column by the aforementioned factors coupled with sediment disturbance such as wind turbulence (Taljaard and Slinger, 1993; Taljaard *et al*., 1992). Marine overwash of seawater into the estuary may adjust estuarine nutrient levels and is dependent on the volume of seawater.

2.6.6. Total dissolved solids (TDS) and Electrical Conductivity (EC)

TDS concentration is a gauge of the amount of all compounds that are dissolved in water. This factor can be represented in three ways such as TDS; conductivity and salinity. Salinity and TDS are measures of the mass of solutes in water but have a difference in the components they measure. TDS is known to be the mass of the dissolved inorganic and organic elements in water (DWAF, 1996a).

Electrical conductivity refers to the amount of charged ions and the measure of waters electrical capacity. Waters ionic content is dependent on the chemical and physical properties of the geological formations (DWAF, 1996a).

Specifically, natural waters that have unstable amounts of TDS due to dissolution of minerals in plant material decomposing, rocks and soil, therefore this is the reason why TDS concentrations of natural waters are not only dependant on the distinctiveness of the geological formations through which the water comes in contact with, but also on other processes such as rainfall and evaporation (Bowen, 1979). TDS concentrations may also be increased by factors such as surface runoff from cultivated, industrial and urban areas, and also domestic and industrial waste matter discharges into aquatic systems (DWAF, 1996a; 1996b).

2.7. Chemical parameters (heavy metals) in estuaries

The heavy metals that are of importance in this study are: Aluminium (Al), Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg) and Zinc (Zn). These metals have different properties that affect the way that each will behave in a particular environment. Each of these metals is discussed below.

Aluminium (Al) - Industries that make use of this metal include the textile industry, leather industry, metal and construction industry, and the paper industry (DWAF, 1996a). DWAF (1996a), further states that excessive levels of aluminium may be toxic to fish as it causes respiratory problems due to mucus coagulation in their gills. Water birds that consume invertebrates or fish that have been contaminated may experience effects such as eggshell thinning, and giving birth to hatchlings with very low weights. The impacts of aluminium from aquatic sources on human health are still not fully understood as there is still insufficient evidence in research. For acid-soluble aluminium, TWQR is ≤ 5 $\mu g.L^{-1}$ (when pH < 6.5) and TWQR is ≤ 10 $\mu g.L^{-1}$ (when pH > 6.5) (DWAF, 1996b).

Cadmium (Cd) – The element cadmium is present in the earth's coupled with other elements such as copper, lead, ore bodies, sulphide and zinc at a concentration of approximately 0.2 $mg.kg^{-1}$. The process in which cadmium enters water environments is through natural weathering processes and also through anthropogenic industry activity as a trace concentration (DWAF, 1996a). Cadmium in water is known to behave similarly to zinc. Cadmium toxicity in water is highly dependent on factors such as chemical speciation and water hardness in which these are influenced by ligands, temperature of water, pH and the presence of metal cations in water. The aforementioned factors influence the uptake of bio-availability of cadmium by aquatic organisms. The effect of temperature coupled with cadmium only effects organism that reside in the water and when salinity decreases the potential for the toxicity of cadmium to increase is highly likely. The sources of anthropogenic cadmium concentrations into water environments is through emissions to water and air as a result of mining activity, the manufacturing of alloys, batteries, paints and plastics by industries, fossil fuel burning and the use of fertilizers, pesticides and sludges containing cadmium for agricultural practises. The TWQR for cadmium is <60 $mg.L^{-1}$ when lead concentration is(0.15 µg).

Table 2.2: The criteria and TWQR of total cadmium at dissimilar water hardness in aquatic ecosystems

Hardness (mg $CaCO_3$. L^{-1}	< 60 (soft)	60-90 (medium)	120-180 (hard)	>180 (very hard)
TWQR – Lead concentration (µg.*)	0.15	0.25	0.35	0.4

(DWAF, 1996a).

Copper (Cu) - copper is one of the most commonly used metals worldwide (DWAF, 1996a). It is naturally present in most aquatic systems and is considered to be a potential hazardous metal. Copper is naturally produced in the environment by weathering processes and the dissolution of various copper minerals. Anthropogenic sources of copper from the corrosion of copper pipes result from acidic waters and sewage effluents which account for 33 – 60 % of the total global input of copper in aquatic ecosystems (DWAF, 1996a). The impacts of high concentrations of copper in aquatic environments have an effect on humans and biota (Sukdeo, 2010). Various impacts of high copper concentrations in aquatic environments include brain damage to mammals (DWAF, 1996a), as well as gastrointestinal disturbances, and damage of the liver, kidneys and red blood cells (DWAF, 1996b).

Iron (Fe) - Iron is known to be the fourth most copious element in the earth's crust which maybe naturally occurring in waters dependent on the chemical properties of the water in the environment and the relevant geology of the area. Iron is an imperative micronutrient for all living organisms in estuarine environments but its toxicity is determined by its ferric or ferrous state and in solution or suspension (DWAF, 1996a). The weathering of all geological rocks such as igneous, metamorphic and sedimentary rocks and sulphide ores brings about natural occurrence of iron in the environment. The leaching from sandstone gives rise to iron hydroxide and oxide into water environments. Furthermore, iron is released into water environments by human induced anthropogenic activities such as acid mine drainage, burning of coal and coke, sewage, mineral processing, iron and steel corrosion, fungicide and domestic chemical industry and landfill leachates. The TWQR for iron should not exceed 10% of the background dissolved iron concentration of a site at any given time (DWAF, 1996a).

Lead (Pb) - Lead is an important environmental metal which occurs in several different oxidation states such as 0, I, II and IV. The most stable lead state in the environment is Lead (II) which aquatic organisms can bio-accumulate. Lead is generally found as $PbCO_3$ in freshwater and also as lead-organic complexes, with small amounts as free lead ions. However, lead is also known to adversely affect most living organism, especially as a result of its accessibility and toxicity to aquatic organisms (DWAF, 1996a). Lead enters water environments through natural weathering of suphide ores, particularly galena. The levels of dissolved lead are typically low due to common lead minerals and metallic lead inability to be soluble in water. The human induced anthropogenic activities that cause lead entering the water environments are precipitation, street and dust runoff (related with lead discharges from gasoline-powered motor vehicles), wastewater discharge from industries, mining activities, milling and smelting of lead and combustion of fossil fuels.

Table 2.3: The criteria and TWQR of dissolved lead at dissimilar water hardness in aquatic ecosystems

Hardness (mg $CaCO_3.L^{-1}$	< 60 (soft)	60-90 (medium)	120-180 (hard)	>180 (very hard)
TWQR – Lead concentration (ug.L^{-1})	0.2	0.5	1.0	1.2

(DWAF, 1996a).

Manganese (Mn) - Manganese is an important micronutrient for animals and plants, but can be lethal at high concentrations in aquatic ecosystems. Manganese does not occur as a metal in an aquatic ecosystem but as soluble manganous (Mn^{2+}) or insoluble manganic (Mn^{4+}) forms. Natural sources of manganese are from metamorphic and sedimentary rocks or soils and sediment (DWAF, 1996a). Discharge of various forms of pollution form industries are accountable for the increased concentrations of manganese in aquatic ecosystems. The use of manganese by industries are as an alloy and manganese compound in their products or processes to create a product. Industries that use manganese are fertilizer producing industries as a micronutrient preservative, acid mine drainage and the chemical industry for items such as ceramics, dyes, firework, glass, paints and matches. The TWQR for manganese is $\leq$ 180 µg. L^{-1} (DWAF, 1996a).

Mercury (Hg) – The presence of mercury naturally is quite rare and its concentration in environments is typically low. Mercury is known to have three oxidation states which are as a metal as mercury (I) and mercury (II) and as an organo-mercurial salt. Mercury is extremely toxic and has the ability to bio-accumulate in aquatic food chains and can be taken up by organisms through air, food and water (DWAF, 1996a). The main source of mercury is through industrial pollution which utilise mercury compounds and discharge waste that contains mercury. The industries that use mercury are electrical equipment industries, dental and medical industries, paint and fungicide industries, paper and pulp industries and chlor-alkali industries. The TWQR for mercury is approximately 0.04 (SI unit dependent on analysis) and not more than 10% of the sampling environment at any given time of sampling (DWAF, 1996a).

Zinc (Zn) - Zinc occurs in metal and zinc (II) ion forms in aquatic ecosystems. Fish and aquatic organisms are vulnerable to zinc (II) ions as it is extremely toxic even at low concentrations. Although zinc (II) is toxic to organism, zinc is still an important micronutrient for all organisms. Zinc occurrence is natural as well as anthropogenic. The natural state is directly from weathering and erosion of rocks and ores, whereas, it can also be readily available in a pure stable metal form from industrial activities (DWAF, 1996a). The occurrence of zinc in industrial water can be in soluble or insoluble zinc salt form. Three forms are broadly used in industries which are the carbonate, hydroxide and oxide forms which are used as dye processing and manufacturing, pigments (cosmetics and paints), pharmaceuticals, insecticides and fertilizers. The TWQR for dissolved zinc in aquatic ecosystems is $\leq$ 2ug.L^{-1} (DWAF, 1996a).

2.7.1. Heavy metals and their properties

Heavy Metals are classified as those metals with a high atomic weight, as well as a specific gravity of 5.0, or higher (Duffus, 2002). The term ‘heavy metal’ may also be used to classify those metals acknowledged for obtaining properties harmful to human health. Such metals include toxic transition metals like lead, mercury and cadmium, which are known for having no biological purpose (Duffus, 2002).

Heavy Metals can be found naturally occurring in the environment in trace amounts (Obasohan *et al*., 2008). They are derived from terrigenous sources like the weathering of rocks and are always found to occur in fresh water bodies, due to the natural supply of sediment produced from geological weathering (Sekabira *et al*., 2010). Sediments found in rivers are responsible for the transporting of heavy metals found in aquatic bodies (Chalrabarty and Patgiri, 2009).

Raised concentrations of trace metals in sediments can be correlated to anthropogenically induced pollution, and the increased levels of heavy metals in rivers can be attributed to human induced influences (Sekabira *et al*., 2010).

All metallic elements (inclusive of heavy metals), have common characteristics, however each individual element is unique and has its own distinct physico-chemical properties. These distinctive characteristics aid in defining their toxicological and biological characteristics, and furthermore how they will be transported through the environment (Duffus, 2002).

Sources of heavy metals

- Industrial Emissions

Waste materials generated from electroplating, smelting, chemical and mining industries all consist of heavy metals (DWAF, 1996a). In most of these cases, these heavy metals travel to rivers due to the release of waste products from their respective industrial plants. Mine tilling deposits are one of the most significant contributors to the presence of heavy metals in rivers (Coetzee, 1995). These tilling deposits are left unprotected and exposed to the elements, thus making it extremely prone to being washed off into surrounding water systems. The focus point of heavy metal pollution are those areas that are heavily industrialised and urbanised (Coetzee, 1995).

- Vehicle Emissions

In order to give motor fuel its ‘anti-knock’ characteristic, lead is added to the fuel. As a result, a significant amount of this lead is released back into the atmosphere, in the form of exhaust fumes, which is known to settle on road surfaces. Therefore, when rainy conditions prevail, the accumulated lead deposits on the road surfaces are washed off and are transported to the surrounding water bodies (Coetzee, 1995).

- Agricultural Sources

Agricultural activities are a significant source of heavy metal deposits into rivers. This is a negative consequence of the application of fertilizer, utilisation of pesticides and resulting sediment runoff from activities concerning land management (Coetzee, 1995).

2.7.2. Sources of heavy metal pollution in the Sezela estuary and river

Heavy metals are normally found in trace amounts within aquatic systems. Increased amounts of trace metals found in sediments can be attributed to pollution caused by human activity. High levels of heavy metals in aquatic systems can be due to anthropogenic causes. In aquatic systems, the major contributors of heavy metals are river sediments (Shozi, 2011).

Past studies of the Sezela estuary and river have indicated that the concentrations of heavy metals in the Sezela estuary are higher than what should naturally be so. The elevated concentrations of heavy metals can be attributed to land use and anthropogenic causes (Begg, 1978). This is primarily due to the Sugar-Mill industry adjacent to the Sezela estuary and secondary sources from industrial and subsistence agricultural activities. The main sources of heavy metal pollution are industrial emissions, vehicle emissions and agricultural sources (Shozi, 2011).

Vehicle and industrial emissions can cause large metal contamination of the ecosystems of the neighbouring roadsides and to the air in which their waste gasses are released (Ahmed and Erum, 2010). Lead is not the only metal associated with automobile sources of pollution; copper, zinc and cadmium are all included in petrol engines, lubricant oils, galvanised parts of vehicles and tyres. Cultivated soils in rural areas, adjacent to the road surfaces exhibit signs of heavy metal contamination from automobile use. Soils containing heavy metals can be transported during times of heavy precipitation contaminating water bodies (Ahmed and Erum, 2010).

Heavy metal pollution in rivers from agricultural sources can be from natural or anthropogenic causes. Natural sources of heavy metals include transport of continental dusts, weathering of metal enriched rocks and atmospheric emission from volcanoes (Naveedullah *et al.*, 2013). Anthropogenic sources of heavy metal pollution in agriculture are linked to metal enriched sewage sludge’s, livestock manure, use of electronics and automobiles, application of metal based pesticides and use of heavy metals in fertilisers. These causes of heavy metal pollution result in the heavy metal pollution of agricultural and rural soils and in heavy metals deposited on surfaces. Heavy metals are washed off with rain and transported through water runoff into rivers and surrounding water bodies (Naveedullah *et al*., 2013).

2.8. Definitions of wetlands

According to National Water Act (NWA) Act No. 36 (1998), a wetland can be defined as an area that transitions between aquatic and terrestrial systems, as a result of the water table typically near or at the surface, or the land is intermittently flooded by shallow water which typically if natural support vegetation that prefer continuous saturated conditions (Cowardin *et al*., 1979).

The aforementioned definition was formulated by Cowardin *et al* (1979) in which one of three characteristics must be present to be considered a wetland: a substrate must persist in saturated hydric soil, land should temporarily support hydrophytes and substrate must be intermittently appear saturated or submerged under shallow waters (Cowardin *et al*, 1979).

Definitions by NWA and Ramsar differ in some manner, in which according to Ramsar COP 7 (1999), wetlands are areas of fen, peatland, marsh and water, artificial or natural in nature, temporary or permanent, with water that is flowing or stationary, fresh or saline, and is inclusive of marine waters at depths of no more than six meters during low tide.

Therefore, it is noted that a clear distinct difference between the NWA definition which is not inclusive of rivers and estuaries, whereas, the Ramsar definition is inclusive of these aquatic environments. The wetland classification system used today promotes compatibility with the definition given by Ramsar and inclusive of what Cowardin *et al* (1979) referred areas of wetland as possible deep-water habitats. The deep-water habitats are referred to as lands that are permanently flooded lying below the deep-water boundary of wetlands. The aforementioned statement is typical of estuarine environments in which land is typically inundated throughout the year in which organisms do reside attached to substrate or not attached to substrate. However, there are similarities and differences between estuaries and wetlands which will be discussed further in the next heading.

According to the wetland Reserve Determination Method (DWAF, 1999), there are three types of wetlands that occur in South Africa:

- Endorheic – seasonal and permanent pans;
- Lacustrine – freshwater lakes;
- Palustrine – freshwater peat floodplains, marshes, peatlands, springs and swamp forests.

2.9. Similarities and differences between estuaries and wetlands

An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea dependent on if it is a POE or TOCE. Estuaries are often associated with high rates of biological productivity (Potter *et al*., 2010).

A wetland is an area that features temporary or permanent inundation of large areas of land by shallow bodies of water, generally with a substantial number of hammocks, or dry-land protrusions, and covered by aquatic vegetation, or vegetation that tolerates periodical inundation. In some cases, depression terrain accumulates deep waters which are considered wetlands as well (Cowardin *et al*., 1979).

In geography, a marsh is a type of wetland which is subject to frequent or continuous inundation. Typically, a marsh features grasses, rushes, reeds, typhas, sedges, and other herbaceous plants (possibly with low-growing woody plants) in a context of shallow water (Cowardin *et al*., 1979). A marsh is different from a swamp, which has a greater proportion of open water surface, and is generally deeper than a marsh. In North America, the term swamp is used for wetland dominated by trees rather than grasses and low herbs. The water of a marsh can be fresh, brackish or saline (Cowardin *et al*., 1979).

Coastal marshes may be associated with estuaries and along waterways between coastal barrier islands and the inner coast. The estuarine marsh, or tidal marsh, is often based on soils consisting of sandy bottoms or bay muds (Potter *et al*., 2010).

There are various similarities and differences that exist between wetlands and estuaries, however, many of the processes involved in both systems are similar in nature(Cowardin *et al*., 1979).

2.10. Distribution of wetlands in South Africa

The most predominant areas where wetlands are found are in areas that experience high mean annual rainfall such that incoming rain water is greater than water loss by evapotranspiration and surface runoff (Botes, 2009).

Studies in the past with emphasis on wetland environments disclose that a low number of wetlands exist in South Africa which is directly related to their limited extent as a result of the climate regimes and physiographic nature in the landscape (Begg, 1986). Hence, the low annual rainfall and predominant steep topography of the South African coastlines and inland margin are unfitting for wetland formation (Begg, 1986). However, the interior plateau zone of South Africa is fairly more gently sloped which is more preferable for wetland formation although mean annual rainfall is less in this region. In some instances, in the inland margin, riverine wetlands are found in this region along river banks and drainage lines but are limited along the coastline of South Africa (Barnes *et al*., 2001).

As a result of wetlands occurring predominantly in the interior plateau zone but also in the inland margin and coastline, all of these wetlands should be protected regardless of their type, location, size or classification in our current drought situation (Barnes *et al*., 2001).

2.11. Wetland Classification

Wetland classification is used to categorise wetlands of a similar type into groups and subgroups, for the purpose of cataloguing wetlands. Wetland types each have their own set of characteristics whereby it be ecological, hydrological or geomorphological in nature which is classified individually (Cowardin *et al*., 1979). The purpose to determine and classify wetlands are to identify and understand the major wetland type in a specific area, which offers a classification on a broad-level within a region (Cowardin *et al*., 1979).

The system developed by Cowardin *et al* (1979) was initially used as the wetland classification system in South Africa which identifies six types of wetland groups which are endorheic, estuarine, lacustrine, palustrine, marine and riverine. This method of classification is utilised for the Wetland Reserve Determination Process as well as for early wetland mapping and cataloguing in South Africa (DWAF, 1999).

The hydrogeomorphic classification (HGM) was initially recognised by Brinson (1993) for the US Army Corps of Engineers, in current day in America is still highly utilised. The system identifies wetlands with similar functional properties and places them into groups despite their unique individual characteristics. This HGM classification system places emphasis on hydrological and geomorphological characteristics which sustains several functional facets of wetlands (Kotze *et al*., 2004).

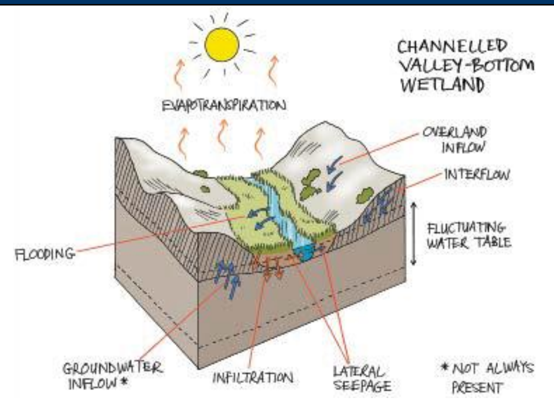
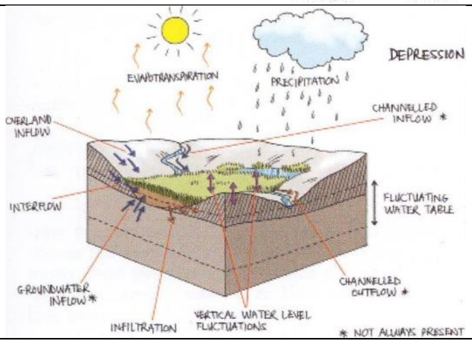
The HGM classification system was initially modified by Marneweck and Batchelor (2002), and later improved by Colins, Lindley and Kotze (2004) to suit the South African conditions. The adaptation of this system was pivotal for the use in wetland assessments and cataloguing, and further accepted for the use in the Wetland Reserve Determination method. This systems focus is with the topographic setting and hydrogeomorphic factors of wetland environments (DWAF, 2006).

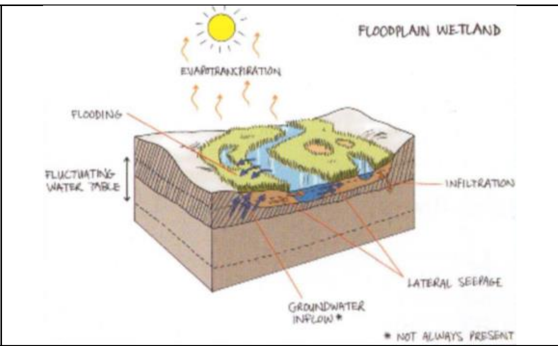
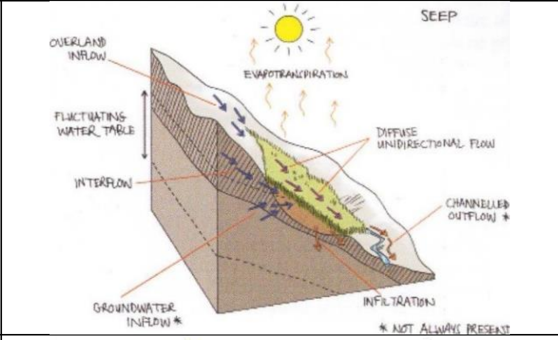
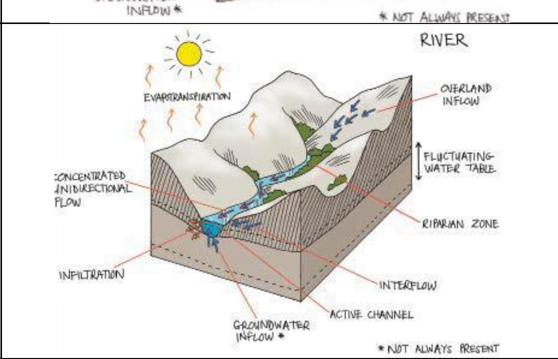
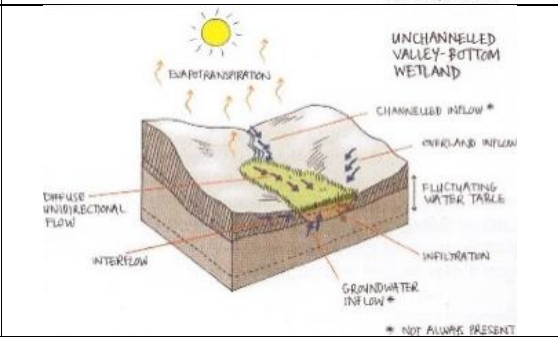
The HGM classification system identifies wetlands by their position such as on the crest, slope or in the valley and the manner in which water moves in, out and through the wetland environment (DWAF, 2006). This HGM classification system identifies five palustrine wetland types which are floodplain, depressions and pans (inclusive of lakes), channelled and unchannelled valley bottom and seepage wetlands (Kotze *et al*., 2004).

2.12. Types of wetlands

To completely understand the HGM classification of wetlands in South Africa, DWAF (2008) and Ollis *et al* (2013) created a generic description which describes different types of wetlands and is shown in Table 2.4 below.

Table 2.4: HGM classification of different wetland types.

<table>
<tr><th>Wetland type</th><th>Illustration</th><th>Description</th></tr>
<tr><td>Channelled
valley bottom</td><td>
</td><td>Linear fluvial, net depositional valley bottom surfaces which have a straight channel with flow on a permanent or seasonal basis. Episodic flow is thought to be unlikely in this wetland setting. The straight channel tends to flow parallel with the direction of the valley. The valley floor is a depositional environment such that the channel flows through fluvially-deposited sediment. These systems tend to be found in the upper catchment areas.</td></tr>
<tr><td>Depression
(includes pans)</td><td>
</td><td>A basin shaped area with a closed elevation contour that allows for the accumulation of surface water (i.e. it is inward draining). It may also receive sub-surface water. An outlet is usually absent.</td></tr>
</table>

Floodplain		A wetland area on the mostly flat or gently-sloping land adjacent to and formed by an alluvial river channel, under its present climate and sediment load, which is subject to periodic inundation by over-topping of the channel bank.
Hillslope Seep (isolated or linked to a stream channel)		Slopes on hillsides, which are characterized by the colluvial (transported by gravity) movement of materials. Water inputs mainly from sub-surface flow and outflows either very limited, through diffuse sub-surface and/or surface flow, or with a direct surface water connection to a stream channel.
River		Linear fluvial, eroded landforms which carry channelized flow on a permanent, seasonal or ephemeral/episodic basis. The river channel flows within a confined valley (gorge) or within an incised macro-channel. The "river" includes both the active channel (the portion which carries the water) as well as the riparian zone.
Unchannelled valley bottom		Linear fluvial, net depositional valley bottom surfaces which do not have a channel. The valley floor is a depositional environment composed of fluvial or colluvial deposited sediment. These systems tend to be found in the upper catchment areas, or at tributary junctions where the sediment from the tributary smothers the main drainage line.

(DWAF, 2008; Ollis *et al.*, 2013).

2.13. Hydrological zones

The hydrological regimes differ throughout the wetland environment owing to the topographic settings that wetland environments typically form in (Macfarlane *et al*., 2007).

Wetland systems have areas that are completely saturated throughout the year which are known, areas that are periodically saturated for approximately 5-11 months in a year and areas which are momentarily saturated for approximately 1-5 months a year that still support anaerobic soil conditions (DWAF, 2003). Therefore, wetlands can occur with all three hydrological zones which are permanent, seasonal and temporary zones, or two of the zone, or just one, which are all dependent on the hydrology of the wetland system. Furthermore, wetlands are highly dependent on climate patterns and rainfall (DWAF, 2003).

In order to determine the different hydrological zones in wetlands, redoximorphic features within the soils matrix play a pivotal role. One method to determine the difference between the seasonal and temporary zone, are typical seasonal soils will consist of redox mottles in the soil surface, whereas, redox mottles will only be found at depth in the temporary zone (DWAF, 2006). The permanent zone typically consists of low or not redox mottles as a direct result of anaerobic conditions persisting in this zone. However, oxidation of the colourless Fe^{2+} to Fe^{3+} occurs in this zone as compared to the seasonal and temporary zone. The aforementioned statements are critical in determining the different hydrological zones in a wetland system. The classification of wetlands can only be determined if these redoximorphic features exists in the upper 500 mm of the soil profile (DWAF, 2006).

2.13.1. Temporary wetland zone

The temporary zone of a wetland is typically characterised by low amounts of grey matrix of approximately less than ten percent of the volume of soil, limited high chroma mottles and periods of saturation is approximately three months per annum. Hence, the temporary zone is the area between the terrestrial and wetland environments (DWAF, 2006). The temporary zones hydrological functioning are not of much significance as a result of its small surface area of saturated zone, water volumes in this zone are limited, anaerobic and aerobic conditions are absent, organic matter is limited as a result of anaerobic conditions that are short and poor plant productivity. However, the temporary zone can perform hydrological functions that the surrounding terrestrial zone cannot and will be exceptionally important if the other hydrological zones are absent (DWAF, 2006).

2.13.2. Seasonal wetland zone

The seasonal zone is characteristic of more than ten percent of grey soil matrix volume coupled with a significant amount of chroma mottles and this zone is saturated at least three months of the year. This zone is more favourable to perform water purification as compared to the permanent zone and as a result of flooding and changing water table experiences aerobic and anaerobic conditions. The frictional value of the seasonal zone is lower than the permanent zones frictional value but still is adequate in most scenarios (DWAF, 1996a). The frictional value is highly dependent on the flat nature of the wetland, the inflow ratio and surface area, which in turn has the ability to decrease velocity adequately in order for the water purification process to occur. The seasonal zone typically has less organic matter than the permanent zone as a direct result of aerobic conditions occurring in this zone which has the ability to decay organic matter. Although organic matter is lower in the seasonal zone as compared to the permanent zone, the mere existence of organic matter in this zone still assist with the water purification process (DWAF, 2006).

2.13.3. Permanent wetland zone

The permanent zone is characteristic of a grey (gleyed) matrix, with few to no high chroma mottles, and is saturated throughout the year with a sulfuric odour (DWAF, 2006). This zone has the greatest potential to decrease water flow velocity as a direct result of the flat nature of this wetland zone, the abundant nature of hydrophytes but in some instance where hydrophytes don't exist, this zone still has the ability to slow down water flow velocity. Due to this zone continuously being saturated anaerobic conditions are prevalent and is associated with high organic content as a result of hydrophytes and anaerobic conditions slowing down the decomposition process. The functions such as flood attenuation and regulation, water purification allied with organic matter are the most efficient in the water purification process in this zone in comparison to other zones as well (DWAF, 2006).

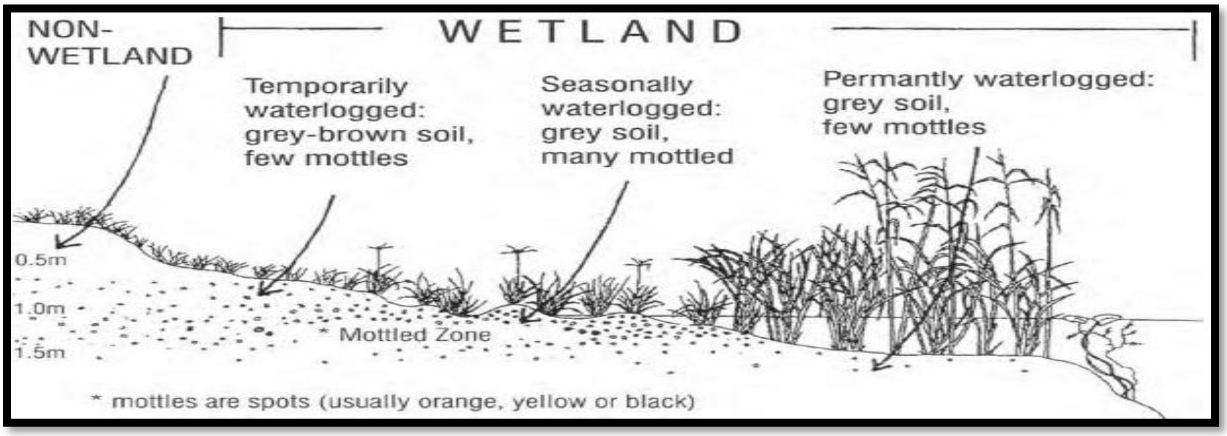


Figure 2.5: Wetland and non-wetland zones.

(DWAF, 2006)

2.14. Impact of water quality on the health and integrity of wetlandsF

2.14.1. Interstitial water

Inflows and outflows exist in aquatic ecosystems and wetlands. Processes such as groundwater inflows into rivers, wetlands or from higher upland catchment areas, evapotranspiration, precipitation, surface water inflows and outflows and, tidal inflows and outflows all play an important role in the input and output of water into a wetland (van der Valk, 2012). Wetlands will only form if the total amount of water input exceeds the total amount of water output within a certain area (Schwirzer, 2006).

It must be noted that several flows such as surface, sub-surface and generally water flow levels are subject to change yearly in the wet and dry seasons, therefore, changes to other characteristics in an area will occur such as climate and geomorphology (Schwirzer, 2006). In floodplain wetlands in the dry season or from periods of drought, receive water from alternative sources such as the adjacent river environment (Nyarko, 2007).

2.14.2. Water Quality

Water quality is the term used to define the biological, chemical, aesthetic and physical aspects of water which determines the various uses of water and for conservation purposes for aquatic ecosystems (DWAF, 1996a). Water quality plays an important role on determining the health status and integrity of a wetland environment (Reddy and Gale, 1994). The determining of water quality has become compulsory in several South African catchment areas and water quality monitoring and testing has become a pivotal process in Catchment Management Plans (Dickens *et al*., 2003).

2.15. Assessments of wetlands

The assessment of wetlands health are determined by national and international methodologies that have been developed. The USEPA in the United States of America assess wetlands health status by means of a bio-assessment (Uys, 2004).

The bio-assessment is dependent on the hypothesis that organisms that reside in wetland ecosystems have resided in it for thousands of years and are resilient to any external factor or modification. Due to this hypothesis, intense alteration by humans on resident organisms in the wetland ecosystem can be predicted (Botes, 2009). Nevertheless, the utilisation of this bio-assessment in other parts of the world may not yield the same results as in North America and thus will be questionable if utilised in any other region of the world (Botes, 2009).

The hydrogeomorphic approach was another assessment of wetland health status which was established by Brinson and Rheinhardt (1996). This approach outlines goals and standards essential for the formation and restoration of wetlands by using reference wetland conditions as a marker. Although this approach is utilised on a global scale, this approach may fail in South Africa as many wetland sites have already been altered and lack of baseline data. However, this approach could be utilised in the future as more detailed studies with regards to the evolution and origin of South African wetlands are being conducted (Botes, 2009; USEPA, 2002).

Although there have been several assessment methods and approaches recognized within the national bound for assessing wetlands health status, the WET-Health tool is recognised as the most acceptable and complete assessment tool (Botes, 2009). This tool outperforms other assessment methods or approaches due to its comprehensive focus on factors such as hydrology, geomorphology and biology processes that support wetland environments and the residing organism, in comparison to just relying on the identification of indicator communities in seclusion in the wetland environment (Macfarlane *et al*., 2007).

The WET-Health tool assesses the three factors separately as modules and calculates the current condition of each module as compared to the reference condition (Macfarlane, 2007).

2.15.1. Assessment of wetlands in South Africa

The assessment of wetlands in South Africa follow a procedure which involves determining the pre-impacted or reference condition wetland, hence, the present ecological state (PES), and the ecological importance and sensitivity of a wetland. Furthermore, a wetland assessment requires both desktop and fieldwork surveys for a proper assessment (DWAF, 2004).

The desktop survey is conducted to acquire a sound knowledge of the study site before the field visit. The desktop survey utilises aerial and satellite imagery to identify areas of interest such as possible wetland areas or areas that host wetland characteristics (DWAF, 2004). The field visit is to determine the boundary of the wetland by taking numerous sediment cores. Furthermore, vegetation and other ecological features should be noted when in the field. The data obtained from the desktop and field survey will thereafter be utilised on the Geographic Information System (GIS) and the methods developed by SANBI, Working for Wetlands, Water Research Commission and other wetland organisations (DWAF, 2004).

There are two different levels of assessment which can be conducted which are a level one and level two assessments. The level assessment consists of predominantly desktop level assessment with little to no field verification (Macfarlane *et al*., 2007). Whereas, the level two assessment it far more comprehensive which requires methodical collection of data from the catchment and wetland areas. Level one assessment are usually utilised if a large area is being assessed with several possible wetland systems, whereas, a level two assessment is used when a single wetland unit requires assessment.

2.16. Modules utilised to assess wetland conditions

The hydrological, geomorphological and vegetation modules in the WET-Health tool assessment are utilised in determining the health status of a wetland. The WET-Health modules can be utilised individually or in conjunction with other assessment approaches/techniques, dependent on the assessments priority and the relevant outcome of data required (DWAF, 2003).

The ecological characteristics of the wetland is determined by utilising physical variables such as, area, bathymetry, length, geomorphic setting, soil composition, water regime and source (Butcher, 2003). The physical variables water regime and source are imperative to giving an understanding on the wetting regime of a wetland, and the comparison of the difference between a pristine and present condition wetland. This aspect is imperative for wetland delineation and classification (Adamus *et al*., 2001).

The definition developed by Cowardin *et al* (1979) is known to be the most acceptable definition which describes wetlands (defined at the beginning of chapter) and the establishment of three key characteristics of wetlands which are hydrology, hydrophytes and hydric soil.

According to the National Research Council (1995), a wetland is described as an environment which is dependent on continuous or recurring, shallow flooding, or saturation close or at the substrates surface area. The imperative but minimum properties of a wetland are therefore, constant or recurring flooding, or saturation close or at the surface and the existence of biological, chemical and physical features which are reflective of the wetland properties of constant or recurring inundation or saturation. Physical features that are typical of wetlands are hydrophytic vegetation and hydric soil. These features should always be present within a wetland environment unless, human induced anthropogenic activities have removed or prohibited them to develop (National Research Council, 1995).

The common grounds of both of the aforementioned definitions are references to hydrology, soil and vegetation, therefore, emphasising the importance of the variables soil and vegetation when conducting a wetland assessment (National Research Council, 1995).

The hydrology, geomorphology and vegetation modules have an imperative connection, such that, if the hydrological module were to be affected by some anthropogenic source, this in turn could also affect the vegetation module which could have an increase or decrease dependent on the type of anthropogenic activity. An example is discharging of waste water into a wetland which can uptake nutrients from the wastewater and an increase in water will help promote vegetation growth (Macfarlane *et al*., 2007).

A similar case is a decline of the geomorphological integrity which in turn can cause a decline in the hydrological integrity but is dependent on local features which are wetland slope and soils texture. Furthermore, a decline in geomorphology module may indirectly impact the vegetation module as desiccation will cause erosion gullies and increased runoff such that the surrounding vegetation will not receive an adequate substrate and water to grow (Macfarlane *et al*., 2007).

The vegetation module plays an imperative role on the geomorphological module. This is due to if vegetation cover is removed, erosion will increase drastically, and the formation of erosional features can occur and further causing erosion in geological settings which encourage erosional activity, hence, impacting the wetland environment negatively (Macfarlane *et al*., 2007).

2.16.1. Hydrology

According to Macfarlane *et al* (2007), the term hydrology can be defined as water flowing through a wetland at surface and subsurface levels. The hydrology is an essential module in the assessment of wetlands as it donates to several major processes which are anaerobic condition production within soil, availability of nutrients and solutes and sediment fluxes. The aforementioned processes will determine which fauna and flora will structure the wetland ecosystem, hence, having a response effect to the hydrological module (Mitsch and Gosselink, 2000). Therefore, disturbing or modifying the hydrological module of a wetland will be major for the structure and biophysical process that occur within it (Macfarlane *et al*., 2007).

2.16.2. Geomorphology

In wetlands, soil saturation for long periods are recognizable impacts on the soil morphology, therefore, affecting the soil matrix, chroma and mottling (Natural Resource Conservation Service, 1995).

Mottling in soil refers to the colour sequence which is separated in the soil profiles within saturated layers as a result of predominant precipitation and solution of iron and manganese due to differences between anaerobic and oxidation states (Kotze and Marneweck, 1999). The background colour of the soils is known as the matrix, whereas, the spectral colour and its purity is regarded to as the chroma, therefore, the chroma will decrease as the greyness of the soil increases (DWAF, 2003).

The aforementioned factors above are affected by degree and period of soil saturation, soil profile wetness throughout and the soil present, which in turn generates specific features such as distinctive colouring, odours and staining in the soil profile (Kotze and Marneweck, 1999). Hydric indicators are utilised from soil profiles if depth information about hydrology is unavailable (DWAF, 2004).

2.16.3. Vegetation

Hydrophytes are plants in wetlands which are categorised as submerged and emergent hydrophytes. Emergent hydrophytes are plants that are predominantly not submerged in water and in direct contact with the atmosphere, whereas, submerged hydrophytes photosynthetic components are submerged by water (Glen *et al*., 1999). Helophytes are plants that do not require to be submerged in their life cycle but can adapt to being submerged, therefore, known as semi-aquatic plants (DeKyser *et al*., 2003).

Hydrophytes can be further categorised as obligate and facultative hydrophytes which are highly dependent on the environment in which they reside in. Furthermore, hydrophytes have developed numerous morphological, physiological and reproductive adaptation methods which permits them to grow, reproduce and thrive in almost any dry or saturated soil conditions (DWAF, 2003). Table 2.5 below further explains the difference between obligate and facultative hydrophytes.

Table 2.5: Classification of plants as per occurrence in wetland environments

Type	Description
Obligate Wetland Species	Almost always grow in wetlands (> 99% of occurrences)
Facultative Wetland Species	Usually grow in wetlands (67-99% of occurrences) but occasionally are found in non-wetland areas
Facultative Species	Are equally likely to grow in wetlands and non-wetland areas (34-66% of occurrences)
Facultative Dry-land Species	Usually grow in non-wetland areas but sometimes grow in wetlands (1-34% of occurrences)

(DWAF, 2008).

Delineation of wetland boundaries utilises vegetation due to its sensitivity to hydrology. However, if this method of delineation is used for delineation determinations, individual wetland plant identification will not suffice wetland delineation, thus, hydrophilic plant species that are predominant of the wetland must be identified. Furthermore, if an area consists of predominantly terrestrial plants with minimal wetland plants, that area cannot be considered a wetland (Adamus *et al*., 2001).

Wetlands also provide imperative qualities that are required for a functioning wetland environment which are; important habitats for a host of species such as amphibians, fish and macro invertebrates, as well as organisms such as algae, epiphytic and periphyton bacteria and phytoplankton (Mitsch and Gosselink, 2000). In addition, wetland vegetation are regarded as the base of the food pyramid meaning, wetlands are the primary pathway for energy flow through a system. Primary productivity in wetlands may vary but, productivity may rival that of tropical rainforests (Mitsch and Gosselink, 2000).

The existence of a strong link between water chemistry and wetland vegetation exist in wetlands. This is due to the ability of hydrophytes to remove contaminants, metals and nutrients from water by accumulation and uptake in their tissues. In addition, sediment regime and hydrology are other factors that wetland vegetation can influence as it has the ability to adjust shoreline currents and stabilise sediment (Macfarlane *et al*., 2007).

Wetland vegetation is affected by factors such as water quality and quantity and the proliferation of alien invasive plant species in wetland environments (Macfarlane *et al*., 2007). Wetland vegetation may therefore undergo changes in biotic, structural, spatial and temporal attributes e.g. moving to a more suitable location, changing growth form or being eliminated (Brock, 2003).

2.17. Wetland health

The sanction of legislation and environmental policies regarding the protection and preservation of wetland ecosystems situated in South Africa originally encouraged an important interest to ensure wetland ecosystems are kept undisturbed or impacted minimally (Cronk and Fennessy, 2001).

Wetland loss due to impacts experienced in these areas were documented in the form of reports by using wetland health as the main indicator which was based only on loss of wetland land (Cronk and Fennessy, 2001). However, due to the rapid declination of wetland ecosystems, it was recognised that the land should be preserved to maintain the functionality and health of the ecosystem. Therefore, shape and size of a wetland were not the only assessment factors that were considered but also condition and quality have become imperative factors (Horwitz *et al*., 2012).

According to Macfarlane *et al* (2007), a wetland is a measure of deviation of function and structure in comparison to the wetlands natural pristine condition. The term pristine condition refers to a wetland environment that has not been disturbed by any human induced anthropogenic activity to the point that is has changed is functionality and does not function to its potential (Uys, 2004).

2.18. Carbon, nitrogen and phosphorous cycles in wetlands

2.18.1. Carbon (C)

Wetland systems in generally accumulate OM and therefore are a good carbon sink. Two processes are involved in the build-up and balancing of organic carbon in wetlands which are carbon fixation due to photosynthesis and carbon loss due to decomposition (USEPA, 2008). The carbon storage pools in wetlands are inclusive of dissolved organic carbon, microbial biomass, detrital and soil OM and plant biomass (Kotze *et al*., 2007). Resistant carbon composites to processes such as aerobic and anaerobic decomposition tend to build-up in wetland environment as humic and peat materials. Humic substances in conditions that lack oxygen in wetland environments tend to become reluctant to decompose, hence, providing carbon and other nutrient storage in wetlands. However, during drained conditions, humic substances are degraded easily which cause the release of stored nutrients into waters, hence, affecting the quality of water *in-situ* and further downstream (USEPA, 2008).

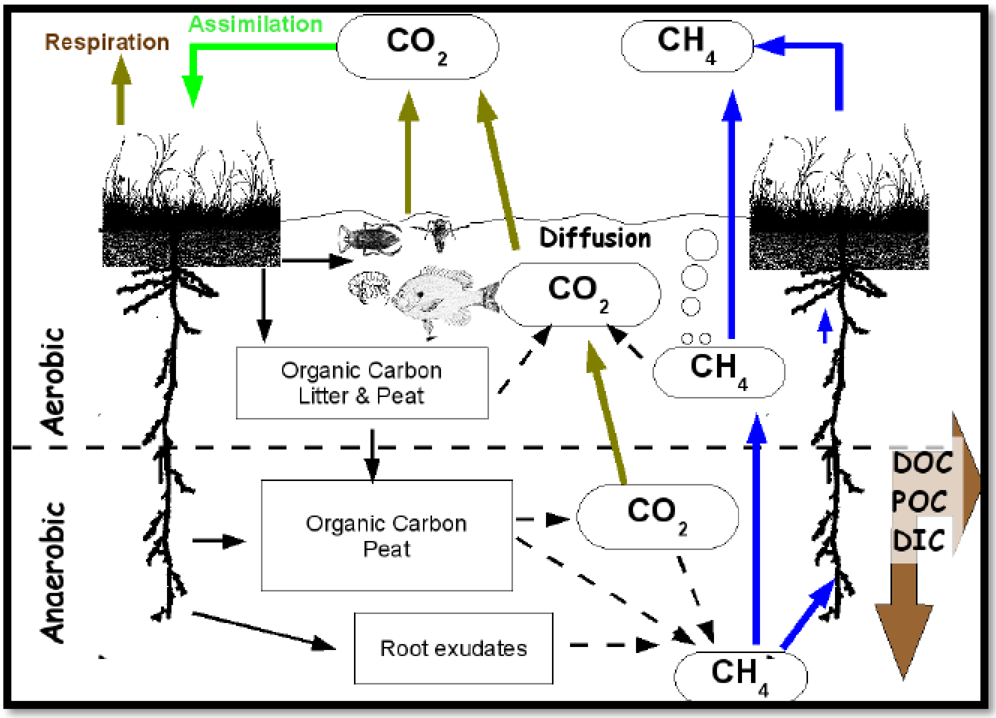


Figure 2.7: Carbon cycle in wetland environments.

(USEPA, 2008)

2.18.2. Nitrogen (N)

Nitrogen has the ability to enter wetland environments in organic and inorganic forms. Organic and inorganic nitrogen entering a wetland is highly dependent on source and type of water entering the wetland environment (Kotze *et al.*, 2007). Nitrogen removal particulates are accomplished by burial and settling of particulates, whereas, nitrogen in its dissolved form is overseen by several biogeochemical reactions which occur in soil and water column. The aforementioned processes rates are highly dependent on biological and physiochemical characteristic of the organic substrate, soil and water column (Kotze *et al.*, 2007).

Wetlands prove to be efficient in the processing of inorganic nitrogen through ammonia volatilization, denitrification and nitrification and plant intake which in turn decreases inorganic nitrogen quantity in water (Kotze *et al.*, 2007). Alternatively, dissolved organic nitrogen taken up by plants in the wetland environment predominantly returns to the water column due to organic matter and detrital tissue breakdown in the soil and as these materials are not easily broken down. The aforementioned conditions will exhibit wetland environments with increased levels of nitrogen in its organic form. The rates of these reactions are however, overseen by certain environmental conditions which will be representative of the wetlands soil and water column (Kotze *et al*., 2007).

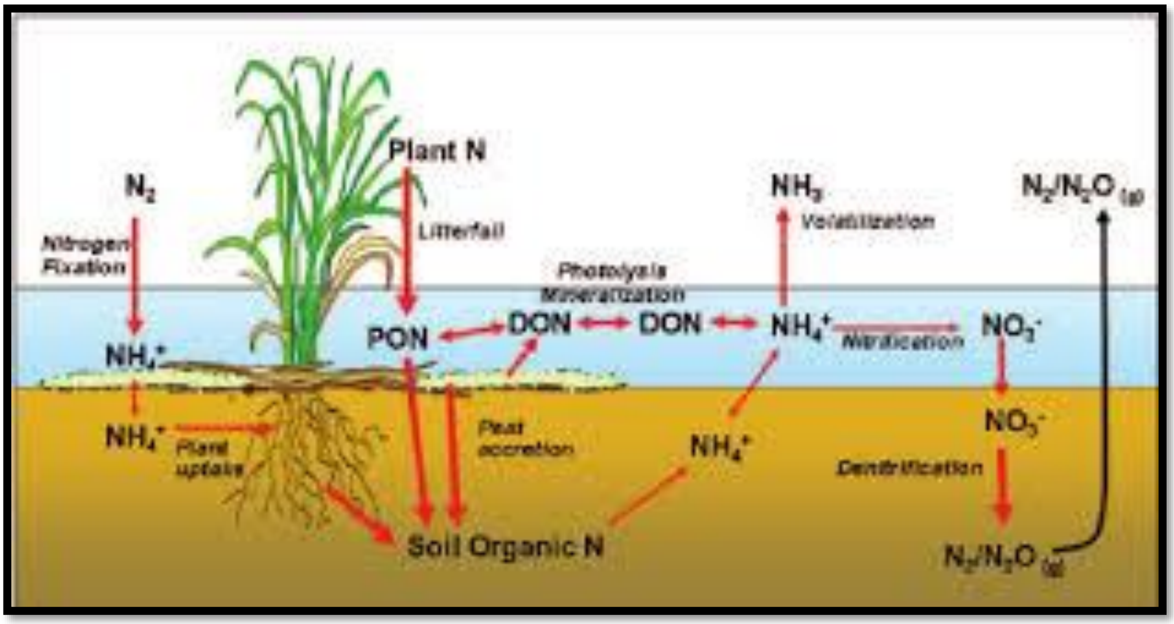


Figure 2.8: Nitrogen cycle in wetland environments.

(USEPA, 2008)

2.18.3. Phosphorous (P)

Phosphorous in wetlands can be retained or released by biological processes such as uptake and release by micro-organisms and vegetation, and physical processes such as entrainment and sedimentation (USEPA, 2008; Kotze *et al*., 2007). Phosphorous in the water column typically occurs in both the particulate and dissolved forms which consists of certain amounts in the organic and inorganic form. The amounts of organic and inorganic matter are highly dependent on source and type of water entering the wetland environment (USEPA, 2008; Kotze *et al*., 2007).

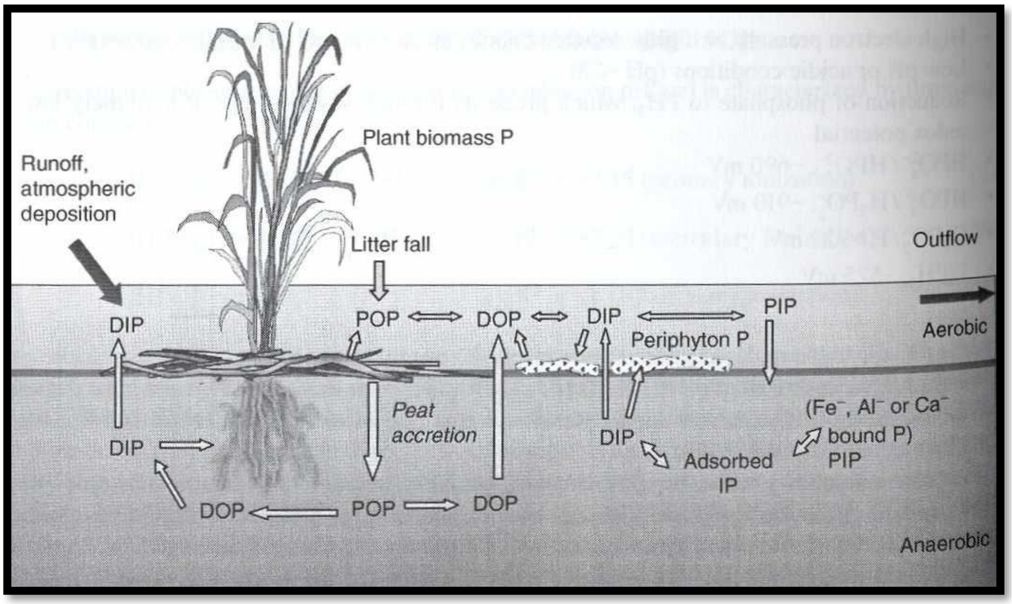


Figure 2.9: Phosphorous cycle in wetland environments.

(USEPA, 2008)

2.19. The benefits of wetland environments

Wetlands have several present and possible future functions and values which have been recognised and evident to be valuable to society (Scodari, 1997). According to Howe *et al* (1991), wetland benefits refer to the qualities, functions, products and services that are provided by a wetland ecosystem which are valuable to the surrounding environment and humans in terms of importance, quality, merit and worth. Wetland benefits are gained directly and indirectly by consumption and by wetland land providing services (Collins, 2005; Georgiou and Turner, 2012).

2.19.1. Direct benefits of wetlands

Water in wetlands are typically used for agricultural, industrial and domestic purposes. The extraction of water from wetlands for the aforementioned purposes are either done by direct removal or taking from shallow wells (Dickens *et al*., 2003). In addition, wetland waters have the ability to travel into underlying aquifers which aid as a water source and also into groundwater which then maintains this water for a prolonged period especially for communities a distance away from the wetland environment (Dickens *et al*., 2003).

Animals and plants products harvested from the wetland are utilised as craft making items, animal fodder, food, medicine and even fuel (Day, 2009; Macfarlane *et al*., 2007). Some products which are migratory such as birds and fish can also be harvested and utilised when they are located within the wetland environment.

Besides the physical environment benefits a wetland provides, there are various socio-cultural benefits which are related to the usage of wetland resources (Maltby and Barker, 2009). The communities that rely on wetland environment predominantly are rural communities in close proximity to the wetland, which use the wetland as a source of water, subsistence farming and as an income for utilising material for craft making. Wetland areas are usually also utilised for cultural and religious rituals, which in turn increase the visual appeal of the land and many may feel spiritually uplifted by these activities occurring in this area. (Maltby and Barker, 2009; Dickens *et al*., 2003). In addition, certain wetland environments are recognised as significant historical lands which play a role in the countries cultural heritage (Dickens *et al*., 2003).

Wetlands in South Africa are renown on a global scale for sustaining rare flora and fauna communities coupled with aesthetic landscape (Alexander *et al*., 2000). The Isimangaliso Wetland Park and Greater Saint Lucia Wetland Park in South Africa has become a popular tourist destination which not only has aesthetic beauty viewing for tourist but helps grow the South African economy at the same time (Dickens *et al*., 2003).

Recreational activities in wetlands are also present such as fishing, canoeing and bird watching (Day, 2009). On a scientific front, wetlands in South Africa are important for experimenting, determining and monitoring environmental trends on short and long-term basis. In addition, wetland environments present information on present and past conditions, which in turn serve as educational tool for a more comprehensive understanding on wetland functionality and services it provides (Day, 2009; Dickens *et al*., 2003).

2.19.2. Indirect benefits of wetlands

According to the North Atlantic Treaty Organisation (2006), wetlands are recognised as kidneys of the land, due to their imperative role in chemical and hydrological cycles, as well as biological processes, as wetlands sustain a host of organisms and resources (food chains). Due to their ability to trap sediment, wetlands are known to be areas of sediment deposition and not sediment deriving (Mullins, 2012). Furthermore, as a result of the extensive vegetation in wetlands, water flow which carries sediment is slowed and in turn removed by vegetation, which is known as a process called sedimentation (Schwirzer, 2006).

Wetlands also offer food and refuge to a vast array of animal and vegetation species, such as birds, amphibians, invertebrates, fish, micro-organisms, mammals and reptiles (Aber *et al*., 2012). Wetlands also house various rare and endemic organisms, hence, acting as a protected area. The disturbance or complete damaging of a wetland environment can be detrimental to the biota, the integrity of the habitat, which may lead loss of wetland functionality and ecosystem (Aber *et al*., 2012).

The most recognisable role that wetlands play is their ability hydrologically cycle water (Bullock and Acreman, 2003). Wetlands ability to attenuate floods is of a massive role as it stores volumes of sediment and water which could cause severe damage to surrounding or downstream areas (Dickens *et al*., 2003; Renwick and Eden, 1999). In addition, due to their ability to store large volumes of water, wetlands can also store runoff water by intense rainfall and melting snow, which in turn functions to maintain good river or stream flow (USEPA, 1995).

Due to the complex relationship of groundwater and wetlands, the sediment water equilibrium is maintained in this environment (USEPA, 1995). The association between groundwater and wetlands is such that when periods of dry conditions are experienced groundwater tends to feed wetlands, whereas, when periods of wet conditions are experienced groundwater tends to be fed by wetland environments. These processes of the aforementioned statement are known as groundwater discharge and recharge (Dickens *et al*., 2003).

One of the most admired functions of wetlands is its ability to purify water. Due to its natural filters, wetlands purify and enhance water quality from receiving catchment areas through several processes (Begg, 1986; Collins, 1995). The processes that are involved in this purification are OM accumulation, aerobic and anaerobic processes, decomposition of plants and organisms and mineral uptake by wetland vegetation, which all assist in removing chemicals and harsh metals from waters in wetlands, keeping the surrounding environments safe from possible hazardous conditions (Dickens *et al*., 2003).

2.20. Pressures/threats to health of wetlands

Although natural occurrences such as climate change and sea level rise will affect the functioning and thus the health of wetlands, human induced anthropogenic activities are far more of a negative impact on wetland environments in South Africa (Dickens *et al*., 2003). Due to an ever-growing population, wetland environments are put under stress by housing or industrial development which degrade and ultimately destroys wetland environments (Horwitz *et al*., 2012). Due to a lack of awareness and knowledge on the various benefits that wetlands can provide, their destruction by mankind is ever present and unsustainable practices is still an ongoing scenario (Dickens *et al*., 2003).

The main driver today is an economic benefit by commercial and industrial companies without taking the environment into consideration (Uys, 2004). The aforementioned problem coupled with legislation execution which is poor, absence of local institutional capacity and absence of development and implementation of improvement of existing policies, have all effectively shown the need to construct proper and effective wetland conservation and protection programmes in South Africa (Dickens *et al*., 2003).

Wetland environments are also put under severe pressure from other factors such as increasing human population, urbanisation and unsustainable agricultural practices (such as dryland sugarcane plantation in wetlands) (Sahu and Choudhury, 2005). According to Kotze *et al* (1994), the aforementioned statement is the main driver of wetland destruction, which involves the reduction of wetland area by activities such as draining or filling wetlands for human residence, agriculture and silviculture.

The main factors leading to the destruction and degradation of wetlands are afforestation, constructions of roads and dams, erosional degradation, mining, water abstraction and waste disposal (whether solid or toxic). (Kotze *et al*., 1994). The indirect main causes of wetland destruction and degradation are due to input of excess nutrients through human induced factors which is also inclusive of other contaminants and the proliferation of alien invasive vegetation in wetland environments (Zedler, 2004). Although all of the above-mentioned factors are detrimental to wetland environments, the most significant factor which affects wetlands is the areas outside of wetlands and the activities that occur within these areas (Dickens *et al*., 2003).

The quantifying of disturbances on wetlands is a good method to calculate the response of wetland environments to certain alterations (Mitsch and Gosselink, 2000). Due to the fact that there are several different wetland disturbances that can occur, the feasibility to quantify factors that affect wetland functioning and their ecosystems is not cost-effective approach. Hence, wetland specialist utilise standard parameters as an indicator during the assessing of wetlands health and services it provides (Mitsch and Gosselink, 2000; Uys, 2004).

2.21. Loss of wetland environment

According to Fraser and Keddy (2005), the loss of wetlands on a global scale is approximately 50% over landscapes in the last hundred years. In South Africa, approximately 35-50% wetlands have been lost or degraded (Dini, 2004).

Direct and indirect anthropogenic factors mentioned in the previous heading is the main driver to the loss of these wetlands (McInnes, 2010). Although the destruction and degradation of wetlands have increased substantially over the years, man-made wetlands have subsequently mitigated the loss of wetland environment in some regard. The idea of mad-made wetlands mitigating loss of wetlands is justly logical, however, successful man-made wetlands are subjective to assumption and belief of mankind (Fraser and Keddy, 2005). Research conducted on man-made wetlands have proven to be fruitless in its attempts due to lacking information associated to maintaining animal and plant communities which are pivotal to a wetland environment (Fraser and Keddy, 2005).

Due to South Africa regarded as a semi-arid country, it is not entirely conductive for the creation of wetland environments, thus, the loss of wetlands has been made a serious issue on a national scale and the need to implement and encourage better management strategies and conservation and rehabilitation programmes has become a necessity to ensure this important ecosystem does not diminish (Kotze *et al*., 1995).

South Africa requires a strong focus on the unfavourable consequences of loss and degradation of wetland environments in a semi-arid country which does not favour wetland formation (Turner, 1991). If wetlands are continuously degraded and loss, this will lead eventually to the threat to wildlife resources, increased flooding in areas where wetlands are completely loss, extinction of species, poor water quality, reduction in water supply and agricultural productivity will be lowered significantly (Millennium Ecosystem Assessment, 2005).

The loss of wetlands will further cause ecosystems to become unstable and cause a loss of biodiversity and rural communities may suffer more as they cannot rely on wetlands as a source of provision (Kotze *et al*., 1995). In addition, the South African economy will suffer as the requirement of rehabilitation programmes for wetlands will increase and the creation of man-made wetlands will become a priority which could equate to excessive amounts of money (Kotze *et al*., 1995).

Therefore, conventions, legislation and policies created to ensure sustainable utilisation, conservation, monitoring and management and protection of wetland environments in South Africa should be governments key priority to ensure this natural environment does not disappear from existence (Dickens *et al*., 2003).

2.22. Wetland offsets

Wetland offsets is an important method which implements conservation approaches which are articulated to offset any foreseeable impact to a wetland environment. The methods applied by a wetland offset plan take into consideration major effects of developing activities on wetlands (SANBI and DWS, 2016).

The main aim of a wetland offset is to ensure that no loss of wetland landscape is achieved and that benefits of a wetland environment and functionality are gained (SANBI and DWS, 2016). The implementation of wetland offset are conducted to compensate for massive impacts on wetlands created by development projects and is only performed if all feasible measures are taken into account to avert, minimise and rehabilitate impacts on wetlands (SANBI and DWS, 2016).

2.23.1. Achieving a wetland offset

If a wetland offset is required, several methods will need to be applied for the desired outcome to be achieved. The several methods are elaborated in broad categories below (SANBI and DWS, 2016):

- *Protection*: The utilization of legal approach is imperative in this method. This may require a detailed assessment of relevant acts and legislation, to ensure locations of offset are in an appropriate land use zone, which will ensure the results of conservation are preserved for a long period of time.
- *Rehabilitation*: Rehabilitation will be conducted to ensure wetland conditions are improved. The rehabilitation procedure involves modification of the biological, chemical and physical properties of a tarnished wetland with the aim to improve its functionality. The removal of alien vegetation and obstructions of water flows will contribute to the rehabilitation program,
- *Avert loss*: refers to the prevent the loss or degradation to a wetland environment and the ecosystem services it provides. This scenario is possible if erosion in a wetland is stabilized and prevents the creation of gullies or rills in the wetland environment.

- *Establishment*: this refers to creating a wetland environment in an area where none have occurred before. This is conducted by modification of an areas biological, chemical and physical characteristics of that of a wetland environment. The success of a creation of a wetland environment will bring about wetland ecosystem services and benefits.
- *Direct compensation*: this process encompasses the compensating of communities affected due to the loss of a wetland environment and the services it produced for them. This process is conducted by supplying the community with the services that have been loss as a result of loss of wetland or compensating the community through a financial method.

2.24. Summary

Chapter two encompasses of two components which are the estuary section and then the wetland section. The estuary consists of several sections such as hydrodynamics of TOCEs, sediment dynamics in estuaries, indicator organisms, macrophytes, TOCEs and the aspects and the aspects that affect distribution of macrophytes, Zoobenthos in sediment and water quality during different mouth states. The wetland section encompasses various sections such as initially different definition of wetlands and their similarities and differences, classification of wetlands and their distribution, different wetland types found in South Africa and their three hydrological zones, the different types of sediment in wetlands and their characteristics, three different modules to assess wetlands and vegetation as a main indicator, different cycles in wetlands (e.g. nitrogen, phosphorous and carbon), direct and indirect benefits of wetlands, threats and how to offset threats in wetlands. Both sections are presents comprehensive literature which explains the dynamics and functioning of each ecosystem.

3. STUDY AREA

3.1. Introduction

The study area consists of wetlands and the riverine and estuarine environments in the vicinity of the Sezela Illovo Sugar Mill, located approximately 70 km to the southwest of Durban, KwaZulu-Natal province (Figure 3.1). Each of these environments are discussed below.

3.1. Sezela Illovo Sugar Mill

The Illovo Sugar Mill is situated on the north bank of the Sezela Estuary approximately 70 km south of Durban along the KwaZulu-Natal coast (CSIR, 2015) (Figure 3.1). Approximately 3100 m^3 of effluent is pumped out to the surf zone of the Sezela beach area, which is 200 m north of the Sezela Estuary (CSIR, 2015). Whilst it is not known whether any of the mill effluent is discharged into the estuary, a storm water drain that runs from within the Illovo Sugar Sezela factory is known to exist and drains into the estuary (CSIR, 2015).

The effluent pumped into the surf zone of the Sezela beach area is known to contain a mild acetic acid with a trace of furfuraldehyde. The chemical oxygen demand (COD) and pH of the effluent are known to be 16000 $mg.l^{-1}$ and 2.8 (CSIR, 2015). According to Illovo Sugar Sezela, effluent discharge stops after the milling period is over but there have been cases where effluent was seen even after the milling season (CSIR, 2015).

3.2. Sezela estuary

The Sezela Estuary Figure 3.1 which is a temporarily open/closed estuary (TOCE) is situated on the east coast of KwaZulu-Natal and south of the city of Durban, at $30^0$24’50.4”S and $30^0$40’39.1”E. Due to seasonal variations, the catchment of the estuary represents an area of approximately 19 km^2 to 21 km^2 and similarly, the river length varies from approximately 10 km to 14 km. Fluvial discharge is approximately 14 m^3/sec. Structures such as roads (including the N2 National Road) and a 151000 m^3 dam constructed approximately 3.5 km upstream of the estuary constitute sources of impacts together with the adjacent sugar mill, agricultural lands, formal and informal housing. The main function of the dam is to supply water to the Sezela Township (Begg, 1978).

The most unique characteristic of the Sezela estuary is its shape. It has a dendritic shape pattern with several arms radiating out from the main estuary trunk section and is the only one of its type in the KwaZulu-Natal region. There are many side channels, backwaters and creeks, each of which add to the shoreline length of approximately 6.4 km. The mean depth of the estuary is about 3 m although bathymetric studies have recorded depths in excess of 4 m in places (Begg, 1978).

Figure 3.1: Sezela estuary, Illovo Sugar Mill and surrounding environment.

(Google Earth®)

3.3. Sezela wetlands

The Sezela wetlands site occupies several portions of the study site. The wetland areas are predominantly found within the valleys; however, some wetlands are found on hillslopes and on the floodplain of the Sezela River (Ollis *et al*., 2013; DWAF, 2008). The floodplain wetland vegetation was predominantly a reed type (*Phragmities australis*) with patches of alien invasive vegetation. The channel valley bottom wetlands also contained reed type vegetation (*Phragmities australis and Cyperus dives*) as well; however, the reed vegetation was not predominant and a fair amount of alien invasive vegetation was present within these wetlands.

3.4. Climate of study area

The Sezela area experiences a sub-tropical climate of cool dry winters and warm wet summers (Ngetar, 2002) which is characteristic of the South African province of KwaZulu-Natal. The Sezela estuary and surrounding wetland areas are in close proximity to the marine environment, hence, resulting in the high humidity experienced in the area. The average temperatures within the area ranges from 22.4^{0}C during the winter months and 27.6^{0}C during summer months. The

Mean Annual Precipitation (MAP) and Mean Annual Evaporation (MAE) of the study area is 1013 mm and 1200 mm respectively. The Sezela area is therefore located in a high rainfall region of South Africa with a potential unit Mean Annual Runoff (MAR) of 232 mm (Umgeni Water and WRP Consulting Engineers (Pty) Ltd., 2009).

3.5 Hydrology of study area

The hydrology of the Sezela study site has not been altered drastically, however, anthropogenic activities around the area have modified the hydrology in the area to some extent. The Sezela estuary acts as the interface between the marine environment and the riverine environment (Potter *et al.*, 2010). The riverine environment acts as the central channel and is fed by several non-perennial tributaries. The Sezela river eventually drains into the Sezela dam which is utilised to provide the Sezela community, agricultural fields and industry with water. Furthermore, a bridge is constructed at the mouth of the estuary affects sedimentation and hydrological processes (Ngetar, 2002).

3.6 Geology of the study area

The geology of the area is characterized by underlying alluvial sediment and the estuary is cradled by two mountain-like features to the south which is composed of Dwyka tillite whilst to the north is of Sandstone in nature respectively. The bottom of the Sezela estuary is known to be have a high percentage of mud and silt (Begg, 1978). Furthermore, the shoreline is shallow from before the Illovo Sugar Mill and steepens past the estuary and continues in this manner towards Mdesingane estuary. The sandbar of the Sezela estuary is closed most of the time and usually opens with heavy rain or may be anthropogenically breached by the Sezela mill to repair the foot valves of the intake pipe. The period in which the mouth remains open is not long as a result of marine processes closing the mouth rapidly. (Begg, 1978).

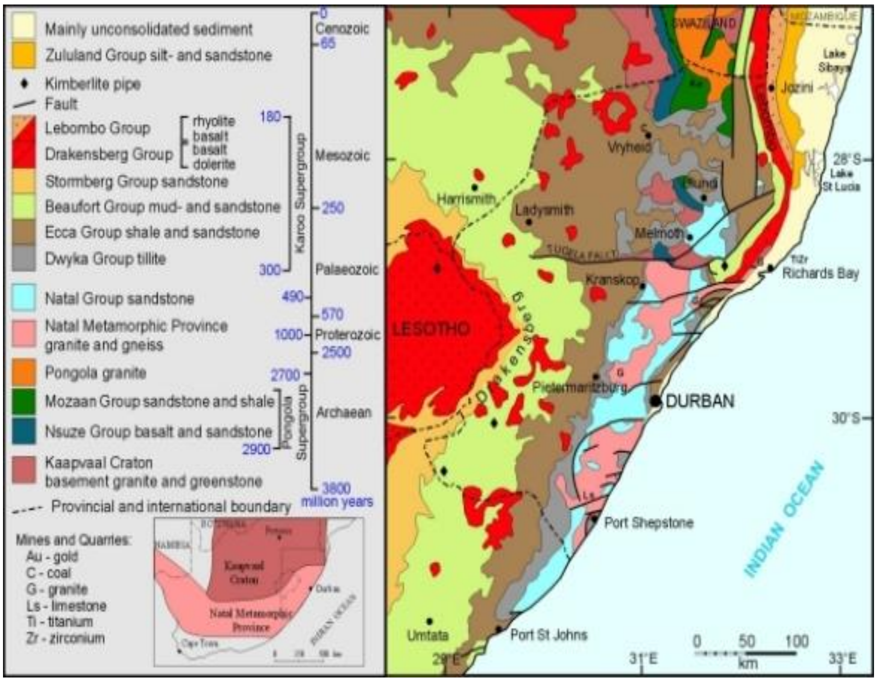


Figure 3.2: Underlying Geology of the KZN Coastal Belt.

(University of KwaZulu-Natal, Department of Geology map)

3.7. Topography of the study area

The topography of the Sezela study site is characterised by undulating hills and moderate sloping landscape cut by drainage lines. The Illovo Sugar Mill is situated on a minor ridge of the landscape in close proximity to the adjacent Sezela estuary. The terrain within the study site has been altered drastically by dryland sugarcane agriculture and infrastructure which is the Illovo Sugar Mill (Adams *et al*., 2004).

3.8. National Freshwater Ecosystem Protected Areas (NFEPA)

According to Nel *et al* (2011), The National Freshwater Ecosystem Priority Areas (NFEPA) provides strategic spatial priority areas for conserving freshwater ecosystems and supporting sustainable use of water resources in South Africa. The aim that NFEPA strives on is to conserve a sample of freshwater ecosystems and diversity of organisms and also conserve the ecosystem processes which create and uphold diversity of organisms and the environment (Nel *et al*., 2011).

According to the coverage of NFEPA within the study site, a few NFEPA areas are present. One of the main NFEPA found on the site is the Sezela estuary. Other NFEPA found within the study footprint is a channeled valley bottom wetland close to the mouth of the estuary, and a channeled valley bottom wetland and unchanneled valley bottom wetland towards the upper reaches of the study site footprint (Nel *et al*., 2011).

3.9. Vegetation of the study area

The Sezela study site footprint consists of a diverse array of vegetation. The study site falls within the Ecoregion 17 which is usually characterised by closed hills, mountain plains and the main vegetation types present are grassland, bushveld types and valley thicket (Kleynhans *et al*., 2005). The study area is located within the Indian Ocean Coastal Belt Biome of KwaZulu-Natal. The types of vegetation found within the study site and especially within the floodplain, channel valley bottom, unchanneled valley bottom and hillslope seepage wetlands are *Phragmites australis* (Macfarlane *et al*., 2007). As a result of the land being transformed, the main vegetation found within the study site footprint was dryland sugarcane plantation (*Saccharum officinarum*). Numerous alien invasive vegetation wad identified which were *Ageratum conyzoides*, *Bidens pilosa* and *Chromolaena odorata* (See Appendix for full list, Tables 9.2 – 9.5) The indigenous vegetation identified were *Asystasia gangetica*, *Centella asiatica* and *Commelina erecta* (See Appendix for full list, Tables 9.2 – 9.5) (Bromilow, 2010; Van Wyk and Van Oudtshoorn, 2009).

3.10. Chapter summary

Chapter three which constitutes the study area explains different areas within the study site footprint such as the sugar mill, estuary and surrounding wetlands. It explains the characteristics of the areas such as climate, hydrology, geology, topography, NFEPA and vegetation within the study sites footprint.

CHAPTER 4: METHODOLOGY

4.1. Introduction

This chapter presents a comprehensive explanation of the various methods utilized in conducting this study.

The initial step was to conduct the estuarine sampling. Estuarine sampling involved obtaining water samples for physical, chemical and biological analysis; and sediment samples for macro-invertebrates, granulometric and chemical analysis. Samples were taken at the upper, middle and lower portions of the estuary

Statistical analysis comprised of linear regression for sediment and camparion to the South African Water Quality Guideline for aquatic ecosystems for water quality parameters. Exponential and frequency graphs were used to depict granulometric analysis in order to determine factors such as mean, mode and range. Furthermore, water samples taken were compared to the South African Water Quality Guideline for aquatic ecosystems to assess the water quality in the area. Therefore, all of the procedures conducted for estuarine part of the study provided a holistic ecological health status and geochemical regimes for the Sezela estuarine environment.

The wetland study conducted involved initially to delineate wetlands at a desktop level and thereafter in the field within the study site footprint. In addition, after HGM units are identified which make up the wetland system, a wetland assessment was conducted to determine the health status of the wetlands in the Sezela study site. The wetland assessment was conducted used tools such as Google Earth, Arc GIS, WET-Health and WET-EcoServices.

Based on the above, the overall ecological health status of the Sezela study footprint was determined on the Sezela estuary and surrounding wetland areas.

ESTUARY METHODS

The following methodology deals with estuary sampling and analysis.

4.2. Sample Collection

The collection of samples was conducted in the Sezela estuary which is adjacent to the Sezela Sugar Mill Plant. The main reasoning for the choice of location sites for sampling was the relatively close proximity of the sugar-mill to the Sezela estuary and the likelihood of direct and indirect impacts to this estuarine system. Therefore, this study was conducted in order to establish the geochemical regimes and biological indicators within the estuary.

The total number of samples collected at each sampling point were collected from the upper, middle and lower parts of the estuarine system and from any other points of interest within the field. At each sampling station, a range of samples were collected including sampling for macro-invertebrates, sediment and water. All samples with the exception of the macro-invertebrate's samples were immediately labelled and put on ice in a cooler box while the sampling was being conducted as specified by Whitfield and Bate (2007).

The method used for collecting water was the simplest as this involved collecting water into three 1-liter bottles for chemical (nutrients and metals) and biological analysis. Furthermore, all sample bottles were acid cleaned before taken out to the field to preclude contamination (Chambers *et al*., 2006). Water samples were collected approximately at mid-depth in the water column. At the specified sampling depth bottles were initially rinsed thrice before a sample for analysis was taken to ensure no contamination existed in the sample.

Biological samples were taken immediately to the laboratory and were analyzed within 6 h after collection. Chemical analyses were completed not more than 4 days after collection to ensure qualitative and quantitative results (Chambers *et al*., 2006).

A van Veen grab with a bowl and scoop was used for sediment sampling. The van Veen grab was deployed at each station three times; water drained out through the sides (letting it bleed) and thereafter sediment emptied into the bowl. This was done three times at each station to give a good representation of the sediment at each site (as outlined in Greenfield *et al*., 2007). After transferring the sediment to the bowl, the sediment was homogenized and transferred into plastic containers for further analysis. To ensure no contamination occurred after collecting from subsequent sites, all equipment being used for sediment collection were pre-rinsed and hexane sprayed. Furthermore, all sediment samples were transferred to a freezer on arrival to laboratory; physical and chemical analysis were completed at a later stage. Chemical analysis for sediment did not have to be completed within a rapid time period as it is much more stable as compared to water. However, the analysis of sediment was completed within a month of sampling (Greenfield *et al*., 2007).

Macro-invertebrate collection required buckets, a ponar grab (152 X 152 cm; sampled area = 231.04 cm^2), 0.5mm cone net and stained formaldehyde. The collection of macro-invertebrates began with deploying the grab three times at each station. After each grab sample was taken, the sediment and organisms contained (residing within that sediment sample) were transferred into a plastic bucket (as outlined in Perissinotto *et al*., 2004). Thereafter, the contents in the bucket were transferred into a 0.5 mm cone net to trap all organisms of that size and bigger; and at the same time washing out any excess sediment. Once most of the sediment was washed out, the remaining contents are transferred into a 250 ml plastic container and stained formaldehyde was added to preserve the contents. The samples were transferred to the laboratory for further processing and identification of different macro-invertebrate (Perissinotto *et al*., 2004)

4.3. Laboratory analysis

The physical analysis began with defrosting frozen sediment samples. Thereafter, keeping an appropriate amount of sediment (such as 250 ml container of sediment) for moisture content, organic matter content, calcium carbonate content and sediment sent to the University of KwaZulu-Natal Chemistry Department to the chemistry laboratory in which chemical analysis occurred. Macro-invertebrate identification was preceded by washing out the formaldehyde from the sample into a 0.5 mm sieve under a tray to ensure no sample was lost during the process. Thereafter, the samples were processed and will be discussed further below. Water and sediment samples were taken to the Chemistry Department of the University of KwaZulu-Natal (Westville) for further analysis, whilst nutrient and microbial analyses of the water samples were conducted at the CSIR laboratory in Durban and Mangosuthu University of Technology respectively.

4,3.1. Sediment samples

4.3.1.1. Sediment analysis

Sediment analysis consisted of running the sediment samples through a series of tests including the determining of moisture content, organic matter content, calcium carbonate content and granulometric analysis.

- **Moisture Content**

Fifty milliliter empty beakers were initially pre-weighed and thereafter re-weighed with the sediment samples in them, which were all recorded. Thereafter, the samples were placed in beakers and oven dried overnight at a temperature of 110^{o}C. After overnight drying, samples were kept in a low temperature oven at 60^{o}C prior to weighing in order to prevent moisture absorption from the ambient atmosphere (Avinimelech *et al*., 2001). Therefore, water loss was calculated by the weight difference between the wet and dry samples (Avinimelech *et al*., 2001):

Water loss (g) = (Sample Wet Weight) – (Sample Dry Weigh) (1)

- **Organic Matter Content**

Loss on ignition is a commonly utilised procedure which can be used to determine organic matter content of sediment samples (Heiri *et al*., 2001). Sediment samples from the 50 ml beakers were transferred into clean ceramic crucibles and thereafter pre-dried in the low temperature oven at 60^{o}C for a period of 4 hours (Beaudoin, 2003). Thereafter, the samples in the crucible were transferred to a muffle furnace and the samples were ignited at a temperature of 550^{o}C for 4 hours in order to facilitate the oxidization of organic matter to carbon dioxide and ash (Battarbee *et al*., 2002). After ignition, samples were transferred to a low temperature oven and allowed to cool at 60^{o}C for 2 hours. Weights of the dried crucibles, post-60^{o}C dried sediment and post-550^{o}C sediment were all recorded. Organic matter content was therefore calculated as the mass difference between the sediment dried at 60°C and the ash produced following ignition at 550°C (Meyers and Terances, 2001). The following method was used to establish the percentage of total organic matter content in sediment samples (Beaudoin, 2003):

$$\% \text{ OM} = \frac{(\text{Weight post } 60^{0}\text{C dry - Weight of post } 550^{o}\text{C ash})}{(\text{Weight post } 60^{o}\text{C dry})} \times 100 \qquad (2)$$

- **Calcium Carbonate Content**

The method utilised to determine the calcium carbonate content was also the loss on ignition analysis. Following the 2 hour cooling period in a low temperature oven at 60^{o}C for organic matter content, the sediment samples within the crucibles were further ignited at a 1000^{o}C for a period of 2 hours to determine the respective calcium carbonate concentration that exist within the samples (Heriri *et al*., 2001; Battarbee *et al*., 2002). In addition, once the 2 hour ignition process was completed, samples were transferred to a low temperature oven which was set at 60^{o}C for a 2 hour cooling period (Dean, 1974). Once the process was completed, the post-1000^{o}C dried sediment was weighed and recorded (Beaudoin, 2003). The calcium carbonate content of sub-samples was calculated by using the following equation (Dean, 1974):

$$\%CCC = \frac{(\text{Weight of post-550}^{o}\text{C ash} - \text{Weight of post-1000}^{o}\text{C ash})}{(\text{Weight post-60}^{o}\text{C dry sample})} \text{x}2.274\text{x}100 \qquad (3)$$

- **Granulometric Analysis**

The textural analysis of the sediment was carried out *via* the dry sieving method using a Retch® sieve shaker. Sediment was dried in the low-temperature oven at 110°C for 48 hours. Thereafter, sediment samples were disaggregated by using a pestle and mortar in order to separate the larger grain sizes from the smaller grain sizes (Dyer, 1986). Furthermore, samples were then placed on the uppermost member of the column of metal sieves, and passed through sieves of aperture sizes 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.053 mm and tray from top to bottom respectively (Morgan, 1995). These sieves were shaken for 8-10 minutes, using a Retch® sieve shaker. After sieving, the quantity of sediment retained on each sieve were emptied into their respective plastic boats which were labelled 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.053 mm and tray, and thereafter weighed and recorded (Mitsch and Gosselin,1993).

4.3.1.2 Metals

Sediment samples were initially freeze dried and ball milled to a fine consistency. Thereafter, one gram of each sediment sample was weighed into a high-pressure digestion vessel. Concentrated nitric (HNO_3) and perchloric ($HClO_4$) acids; and hydrogen peroxide (H_2O_2) with the assistance of a microwave were used to digest sediment (CSIR, 2014; Skoog *et al*., 2004). The digested sediments were then diluted to volume with deionized water and concentrations of various minor and major elements quantified and detected using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). A mercury analyzer was used to determine the level of concentration within the sediment samples. The Systeme Internationale (SI) units used for metal concentrations were $mg.L^{-1}$(CSIR, 2014; Skoog *et al*., 2004).

4.3.2. Water samples

4.3.2.1. Faecal indicator bacteria

The laboratory microbial analysis was conducted using the membrane filtration technique for the enumeration of the three indicator organisms for each of the four water samples in accordance to the standard protocol (Singh & Lin, 2015). Prior to filtration, serial dilutions from 10^1 to 10^6 of the samples were prepared using distilled water (Singh & Lin, 2015). From the dilution series, 50 ml samples were vacuum filtered through a 0.45 μm pore size GN-6 Metricel membrane filters of a 47 mm millipore which is held in a glass filtration unit (GLASCO). The filters were transferred with the right side up onto petri dishes containing the various selective media for the recovery of each indicator group namely total coliform bacteria, *E.coli* and faecal *Streptococci* (Table 2). After the recommended incubation period, the typical colonies for indicator bacteria according to standard protocol had grown on the filters and were recorded as presumptive counts for an approximation of colony-forming units per 100 ml (cfu/100 ml) (Singh & Lin, 2015). All the water samples were conducted in triplicate to ensure the accuracy of the technique (Buckalew *et al.,* 2006; Singh & Lin, 2015).

Table 4.1: Selective media and incubation conditions to be used for the isolation and enumeration of the bacterial indicator organisms.

Indicator microorganism	Selective media	Incubation conditions
Total coliforms	M-Endo agar	24 hours at 35 ºC
Escherichia coli	M-FC agar	24 hours at 44.5 ºC
Faecal S*treptococci*	Membrane *Enterococcus* Agar (MEA)	Presumptive test: 4 hours at 37 ºC followed by 44 ºC

(Singh and Lin, 2015)

4.3.2.2. Nutrients

The first step to identifying the concentration of nutrients in water samples was to vacuum filter the water samples through a 0.45um pore size membrane filter. A colorimetrical four-channel flow injection autoanalyzer was used to measure the dissolved concentrations of orthophosphate-phosphorous (PO_4^{3-}), nitrite-nitrogen (NO_2^-), nitrite and nitrate-nitrogen (NO_3)

and total ammonical nitrogen (sum of NH_3^+ and NH_4^+) in the filtrate. The SI units used to report the concentration of nutrients were $mg.L^{-1}$ (Harrison, 2004).

4.3.2.3. Metals

Dissolved metal concentrations in water were determined by initially further concentrating the dissolved metals by adding a chelating agent to the vacuum filtered water samples through a 0.45um pore size membrane. Thereafter, the metal-chelate compound was removed using an organic solvent, and the organic compound was removed by heating. Finally, nitric acid was used to dissolve the metal-chelate compound before concentrations in solution were quantified and detected using an ICP-OES. Similarly, to sediment analysis, a mercury analyzer was used to measure concentrations of mercury in water samples. The SI units used to measure the metal concentrations of the elements measured were $mg.L^{-1}$ (CSIR, 2014; Skoog *et al*., 2004).

4.3.2.4. Physical parameters and Yellow Springs Instrument (YSI)

Physical water parameters such as salinity, electrical conductivity, Total Dissolved Solvents (TDS), Dissolved Oxygen (DO) and pH were measured using a YSI 6920 Multi-parameter Sonde (Sukdeo, 2010). In order to acquire the measurements of these parameters, water samples were initially poured into a safety cup holder which protects the YSI probes to acquire readings of these measurements. The cup holder was filled to a point until the probes were submerged into the water sample. Furthermore, water samples were left in the cup holder with the submerged probes for approximately five minutes in order for the YSI to stabilize and warrant accurate readings for the parameters being measured. Once readings on the handheld device were seen to be stable, these measurements were taken. To ensure qualitative results, the cup holder was rinsed with deionized water before a new sample was poured into the cup holder and further rinsed three times with the sample water being measured (Sukdeo, 2010).

4.3.3. Estuarine macro-invertebrates

The procedure to obtain macro-invertebrates began by washing the sample into a 0.5 mm sieve and ensure all the formaldehyde was removed before transferring all the contents onto a tray. Furthermore, a tray was placed under the 0.5 mm sieve to ensure no macro-invertebrate species may have been lost (Whitfield and Bate, 2007). Thereafter, species from the tray were removed using fine forceps, while the rest of the debris was discarded. Species removed were transferred into a 100ml container and preserved with 70% ethanol. The species preserved were subsequently identified to broad taxonomic groups under a binocular microscope (Whitfield and Bate, 2007).

4.4. Statistical analysis

4.4.1. Granulometric analysis

Particle size distribution and its analysis require the determining of size parameters and the constitute of measures of central tendency, namely; mean, mode and median (Friedman *et al*., 1978; Selly 2000; Leeder 1982).

As recognised by Tucker (1998), determining the mean is regarded as the most favoured measure for average particle sizes, and a better measure of the whole distribution when compared to its counterpart parameters such as the median or mode. The median however, which provides a good indication of where half of the sediment grain size classes are either coarser or finer than the average particle size (Selly, 2000).

The median was calculated by using the percentage finer than curves by utilising the phi values (or mesh sizes), for individual samples intersected by a 50% cumulative percentage finer than (Leeder, 1982). Using the percentage finer than has been favoured over the usual calculation of ($^{n1+n2}/_{2}$), as it allows for better comparison between different samples (Morgan and Briggs, 1997). In obtaining the percentage finer than, relevant graphs were constructed, which allowed for median particle sizes to be determined.

The mode, which is the most frequently occurring grain size, is situated at the peak of a frequency curve (Morgan and Briggs, 1997). The mode for each individual sample was calculated by extracting the particle size with the percentage that is the highest on a distribution table and for the whole estuary by calculating the average of the particles sizes with the highest percentage frequency (Dyer, 1986).

Measures of dispersion such as; sorting, skewness and kurtosis, are determined from cumulative percentages of finer than curves. For the Sezela estuary, the favoured method is that of Morgan and Briggs (1997), due to their accuracy. The equations for the above parameters are as follows:

$$\text{Mean} = \frac{ø16 + ø50 + ø84}{3} \quad (4)$$

$$\text{Sorting} = \frac{ø90 + ø80 + ø70 - ø30 - ø20 - ø10}{5.3} \quad (5)$$

$$\text{Skewness} = \frac{ø84 - ø50}{ø84 - ø16} - \frac{ø50 - ø10}{ø90 - ø10} \quad (6)$$

$$\text{Kurtosis} = \frac{ø90 - ø10}{1.9(ø75 - ø25)} \quad (7)$$

Skewness is the measurement of symmetry or asymmetry of the distribution of sediments, or alternatively it can measure the propensity of all the particles to belong to one particle size class (Leeder, 1982; Selley, 2000). Sorting, also known as a standard deviation is the spread of values distributed around the mean. It is responsible for measuring the degree of uniformity of grain size distribution (Tucker, 1998). Kurtosis measures the peakedness of the distribution of grain sizes and is directly related to sorting as well as the normality of the distribution (Dyer, 1986).

4.4.2 Sediment quality

Linear regression analysis identifies changes in two or more parameters which might be negatively or positively related and the strength of the relationship (Newman and Watling, 2007). Hence, linear regression has the ability to be predictive as long as there is a strong relationship and statistical significance between parameters. Therefore, linear regression was utilised to determine the relationship between certain chemical parameters (Newman and Watling, 2007).

One of the problems encountered to determine whether metals are enriched within the Sezela estuary was as a direct result of these metals naturally occurring in that environment. In order to interpret if sediment was enriched or naturally occurring geochemical normalisation was conducted which mathematically normalises metal concentrations to a co-occurring conservative parameter (the normaliser) which encompasses a baseline metal concentration model with a regression line, prediction limits are defined by quantifying the variability of metal concentrations around the regression line (Newman and Watling, 2007). Hence, anthropogenic enrichment of metal concentrations can be suspected once sediment sample data are superimposed over baseline models and if data on baseline model fall within the prediction limits, these samples are not enriched by anthropogenic contamination, whereas, if data fall above the model upper prediction limit, these samples are considered to be enriched by anthropogenic contamination (Newman and Watling, 2007).

It was found that aluminium and iron were the most appropriate parameters for normalising the concentrations of all metals used in this study besides concentrations of arsenic, cadmium and mercury (Newman and Watling, 2007). For the purpose of this study, the correlation coefficient (r) or correlation of determination (r^2) relationship strengths were categorised as very weak (0-0.39), weak (0.4-0.59), moderate (0.6-0.79) and strong (0.8-1) (Newman and Watling, 2007).

4.4.2.1. Enrichment factor calculation

The utilisation of baseline models is known to be an effective method to determine whether or not metals in sediment are enriched. However, interpretation of large datasets that surpass the upper prediction limit of the baseline model is difficult to visually identify each individual enriched point event if sampling points are identified. Hence, calculating enrichment factors instead of graphically representing the data is considered a more effective method to display data. In order to calculate the enrichment factor, the following equation is used (Newman and Watling, 2007; CSIR, 2014):

$$EF = (M/M_{upl}) \tag{8}$$

- EF = Enrichment factor;
- M = Sediment sample metal concentration;
- M_{upl} = Sediment sample metal concentration at a corresponding aluminium point that is within the baseline model upper prediction limit.

4.4.2.2. Assessment of sediment quality by using sediment quality guidelines

The most important aspect of determining whether or not sediment has been contaminated by anthropogenic activities is to interpret whether or not biota in sediment are being adversely impacted (Pelletier *et al*., 2011). The baseline models were used as an indicator to determine metal enrichment; however, these models do not provide the toxic potential consequence of enriched sediment on bottom-dwelling organisms. Thus, in order to determine if macro-invertebrates in sediment will be adversely impacted by metals in sediment, sediment quality guidelines are utilised in this study to estimate toxicity consequence of metals on macro-invertebrates (Pelletier *et al*., 2011).

The Department of Environmental Affairs determined sediment quality guidelines to assess whether or not dredged sediment from the ports are appropriate quality for open water disposal into the sea. However, this guideline can be utilised to determine toxicity of sediment in other aquatic ecosystems as it is a useful tool to utilise in amalgamation with other sediment quality assessment tools in a method which involves weight of evidence (MacDonald *et al*., 2000).

The sediment quality guideline provides three categories which are a Warning Level, Level 1 and Level 2 (as seen in Table 4.2) (CSIR, 2014; Newman and Watling, 2007). The Warning Level acts as a benchmark for sediment concentrations not to exceed these levels to not adversely impact macro-invertebrates. Sediment concentrations equal to or just below the Level 1 category but not the same as the Warning Level are viewed as a potentially low risk to macro-invertebrates in sediment. Furthermore, sediment concentrations at equal to Level 2 category or just below, poses a high risk to macro-invertebrates in sediment. Hence, the sediment quality guideline was used to assist to determine the potential adverse impacts of metal concentrations on macro-invertebrates in sediment (CSIR, 2014; Newman and Watling, 2007).

Table 4.2: Sediment quality guidelines used to assess the quality of sediment to determine level of toxicity against macro-invertebrates.

Metal	Warning Level	Level 1	Level 2
Arsenic	42	57	93
Cadmium	1.2	5.1	9.6
Chromium	250	260	370
Copper	110	230	390
Mercury	0.43	0.84	1.5
Nickel	88	140	370
Lead	110	218	530
Zinc	270	410	960

4.4.3. Water quality

The surface water samples values/concentrations for biological, chemical and physical parameters were compared to the South African Water Quality Guidelines for Coastal Marine Waters (DWAF 1996a and b). The guideline assists with providing concentrations and target values for a collection of biological, chemical and physical parameters in coastal marine waters of South Africa, however, some guidelines are not provided in which expertise was utilized in order to identify whether a parameters concentration fell within an acceptable range (CSIR, 2014). The following table provides the South African Water Quality Guideline indicator and target value or concentrations for coastal marine waters:

Table 4.3: South African Water Quality Guideline for Coastal Marine Waters, target value or concentration of an indicator in table represent the values that parameters should be above or between to not adversely affect environment or human health.

Indicator	Target value or concentration
Temperature	The maximum acceptable variation in ambient temperature is $\pm 1^0$ C
Salinity	33 -36
pH	7.3 – 8.2
Dissolved Oxygen	Should not fall below 5 mg/L 99% of the time and below 6 mg/L 95% of the time
Electrical conductivity	<156mS/cm
Total Dissolved Solids	No more than 15% change from the normal cycles of the water body under unimpacted conditions
Nutrients	Water should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing DO concentrations below the target range indicated for DO
Faecal indicator bacteria	Maximum acceptable count per 100 ml: 100 in 80% of samples and 2000 in 95% of samples
Arsenic	12 µg/L
Cadmium	4 µg/L
Copper	5 µg/L
Chromium	8 µg/L
Mercury	0.3 µg/L
Nickel	25 µg/L
Lead	12 µg/L
Zinc	25 µg/L

(DWAF 1996a and b).

The results obtained are then compared to the South African Water Quality Guideline for aquatic ecosystems, in which the quality of water is determined through the TWQR of the guideline (DWAF 1996a and b).

4.4.4. Macro-invertebrates

Macro-invertebrates were identified and collected into major taxonomic groups. The level of taxonomic identification used ranged from Phylum to Suborder, based on factors such as behavioral, morphological, physiological and taxonomic considerations (Whitfield and Bate, 2007).

Macro-invertebrate datasets were graphically presented in relative abundance bar graphs of different taxonomic groups in order to compare these species in the different stations sampled. Furthermore, this gives rise to the interpreting the differences and similarities between the macro-invertebrate species at different sampling station, and the effects of sediment and water quality on the invertebrates at each sampling stations (Whitfield and Bate, 2007).

WETLAND METHODS

The vast majority of the Sezela study coastal area is used for sugarcane agriculture and patches of wetland areas in close proximity to the sugarcane agriculture. Therefore, a wetland functional assessment was conducted in order to delineate and to determine the ecological health status of these wetlands.

4.5. Sezela study wetland delineation

4.5.1. Desktop delineation

In order to acquire a broad understanding of the general study area, it was imperative to conduct a desktop study. The desktop delineation is not the final delineation boundaries of wetland areas and is merely used as a tool to assist with the delineation when fieldwork is conducted (Macfarlane *et al*., 2007) Desktop delineation was conducted using Google Earth®, as the polygon tool was utilized to digitize possible boundaries of wetlands by identification through factors such as possible vegetation change, topography and floodplains. Furthermore, desktop data included sourcing information on vegetation characteristics, hydrology, Ecoregion classification, National Freshwater Ecosystem Protected Areas (NFEPA's), NBA (2011) areas and land uses occurring in the area (Macfarlane *et al*., 2007; Ollis *et al*., 2013).

4.5.2 Wetland delineation: Field survey

A comprehensive wetland delineation was conducted on the 3rd February 2017 and 24th June 2017 to assist with the desktop delineation and to obtain a more accurate wetland delineation.

In order to identify wetland areas with the study site, four specific indicators were used which were:

- Vegetation (Primary indicator);
- Topography of the terrain;
- Soil: texture (sand and clay); colour (chroma, hue and value), organic matter content; and
- Degree of saturation (Macfarlane *et al*., 2007).

Once verification of the above-mentioned indicators is present in a possible wetland area, the delineation procedure commenced. The initial step to delineate the wetland was to identify the different hydrological zones present in wetland environments, specifically, the temporary, seasonal and permanent zones (DWAF, 2004). The confirmation of these different hydrological zones begins at the outer edge of the temporary zone which marks the boundary between the wetland environment and the adjacent terrestrial environment. Furthermore, by identifying the temporary boundary of the wetland environment, the seasonal and permanent zones are therefore found within the boundary of the temporary zone if these zones are present (DWAF, 2004).

Sediment cores were obtained using a Dutch soil auger. Soil cores of approximately 50 cm depth were obtained to evaluate in-situ for redoximorphic soil features such as mottling, gleying, soil chroma and soil saturation; thereafter, soil cores were discarded. Additionally, GPS co-ordinates were logged at the location of sediment cores, which were captured and mapped in Google Earth® for analysis and processing at a later stage (Macfarlane *et al*., 2007).

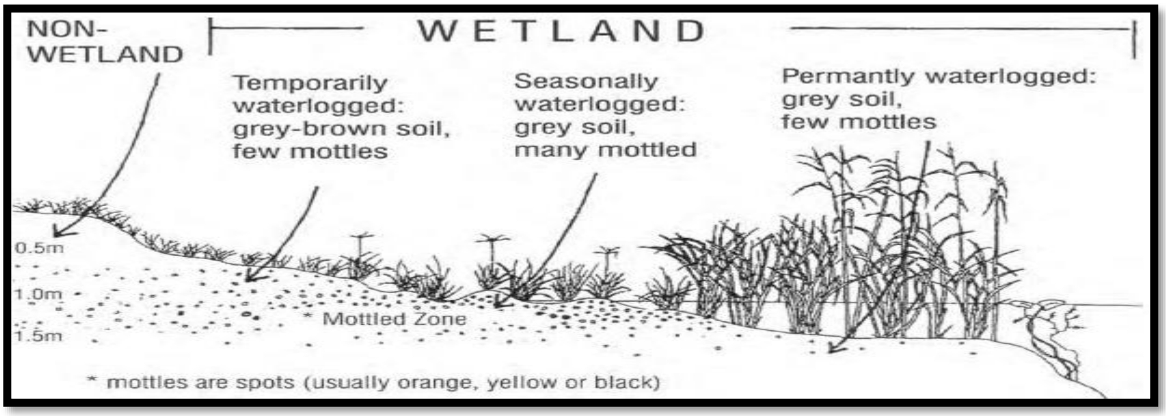


Figure 4.1: Represents wetland zones and non-wetland zone.

(DWAF, 2004).

Table 4.4: Classification of plants according to occurrence in wetlands.

Type	Description
Obligate wetland species	Almost always grows in wetlands (> 99% of occurrences in wetlands).
Facultative wetland species	Usually grows in wetlands (67-99% of occurrences in wetlands), are occasionally found in non-wetland.
Facultative species	Are likely to grow in wetland and non-wetland areas (34-66% occurrences in both non-wetland and wetland).
Facultative dry-land species	Predominantly grow in non-wetland conditions but sometimes in wetland conditions (1-34% occurrence in wetlands).

(DWAF, 2008).

4.6. Wetland classification

Due to the topography and natural terrain, wetland areas may incorporate more than one hydrogeomorphic (HGM) unit. The wetland areas identified in the Sezela study site were classified according to the National Wetland Classification System developed by the SANBI (Ollis *et al*., 2013; DWAF, 2008). The hydrological and geomorphological features of wetlands delineated are used to classify the wetlands found in the field. Although vegetation is used as a primary indicator of identifying and classifying wetland environments, some wetland areas lack wetland vegetation as a direct result of the land being historically changed, hence, hydrological and geomorphological feature are thus used to delineate wetland environments (Ollis *et al*., 2013).

4.7. Wetland functional assessment

A wetland functional assessment was conducted on all HGM units within the Sezela study site. The functional assessment methods used were: WET-Health Level 2 assessment and WET-EcoServices Level 2 assessment (Macfarlane *et al*., 2007).

4.7.1. WET-Health Tool

According to Macfarlane *et al* (2007), the WET-Health tool has been established to assess the health status of wetlands in South Africa which can be utilized in a range of contexts such as wetland rehabilitation and management.

The tool has been created on two different platforms which is a WET-Health Level 1 and 2. The reason for creating different assessment levels is a direct result of different users having different requirements of the tool. A level 1 assessment is less comprehensive as compared to a level 2 assessment, hence, for the purpose of this study a level 2 assessment was used. The WET-Health Level 2 assessment encompasses a data collection procedure from catchment and wetland areas that is more structured and integrates all facets of the level 1 assessment (Macfarlane *et al*., 2007).

The WET-Health Level 2 assessment main object is to establish the Present Ecological State (PES) of the wetland environments. In order to determine the health status of the wetlands in the area three main functional aspects need to be considered for the WET-Health tool which are; 1-hydrology, 2-geomorphology and 3-vegetation. A three-step process is utilized to determine the overall health status of the above-mentioned aspects (Macfarlane *et al*., 2007).

Step 1: Hydrological, geomorphological and vegetation PES determination

The initial step was based on determining natural and human impacts within the catchment and wetland areas and to determine the PES for hydrology, geomorphology and vegetation separately for each HGM unit based on a scoring from 0 (wetland unmodified and natural environmental conditions) to 10 (wetland drastically modified). The scoring of 0-10 for each HGM unit is then translated into six health classes which are A-F for easier understanding (as seen in Table 4.4) (Macfarlane *et al*., 2007).

Table 4.5: PES categories and relevant descriptions of each modification level

Impact Category	Health Category	Description	Range
None	A	Unmodified/natural	0 – 0.9
Small	B	Mostly Natural with a few modifications. A slight change in ecosystem processes is discernable and a small loss of natural habitats and biota may have taken place.	1 – 1.9
Moderate	C	Moderately modified. A moderate change in the ecosystem processes and the loss of natural habitats has taken place but the natural habitat remains predominantly intact	2 – 3.9
Large	D	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4 – 5.9
Serious	E	A very large change in ecosystem processes and loss of natural habitat and biota but some of the remaining natural habitat features are still recognizable.	6 – 7.9
Critical	F	The modification has reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota	8 – 10

(Macfarlane *et al*. 2007).

Step 2: Determination of wetland vulnerability

The vulnerability determination was conducted by evaluating the level of threat and/or vulnerability to each HGM unit and assess the likely **trajectory of change** within the wetland over the next 5 years (Davis and Slobodkin, 2004; Lackey, 2001). The trajectory of change is broken up into 5 categories and is dependent on the degree of probably change within the HGM unit (as seen in table 4.5).

Table 4.6: Trajectory of change score and symbol over the next 5 years.

Change Class	Description	HGM change symbol	Change Symbol
Substantial improvement	State is likely to improve substantially over the next 5 years	2	↑↑
Slight improvement	State is likely to improve slightly over the next 5 years	1	↑
Remain Stable	State is likely to remain stable over the next 5 years	0	→
Slight deterioration	State is likely to deteriorate slightly over the next 5 years	-1	↓
Substantial deterioration	State is likely to deteriorate substantially over the next 5 years	-2	↓↓

(Davis and Slobotkin, 2004; Lackey, 2001).

Step 3: Overall PES determination

The final step was achieved by calculating the overall health status of each HGM units PES, therefore, (combining hydrological, geomorphological and vegetation health scores) and the likely **trajectory of change** (Macfarlane *et al*., 2007). Therefore, to calculate the overall health status of each HGM unit, the following equation was used:

$$\textbf{Overall PES} = \frac{(\text{Hydrology X } 3) + (\text{Geomorphology X } 2) + (\text{Vegetation X } 2)}{7} \qquad (9)$$

<u>4.7.2. WET-EcoServices Tool (Ecological Goods and Services)</u>

The WET-EcoServices Level 2 assessment is a tool used to establish the ecological goods and services that a HGM unit provides. These services provided by the HGM unit are split into physical ecosystem services and socio-cultural ecosystem services. The use of this tool is imperative in a wetland functional assessment as it provides the different ecosystem services a wetland can provide and categorize these services in different factors (Macfarlane *et al*., 2007) (as seen in Table 4.6).

The WET-EcoServicess tool plays a vital role in assessing the degree of ecosystem benefit provided by a wetland, based on the wetlands effectiveness to provide ecosystem benefits and the ability to opportunistically provide ecosystem benefits (Macfarlane *et al*., 2007).

A scale scoring system which includes; **low (0), moderately low (1), intermediate (2), moderately high (3) and high (4)** are used to score a host of scenarios given in the WET-EcoServices tool. These scores obtained from the different characteristic of each wetland HGM integrate into WET-EcoServices scores for each of the fifteen ecosystem services (as seen in Table 4.6) (Macfarlane *et al*., 2007).

Table 4.7: Wetland ecological goods and service assessed by WET-EcoServices tool.

WET-EcoServices	
Physical ecosystem services	**Socio-cultural ecosystem services**
Flood attenuation	Biodiversity maintenance
Stream flow regulation	Provision of water for human use
Sediment trapping	Provision of cultural floods
Phosphate assimilation	Cultural significance
Nitrate assimilation	Tourism and recreation
Toxicant assimilation	Education and research
Erosion control	
Carbon storage	

(Macfarlane *et al*., 2007).

4.7.3. Hectare Equivalence

Hectare equivalence was used to determine the quantity of wetland that is healthy and in turn determining the degree of degradation the wetland experienced. Hectare equivalence is directly dependent on the WET-Health assessment. Furthermore, hectare equivalence clearly distinguishes a percentage of healthy and degraded wetland (Kotze *et al*., 2007).

Hectare equivalence plays a pivotal role in the decision-making process if wetlands are degraded and require rehabilitation. Therefore, it contributes directly to rehabilitation programs and is also a feasible method of determining the degree of impacts a wetland incurred. Hectare equivalence was calculated using the following equation:

<u>10 – Overall PES</u> X Area of Wetland (10)

10

<u>4.7.4. Longitudinal Profile and Vulnerability</u>

In order to determine the longitudinal profile of each HGM unit, it is required that the slope is calculated and plotted against the elevation (Kotze *et al*., 2007).

Thereafter, the vulnerability of each HGM unit can be determined by using a graph provided by the WET-Health series (as seen in Figure 4.2). The use of the vulnerability diagram is to represent a HGM unit's inherent vulnerability to changes in geomorphology (Kotze *et al*., 2007). Erosional features such as head-cut erosion is an aspect of geomorphological change that can occur over time as a result of many different factors, however, it is determined that slope plays a massive role in creating this erosional feature which could occur in HGM units depending on their slope; thus, the steeper the slope, the greater the degree of head-cut erosion for any given discharge point. Therefore, vulnerability of a wetland is determined by the relationship between discharge and the longitudinal slope (Kotze *et al*., 2007).

The vulnerability factor can therefore be established by plotting the longitudinal slope of the HGM unit against the area of the HGM unit (which is equivalent to mean annual discharge). It is then determined whether or not if the wetland falls within the vulnerable plot of the graph (5-10) or the protected plot of the graph (0-2). Furthermore, if the HGM unit plots between (0-2) it was deemed aggregational, whereas, if the HGM unit was plotted between (5-10) it was deemed degradational (Kotze *et al*., 2007; Macfarlane *et al*., 2007).

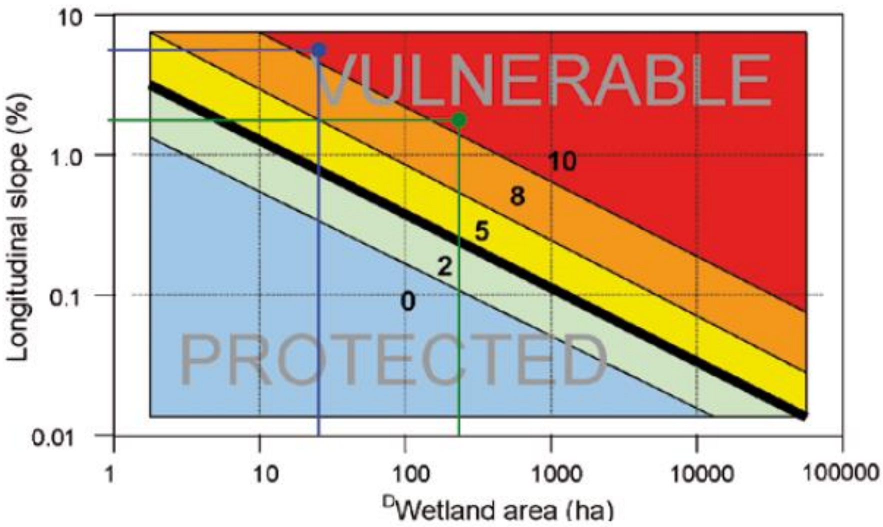


Figure 4.2: Longitudinal slope vs. wetland area graph.

(Kotze *et al*., 2007; Macfarlane *et al*., 2007)

4.8. Conclusion

The methods discussed above were adopted and used determine the ecological and geochemical regimes of the Sezela estuary and the health status of the surrounding Sezela wetlands. Furthermore, although the land is privately owned by the Illovo Sugar Mill, it is still imperative that the surrounding ecosystems are kept intact in order to preserve ecosystem processes and to ensure that the structural integrity of this important system remains intact.

5. RESULTS

5.1. Introduction

This chapter incorporates all the data obtained through desktop and field surveys. The data which encompasses sediment distribution, calcium carbonate and organic matter content, sediment and water quality and, macro invertebrates in the estuarine environment are displayed below coupled with the wetland data which encompasses delineation of wetland zones, WET-EcoServices and WET-Health tools data display and, longitudinal and vulnerability profiles in the study site area.

Results obtained for Sezela estuary

5.2. Grain size composition

Grain size composition of sediment refers to the proportion of gravel, sand and mud within a system and provides important information such as macro invertebrate's habitat and possible presence and structure in certain types of sediment (Hyland *et al*., 2004; Melwani and Thompson, 2007).

Table 5.1: Gravel, sand and mud percentage at each sampling station at the Sezela Estuary and River during summer.

	% Gravel	% Sand	% Mud	Total
SE1	1.22	97.7	1.08	100
SE2	51.6	48.06	0.34	100
SE3	61.82	38.02	0.16	100
SW5	27.94	70.11	1.95	100

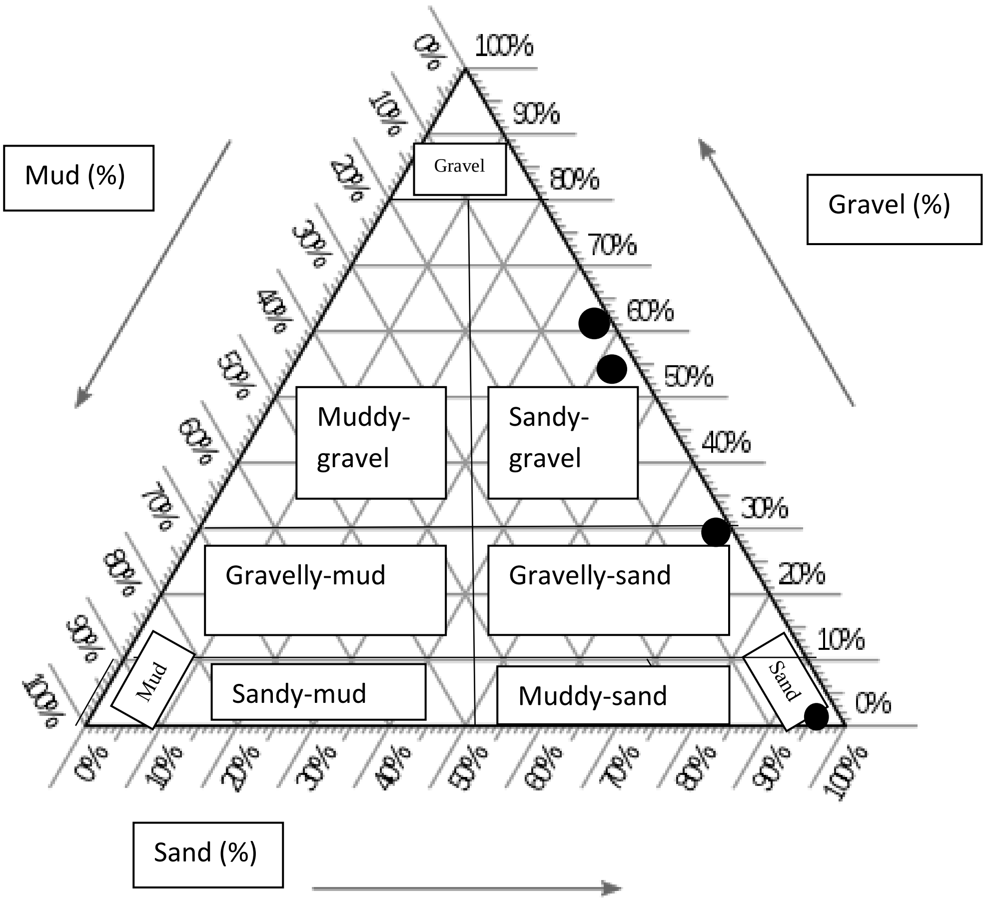


Figure 5.1: Ternary plot illustrating the proportional contribution of gravel, sand and mud at each sample station at the Sezela Estuary and River during summer.

Table 5.2: Gravel, sand and mud percentages at each sampling station at the Sezela Estuary and River during winter.

	% Gravel	% Sand	% Mud	Total
SE1	2.75	96.97	0.28	100
SE2	63.59	36	0.41	100
SE3	70.45	29.45	0.1	100
SW5	27.03	72.52	0.45	100

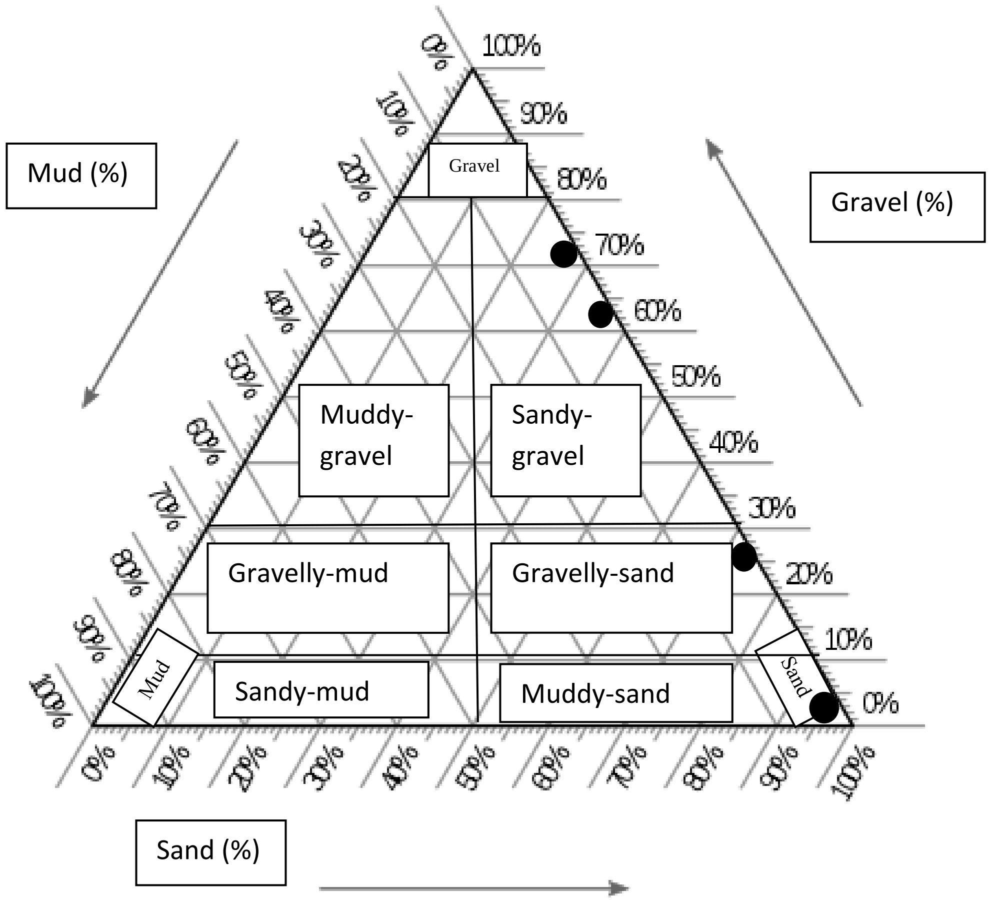


Figure 5.2: Ternary plot illustrating the proportional contribution of gravel, sand and mud at each sample station at the Sezela Estuary and River during winter.

The textural character of the sediment collected from the Sezela Estuary and River areas in the summer sampling period (16th February 2017) was classified as sand for SE1 sampling point, sandy-gravel for SE2 and SE3 sampling points and gravelly-sand at sampling point SW5 (Figure 5.1). During the winter sampling period (10th July 2017) the textural sediment results revealed a similar class composition as for the summer sampling period (Figure 5.2).

Sediment station SE1 which was located at the lower reaches of the estuary displayed a sandy sediment bed, whereas SE2 which was located at the upper reaches of the estuary displayed a sandy gravel bed. Similarly, SE3 which is located in close proximity to the upper reaches of the estuary had a similar sandy-gravel bed, whereas, SW5 which was influenced by a river dominated environment displayed a sandy-gravel bed. The distribution of sediment at these sampling stations were similar for both the summer and winter sampling periods (Tables 5.1

and 5.2), however, the sediment did become slightly coarser at SE2 and SE3 from the summer to winter periods.

The sediment found at all the sampling stations are possibly due to the hydrodynamic nature of the environment in the area such as mouth breaching or not, river dominated or marine dominated estuary and over wash events from the marine environment (Whitfield and Bate, 2007).

5.3. Sediment Statistical Distribution

Measures of central tendency were calculated for the Sezela estuary and river sediment which are represented in Tables 5.3 and 5.4. The measures of central tendency presented are mean, median, skewness, sorting and kurtosis (in phi values, $\phi = -log_2 (D/D_0)$) for summer and winter sampling periods.

Table 5.3: Measures of central tendency in phi values for summer sampling points.

Sampling point	Mean	Median	Skewness	Sorting	Kurtosis
SE1	0.67	0.40	0.24	0.38	1.49
SE2	1.02	1.10	0.09	0.80	0.22
SE3	0.76	1.00	0.08	0.98	0.24
SW5	0.97	1.30	0.10	0.10	0.25

Table 5.4: Measures of central tendency in phi values for winter sampling points.

Sampling points	Mean	Median	Skewness	Sorting	Kurtosis
SE1	0.81	0.45	0.39	0.42	1.25
SE2	0.64	1.20	0.07	1.31	0.31
SE3	1.14	1.10	0.08	1.30	0.24
SW5	1.29	1.60	0.01	0.27	0.35

The mean and median grain sizes for the Sezela estuary and river sampling points during the summer and winter period were an average 0.90 and 1.08 respectively.

The mean values of all sites during the summer and winter sampling period differ in value at all sampling points. Furthermore, the individual values of the mean and median for all sites but SE2 in the summer sampling period and SE3 during the winter sampling period differ in value by small amount. The dissimilar values for mean and median could be reflective of the varying transportation and depositional mechanisms (Morgan, 1995).

Furthermore, sediments are well sorted for SE1 for the summer and winter sampling periods respectively, sediment were moderately sorted and poorly sorted for SE2 and SE3 for the summer and winter sampling periods respectively and very well sorted for SW5 for both sampling periods. Point SE1 present well sorted sediment in both sampling periods, the sediment at SW5 was well sorted which is the Sezela downstream river point which receives good flow, transportation and reworking of sediment. However, at SE2 and SE3 transportation and re-working processes of sediment were moderate and was less moderate during the winter period (Blatt, 1970).

Kurtosis calculations for transects SE1 presented a leptokurtic curve for SE1 for both sampling periods, whereas SE2, SE3 and SW5 presented a very platykurtic curve. The skewness of sampling points for SE1 in both sampling periods is positively skewed representing an excess of fine sediment. Sampling points SE2, SE3 and SW5 during the summer and winter sampling periods represented a near symmetrical skewness, which indicates an even distribution of coarse and fine sediment (as per Folk and Ward, 1957).

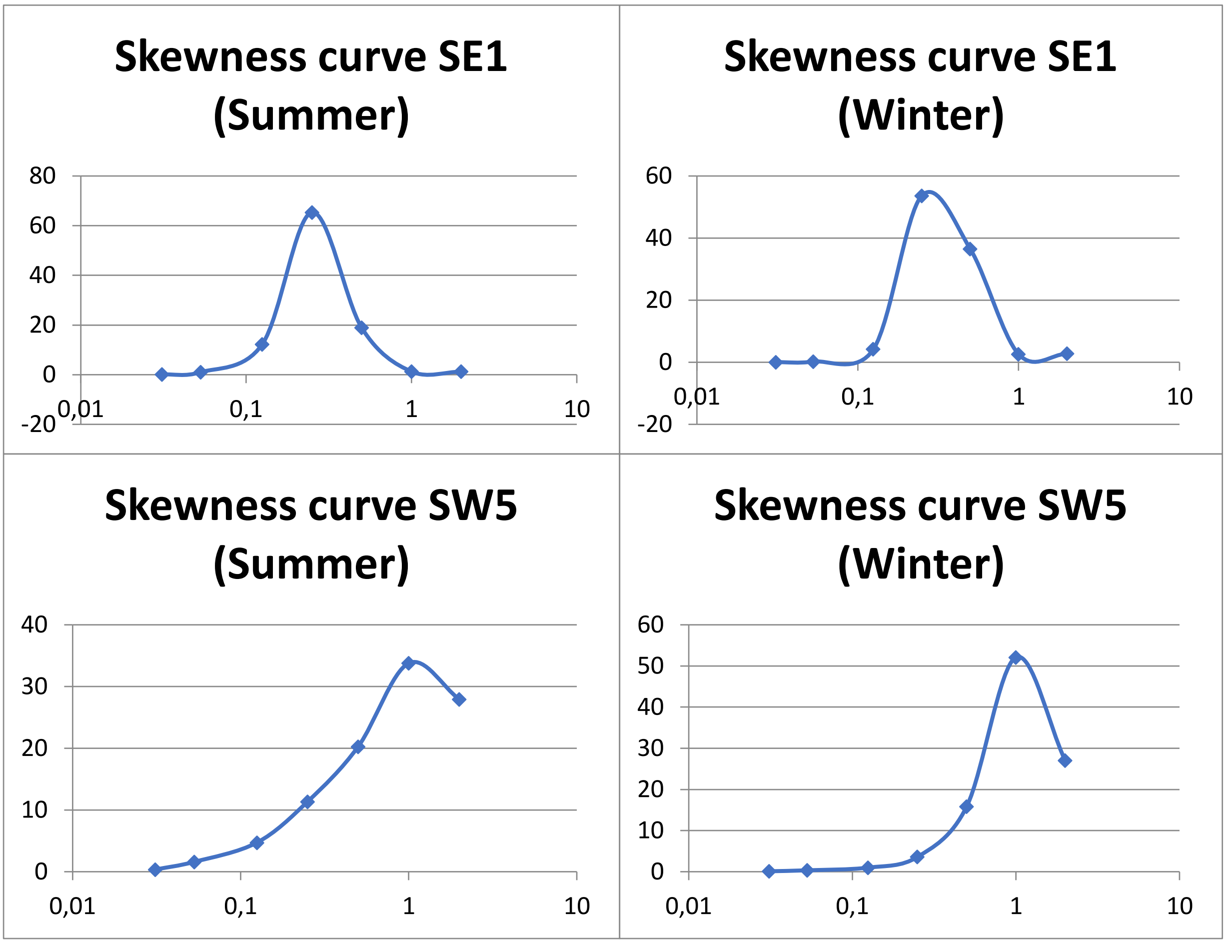


Figure 5.3: Skewness curve of SE1 and SW5 during the summer and winter sampling periods.

Sampling point SE1 is positively skewed, thus presenting an excess of fine sediment and skewed towards a fine tailed side, whereas, sampling point SW5 presents is sysmetrically skewed which represents a fair distribution of fine and coarse sediment.

5.4. Organic Matter (OM) and Calcium Carbonate (CC) Content

In Figure 5.4 loss on ignition calculations results of % OM for sampling stations SE1, SE2, SE3 and SW5 during the summer and winter periods are 0.45, 0.58, 0.36 and 0.59 and; 0.41, 0.52, 0.3, 0.48 respectively. The % CC was calculated to be 0.58, 0.75, 0.52 and 2.21 during the summer and 0.51, 0.70, 0.45 and 2.03 during the winter for the aforementioned sampling stations. In addition, the percentages of OM and CC content in the lower and upper reaches of the estuary are low, however, increases at station SW5 (Sezela River) drastically. This could be a direct result of pollution and loss of biota in the estuary in comparison to the river system (Whitfield and Bate, 2007). Furthermore, the relationship between mud, OM and CC for the winter sampling period is directly correlated, however, sampling station SE1 for the summer sampling period is inversely correlated. This could be as a resultant of possible marine overwash at the time period or decomposition of living organism as compared to the at the time constant mud percentage (Figure 5.5) (Whitfield and Bate, 2007).

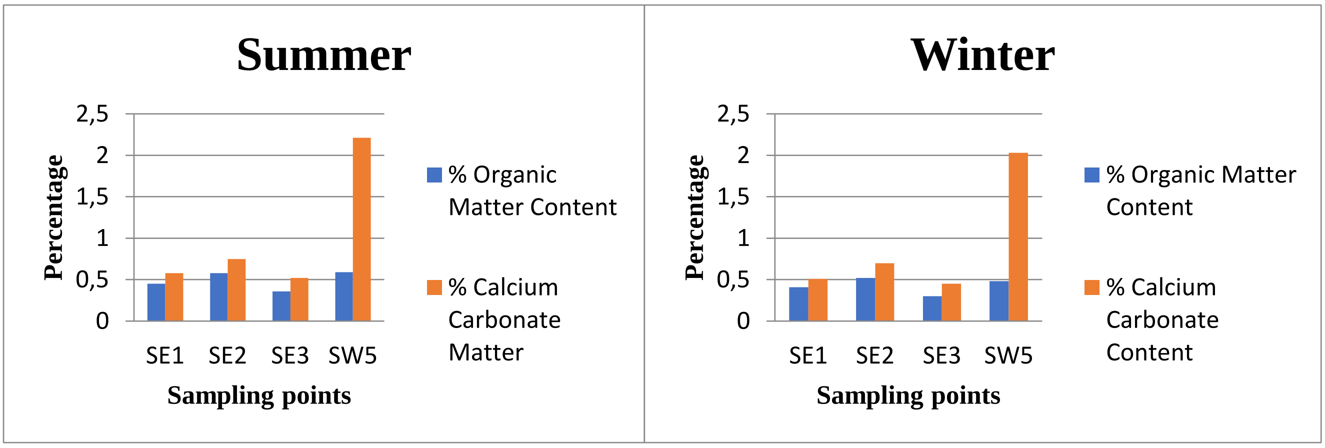


Figure 5.4: Percentage organic matter and calcium carbonate content at sampling stations for summer and winter respectively.

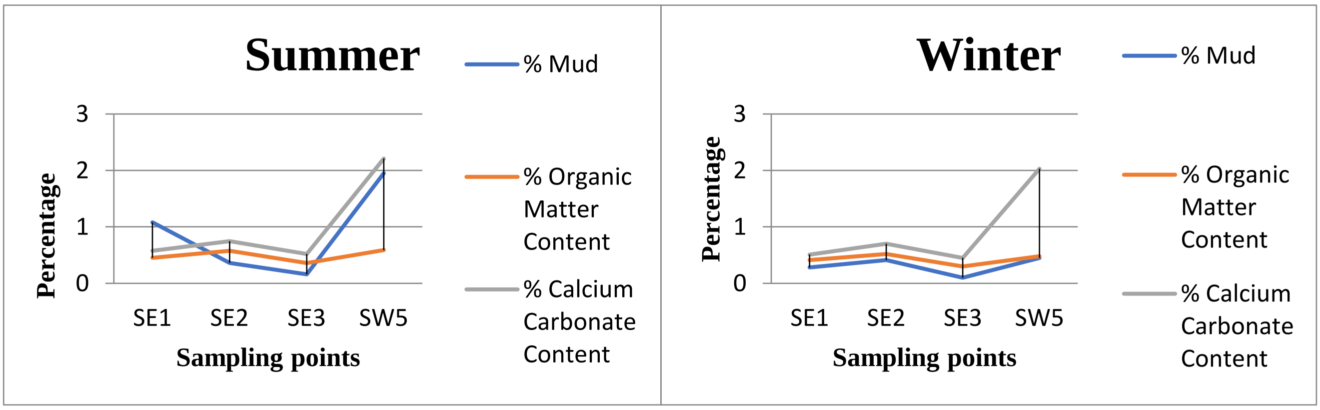
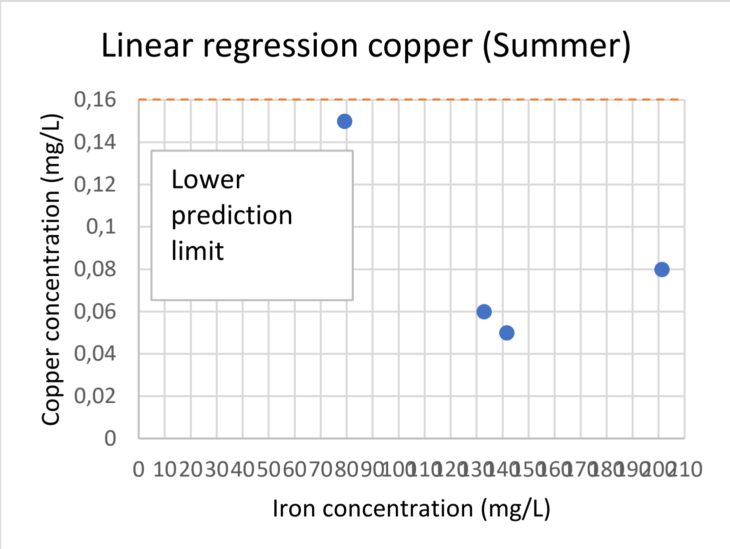
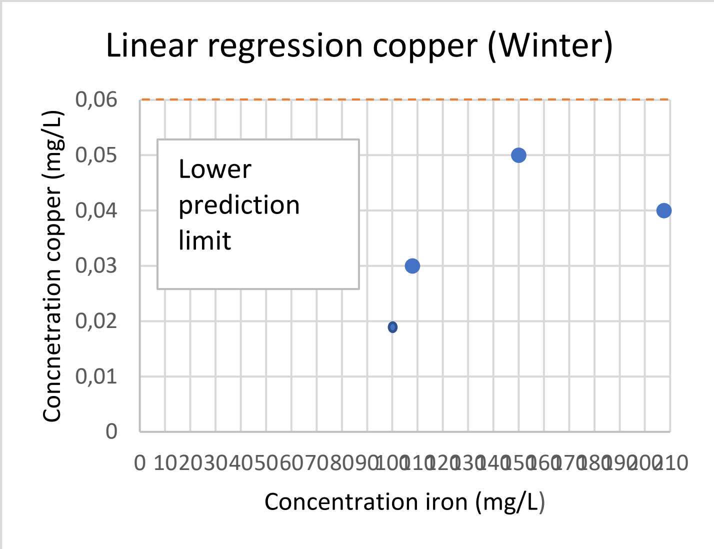


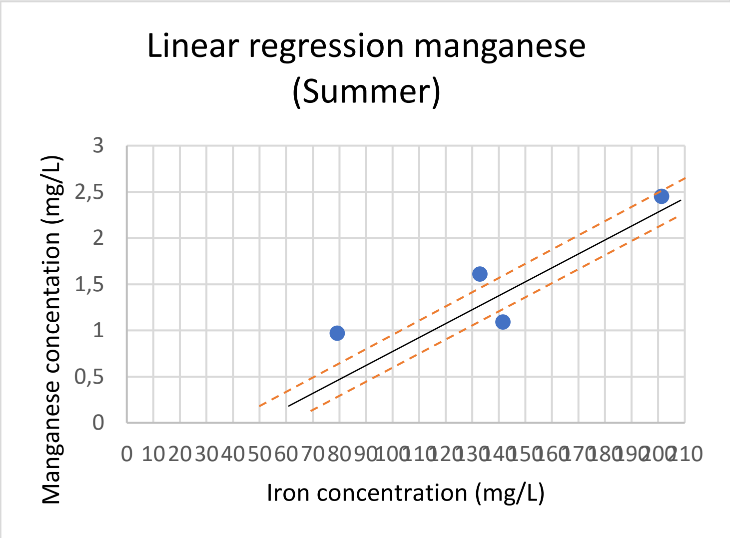
Figure 5.5: Relationship between mud, organic matter and calcium carbonate percentages.

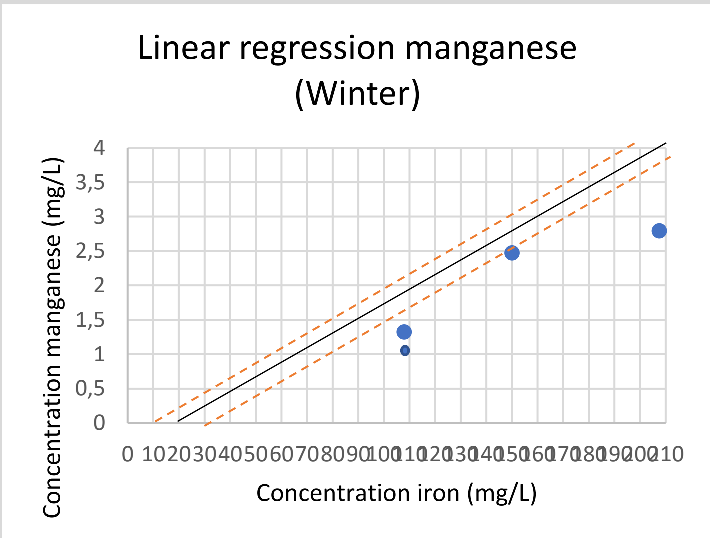
5.5. Sediment quality

5.5.1. Linear Regression









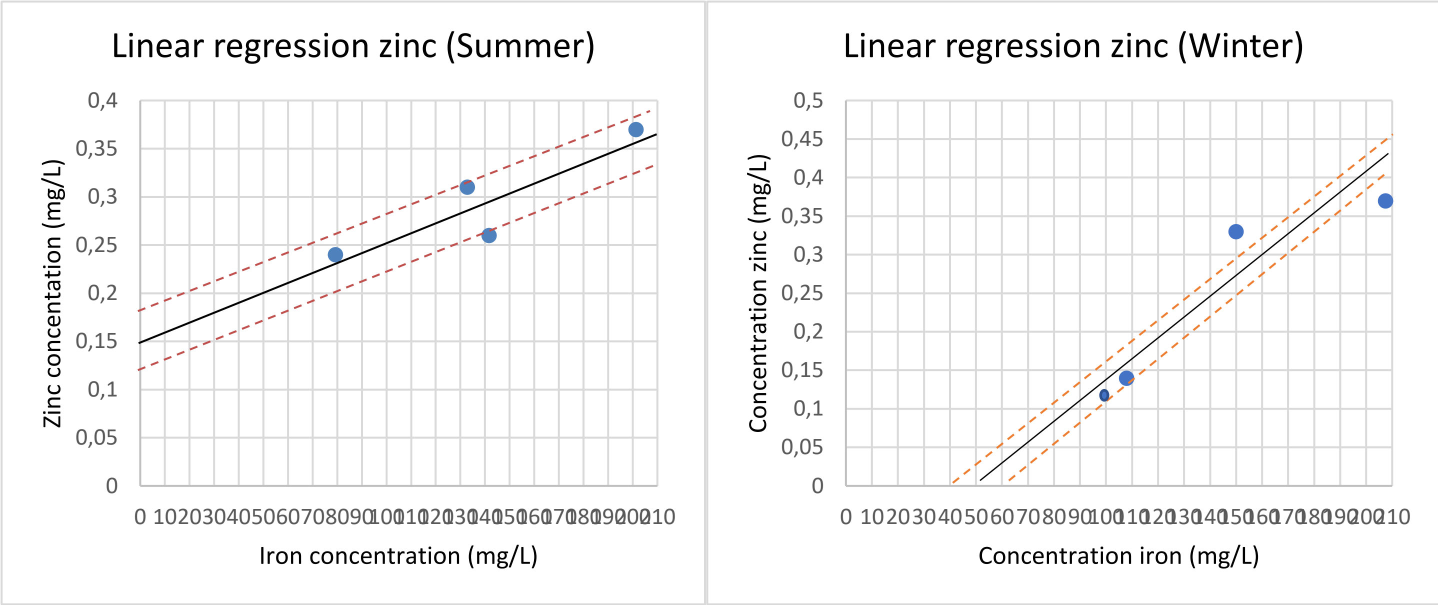


Figure 5.6: Baseline metal concentration models with the metal concentrations of sediment collected superimposed for the summer and winter sampling periods.

Linear regression models were only drawn for copper, manganese and zinc as metals such as cadmium, lead and mercury were too low to detect by ICP-OES. It was evident that the sediment for the summer and winter period was not enriched by copper as a result of lower prediction limit of the model. Manganese during the winter sampling period fell within or below the baseline models prediction limit, hence, no enrichment by manganese during these periods. However, during the summer sampling periods, sampling sites SE2 and SW5 fell above the baseline model prediction limits, hence, anthropogenic factors could be due to. The zinc metal concentration fell all within the prediction limits of the linear regression models, however, sampling site SW5 during the winter sampling period fell above the prediction limit.

The low manganese enrichment factor for sampling station SE2 during summer indicated that the concentration was not enriched due to anthropogenic factors. Conversely, sampling station SW5 revealed an enrichment of 1.13 and 1.27 for managese during the summer sampling period and zinc during the winter sampling period respectively. Therefore, this indicates that these metals were little over one times higher than the concentration predicted at the baseline model upper prediction limit as a result of metal contamination in these areas.

Table 5.5: Enrichment factor calculation for winter and summer sampling station points.

Sampling stations	Copper		Manganese		Zinc	
	Summer	Winter	Summer	Winter	Summer	Winter
SE1	-	-	-	-	-	-
SE2	-	-	0.68	-	-	-
SE3	-	-	-	-	-	-
SW5	-	-	1.13	-	-	1.27

5.5.2. South African Sediment Quality Guidelines for open water disposal

Table 5.6: Sediment quality guidelines used to assess the quality of sediment to determine level of toxicity for macro-invertebrates.

Metal	Warning Level (mg/L)	Level 1 (mg/L)	Level 2 (mg/L)
Cadmium	1.2	5.1	9.6
Copper	110	230	390
Mercury	0.43	0.84	1.5
Nickel	88	140	370
Lead	110	218	530
Zinc	270	410	960

Table 5.7: Sediment chemistry results of metal concentrations during the summer and winter sampling periods.

Sampling stations	Cadmium (mg/L)		Copper (mg/L)		Lead (mg/L)		Iron (mg/L)		Manganese (mg/L)		Mercury (mg/L)		Zinc (mg/L)	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
SE1	-	-	0.15	0.02	-	-	79.2	105.71	0.97	1.11	-	-	0.24	0.12
SE2	-	-	0.05	0.03	-	-	141.6	107.92	1.09	1.32	-	-	0.26	0.14
SE3	-	-	0.08	0.04	-	-	201.3	207.49	2.45	2.79	-	-	0.37	0.37
SW5	-	-	0.06	0.05	-	-	132.87	150	1.61	2.47	-	-	0.31	0.33

The concentration of copper and zinc fall below the sediment quality guideline used to assess the quality of sediment to determine the level of toxicity against macro-invertebrates. Metals cadmium, lead and mercury were not assessed as these metals were too low to be detected by the ICP-OES, which probably was lower than concentrations in the sediment quality guideline. Iron and manganese are not considered in this guideline; therefore, this guideline could not be used for the detection of those metal levels.

5.6. Water Quality

According to DWAF (1996a), water quality is used to explain the aesthetic, biological, chemical and physical properties of water and determine the overall quality of water for various uses, for health protection purposes and to minimize aquatic ecosystem pollution. Furthermore, the above-mentioned properties are known to be controlled and influence by dissolved or suspended constituents found in water.

Table 5.8: South African Water Quality Guideline for Coastal Marine Waters.

Indicator	Target value or concentration to protect environment & humans
Temperature	The maximum acceptable variation in ambient temperature is $\pm 1^0$ C
Salinity	35
pH	7.3 – 8.2
Dissolved Oxygen	Should not fall below 5 mg/L 99% of the time and below 6 mg/L 95% of the time
Electrical conductivity	<156 mS/cm
Total Dissolved Solids	No more than 15% change from the normal cycles of the water body under unimpacted conditions
Nutrients	Water should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing DO concentrations below the target range indicated for DO
Faecal indicator bacteria	Maximum acceptable count per 100ml: 100 in 80% of samples and 2000 in 95% of samples
Arsenic	12 µg/L
Cadmium	4 µg/L
Copper	5 µg/L
Chromium	8 µg/L
Mercury	0.3 µg/L
Nickel	25 µg/L
Lead	12 µg/L
Zinc	25 µg/L

5.6.1. Faecal indicator organisms

Table 5.9: *E coli*, *Streptococcus and* Total coliforms TWQR for recreational use.

E coli	***Streptococcus***	**Total coliforms**
TWQR (0-130)	TWQR (0-30)	TWQR (0-130)
Small effect (130-200)	Small effect (30-60)	Small effect (130-600)
Moderate effect (200-400)	Moderate effect (60-100)	Moderate effect (600-2000)
High effect (>400)	High effect (>100)	High effect (>2000)

(DWAF, 1996c)

Table 5.10: Selected microbial site counts during summer

Stations	***E coli***	***Streptococcus***	**Total coliforms**
SE1	98	60	94
SE2	58	8	64
SE3	94	42	29
SW5	60	30	120

*Units, colony counts /100 ml water

Table 5.11: Selected microbial site counts during winter

Stations	***E coli***	***Streptococcus***	**Total coliforms**
SE1	90	52	90
SE2	55	12	60
SE3	86	45	25
SW5	56	28	110

*Units, colony counts /100 ml water

The *E coli* count for all stations fall within the TWQR for winter and summer sampling periods, however, although these sampling stations fall within the TWQR a low risk of gastrointestinal is still possible (<8/1000 swimmers) (DWAF, 1996c). The *Streptococcus* count falls within the TWQR for stations SE2 and SW5 for both sampling periods. Stations SE1 and SE3 fall within the small effect range which bring about a slight risk of gastrointestinal effects. *Total coliforms* count for all stations during the summer and winter sampling period fall within the TWQR, hence, the risk of gastrointestinal infections is unlikely (DWAF, 1996c).

5.6.2. Nutrients

Nutrients in water play an important role for the life cycle of biota in aquatic ecosystems (Whitfield and Bate, 2007). However, an excess of nutrients in aquatic ecosystems can become a nuisance to the environment and promote an excess of algae and in some serious cases eutrophication. Eutrophication can decrease DO concentrations which can be detrimental to the aquatic ecosystem and the biota that reside within it. Nutrients such as Nitrite, Nitrate and Orthophosphate are parameters that are not within the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996a). However, Ammonia is measured in this guideline. To compensate for not having information on these parameters to assist in determine if they are in excess or not in an aquatic environment, DWAF (1996a) has stated that “Water should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing DO concentrations below the target range indicated for DO.” Hence, visual field identification of algae and DO results were used to determine if the aforementioned nutrients besides Ammonia were causing stress upon the Sezela estuary and river.

Table 5.12: Ammonia TWQR for aquatic ecosystems.

TWQR and Criteria	Ammonia concentrations (mg.L^{-1})
TWQR	7
Chronic Effect Value (CEV)	15
Acute Effect Value (AEV)	100

Table 5.13: Nutrients results of the study and their stations.

Stations	Nitrite (mg.L^{-1})	Nitrate (mg.L^{-1})	Nitrate and Nitrite (mg.L^{-1})	Orthophosphate (mg.L^{-1})
SE1	<0.001	<0.005	<0.005	0.059
SE2	0.012	0.190	0.202	0.188
SE3	0.013	0.193	0.206	0.193
SW5	0.021	0.222	0.243	0.032

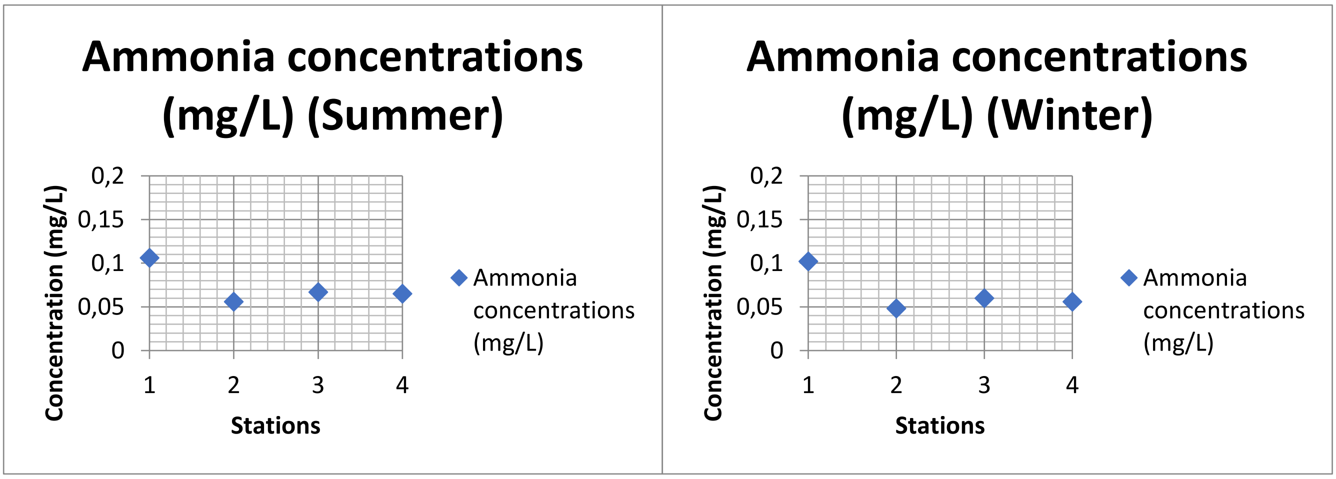


Figure 5.7: Concentrations of ammonia at sampling stations as (1-SE1, 2-SE2, 3-SE3 and 4-SW5).

The concentrations of ammonia all fall within the TWQR, therefore, there is no stress on the aquatic system by ammonia. Nitrite, Nitrate and orthophosphate do not incur as stress upon the aquatic environment of Sezela, as no visual excess or nuisance algae was seen on field visits and the DO concentrations fall below the TWQR, however, this occurrence is not directly related to the excess of nutrients in the aquatic system due to no algal blooms or eutrophic conditions encountered in the field.

5.6.3. Physico-chemical water parameters

- ***Dissolved Oxygen***

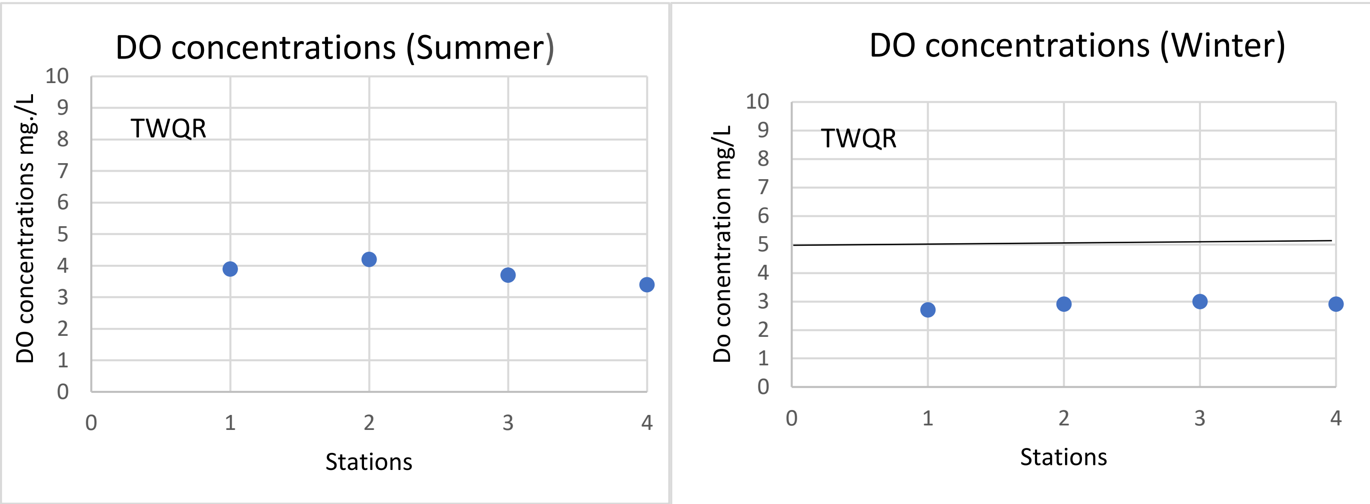


Figure 5.8: Concentrations of DO at sampling stations as (1-SE1, 2-SE2, 3-SE3 and 4-SW5).

The concentrations of DO for the winter and summer sampling periods fall below the TWQR. In the summer sampling period the DO concentrations fell just below the TWQR for stations SE1, SE2 and SE3 whereas, SW5 was slightly more below from the TWQR. The winter sampling period revealed that DO concentrations drop even further away from the TWQR (approximately 1 $mg.L^{-1}$ for sampling stations SE1, SE2 and SE3) whereas, SW5 dropped slightly in DO concentrations. This could be due to high TDS results seen in Table 5.16 which has the ability to be oxygen scavenging (DWAF, 1996a).

Table 5.14: Showing TWQR applicable saturation concentrations and their likely applications.

TWQR and criteria (DO)	Concentration	Application
TWQR (DO)	80% - 120% of saturation	Will protect all life stages of most southern African aquatic biota endemic to, or adapted to, aerobic warm water habitats. Always applicable to aquatic ecosystems of high conservation value
Minimum allowable values	>60% (sub lethal)	Likely to cause acute toxic effects on aquatic biota
	>40% (lethal)	

(DWAF, 1996a)

Table 5.15: DO concentrations and % saturation.

Sampling stations	DO (mg/l) concentrations (summer)	% Saturation (summer)	DO (mg/L) concentrations (winter)	% saturation (winter)
SE1	3.9	36.8	2.7	25.5
SE2	4.2	39.6	2.9	27.4
SE3	3.7	34.9	3	28.3
SW5	3.4	32.1	2.9	27.4

Average DO concentrations were calculated to be 3.8 mg.L^{-1} and 2.9 mg.L^{-1}. In order to see if the average DO concentration is within South African TWQR, mg.L^{-1} was converted into % saturation by dividing the concentration by 100% solubility of DO which is 10.6 and thereafter multiplying it by 100 (Dallas and Day, 1993). The winter and summer sampling periods reveal percentages that fall below the minimum allowable values (below >40%), hence, acute toxic effects on aquatic biota will be evident.

- ***Electrical Conductivity and TDS***

Table 5.16: Conductivity and TDS at sampling stations SE1, SE2, SE3 and SW5

Sampling stations	Electrical Conductivity ($mS.m^{-1}$) (summer)	TDS in ($mg.L^{-1}$) (summer)	Electrical Conductivity ($mS.m^{-1}$) (winter)	TDS in ($mg.L^{-1}$) (winter)
SE1	355	1889	1341	312
SE2	210	305	1446	535
SE3	238	522	1202	517
SW5	352	156	657	283

The conductivity and TDS results for the summer sampling period revealed a high TDS concentration at SE1 and the lowest at SW5. Conductivity in the winter sampling period at all stations are much higher, however, TDS at sampling station SE1 is fairly lower. Furthermore, a directly proportional relationship exists between TDS and conductivity in both the sampling periods. The average conductivity and TDS for the summer and winter sampling periods were 288.8 and 718 and; 1161.5 and 411.8 respectively.

- ***pH***

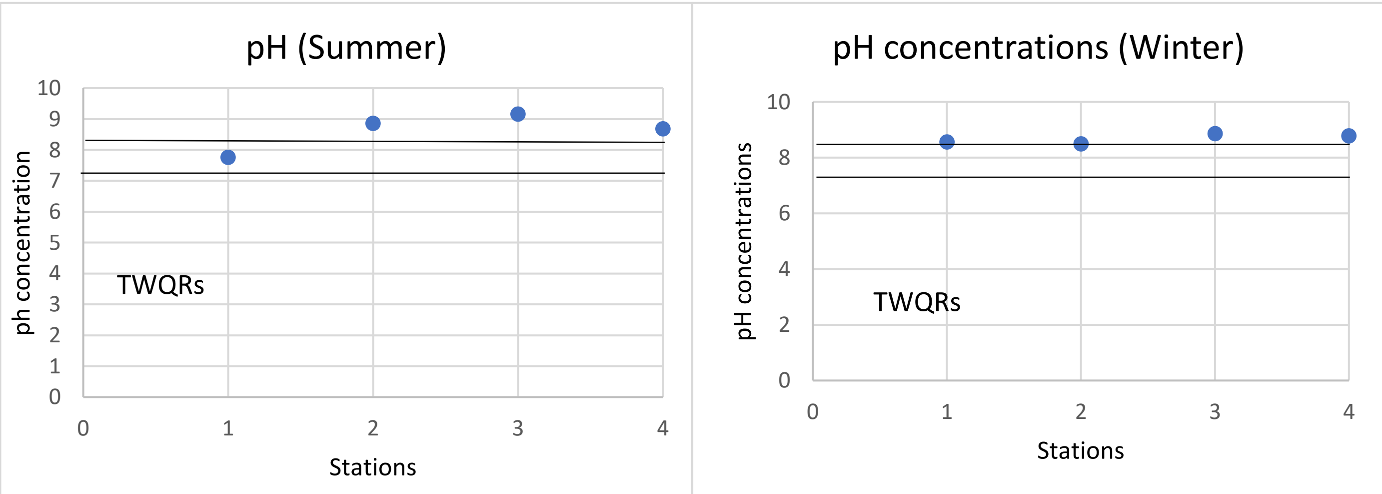


Figure 5.9: Concentrations of pH at sampling stations as (1-SE1, 2-SE2, 3-SE3 and 4-SW5).

The pH concentration for the summer sampling period was in the TWQR for sampling station SE1, however, sampling stations SE2, SE3 and SW5 were above the TWQR and revealed a slightly alkaline pH. Conversely, all sampling stations in the winter sampling period revealed a slightly alkaline pH which was above the TWQR.

- ***Salinity***

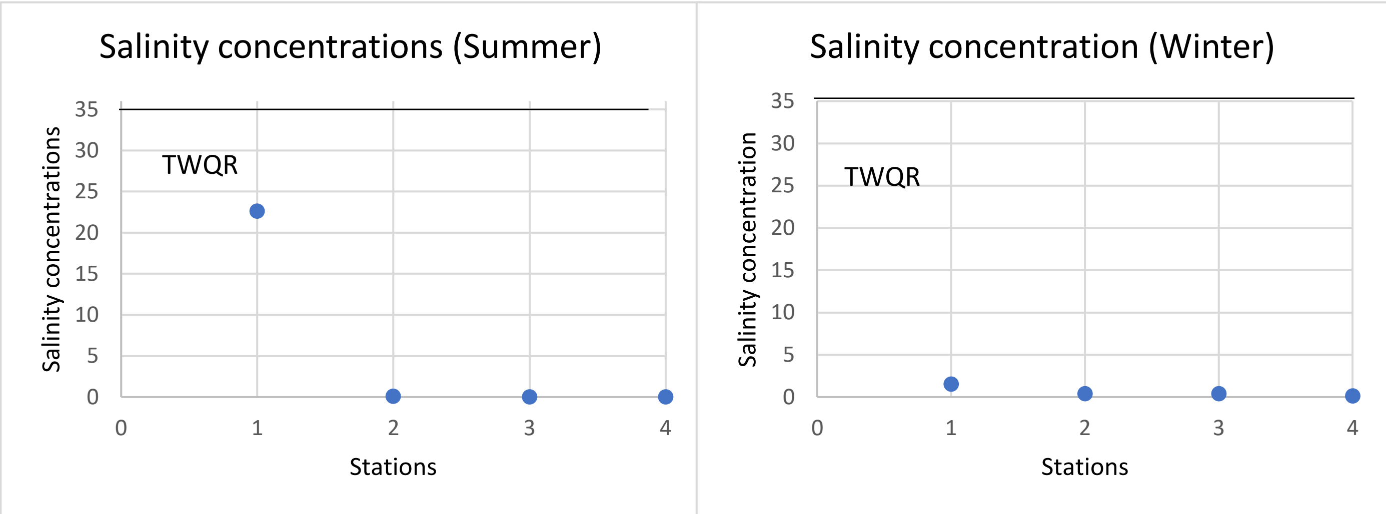


Figure 5.10: Concentrations of Salinity at sampling stations as (1-SE1, 2-SE2, 3-SE3 and 4-SW5)

The salinity concentrations for the summer and winter sampling periods were below the TWQR. However, this TWQR is specified for marine waters and the Sezela estuary comes in to contact with the marine environment temporarily. Therefore, this gives rise to the high salinity result in comparison to SE2 and SE3 due to this station being in close proximity to the mouth of the estuary. Sampling stations SE2 and SE3 are influenced by more freshwater, whereas SW5 results is the river environment which is typical of this environment. During the winter sampling period, sampling station SE1 salinity dropped drastically in comparison to the summer sampling period. Furthermore, sampling stations SE2, SE3 and SW5 revealed similar results in the summer and winter sampling periods.

5.6.4. Metals

The results for the metals cadmium, copper, lead, mercury and zinc were too low to detect by the ICP-OES, thus revealing that the water was most probably not enhanced anthropogenically by metals.

5.7. Macro invertebrates

Macro invertebrates are important indicators of the health of estuarine and marine environments which are utilised to assess possible disturbances, impacts and pollution to an environment which could have occurred recently or over a long period of time (Hiddink *et al*., 2006; Simboura and Zenetos, 2002).

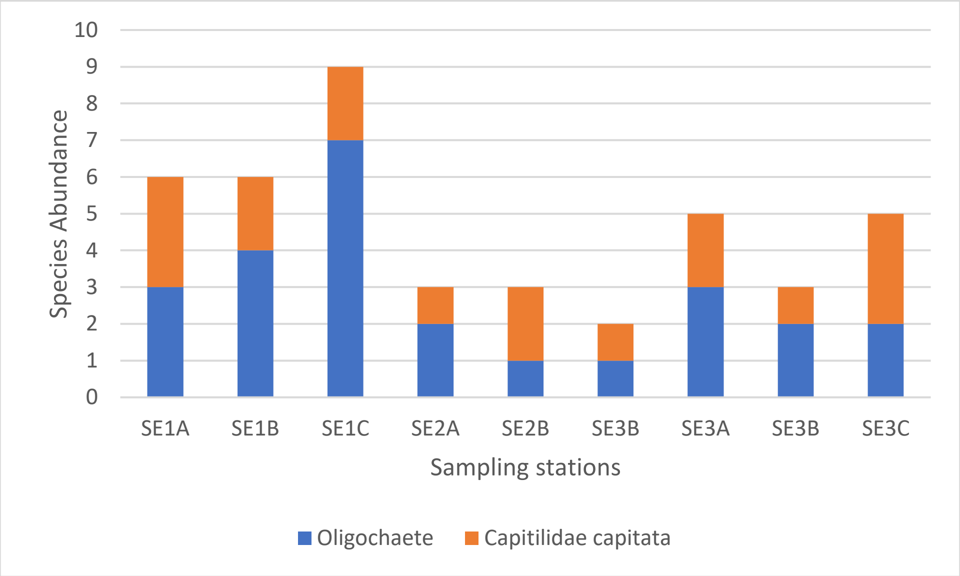


Figure 5.11: Macro invertebrate species composition and abundance at Sezela estuary sampling stations.

The macro invertebrate community within the Sezela estuary lacked a diverse array of species and was composed of only Polychaetes (bristle worms). The triplicate samples taken from each sampling station revealed low species abundance and diversity. The low counts of *Oligochaetes* and *Capitilidae capitata* at all sampling stations were due to the low count of dissolved oxygen (as seen in Table 5.15) and their presence was due to a slight enrichment of organic matter. The lack of species abundance and diversity could be a result of several factors which are discussed in Chapter 6.

Results obtained for Sezela wetlands

5.8. Wetland delineation

The wetland delineation encompassed visually identifying the different hydrogeomorphic units within the Sezela study site according to the characteristics identified by DWAF (2008) and Ollis *et al* (2013) (as seen in Figure 2.4 of Chapter 2). Three HGM units were identified at the Sezela study site. HGM 1 and 3 were identified as channelled valley bottom type wetlands and HGM 2 was identified as a floodplain type wetland. Furthermore, HGM 1 and 2 were identified as National Freshwater Ecosystem Protected Areas (NFEPA) wetlands as channelled valley bottom wetland and estuary respectively (Nel *et al*., 2011). The different zones which determine a wetland are presented in Figure 5.12 as a result of evidence gathered from field the field visit such as soil and vegetation profiles.

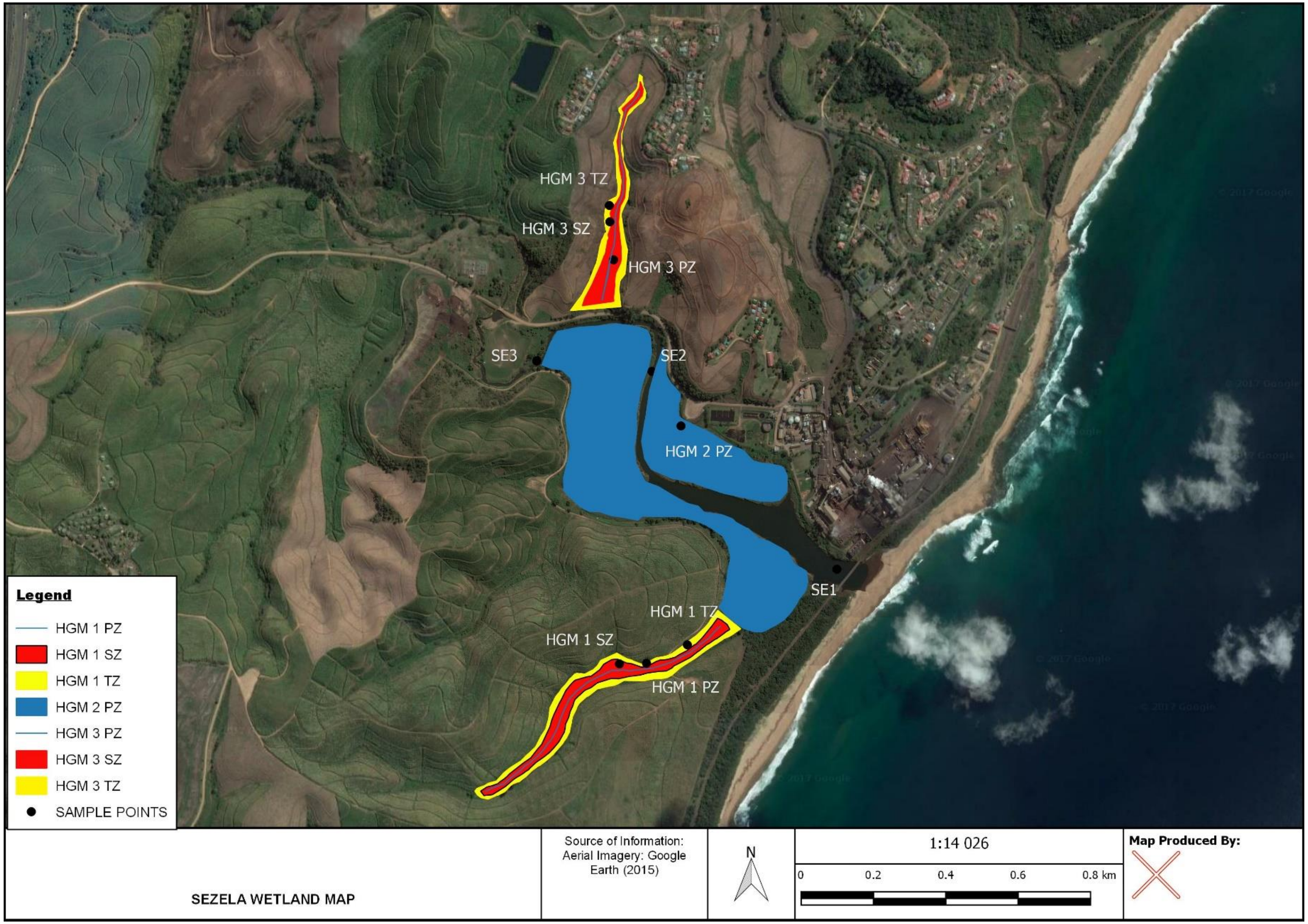


Figure 5.12: HGM units within the study site.

The zones determined in Figure 5.12 were initially determined at a desktop level and later by sediment cores and visual observation of wetland vegetation during a field visit. A brief visual representation of sediment cores in the temporary, seasonal and permanent zone is seen in Figure 5.12. Furthermore, soil profiles with information regarding site description, vegetation in area, matrix and chroma are found in the appendix section (Table 9.1).

The soil profiles depicted in Figure 5.13 are from HGM 3 in which the temporary, seasonal and permanent zones depict different hydrogeomorphic soil features. The first image was determined to be the permanent zone with a few mottles in the upper 0-10 cm and no mottles within the 30-50 cm layers. The matrix and chroma values were 4 and 1 respectively.

The second image depicted the seasonal zone as there was an abundance of mottling in the 0-10 cm and 30-50 cm layers, orange in colour with an intermediate contrast. The matrix and chroma values in the 0-10 cm and 30-50 cm layers were 4 and 2 and 4 and 1 respectively.

The third image presented in Figure 5.13 was the temporary zone in which few orange mottles were observed in the 0-10 cm layer and a moderate number of mottles in the 30-50 cm layer, in which the contrast of the mottles was intermediate. The matrix and chroma values in the 0-10 cm layer were 5 and 2 and in the 30-50 cm layer was 5 and 1.

Temporary zone core at HGM 3

Seasonal zone core at HGM 3

Permanent zone core at HGM 3

Figure 5.13: Soil profiles at Sezela study site of the different zones in HGM 3.

5.9. Wetland area and slope, longitudinal profile and vulnerability

The slope of the wetland was determined by obtaining the longitudinal profile. Slope and area are important factors in determining whether or not a wetland will be aggredational or degradational. Slope and area are thus plotted on a vulnerability graph to determine if the wetland experiences erosion as a result of its slope (Macfarlane *et al*., 2007).

Table 5.17: HGM unit types, area and slope.

HGM Unit	HGM type	HGM area (Ha)	HGM slope
1	Channelled valley bottom (CVB)	9.57	1.20
2	Floodplain (F)	22.20	2.00
3	Channelled valley bottom (CVB)	2.43	6.60

HGM 1


57 m
25 m
7 m
7 m
0.1%
0.25 km
0.5 km
0.75 km
1 km
1.35 km

HGM 2


17 m
10 m
4 m
6 m
0.4%
0.25 km
0.5 km
0.75 km
1 km
1.14 km

HGM 3

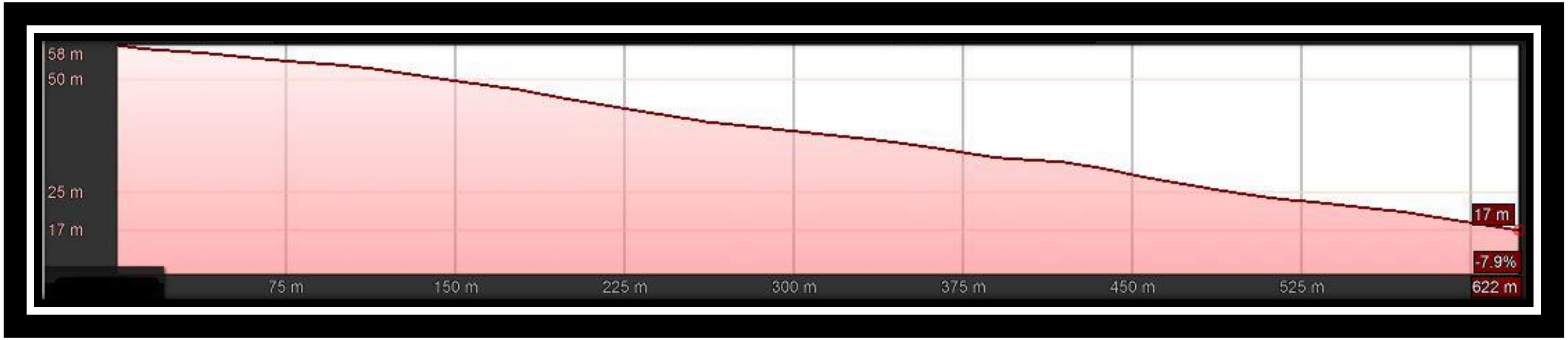
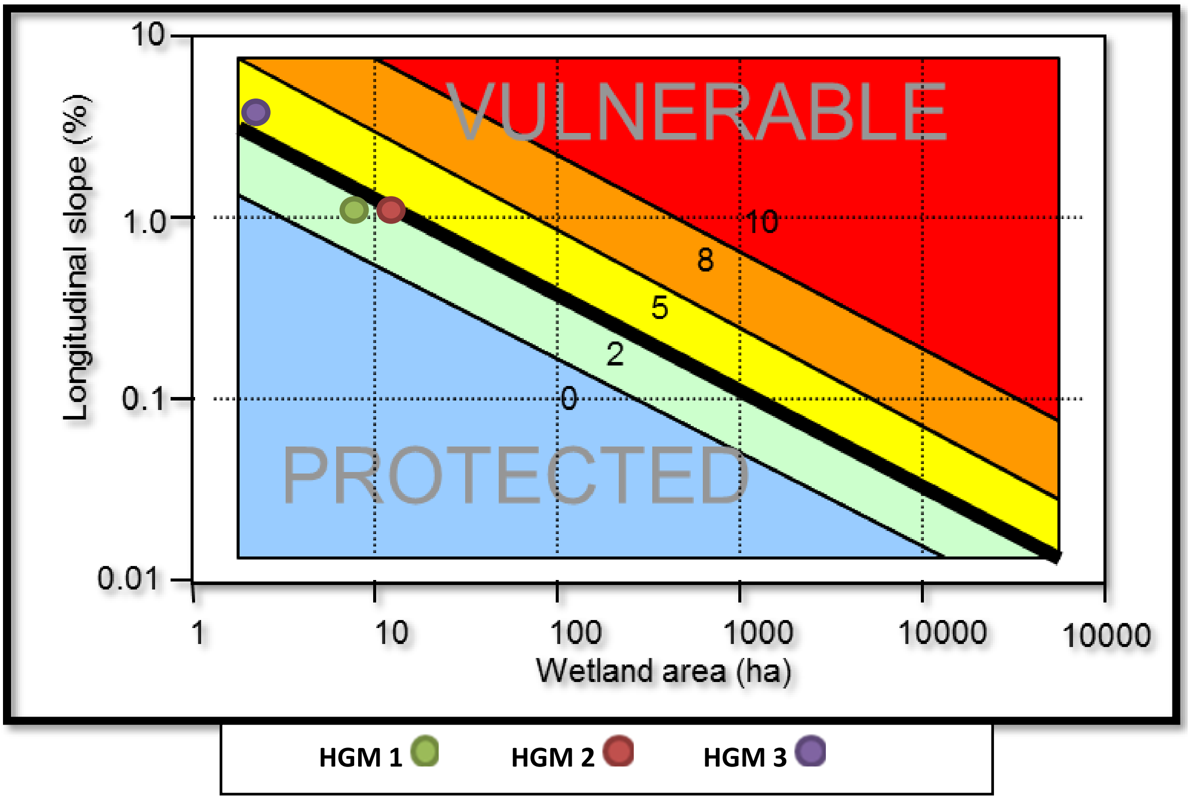


Figure 5.14: Longitudinal profiles of HGM's 1, 2 and 3.

The vulnerability graph above depicts whether the HGM units are under the protected or vulnerable range. Data was extrapolated from Table 5.17 in which wetland area was plotted against the longitudinal slope of the HGM units, hence, determining the vulnerability of the HGM units. All of the HGM units were determined to fall within the protected range.



.

HGM 1, 2 and 3 yielded a vulnerability score of 2, 2 and 5 respectively when plotted against the vulnerability graph. It was determined that HGM 3 slope was the steepest and will experience erosion due to the increased transportation and depositional active mechanisms (Macfarlane *et al*., 2007). Furthermore, HGM's 1 and 2 were determined to be aggradational units, whereas, HGM 3 was determined to be degradational unit.

5.10. EcoServices provided by wetlands

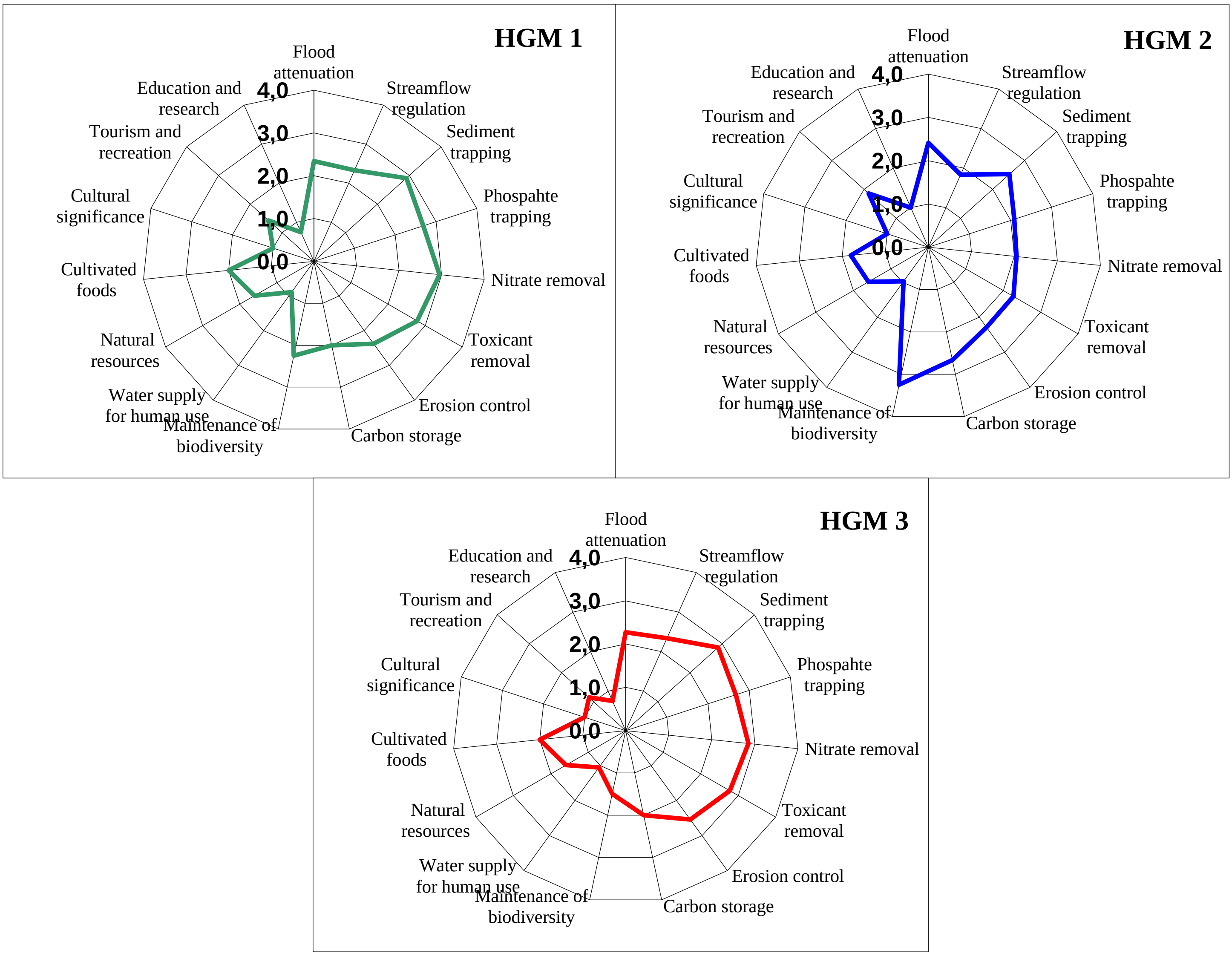


Figure 5.16: Radar diagrams of ecological services provided by the HGM units.

WET-EcoServices refers to the goods and services provided by wetland environments. The goods and services provided by wetlands are influenced by the conditions of the wetland environments, therefore, some goods and services may be more substantially provided in comparison to other goods and services (Kotze *et al*., 2008). The main services that wetland environments provide are represented in the radar or spider diagrams above and can be split into physical environment goods and services (such as streamflow regulation, toxicant removal and carbon storage) and, socio-cultural goods and services (such as cultivated foods, tourism and recreation and water supply for human use).

From Figure 5.16, it is clear that the physical environmental goods and services are substantially provided in comparison to the socio-cultural goods and services of HGM's 1, 2 and 3. For HGM 1 and 3 streamflow regulation and flood attenuation (2.3) scores are similar and so is the sediment trapping (2.9), phosphate trapping (2.7), nitrate removal (3.0 and 2.9), toxicant removal (2.8), erosion control (2.4 and 2.5) and carbon storage (2.0). However, a clear difference between maintenance of biodiversity and water supply to humans exist which are (2.3 and 0.9) for HGM 1 and (1.5 and 1.1) for HGM 2 respectively. All other socio-cultural goods and services such as natural resources, cultivated foods, cultural significance, tourism and recreation and, education and research were all the same scores (see appendix Table 9.7). The main reason for such similar physical and socio-cultural goods and services provided by HGM 1 and 3 is due to their presence in similar environment conditions (Kotze *et al*., 2008).

HGM 2 ecological services reflected similar socio-cultural goods and services as HGM 1 and 2 in which scored education and researched (1.0), tourism and recreation (1.9) and cultural significance (1) (see appendix Table 9.7). However, maintenance of biodiversity (3.3) differed from HGM 3 but was similar to HGM 1 as these HGM units were identified as NFEPA's (Nel *et al*., 2011). HGM 2 supplied substantial physical environment goods and services which scored sediment and phosphate trapping (2.5 and 2.1), nitrate and toxicant removal (2.1 and 2.3) and carbon storage (2.7) (see appendix Table 9.7).

It can be concluded that all HGM units provide imperative physical environmental goods and services, however, the socio-cultural goods and services are relatively poor for all HGM units besides the maintenance of biodiversity for HGM's 1 and 2 which were identified as NFEPA's (Nel *et al*., 2011).

5.11. Functional Health Assessment

5.11.1. Hydrology

The HGM units hydrology refers to the modification in the distribution and movement of water within wetland soils and the environment which is influenced due to activities that occur in the catchment and within the wetland environment itself which in turn has the ability to alter water distribution and retention in wetland environments (Macfarlane *et al*., 2007).

Table 5.18 depicts HGM's 1, 2 and 3 hydrological health in terms of categories ranging from A-F and PES scores, the area of HGM units and trajectory of change.

Table 5.18: Hydrology Health Status.

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	9.57	4.0	D	(-1) ↓
2	22.20	3.5	C	(0) →
3	2.43	8.0	F	(-1) ↓

HGM units 1, 2 and 3 scored PES scores of D, C and F respectively. As a result of the impacted wetland hydrology, a score of D for HGM 1 was obtained, approximately 50% of the integrity of the hydrological regime has been modified. HGM 2 experienced a slightly less detrimental effect to the hydrological regime and HGM 3 experienced the most detrimental impacts on the hydrological regime with approximately 80% hydrological functioning loss in this wetland system.

The trajectory of change analysis for HGM 2 indicates that it will remain stable for the next five years, whereas the trajectory of change for HGM's 1 and 3 shows that they will experience a slight deterioration in the next five years. This suggests that these wetlands' hydrology may further degrade over the years.

5.11.2. Geomorphology

The HGM unit's geomorphological health refers to the sediments distribution and preservation patterns within the wetland. A HGM unit's geomorphological health is influenced by factors such as increased sediment input, loss of organic matter and loss of mineralogical sediment (Macfarlane *et al*., 2007).

Table 5.19 depicts HGM's 1, 2 and 3 geomorphological health status in terms of categories ranging from A-F and PES scores, the area of HGM units and trajectory of change.

Table 5.19: Geomorphological Health Status.

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	9.57	0.7	A	(0) →
2	22.20	0.4	A	(0) →
3	2.43	1.2	B	(-1) ↓

HGM's 1, 2 and 3 represented fairly good geomorphological PES scores which were A, A and B respectively. HGM's 1 and 2 were unmodified and fairly in its natural condition with regards to geomorphic state. HGM 3 experienced slight modification of approximately 10-15% to its geomorphic state as a result of activities occurring with the wetland environment.

The trajectory of change for HGM's 1 and 2 shows that they will remain the same over the next five years, whereas HGM 3 may experience a slight deterioration over the next five years and will experience degradation to the geomorphic state in this time period.

5.11.3. Vegetation

The HGM's vegetation health refers to the structure and composition of vegetation within the wetland environment which is influenced by factors such as historical impacts and current anthropogenic activities and transformation occurring within and around HGM units.

Table 5.20 depicts HGM's 1, 2 and 3 vegetation health in terms of categories ranging from A-F and PES scores, the area of HGM units and trajectory of change.

Table 5.20: Vegetation Health Status.

HGM UNIT	AREA (Ha)	PES SCORE	PES CATEGORY	TRAJECTORY OF CHANGE
1	9.57	5.8	D	(-1) ↓
2	22.20	3.5	C	(0) →
3	2.43	6.4	E	(-1) ↓

HGM's 1, 2 and 3 all experience impacts to the vegetation state with PES scores of D, C and E respectively. HGM 1 experienced a detrimental deterioration of approximately 50%, HGM 2 experienced a relatively better change in the vegetation state with approximately 20-30% of its state being changed (moderately altered) and HGM 3 was impacted the most with regards to the vegetation state, with a 60-75% deterioration to its vegetation state.

The trajectory of change for HGM 2 will remain the same over the next five years, whereas HGM's 1 and 3 will experience a slight deterioration in its vegetation state over the next five years.

5.11.4. Overall Health Status of HGM units

Table 5.21 depicts the overall PES scores for each HGM units hydrological, geomorphological and vegetation health status and their hectare equivalence of healthy wetlands as well as the area of wetlands that have been lost in terms of its functionality (Scores were obtained from Tables 5.18 – 5.20).

Table 5.21: Overall health status and hectare equivalence of HGM’s 1, 2 and 3

HGM UNIT	AREA (Ha)	OVERALL PES SCORE	PES CATEGORY	HEALTHY WETLAND (Ha)	LOSS OF WETLAND (Ha) (HECTARE EQUIVALENCE)
1	9.57	3.57	C	6.1535	3.4165
2	22.2	2.61	C	16.4058	5.7942
3	2.43	5.60	D	1.0692	1.3608
TOTAL	34.2			23.6285	10.5715

The overall PES scores were determined and HGM’s 1, 2 and 3 were established to be categories C, C and D respectively. Hectare equivalence was calculated for each wetland and it was determined that HGM 1 had 6.1535 Ha of healthy wetland and 3.4165 of loss of wetland, HGM 2 had 16.4058 of healthy wetland and 5.7942 of loss of wetland and HGM 3 had 1.0692 of healthy wetland and 1.3608 of loss of wetland. It can be determined that HGM 2 was the healthiest from the three HGM units with a 73.9% healthy wetland as compared to HGM’s 1 and 3 which were 64.3% and 44% respectively. HGM 3 was determined to have the greatest loss of wetland percentage of 66%.

In conclusion, it was determined that the HGM’s assessed in the Sezela study area provided healthy wetlands of 23.6285 Ha and loss of wetlands of 10.5715 Ha.

5.12. Conclusion

The results presented in chapter five depicted above have indicated the sediment dynamics and pollution status of the Sezela estuary and river systems. Furthermore, wetland environments were identified by their hydrogeomorphic features, identification of the different hydrological zones are presented, the ecological goods and services that these wetlands provide and their functional health status was established. The results obtained from this chapter are further discussed in Chapter 6.

6. DISCUSSION

6.1. Introduction

The discussion chapter offers a comprehensive explanation of chapter 5 (Results). The estuary section is first represented with emphasis on sediment dynamics, organic matter and calcium carbonate content in the Sezela estuary and further, the river environment. Thereafter, sediment and water quality is explained. The wetland section comprehensively explains classification of different zones of the wetland environment centred on soil profiles and vegetation observed. Thereafter, vulnerability of the wetlands is discussed, and the section concludes with the reasoning of the ecological services and functional health status of the Sezela wetlands.

Characteristics of the Sezela estuarine aquatic system

6.2. Sediment dynamics of the study area

As seen in Figure 5.1 and 5.2 for the summer and winter sampling periods, sampling site SE1 falls under the sand zone in the ternary plot. Although this site is in close proximity to the mouth of the estuary and sediment usually is of an extremely fine nature such as silt and mud, wave overwash can cause sediment texture to be of a coarser nature in the estuarine environment (Whitfield and Bate, 2007).

Sampling stations SE2 and SE3 for the summer and winter sampling periods yielded similar sediment textural types for both periods, however, from the summer to the winter sampling period sediments became coarser. This could be a direct result of the mouth of the estuary not being naturally breached often which prevents flushing of the system of the coarse marine sediment. The sediment at these stations were identified as sandy-gravel which originated from the marine environment due to sediment overwash over a prolonged period of time (as per Whitfield and Bate, 2007; Theron, 2004a and b).

Sampling station SW5 was located 2.14 km away from the estuary environment and within the Sezela river sediment texture. The river dominated sediment was of a gravelly-sand texture in both seasons derived directly from the weathering of the exposed sandstone bedrock and soils of the catchment.

It can therefore be deduced that Figures 5.1 and 5.2 were not of typical environmental conditions compared to sampling station SE1 which was in close proximity to the mouth of the estuary and which revealed a sandy bed. The sediment at sampling stations SE2 and SE3, were of a coarser nature at the upper reaches of the estuary as a result of eroded catchment sediment and the lack of breaching of the estuarine mouth to flush out coarse sediment into the marine environment. Sampling station SW5 was furthest from the estuary, with river-dominated sediment composition.

6.3. Variation of sediment grain sizes

Sediment grain size distribution is dependent on a number of factors such as parent material, weathering history, transport processes and depositional environment. In some cases, grain size can show information about diagenetic processes. Sand-size distribution is of interest here due to the high percentage which can be seen in Figures 5.1 and 5.2 and Tables 5.1 and 5.2. According to Moss (1962), sand grain sizes can be found in three different populations such as the coarse tail, fine tail and, the central and generally the most abundant part of the distribution which is known to be the most well sorted from all populations. Moss (1962) and Folk and Ward (1957), also stated that the general statistical connection are observed among diverse size statistics, such as mean, sorting and skewness. However, size and sorting is known to have the best statistical relationship and according to Griffiths (1967); fine sands are the best sorted sediments.

Grain size also is indicative of energy conditions during transport and deposition. Estuarine sediment are known to be poorly sorted with positive skewness as indicated in Figure 5.3. Sampling site SE1, however, the sediment is well sorted which is not indicative of estuarine sediment due sediment overwash of well sorted marine sediment and the lack of breaching of the mouth. Sampling points SE2 and SE3 are more indicative of an estuarine environment with moderately to poorly sorted sediment, however, these points are negatively skewed which are not indicative of estuarine environments with breached mouths (Whitfield and Bate, 2007; Theron, 2004a and b). Sampling point SW5 was found to be symmetrically skewed and well sorted as a result of persistent depositional and transportation mechanisms occurring in this area and the derived parent material. The sorting and skewness achieved by SW5 is typical of riverine conditions.

Furthermore, the variation of sediment grain sizes were similar for both the summer and winter sampling periods with a noticeable difference in only the sorting for sampling sites SE2 and SE3 as a result of the poor transportation mechanisms achieved in the low energy estuarine environment (Whitfield and Bate, 2007; Theron, 2004a and b).

6.4. Competence of river discharge to entrain bed sediments

According Engelund and Eggert (1972), sediments that are located on the bed of river will begin to move when the intensity of river flow is increased. Therefore, depending on the increase in intensity of flow velocity achieved, certain grain size sediments can be transported, re-worked and deposited into further reaches. Furthermore, this determines the maximum sediment size that a river, stream or estuary can carry reflected in the flow competence, which therefore gives a direct proportional relationship between sediment size and flow velocity (Leopold *et al*., 1964).

The Sezela estuary and river environment closely resembles estuarine and riverine conditions at the different sampling points. Therefore, at certain reaches it does experience the tidal effects throughout an entire day. The incidence of high percentage of coarse sand which is shown in Figure 5.1 and 5.2 and some gravel percentages are due to sediment overwash from the marine environment, and lack of breaching of the mouth. Although the estuarine environment should be able to carry silt, mud and certain sand sized particles, it is unable to do so in certain areas of the estuary due to the nature of coarse sediment burying the finer particles and the inability of the system to transport the coarse sediment (Engelund and Eggert, 1972). In addition, spring tides could have moved heavy beach sediment from the marine environment into the mouth of the estuary to the upper reaches which is reflective in the higher mean values experienced at SE2 and SE3.

Therefore, it can be deduced that the flow competence of the Sezela estuary is low velocity and can transport and deposit sediment sizes such as silts, mud's and fine sand grain sizes. However, due to wave wash-over, estuarine muds are buried under the marine sediment which is too heavy to transport and deposit due to low flow competence. However, spring tides could be accountable for the transporting of the heavy beach sediment which is shown in Table 5.3 and 5.4 in the increased mean and median respectively at sampling points SE2 and SE3.

6.5. River capacity and sediments transportation

Movement of sediment is dependent on grain size. Rolling and sliding on the sediment bed is the usual movement of sediments larger than sand grains or very coarse sand in the presence of water. However, sand grains that are not very coarse can also roll and slide along the sediment bed, but mainly in a succession of fairly short leaps and hops. According to Schnurrenberger *et al* (2003) when shear stress or velocity increases, the leaps and hops that sand grains become more irregular and longer as seen in Table 5.3 and 5.4 with the increased mean and median in sampling stations SE2 and SE3 from sampling station SE1. Therefore, increased flow strength would increase intensity of turbulence close to the bed, further increasing settling velocity of sediment, as sediments would be carried from SE3 and deposited at SE1 due to a decrease in turbulence intensity at the latter site, hence as well the increased skewness seen in Figure 5.3. Therefore, sediment capacity which passes certain points in the Sezela estuary and river depends the volume of sediment that is carried by a certain flow rate; and not the local hydraulics. Hydraulic conditions are known to be restricted by rate of sediment supply (Raudkivi, 1976).

6.6. Association of organic matter and calcium carbonate in mangrove communities

Organic matter and calcium carbonate are found in estuarine and riverine environments due to several factors. Organic matter is found in muds due to branches that break into the waterways of estuary and river environments. However, muds are known to be packed and have very poor spacing in between them, hence, oxygen content is typically poor. Bacteria can break down dead organic matter which can be taken up by many surrounding organisms; hence estuarine areas are usually rich in different organisms and species (Kinjo and Shimo, 2005).

However, organic matter content within the Sezela estuarine and riverine environments was low possibly due to low rates of supply and to rapid decomposition rates. Furthermore, this decrease could be due to the fact that muds are not predominant in all samples stations as seen in Figures 5.1 and 5.2 thus reducing the potential for incorporation into the fine sediments. In addition, the drop in organic matter at sampling station SE1 during the summer sampling period could be due to increase salinity levels as shown in Figure 5.10, since a direct relationship exists between salinity and organic matter (Kinjo and Shimo, 2005).

On the other hand, calcium carbonate can exist in over-washed marine shells which take a longer period to decompose, in benthic organisms that exists in the region and also due to the mixing of marine carbonate and terrestrial siliclastic material (Davies and Abowei, 2009). However, sampling points SE1, SE2 and SE3 revealed low calcium carbonate content as there was a lack of macro invertebrate crustaceans and the lack of submerged macrophytes in the estuarine environment. SW5 proved to have a higher calcium carbonate content due to macrophytes present in this riverine site (Davies and Abowei, 2009).

Organic matter content is also known to be linked to the amount of mud present in sediment. Sediments that are fine are known to have larger surface areas than coarse sediments enabling greater absorbtion of dissolved organic matter from sedimentary complexes. Furthermore, incorporation of organic matter can be accomplished into the bottom complexes once deposited (Griggs, 1975). According to Griggs (1975), sediment with organic matter values that exceed 1% are known to be organically rich. Data in Figure 5.4 indicates that none of the sampling sites reach a percentage of one, hence, the sampling stations are not organically rich. Therefore, it is clear that finer fractions of sediments are able to store more organic matter than larger sediments. Figures 5.1 and 5.2 reveal that sediment present are not of a totally fine nature in the estuary and river (Davies and Abowei, 2009).

Therefore, percentages of calcium carbonate were higher than organic matter due to the longer breakdown of this element compared to the easier breakdown and decrease of organic matter content via many pathways.

6.7. Water quality in the Sezela estuary and river systems

In aquatic ecosystems, two microbial groups exist; environmental microbes and those associated with human and animal waste. The presence of environmental microbes in coastal waters is usually quantitively high due to the interaction of all organisms in this water body (Singh and Lin, 2015). Furthermore, environmental microbes play a pivotal role in aquatic ecosystems that ensures a healthy environment by processes such as cycling of energy, carbon and nutrients. Conversely, the presence of faecal microbes into the environment are typically in a form of contamination. The main reasons to determine microbial concentrations is to establish if the contamination is recent and its potential effect on human users of the aquatic ecosystem. Faecal coliforms were analysed due to its presence in the intestinal tract of humans and warm blooded mammals. Furthermore, faecal streptococci is known to not rapidly die off in saline waters in comparison to other *in-situ* microbes, hence, it is a good determinant of faecal pollution (Buckalew *et al.,* 2006; Singh and Lin, 2015).

The summer and winter surveys revealed that the *E coli* and *Streptococcus* sp. did not impact the quality of the aquatic ecosystem through faecal pollution. However, stations SE1 and SE3 proved to have a minor effect with regards to *Streptococcus* sp. at these stations, hence, the possibility of a gastrointestinal infection could occur to humans that are water body users but is unlikely. Although it was determined the Sezela estuary was predominantly user water friendly past studies by Begg (1978) determined high faecal levels in the waters. In addition water pollution was high due to nutrient and metal concentrations (Begg, 1978). Since that study, no further work has been done on this estuary until the present study.

Nutrients in aquatic ecosystems play a pivotal role for microalgal growth which is essential for the functioning of an aquatic system (Harrison, 2004; Whitfield and Bate, 2007). Nutrients such as nitrogen and phosphorus are vital indicators of water quality in aquatic ecosystems and play an essential role in the growth of plants in estuaries. The introduction of nutrients through natural processes are directly from animal waste that enters estuaries, rivers or streams and runoff from the presence of geological lithologies which are rich in nutrients. Human induced introduction of nutrients into the aquatic ecosystems are from industrial waste waters, fertilizer runoff from catchment areas and residential waste. The excessive amounts of nutrients in waters can be a nuisance which can cause eutrophication and hypoxic conditions (DWAF, 1996a).

The nutrients in the Sezela estuary, especially ammonia fell within the TWQR. Although it could not be determined if nitrite, nitrate and orthophosphate caused a nuisance to the environment, the DO concentrations were below the TWQR suggesting an excess of nutrients were present. However, due to ammonia falling within the TWQR and no algal blooms or eutrophic conditions present, the excess of nutrients in the water was unlikely the case (DWAF, 1996a).

Physical chemical parameters in aquatic waters help determine the healthy functioning of this ecosystem. Parameters such as DO, electrical conductivity and total dissolved solids, pH and salinity all play a major role in aquatic ecosystems (Sukdeo, 2010). Dissolved oxygen is the most fundamental parameter of all as it maintains balance of organism in aquatic ecosystems. Dissolved oxygen concentrations are higher at the surface due to its close interaction with the atmosphere. Temperature and salinity affect DO concentrations as colder and less saline waters will produce higher concentrations in comparison to warmer more saline waters (Sukdeo, 2010; DWAF, 1996a). Total dissolved solids play a pivotal role in ecosystems as in some cases an excess of oxygen can cause algal blooms which can be detrimental in the long-term. The ability of total dissolved solids is essential in depleting oxygen in these cases but sometimes is not favourable in cases where oxygen levels reach hypoxia anoxia (DWAF, 1996a). Salinity and pH refers to the concentrations of salts in water and the negative logarithm (base 10) of the chemical activity of the solution of hydrogen ion. The presence of salinity in aquatic environments can determine the composition of species in certain areas, especially macro invertebrates. The pH levels in marine waters are fairly stable and range between 7.5-8.5. pH levels below 7 bring about acidic conditions which are not favourable environmental conditions. pH levels can be slightly more basic (above 7) rather than acidic in aquatic ecosystems (DWAF, 1996a).

Dissolved oxygen (DO) is one of the most important parameters that need to be available in waters in order for organisms to survive is). According to DWAF (1996a), unpolluted aquatic waters will be within the TWQR of 80-120% and also have TDS values of around 9.09 mg/L at 20^{0}C, which shows it is dependent on temperature. The DO concentrations and % saturation was below the TWQR as seen in Figure 5.8 and Table 5.15, which gives rise to the scarcity of aquatic biota present in the estuarine environment and the sampling river stations further upstream. Furthermore, TDS results as seen in Table 5.16 are of a high concentration which could result further in the detriment of DO concentration as DO can be reduced chemically through the oxygen scavenging attributes of TDS (Whitfield and Bate, 2007; DWAF, 1996a).

The pH levels in summer and winter revealed a more alkaline condition, thus, metal availability in the water was low. Conditions were not acidic which accounted for the inability of the ICP-OES to detect metals in the water. Furthermore, alkaline pH levels could arise from the photosynthetic process which removes carbon dioxide and releases oxygen back in the water. *Phragmites australis* may utilize available carbon dioxide preventing carbonic acid buildup thereby reducing the pH levels. The alkaline pH levels were not due to algal blooms as the presence of excessive nutrients were limited and absence supported by visual observation (DWAF, 1995).

The salinity levels at the mouth during the summer sampling period at station SE1 was typical of estuarine conditions at that point (as seen in Figure 5.10). However, the remaining stations proved to be more freshwater influenced. This could be attributed due to the estuary not breaching regularly and experiencing a more freshwater influence. Station SW5 was typically of riverine salinity as seen in Figure 5.10 (van Niekerk *et al*., 2005).

Metals play an important role in aquatic ecosystems, especially copper, iron and zinc which are important for living tissues physiological functioning. However, metals at high concentrations are toxic to aquatic ecosystems and should only be in trace amounts. Metals such as mercury are not known to have any biological function, hence, this metal can be toxic even at low concentrations. Therefore, the monitoring of metals is important due to the carcinogenic and toxic effects of metals in aquatic ecosystems which can be detrimental to the environment in the short and long term (DWAF, 1996a).

Metal has the ability to acutely and chronically affect organisms in aquatic ecosystems. Besides reproductive complications, the concentration of metal in its methylated form can increase at trophic level of organisms (where fish reside), thus, becoming toxic for human consumption (DWAF, 1996a).

The non-detectable concentrations of cadmium, copper, iron, lead, manganese, mercury and zinc were possibly due to the favourable alkaline conditions in the waters. Furthermore, this is indicative that the water was not polluted anthropogenically by an excess of metals (DWAF, 1996a).

Therefore, it can be said that the Sezela estuary is not entirely in compliance with TWQR of DWAF, however, the waters were not polluted by an excess of nutrients or metals. The lack of DO in the water was particularly a major problem as those conditions were not conducive for living organisms.

6.8. Sediment quality in the Sezela estuary and river systems

The sediment quality with regards to metals has similar effect on water, however, the ability of sediment to accumulate metals instead of them dissolving in a water column makes them detrimental to bottom-dwelling organisms if concentrations are at a level which can be toxic.

The metal concentrations obtained for the summer and winter sampling periods were superimposed in a linear regression baseline model with 99% prediction limits (Figure 5.6). The determination of the regression line was accomplished by defining average metal concentrations at each co-occurring iron concentration sampling stations.

The linear regression models revealed that metals copper, manganese and zinc could only be assessed as the other metals were too low to detect by the ICP-OES. Sampling station SW5 which was the river station near to the dam which was influenced by excess metal input as revealed by the regression model. It was noted that manganese and zinc were the metals enriched at sampling station SW5 which could be a direct result of domestic effluent discharge upstream of the river (Newman and Watling, 2007).

The magnitude of enrichment cannot be determined by the baseline model although it offer much insight on assessment and identification of enrichment of metal concentrations.

Therefore, in order to determine the magnitude of metal concentration from the upper prediction limit of the baseline model, the Enrichment Factions (EF) were calculated.

The enrichment factor calculation revealed that with reference to manganese, sediment at station SE2 was in a good condition, whereas sediment at station SW5 for manganese and zinc was in a fair sediment condition (Newman and Watling, 2007; CSIR, 2014).

The South African sediment quality guideline for open water disposal for metals assessed were below the warning level, thus, if the sediment at these sampling stations were removed to the marine environment, the effects would not be detrimental to macro-invertebrate communities (Pelletier *et al*., 2011).

6.9. Macro invertebrates species composition, richness and pollution indicator in the Sezela estuary

The presence or absence of benthic invertebrates is indicative of disturbance or impacts to an aquatic ecosystem which, in turn, can also determine the health status of an aquatic ecosystem (Hiddink *et al*., 2006; Simboura and Zentos, 2002). The presence of different benthic invertebrates are due to natural or anthropogenic changes that can occur in aquatic ecosystems. The species abundance and composition are strongly related to natural occurrences such as sediment grain size, presence of organic matter and the level of salinity in water. Therefore, in systems such as estuaries which experience changes in salinity in the mouth area in comparison to their upper reaches may reflect differences in the composition of benthic invertebrates (Hiddink *et al*., 2006). Benthic invertebrates behave differently to different scenarios and impacts to the area in which they reside. For instance, an area with an excess of organic matter content is conducive for the species known as capitellids to proliferate. On spatial and temporal scales, certain benthic invertebrates are sedentary and cannot move away from adverse effects, hence their distribution and composition are indicative of the sediment and water quality of the area. Other species of benthic invertebrates tend to exist in an area over months and even years, hence, their survival in that specific area under natural and anthropogenic conditions are indicative of the ability of certain species to exist under those conditions (Hiddink *et al*., 2006; Simboura and Zentos, 2002).

The presence of benthic invertebrates in the Sezela estuary were not diverse and abundant due to the low DO concentration and % saturation (as seen in Table 5.15). These DO levels at these stations are likely to cause acute toxic effects on aquatic biota (DWAF, 1996a). The presence of *Oligochaetes* and *Capitilidae capitata* indicates the presence of organic matter in the sediment as these organisms typically thrive in organic rich sediment (Teske and Woolridge, 2001). However, their abundance is low due to the low DO levels in the water. Furthermore, sediment and water quality proved not to be highly enriched by nutrients and metals, therefore, this was not a factor which affected macro-invertebrate composition and abundance. However, the low levels of DO and destruction of biota were due to past actions of discharging effluent and other pollutants into the estuarine environment by the sugar mill leading to a low faunal biodiversity (Begg, 1978).

Characteristics of the Sezela estuarine wetland systems

6.10. Hydrological zones (Permanent, Seasonal and Temporary)

The hydrological zones of wetlands are classified based on the period in which they are submerged by water (Macfarlane *et al.*, 2007). The temporary zone is inundated for less than three months in a year, whereas the seasonal zone is inundated for more than three months a year and the permanent zone remains permanently inundated throughout the year. The zones in a wetland can be identified by different soil and vegetation profiles which are influenced by different characteristics in the different zones (Macfarlane *et al.*, 2007).

6.10.1. Soil Profiles of the Sezela wetlands

Wetland sediment are known to be either allochthonous (mineral in nature) or authochthonous (organic sediment). In the case study of the Sezela wetlands, autochthonous sediment is derived from decomposition of roots and organisms in the wetlands, whereas, allochthonous sediment is derived from erosional activities from the surrounding estuarine and river environments (Maltby and Barker, 2009).

The origins of allochthonous sediment into the Sezela study wetlands are from major catchment areas obtained for all HGM units from high velocity flows of water in the upper catchment which has a steep gradient. As a result of the steep catchment slope, weathering of sediment occurs and gravel size particles are transported into the wetland environments, especially HGM's 1 and 3 (Maltby and Barker, 2009). Alternatively, HGM 2, the floodplain wetland, receives its sediment from the upper catchment but predominantly from HGM's 1 and 3 in which sand, silt and mud reaches this floodplain wetland as the channels in HGM's 1 and 3 lose energy to transport larger loads further downstream into the floodplain wetland. Wetland environments are known to be extremely low energy environments, resulting in even fine materials such as silt and clay particles sinking to the bed of the wetland or alternatively becoming trapped as a result of hydrophyte roots present in the wetland (Maltby and Barker, 2009).

The origins of autochthonous sediments in the Sezela study wetlands are the result of reducing reactions occurring in the wetlands permanent and seasonal zones. The reducing reactions cause anaerobic conditions to occur in the wetland environment as a result of constant saturation, thus, causing rapid decomposition of plant roots and other dead species in the wetland. Furthermore, the aforementioned processes cause the soil in the wetland environment to be enriched in organic matter, producing characteristically dark and loamy soils (Maltby and Barker, 2009).

HGM’s 1, 2 and 3 all experienced enrichment of allochthonous and autochthonous sediment. HGM’s 1 and 3 transported and deposited allochthonous sediment to HGM 2. The origin of authochthonous sediment in all the wetland environments was a direct result of reducing reactions occurring in all HGM units. Furthermore, coarse sediment was transported and deposited into wetland environments from upper catchment areas.

The values that are obtained for matrix and chroma (see appendix Tables 9.1) are related to the leaching of iron and manganese oxides in soil during saturation conditions, which gives rise to the greyish colour of soil. Saturation affects the values of matrix and chroma; when a wetland area is under saturation their matrix and chroma value will drop, therefore, the temporary zone will have the highest matrix and chroma values in contrast to the seasonal and permanent zones (Verpraskas, 1995).

6.11. Vulnerability of wetlands

In South Africa, one of the most vital activities that cause degradation to wetland environments is erosion. The vulnerability of a wetland is recognized when considering headcut erosion as the underlying causative factor of degradation. Therefore, if a wetland is prone to headcut erosion, the more vulnerable the wetland becomes to degradation.

Slope is one of the most important influencing factors of headcut erosion in a wetland, hence, the steeper the slope, the greater the possibility of erosion. Therefore, the relationship between longitudinal slope and area of a wetland determines wetland vulnerability. Scores obtained from the longitudinal slope against area of wetland (Figure 5.15) depicts different scenarios such as a score of 0 reveals no changes and degradation will occur. Vulnerability scores of 2 and 5 reveals a change due to erosion and degradation can occur but will disintegrate after a period of time. Scores of 8 and 10 will incur headcut erosion in wetland environment which will occur rapidly and cause intense degradation.

HGM's 1 and 2 yielded a vulnerability score of 2 and HGM 3 a score of 5 which reveals that the wetlands may experience erosion which should dissipate after a period of time and will not cause substantial damage. Furthermore, the excess sediment accumulated through erosion can be utilized as a substrate for macrophytes revealing one of many ecological services a wetland can provide.

6.12. Ecological services provided by HGM units

The ecological services provided by wetlands can be considered as physical and socio-economic benefits to the surrounding ecosystem and people.

The services that wetlands provide can be affected positively or negatively by various impacts. According to Howe *et al* (1991), the benefits derived from wetlands can be utilized directly or indirectly as attributes and functions which occur in the ecosystem, or future direct and indirect uses or outputs.

The Sezela study site wetland provided several ecological services which were discussed in Chapter 5, the reasons for the provisions of services supplied by these wetlands is further discussed below.

6.12.1. Flood Attenuation

The dispersion and weakening of flood waters to ensure floods downstream are decreased and do not cause severe damage to surrounding environments refers to flood attenuation. Flood attenuation is an important ecological service, especially for humans which reside downstream of a wetland, as the wetland environment attenuates upstream flood waters which could have impacted human settlements downstream.

Size of HGM unit relative to its catchment

The greater the size of an HGM unit relative to its catchment, the greater its ability to attenuate flood waters which are travelling from the catchment areas of the wetland (Kotze *et al*., 2007). Therefore, HGM 2 has the have the highest ability to attenuate flood waters in comparison to HGM's 1 and 3 due to its size relative to its catchment area.

Slope of the HGM unit

Slope in an HGM unit impacts the flow of water as a steeper slope will rapidly move water downstream as compared to a gentle slope which will attenuate the flow of water (Kotze *et al*., 2007).

HGM 1 has the gentlest slope of (1.2%), hence, having the greatest ability to attenuate flood waters. HGM 3 has the lowest ability to attenuate flood waters as a result of its steep slope of 6.6%. HGM 2 has a similar ability to attenuate flood waters as this HGM unit has a slope of 2% and is also a floodplain wetland which has a good ability to attenuate flood waters. The wetland environments are left largely natural, however extensive agriculture of sugarcane plantation around HGM's 1 and 3 could lead to rapid entry of water in these HGM units causing erosion and degradation, especially in HGM 3, which has a steeper slope.

Surface roughness

The surface roughness of a wetland plays a pivotal role in attenuating flood waters as surface roughness acts as a frictional resistance to the flow of water (Adamus *et al*., 2001). The surface roughness in a wetland is determined by the amount and type of vegetation. Furthermore, minor vegetation covered earth mounds (hummocks) can also contribute substantially to the surface roughness in wetland environments,

The surface roughness in all HGM units are similar as all units are well vegetated and have a good ability to attenuate flood waters and resist rapid flow of water. However, HGM's 1 and 3 experienced a slight decrease in surface roughness as small amounts of vegetation have been removed for sugarcane agriculture. Furthermore, a small bridge has been built towards the south boundary of HGM 3 which causes rapid movement of water at this point in the HGM unit.

Frequency with which storm flows are spread across HGM unit

The ability of a wetland to attenuate a flood will be greater if storm flows exceed the channels capacity through a wetland, hence dispersing water throughout the HGM unit to attenuate possible storm flows. Conversely, if storm flows are confined to a channel in a water passing through a HGM unit, the ability of the wetland to attenuate floods are lowered.

HGM 2 being a floodplain wetland experiences high frequency of storm flows which spread across the floodplain of wetlands, hence, the ability to attenuate flood waters are high. HGM's 1 and 3 being channelled valley bottom wetlands do not experience storm flows frequently throughout the HGM unit as flood waters are sometimes confined to the channel, therefore, the ability to attenuate floods is less in these units.

Sinuosity of the stream channel

The more sinuous a stream channel, the gentler the slope is, hence, the flow of water into the wetland will be of a slower.

HGM's 1 and 3 are channelled valley bottom wetlands with moderate sinuosity, HGM 1 has a gentler slope in comparison to HGM 3 therefore, HGM's 1 will have a better ability to attenuate flood waters in comparison to HGM 3. HGM 2 being a floodplain wetland has a moderate sinuosity as well but its ability to attenuate floods are much higher than HGM's 1 and 3 due to it being a floodplain wetland.

Hydrological zonation

Wetlands that are continuously inundated or inundated before a flooding event can occur, has a lower ability to attenuate receiving flood waters in comparison to a wetland that is not continuously inundated or in a dry state. Therefore, permanent and seasonal zone dominated wetlands will predominantly be in a wet state in comparison to temporary dominated wetlands which are in a dry state (McCartney *et al*., 1998).

From analysis of wetland environments in Chapter 5 it was revealed that HGM 2 was a Floodplain wetland which is permanently inundated in certain areas. HGM's 1 and 3 had permanent, seasonal and temporary zones. As a result of these zones being present in the wetland, HGM's 1 and 3 would be more effective to attenuate floods, however, a floodplain wetland also has the ability to attenuate floods due to its stand of dense macrophyte vegetation present and its capacity to carry water (Macfarlane *et al*., 2007).

Slope of the catchment

Catchment and wetland slopes are similar as the steeper the slope, the faster runoff and runoff intensity will increase flood potential (Kotze *et al*., 2007).

The slope of the Sezela study wetland was calculated to be 5%. As a result of the moderate catchment slope, runoff will occur at a moderate rate and will reach the HGM units faster which does not entirely aid in the attenuation of flood waters.

Inherent runoff potential of soils

If the runoff potential in the wetland is of a great amount, the ability of water will therefore runoff in a greater manner; if the runoff potential in a wetland is of a lesser magnitude, runoff is lessened and infiltration is increased which aids in the flood attenuation ability of the wetland (Schulze *et al*., 1989).

HGM's 1, 2 and 3 revealed moderate runoff potentials, which in turn will result in moderately-low infiltration rates, hence, the flood attenuation with this factor will result in a moderate attenuation for all HGM units.

Effects of land use on runoff intensity

The usage of land in the catchment of a wetland will always have an important effect and influence on the runoff intensity in a wetland environment (Schulze *et al*., 1989).

There are four main activities in the catchment that affect runoff intensity (Schulze *et al*., 1989; Neal, 1998) :

- Poor agricultural practices;
- Poor veld condition;
- The presence of buildings, footpaths and roads have the ability to hardened surfaces;
- Dams and flood retention basins which decrease the runoff intensity.

HGM's 1 and 3 are impacted by poor conservation practices, veld conditions that are poor and presence of hardened surfaces, in which the ability to attenuate floods are reduced. HGM's 1 and 3 are affected similarly due to the sugarcane plantation surrounding the wetland environment which promotes the aforementioned impacts. Conversely, HGM 2 does not experience the aforementioned impacts on HGM's 1 and 3, however, due to a lack of dams in the area attenuating flood waters in not entirely reduced by HGM 2, which occurs in HGM's 1 and 3. Furthermore, the building of the bridge at the south boundary of HGM 3 exacerbates the runoff intensity and increases poor infiltration in this unit.

Rainfall intensity

Rainfall in South Africa can cause storm flows, in which the amount of rain is not as important as the intensity of rain with regards to flood attenuation. According to Kotze *et al* (2007), rainfall intensity zones are allocated in South Africa, in which Zone I (lowest rainfall intensity) to Zone IV (highest rainfall intensity).

The Sezela study area falls within the highest rainfall intensity zone which is Zone IV, hence, the area's ability to attenuate floods during rainfall intensity is low.

Extent of floodable infrastructure downstream of the HGM

If property downstream of an HGM unit is susceptible to flooding events, the HGM unit will be of utmost value to attenuate floods.

There are no floodable infrastructure downstream of any of the HGM units, hence, this condition does not apply for these units.

6.12.2. Stream Flow Regulation

Stream flow regulation refers to the assistance of a wetland downstream when low flows are present. Wetlands are known to not generate water and utilise water for processes such as evaporation and transpiration. Due to the process that occur in wetlands, the ability to provide water during low flow periods is not definite, however, due to the positioning of certain wetlands relative to catchment processes, wetlands are able to control the movement of water in catchment areas, particularly in cases when subsurface water is discharged into surface waters (Kotze *et al*., 2007).

The factors that influence wetlands stream flow regulation are discussed below

Hydrological zonation of HGM units

The hydrological zonation of HGM units are pivotal indicators in determining the ability of a HGM to discharge water in a stream network. A HGM unit which is predominantly permanently wet for prolonged periods of time will discharge water more efficiently in comparison to a seasonally or temporarily wet HGM into a stream network.

HGM's 1, 2 and 3 all contribute water to a stream network from their hydrological zones as permanently wet zones are prevalent in all HGM units.

Presence of any important aquatic systems downstream

The stream flow regulation becomes an imperative factor when there are important aquatic systems downstream.

It was established that HGM 1 and 3 both had important aquatic system downstream conferring the Sezela estuary as a National Freshwater Ecosystem Priority Area. Hence, the stream flow regulation plays an imperative role from HGM's 1 and 3 into HGM 2 which should be of a good standard when entering HGM 2.

6.12.3. Sediment trapping

Sediment trapping refers to the delivery of sediment into a HGM unit as a result of runoff waters, and the ability of the wetland to retain and trap the sediment (Kotze *et al*., 2007).

The factors that influence a HGM to trap sediment are discussed below.

Effectiveness in attenuating floods

Runoff waters are a source of sediment input into HGM units. If runoff waters containing sediment is slowed down, an increased amount of sediment will enter a HGM unit. Hence, if a HGM is able to attenuate flood waters effectively, it is therefore effective in trapping sediment as well (Kotze *et al*., 2007).

HGM's 1, 2 and 3 have a moderate flood attenuation ability, hence, since sediment trapping and flood attenuation are directly related, their ability to trap sediment will be the same.

Direct evidence of sediment deposition in the HGM unit

There was direct evidence of sediment deposition in HGM's 1 and 3 as the vegetation present had sediment particles deposited on them. Conversely, HGM 2 did not have much evidence of sediment deposition, however, due to the nature of the floodplain wetland which works with tides, the sediment could be taken up by the river system as tides were rising and lowering.

Reduction in sediment inputs from the catchment

If an area of where a wetland is presence has impeding structures such as dams and walls which hold back sediment which can be delivered to a HGM unit, the ability of the HGM unit to trap sediment will be reduced (Kotze *et al*., 2007).

In the Sezela wetland study site, there were no dams or impeding structure which could have held back the delivery of sediment into the HGM units, hence, the effect of these structures are negligible to these wetlands.

Extent of sources of increased sediment in the catchment

The closer and the larger sediment input of sediment from a HGM unit's catchment, the ability of the HGM to trap sediment is greatly increased (Kotze *et al*., 2007).

The ability of all HGM units receive sediment input is great as they are in close proximity to agricultural fields (sugarcane plantation) and dirt roads which deliver sediment into the HGM unit. HGM's 1 and 3 experience more direct delivery of sediment from agricultural practices and dirt roads in comparison to HGM 2, however, HGM 2 does experience a moderate amount of sediment delivery, hence, the ability of all HGM units to trap sediment were enhanced.

6.12.4. Phosphate trapping, nitrate and toxicant removal

Due to the amount of commercial sugarcane plantation around HGM's 1 and 3, the trapping of phosphates is enhanced as a result of catchment delivery. Nitrate and toxicant removal is enhanced as a result of the biocides and herbicides utilised in the sugarcane plantation. Conversely, HGM 2 does not experience high amounts of phosphate trapping, nitrate and toxicant removal as a result of its location a fair distance away from the commercial sugarcane plantation. However, delivery of sources of phosphates, nitrates and toxicants from the catchment do enhance the ability of the HGM unit to trap phosphates and remove nitrate and toxicants.

6.12.5. Carbon storage

Wetlands are generally a good sink for carbon as a result of the activities that occur in wetland and the floral ability to trap carbon. As a result of continuous waterlogged conditions in wetlands, decomposition of organic matter occurs at a slow rate, hence, a wetlands ability to store organic carbon is at a high capacity (Roulet, 2000).

Factors that influence a wetlands ability to store carbon are discussed below.

Hydrological zonation

The build-up of organic matter is a direct result of the waterlogged conditions experienced which encourages slower rates of organic matter decomposition.

All HGM units in the Sezela study site consisted of large areas of permanent zones which were waterlogged, hence, the ability of the wetlands to store carbon was enhanced.

Abundance of peat

Peat is strongly related to organic matter as it has an abundance of organic matter in it. If peat is present in an HGM unit, the ability of the HGM unit to trap carbon will be enhanced (Roulet, 2000).

The absence of peat in all HGM units rendered this factor negligible.

Disturbance of soils

If soil is disturbed due to human induced anthropogenic activities, soil exposure to the atmosphere will directly lead to the reduction of organic matter, hence the ability of a wetland to store carbon is reduced (Miles and Manson, 1992).

The disturbance of soils in HGM 2 was not evident, hence, the ability of the HGM unit to act as a carbon sink not disturbed. Conversely, HGM's 1 and 3 soils was disturbed due to sugarcane plantation in the temporary zones of the wetland, hence, the ability to act as a carbon sink is reduced.

6.12.6. Maintenance of biodiversity

Wetlands are key ecosystems in maintaining biodiversity. In order for a wetland to maintain the biodiversity, a wetland must serve specific attributes such as conserving red data species and protect rare wetland biodiversity types.

The following factors influence a wetlands ability to maintain its biodiversity.

Cumulative loss of rare or threatened wetland type

If a wetland is rare or threatened due to anthropogenic activities, its ability to maintain its biodiversity becomes imperative, due to the fact that these wetlands may contain important or rare flora and fauna species. Furthermore, the importance of the wetland will increase if there is a loss to that specific rare or threatened wetland (Mucina and Rutherford, 2006).

HGM 3 was not considered to be a rare wetland but it was considered to be threatened due to surrounding activities. Therefore, the maintenance of this biodiversity is imperative for the ecosystem within it and surrounding it. HGM 2 was identified as a rare NFEPA system but not threatened. It is imperative to ensure this wetland maintains its current state as it poses large stands of macrophytes important for several species in the area. HGM 1 was identified as a rare NFEPA system and threatened due to surrounding sugarcane plantation activities. This system requires rehabilitation to re-establish to its previous historic state and maintain its current state for the surrounding biodiversity.

Red Data Species

Species that are identified to have a specific significance are known to be red data species. Therefore, if a HGM unit has red data species identified within it, the value in terms of maintaining biodiversity is increased (Kotze *et al*., 2007).

Although HGM's 1 and 2 were identified as NFEPA systems, there were no red data species present. HGM 3 did not have any red data species as well. Therefore, this factor is negligible in terms of maintaining biodiversity for HGM units.

Buffer zone surrounding HGM units

A buffer around a wetland is recognised as natural vegetation surrounding an HGM unit. Buffers are sometimes required in wetland and non-wetland areas for several wetland species. Therefore, if natural vegetation is lacking within a wetland area, the maintaining biodiversity is decreased for a specific HGM unit (Kotze *et al*., 2007).

HGM's 1 and 3 had a small loss of vegetation as a result of sugarcane plantation but much of the area had introduced vegetation. Therefore, the maintaining of biodiversity in these HGM's have been diminished to a certain extent. Conversely, HGM 2 had large areas of natural vegetation, hence, increasing the ability of the HGM to enhance biodiversity maintenance.

Alteration of the geomorphological and hydrological regimes

Hydrology is identified to be the most fundamental factor that affects the functioning of a wetland. If the hydrology in a wetland is altered by anthropogenic activities, the ability to maintain biodiversity is reduced (Kotze *et al*., 2007). The maintenance of biodiversity is affected in several ways in terms of geomorphology. For example, sediment input and output can reduce the ability of a wetland to maintain biodiversity if sediment excess causes different plant growth and burial of current natural plants, whereas loss of sediment can cause erosional degradation to a wetland (Kotze *et al*., 2007).

The hydrology module (Chapter 5) has been substantially affected in all HGM units, whereas the geomorphology module has been slightly impacted. As a result of sugarcane plantation, an excess of sediment was noticeable in HGM's 1 and 3, hence, the ability to maintain biodiversity is reduced.

Presence of alien species and removal of natural vegetation

Natural vegetation plays a pivotal role in maintaining the biodiversity of a wetland by providing a habitat and resources for species that reside in a wetland. Unlike natural vegetation, the introduction of alien vegetation is unfavourable to the maintenance of biodiversity. Alien flora possess less binding properties to soils which can lead to excessive erosion, rapid spreading of alien vegetation and high usage of water which can alter the hydrological regime of HGM units (Kotze *et al*., 2007).

HGM 2 natural vegetation stands are of a substantial amount with few areas that do exist of alien vegetation. Therefore, the maintenance of biodiversity in this HGM is enhanced due to the substantial amount of natural vegetation. Conversely, HGM's 1 and 3 natural vegetation have been affected due to sugarcane plantation in the temporary zones of these wetlands, causing natural vegetation to diminish and introduce alien vegetation into the HGM unit. Hence, the ability of these HGM units to maintain biodiversity has been reduced drastically.

6.12.7. Water for human use

Human use for water within a wetland refers to the removal of water directly from the wetland for purposes such as domestic, agricultural and even drinking purposes in some cases. Provision of water for human use is directly related to stream flow regulation, therefore, if the importance of the stream flow regulation is high, the supply of water will be of a high importance as well.

Human use of water from the HGM units are not required, therefore, this factor is negligible in terms of providing water for human usage.

6.12.8. Harvestable resources and cultivated resources by humans

Wetlands have several harvestable resources such as fish, edible plants, reeds, sedges and wood. Furthermore, cultivation in wetlands, especially in rural communities plays a pivotal role in the socio-economic resources for humans.

The factors that influence harvestable and cultivated resources for humans are discussed below.

Number of natural resources utilised

The number of resources used in the all HGM units were absent, hence, this factor was negligible in terms of resources utilised by humans.

Level of poverty and location of HGM unit in a rural area

Although it was noted that the area where the wetlands were located are in a rural area and levels of poverty are of a moderate to high level, the usage of the wetlands for natural resources by humans was negligible. This could be a direct result of the Illovo Sugar-Sezela Mill land being privately owned and restricted people from gaining access to the wetland.

6.12.9. Cultural significance

According to Kotze *et al* (2007), a wetland may be of cultural significance if it is registered by the South African Heritage Resources Agency coupled with the fact that cultural activities occur within the wetland environment.

In the Sezela study site for wetlands, no cultural practices were noticed and wetlands were not registered by the South African Heritage Resources Agency, hence, the cultural significance of these wetlands are limited.

6.12.10. Recreation, tourism and scenic beauty

The Sezela wetlands are not located in a tourism area and the privately-owned land does not rely on wetlands for economic growth. As a result of this area not being in a tourist route, recreational activities within these wetland environments are limited with regards to hunting and fishing, hence, reducing the potential of recreation and tourism. Although these HGM units may not encourage recreation and tourism, due to their predominant natural conditions, scenic beauty in this wetland environments are moderate to high, especially in HGM 2. However, due to the sugar mill, the scenic beauty of these wetlands are diminished to a certain extent.

6.12.11. Education and research

Wetlands value for wetlands for education and research is high due to the fact that an aquatic and terrestrial ecosystem are present, however, accessibility is an important factor when it comes to education and research of these environments. HGM 2 was accessible is certain areas and due to its almost natural existence, it has the ability to be a good reference site. HGM 1 and 3 were accessible to a limited extent, hence, conducting research on these wetlands were a difficult task. Furthermore, there was no other previous data on these wetland environments, hence, no comparison could be made for educational and research purposes.

6.13. Functional health assessment of the HGM units

Wetlands health status refers to a wetlands current state in comparison to its natural reference condition. To establish the health status of a wetland, three modules must be determined that play an imperative role in the functioning of a wetland which are hydrology, geomorphology and vegetation (Macfarlane *et al*., 2007).

6.13.1. Hydrology

The hydrology of a wetland is recognised as the delivery and movement of water in and through the soils of a wetland and the wetland itself. If water distribution and retention is disturbed in a HGM unit, this is altering the hydrological regime which can cause changes to the health of the wetland. HGM's 1, 2 and 3 were largely modified, moderately modified and critically modified respectively. The factors which influenced the modification of the hydrological regime is discussed below (Macfarlane *et al*., 2007).

The ratio of mean annual precipitation: potential evapotranspiration is an imperative factor which affects the input of water into a wetland environment. If potential evapotranspiration is more than mean annual precipitation, the water input from direct precipitation is reduced, therefore, rendering the wetland being more dependent on flows from upper catchment area and vulnerable to reduced inflows. The Sezela wetlands fall in a relatively low ratio of mean annual precipitation: potential evapotranspiration, hence, the wetlands hydrological regime is extremely vulnerable to water inflows from upper catchment areas (Macfarlane *et al*., 2007).

A factor which has detrimental impact on the hydrology of the Sezela wetlands are land uses. The land uses which are present are proliferation of alien vegetation and plantation of sugarcane in the temporary zone of wetlands. HGM 2 is not impacted by the plantation of sugarcane plantation in comparison to HGM's 1 and 3 (Macfarlane *et al.*, 2007). The presence of large quantities of alien vegetation, especially in HGM's 1 and 3 impact the hydrological regime of these wetlands by the intake of water by this vegetation which depletes the water source in the wetland environment. Furthermore, due to the dryland sugarcane plantation in the temporary zones of HGM's 1 and 3, these areas become almost completely desiccated as a result of the aforementioned activity and these plants can further spread into the seasonal zone of the wetlands over time, which in turn negatively impacts the hydrological regime of wetland environments (Macfarlane *et al*., 2007).

There was no canalisation in any of the HGM units, hence, the hydrological regime was not impacted by this factor.

HGM's 1 and 3 experienced small patches of hardened surfaces as a result of the activities occurring in the wetland environment. Hardened surfaces in HGM's 1 and 3 were due to the plantation of sugarcane and in the form of dirt roads. Wetlands are negatively affected by hardened surfaces due to increased runoff potential created by hardened surfaces, especially during flood peaks as infiltration into soils decrease (Macfarlane *et al*., 2007). Furthermore, as a result of the sugarcane plantation in the temporary zones of HGM's 1 and 3, some areas are left as bare soil after the removal of vegetation which can cause the wetland to become degraded further if flooding events continually wash away this sediment (Macfarlane *et al*., 2007).

HGM 3 was the only wetland to have an impeding structure at the south bound of the wetland. The impeding structure was a small bridge which had a single culvert to assist with drainage of water from the wetland environment. The impeding structure can cause back flooding to occur upstream during flood peaks which can significantly affect the hydrological regime of the wetland environment (Macfarlane *et al*., 2007).

6.13.2. Geomorphology

A wetlands geomorphology is the distribution and retention of sediment from outside and inside of the wetland environment. According to Macfarlane *et al* (2007), a wetland in natural reference condition will experience sediment input and output of the same quantity or slight more than the output. It was determined by assessment that HGM’s 1 and 2 were natural in terms of its geomorphological state, whereas, HGM 3 was predominantly natural with a few modifications.

South African wetlands have a massive problem in terms of erosion which occurs due to gullying in the wetland. The origins of erosion activities are through patterns of flow through a wetland, basin morphology and conditions of substratum, which can be severely affected by several factors. Excessive amounts of sediment input in a wetland can be caused due to excessive tilling of soils and removal of natural vegetation. If excessive sediment input in a wetland is continuously occurring, a damming effect can occur which can cause the wetland to desiccate in certain areas (Macfarlane *et al*., 2007).

HGM 3 experiences a small portion of artificial filling in of sediment due to the bridge at the south bound of the HGM unit. Artificial filling of wetlands can enhance the potential of wetlands to decrease the rate of erosion, closer to the channel, as an increase in sediment will slow the frequency and extent to which erosion occurs at the channel.

The alteration of runoff in a HGM unit changes the capability of water to deposit, lift and transport sediment, resulting in deposition and erosion in the HGM unit. Alteration of runoff is a severe factor that causes damage to the geomorphological integrity of a wetland. The Sezela study site wetlands runoff characteristics have been altered to a certain extent, especially HGM’s 1 and 3 in which removal of natural vegetation and construction of a bridge has occurred in HGM 3. The removal of natural vegetation impacts the HGM units by decreasing surface roughness, which allows water to flow at a rapid rate without a frictional barrier, transporting sediment out of the HGM unit due to exposed soil and further reducing infiltration rates in the soil (Macfarlane *et al*., 2007).

6.13.3. Vegetation

A wetlands vegetation status is recognised by the compositional and structure of the vegetation in its current state. There are several habitat and non-habitat benefits that wetlands vegetation provide due to their composition and structure. The vegetation modules of HGM’s 1, 2 and 3 were a D, C and E respectively, hence, in a large modification, moderate modification and very large modification zone respectively.

The vegetation module in HGM 2 was left mostly unaltered but did have a vast array of alien vegetation that resided within the HGM unit which could be result in changes in the hydrological regime over time.

HGM's 1 and 3 had a good portion of natural vegetation removed from the temporary zones of the wetland and replaced with dryland sugarcane plantation. Furthermore, a vast array of alien vegetation was noted in these HGM units, in which alien vegetation has the ability to outcompete indigenous vegetation in the HGM units.

Sediment infilling HGM's 1 and 3 as a result of dryland sugarcane plantation in the catchment caused a change in natural vegetation due to excessive smothering of sediment in the HGM unit (Macfarlane *et al*., 2007).

6.14. Overall Health status of HGM units

Hectare equivalence is an important method of determining the amount of healthy and loss of wetland in that environment. The determining of hectare equivalence provides important information which can assist in the rehabilitation of the impacted wetland environment. HGM's 1, 2 and 3 had an overall healthy wetland of 23.6285 Ha and 10.5715 Ha of loss of wetland. Therefore, 10.5715 Ha has been loss and rehabilitation of this area of wetland will be required to achieve better functionality of these wetland environments.

7. CONCLUSION

7.1. Introduction

The data presented in Chapter 5 and further explained in Chapter 6 reveals that the Sezela estuary and surrounding wetland areas (in terms of hydrology, geomorphology and vegetation) have been modified drastically, hence, the natural functioning of these systems have been altered and do not provide the ecological services that they have historically. Chapter 8 focuses on the vital findings, impacts and applicable mitigation and recommendation measures for the Sezela estuary and surrounding wetland areas in order to improve the functional state of these systems.

The aim of the Sezela study was to investigate human induced changes that have impacted the ecological health status of the Sezela estuaries and wetlands. Therefore, the important findings and impacts were determined by assessing the health status of the environmental systems in the Sezela study site.

7.2. Vital findings

The important findings in the estuary system were:

- Sediment grain size which was sandy to sandy-gravel was not typical of estuarine conditions;
- Natural breaching of the mouth did not occur often due to the coarse material from the marine environment washed-over into the estuarine environment and not flushed out often enough from the estuarine environment into the marine environment;
- Linear regression models revealed that metal concentrations of copper, manganese and zinc predominantly fell between or below the model's prediction limits with the exception of sampling station SE2 and SW5 for manganese and zinc respectively;
- The enrichment factor calculation suggested that SW5 station was enriched by anthropogenic factors such as discharge of domestic waste into river environment;
- The estuarine sediment environment was not enriched by metals (cadmium, copper, lead, iron, manganese, mercury and zinc);
- Faecal indicator organisms predominantly fell within the TWQR with a few falling out of the range which could give rise to a low risk of gastrointestinal disease;
- Nutrient levels in the water all fall within the TWQR;

- Physico-chemical water parameters such as DO did not fall within the TWQR and resulted in falling below the minimum allowable values;
- pH levels were slightly alkaline due to photosynthesis processes;
- Metal availability in water was low as a result of alkaline conditions;
- Macro-invertebrate community composition and abundance was low due to the low DO concentrations and % saturation;
- The estuary has been highly degraded from past activities such as discharge of effluent into the estuary which has destroyed the functionality of the ecosystem which is accompanied by minimal biota.

The findings in the wetland system were:

- There were three HGM units identified in the Sezela study site;
- HGM's 1 and 3 were identified as channelled valley bottom wetlands, whereas HGM 2 was identified as a Floodplain wetland;
- The soil profiles obtained from the field were used to determine the different hydrological zones of a wetland, the matrix and chroma values, the presence of mottling and to further note the surrounding vegetation of where the auger was obtained;
- The presence of the permanent, seasonal and temporary zones was evident in HGM's 1 and 3, whereas HGM 2 was made up of predominantly a permanent zone due to its Floodplain nature of being permanently inundated;
- Wetland tools WET-EcoServices and WET-Health were utilised to determine the physical and socio-economic ecological services the wetlands provided and to determine importantly the functional health status of the wetland in terms of hydrology, geomorphology and vegetation;
- The WET-EcoServices assessment revealed that the Sezela wetlands lacked adequate provision of socio-economic services, however, the physical environmental services such as flood attenuation and sediment trapping (to name a few) were provided at a substantial level by the wetlands;
- The WET-Health functional assessment revealed overall PES scores for HGM 1 (C-moderately modified), HGM 2 (C-moderately modified) and HGM 3 (D-largely modified);
- Hectare equivalence results revealed:
    - HGM 1 (Healthy wetland – 6.1535 Ha, Loss of wetland – 3.4165 Ha)

- HGM 2 (Healthy wetland – 16.4058 Ha, Loss of wetland – 5.7942 Ha)
- HGM 3 (Healthy wetland – 1.0692 Ha, Loss of wetland – 1.3608 Ha).

7.3. Impacts on the Sezela environmental systems

The assessment of the Sezela estuary resulted in the following impacts to the system:

- Due to the lack of natural breaching of the estuarine mouth, sediment grain size within the estuary is of a coarse nature;
- The poor levels of DO concentration and % saturation has severely impacted the ecosystem functionality coupled with low biota in the estuarine environment;
- The past activities of discharge of effluent into the estuarine environment coupled with no rehabilitation to the estuary after relevant legislation was passed not to pollute estuarine environment, has left the system highly degraded with almost no living biota.

The hydrological, geomorphological and vegetation modules in the Sezela study site wetlands were impacted by the following aspects:

- The agricultural practice of sugarcane plantation in the temporary zone of HGM's 1 and 3;
- Exposed hardened surfaces as a result of agricultural activities in the temporary zone of HGM's 1 and 3;
- Excessive input of sediment into the wetlands as a result of hardened surfaces;
- Gravel road and bridge development in nearby wetland environments which cause excessive sediment input and affects the hydrological flow in the wetland;
- Removal of natural vegetation in the catchment and temporary zone of the wetland which acts as a corridor for wetland and non-wetland species into the catchment;
- Proliferation of alien invasive species as a result of several activities occurring within the wetland and surrounding catchment.

The aforementioned impacts occurring at the Sezela wetland and estuarine environments degrade these system to different extents. Therefore, mitigation and recommendation measures are pivotal to be developed for maintaining and improving the current conditions of the Sezela estuary and wetland environments.

7.4. Mitigation and recommendation measures

7.4.1. Sezela estuary

The rehabilitation of an estuary refers to preserving a good health status, ensure water and sediment quality is of a good standard, removal of alien invasive vegetation and introduction of indigenous vegetation in the riparian and instream environments, reduction of excessive sediment introduction in the estuary and improvement of flow of water especially during periods of low flow (Sukdeo *et al*., 2016).

7.4.1.1. Water quality

The quality of water in the Sezela estuary is extremely poor due to the current low DO concentration levels. Therefore, it is imperative that the sugar mill complies with existing legislation to ensure that the estuary is not further degraded. A method which can be utilised to improve water quality in the estuarine is by artificially breaching of the mouth more often in order to flush out the estuary (Sukdeo *et al*., 2016). However, this method should not be a long-term solution as this could lead to an excess of marine sediment in the estuary which can further impact the remaining biota. The establishment of in-stream plant communities will assist not only with the quality of water but also offers resistance of flow of water and sediment load (Clarke, 2002). The procedure of aeration can be conducted at certain points of the estuary to improve water quality, especially for the low DO levels within the estuarine environment.

7.4.1.2. Reducing sedimentation

The Sezela estuary surrounding catchment area is predominantly dryland sugarcane plantation. This activity has replaced natural vegetation in the catchment, hence, the soil has loosened, dried up and becomes easily eroded and deposited into different environments, even the estuary (Sukdeo *et al*., 2016). In order to possibly rectify the situation, re-vegetation of certain areas that do not require dryland sugarcane plantation with indigenous plants which will assist with the restoration of the land and decrease erosion, promote growth of indigenous plants and control alien invasive species (Sukdeo *et al*., 2016).

7.4.1.3. Sediment remediation

The reducing of contaminant entering the Sezela estuary will reduce the introduction of contaminants in sediment. The most feasible option that should be utilised on the sediment in the Sezela estuary is remediation *via* immobilisation treatment. This treatment unlike dredging does not involve the removal of sediment from the environment which is a much more detrimental and expensive method of rehabilitating sediment (Sukdeo *et al*., 2016).

7.4.1.4. Removal of alien invasive species

The removal of alien invasive species from the riparian zone of the estuary and further upstream to ensure relocation of these species do not occur is imperative to the functioning of the estuary. Furthermore, due to the Sezela area being a rural community lacking solid income for many people, the implementation of the removal of invasive alien species can be conducting by the community members for a fee, which will encourage job creation and passing of knowledge to local community members (Kotze *et al*., 2007).

7.4.1.5. Improvement of the habitat integrity

In order to address the problems in the Sezela estuary, past pollution causes need to be addressed and no pollution should re-enter this environment (Begg, 1978). Macro benthic invertebrates which are sensitive environmental indicators can re-establish if turbidity levels are at the required standard and if flushing estuary system by breaching the mouth more often to remove unwanted sediment pollution. Furthermore, breaching of the mouth can remove excess of coarse sediment currently in the estuary system which will encourage more typical estuarine conditions.

7.4.2. Sezela wetlands

According to Kotze *et al* (2007), wetland rehabilitation is a procedure in which wetland maintenance and recovery from a degraded state is of high importance to allow a wetland to improve in its ecological services and functionality. Therefore, in order to enhance the over health status of the Sezela wetlands mitigation and recommendation measures given below are advised.

7.4.2.1. Indigenous re-vegetation

The re-vegetation within wetland environments should ensure that the land which will be utilised for the re-vegetation is clear of any waste and any obstructions that could affect re-vegetation. After the aforementioned rehabilitation is established, the indigenous vegetation being planted in the wetland area should be inclusive of hydrophytic vegetation (Mullins, 2012). The re-vegetation of indigenous plants in the wetland will enhance ecological services and functionality of the wetland such that the hydrological, geomorphological and vegetation modules will improve, thus, promoting less erosion through runoff, slowing of water to enhance infiltration in wetland, sediment trapping and improvement of water quality (Mullins, 2012).

7.4.2.2. Alien invasive plant monitoring and controlling

The monitoring and controlling of alien invasive vegetation is imperative in wetlands as these species negatively impact the biodiversity of the wetland. If establishment of alien invasive species are identified in certain locations, immediate removal should occur. Furthermore, monthly monitoring of areas should be conducted to ensure no new re-establishment of alien invasive vegetation (Kotze *et al*., 2007).

7.4.2.3. Application of relevant buffers to wetlands

According to Macfarlane (2014), a buffer around a wetland is imperative, especially if human induced anthropogenic activities can impact the wetland system and affect the functionality of the wetland systems. In the Sezela study, HGM's 1 and 3 are affected by the introduction of sugarcane plantation in the temporary zone of the wetland. This activity should be stopped and the land rehabilitated with indigenous vegetation. Thereafter, in order for the land to be re-established to a more natural regime which will enhance the functionality and ecological services provided by the wetlands, a buffer of at least thirty meters away from the wetland should be instated. Thus, this will ensure that the sugarcane plantation does not affect the wetland integrity (Kotze *et al*., 2007).

7.4.2.4. Raising water table and obtaining a more natural diffuse flow

According to Kotze *et al* (2007), the integrity of a wetland and the ecological services provided are helped if the natural diffuse flow is established. Ecological services such as removal of toxicants and phosphates and assimilation of nitrates are enhanced if a natural diffuse flow is established in a wetland. Raising of the water table of a wetland can be achieved by installing weirs which in turn will increase the water table by gullies and drains, installing a fence or sediment plug across gullies and drains and installing a spreader canal which will assist in the diffuse flow of water (Kotze *et al*., 2005).

8. REFERENCES

Abed R., 2009. *An investigation into the suspended sediment flux and dynamics of the Mgeni Estuary, Durban*. Unpublished MSc Dissertation, University of KwaZulu-Natal, Durban< South Africa.

Aber J.S., Pavri F., and Aber S.W., 2012. *Enironmental Cycles and Feedback*. Wetland environments: A Global Perspective. John Wiley & Sons, Ltd, Chichester, U.K.

Adams, J.B., Bate, G.C. and O'Callaghan, M.O., 1999. Primary Producers. In: Estuaries in South Africa. (eds. Allanson, BR and Baird D). Cambridge University Press, 91-117.

Adams, J.B., Colloty, B.M. and Bate, G.C., 2004. The Distribution and State of Mangroves along the Coast of Transkei, Eastern Cape Province, South Africa. *Ecology and Management*, 12, 531-541.

Adamus P.R. and Brandt K., 1998. *Impacts on quality of inland wetlands of the United States.* A review of indicators, techniques, and applications of community-level biomonitoring data. US EPA, Environmental Research Laboratory, Corvallis, Oregon. EPA600/3-90/073. Accessible at: ww.epa.gov/OWOW/wetlands/wqual/introweb.html.

Adamus P., Danielson T.J., and Gonyaw A., 2001. *Indicators for monitoring biological integrity of inland, freshwater wetlands*. A survey of North American technical literature (1990-2000). USA Environmental Protection Agency, Office of Water Office of Wetland, Oceans, and Watersheds, Washington, DC 20460.

Adelekan, B.A., 2010. Water quality of domestic wells in typical African communities: Case studies from Nigeria. *International Journal of Water Resources and Environmental Engineering*, 2 (6), 137-147.

Ahmed, S. and Erum, S., 2010. Integrated Assessment of Heavy Metal Pollution along Motorway M-2. *Soil and Environment*, 29(2), 110-116.

Alexander R.B., Smith R.A., Schwartz G.E., 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature*, 403, 758-781.

Avnimelech, Y., Ritvo, G., Meijer, L.E. and Kochba, M., 2001. Water content, organic carbon and dry bulk density in flooded sediments. *Aquacultural Engineering*, 25, 25-33.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. and Silliman, B.R., 2011.The value of estuarine and coastal ecosystem services.*Ecological Monographs*, 81(2), 169-193.

Barnes G., Martin A., and Basheer G., (2001). *Opuatia Wetland Restoration Plan.* Environment Waikato Internal Series: Environment Waikato, Hamilton, New Zealand.

Battarbee, R.W., Grytnes, J.A., Thompson, R., Appleby, P.G., Catalan, J., Korhola, A., Birks, H.J.B., Heegaard, E. and Lami A., 2002. Comparing palaeolimnological and instrumental evidence of climate change for remote mountain lakes over the last 200 years. *Journal of Paleolimnology*, 28, 161–179.

Beck, J.S., Kemp, A., Theron, A.K., Huizinga, P. and Basson, G.R., 2004. Hydraulics of estuarine sediment dynamics in South Africa: Implications for Estuarine Reserve determination and the development of management guidelines. *WRC Report No. 1257/1/04*. Pretoria, South Africa.

Begg, G., 1978. The Estuaries of Natal. *Natal Town and Regional Planning Report*, 41, 379-385.

Begg G., 1986. *The Wetlands of Natal (Part 1): An overview of their extent, role and present status*. The Natal Town and Regional Planning Commission, Pietermaritzburg.

Beaudoin, A., 2003. A comparison of two methods for estimating the organic matter content of sediments. *Journal of Paleolimnology*, 29, 387–390.

Blaber, S.J.M., 2002. "Fish in hot water:" the challenges facing fish and fisheries research in tropical estuaries. *Journal of Fish Biology*, 61, 1-20.

Blatt, H., 1970. Determination of mean sediment thickness in the crust: a sedimentologic method. *Geological Society of American Bulletin*, 81, 255-262.

Botes W., 2009. *Measuring the success of individual wetland rehabilitation projects in South Africa.* Unpublished MSc. Dissertation. University of KwaZulu Natal, Durban, South Africa.

Bowen, H.J.M., 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

Brinson M.M., 1993. *A hydrogeomorphic classification for wetlands*. Prepared for US Army Corps of Engineers. p.101. Wetlands Research Programme Technical Report WRP-DE-4.

Brinson M.M., and Rheinhardt R., 1996. The Role of Reference Wetlands in Functional Assessment and Mitigation. *Ecological Applications*, 6, 69-76.

Bromilow, C. 2010. Problem Plants and Alien Weeds of South Agrica.Briza Publications, Queenswood (SA).

Buckalew, D.W., Hartman, L.J., Grimsley, G.A., Martin, A.E. & Register, K.M. (2006). A long-term study comparing membrane filtration with Colilert defined substrates in detecting faecal coliforms and *Escherichia coli* in natural waters. *Journal of Environmental Management,* 80, 191-197.

Bullock A., and Acreman M., 2003. The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences*, 7(3), 358-389.

Burich B.E., 2008. *Biogeochemical Pathways and Land Use Associations of Potentially Toxic Metals in the Anchorage Watershed, Alaska*. Unpublished MSc Dissertation. University of Alaska, Anchorage.

Butcher R., 2003. *Options for the assessment and monitoring of wetland condition in Victoria, Australia*. Report prepared for the State Water Quality Monitoring and Assessment Committee (SWQMAC), State of Victoria, Australia. Accessible at: www.vcmc.vic.gov.au/Web/Docs/ SWQMACWetlandFinalReport.pdf.

Cao, Y., Williams, D.D. and Williams, N.E., 1998. How important are rare species in aquatic community ecology and bioassessment? *Limnology and Oceanography,* 43**,** 1403- 1409.

Chalrabarty, M. and Patgiri, A., 2009. Metal Pollution Assessment in Sediments of The Dikrong River. *N.E. India, Journal on Human Ecology,* 27(1), 63-67.

Chambers, P.A., Meissner, R., Wrona, F.J., Rupp, H., Guhr, H., Seeger, J., Culp, J.M. and Brua, R.B., 2006. Changes in nutrient loading in an agricultural watershed and its effects on water quality and stream biota. *Hydrobiologia*, 556, 399–415.

Chapin III F.S., Power M.E., and Cole J.J., 2011. Coupled biogeochemical cycles and Earth stewardship. *Frontiers in Ecology and the Environment,* 9, 3.

Chenu C., Le Bissonnais Y., and Arrouays D., 2000. Organic Matter Influence on Clay Wettability and Soil Aggregate Stability. *Soil Science Society American Journal,* 64, 1479-1486.

Clarke, S.J., 2002. Vegetation growth in rivers: Influences upon sediment and nutrient dynamics. *Progress in Physical Geography*, 26(2), 159-172.

Coetzee, M., 1995. Water pollution in South Africa: its impact on wetland biota. *Wetlands of South Africa*, GI Cowan (ed.), 247-261.

Collins N.B., 2005. *Wetlands: The basics and some more*. Free State Department of Tourism, Environmental and Economic Affairs.

Cowardin L.M., Carter V., Golet F.C. and LaRoe, E.T., 1979. *Classification of wetlands and deepwater habitats of the United States*. US Department of Interior, Fish and Wildlife Services Report FWS/UBS, 79-31.

Cronk J.K., and Fennessy M.S., 2001. *Wetland Plants: Biology and Ecology*. CRC Press/Lewis Publishers. Boca Raton.

CSIR, 2005. Department of Water Affairs and Forestry, South Africa. 2005. Kromme/Seekoei Catchments Reserve Determination Study – Technical Component Seekoei. Prepared by CSIR for CES. *CSIR Report ENV/S-C* 2005-061.

CSIR, 2014. Long-Term Ecological Monitoring for the Port of Durban: Surveys made in 2013. CSIR Report CSIR/NRE/ECOS/IR/2014/0011/B.

CSIR, 2015. Assessment of the environmental impact of effluent discharge via the Illovo Sugar Sezela – Downstream surf zone outfall: Survey made during December 2014. CSIR Report CSIR/NRE/ECOS/IR/2015/0041/B.

Dallas, H.F. and Day, J.A., 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Report No. TT61/93, Water Research Commision, Pretoria.

Davenport, J. and Davenport, J.L., 2006. The impact of tourism and personal leisure transport on coastal environments: A review. *Estuarine, Coastal and Shelf*, 67(1-2), 280-292.

Davies, O.A. and Abowei, J.F.N., 2009. Sediment quality of lower reaches of Okpoka Creek, Niger Delta, Nigeria. *European Journal of Scientific Research,* 26(3), 437-442.

Davis M. A. and L. B. Slobodkin, 2004. The science and values of restoration ecology. *Restoration Ecology*. Vol.12, pp. 1–3.

Day, J.H., 1981. The estuarine fauna. In: Estuarine Ecology with particular reference to southern Africa (ed. Day, J.H.), 147-186. A.A. Balkema, Cape Town.

Day J.A., 2009. Rivers and wetlands. In: H.A. Strydom and N.D. King (Eds). *Environmental Management in South Africa*. Second edition, Juta, Cape Town, 842-867.

DeKeyser, E.S., Kirby D.R., and Ell M.J., 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. *Ecological Indicators,* 3 (2), 119-133.

De Villiers, C., Hodgson, A. and Forbes, A.T., 1999. Studies on estuarine macrobenthos. In: Estuaries of South Africa (eds Allanson, B.R. and Baird, D), 167-207. Cambridge University Press, Cambridge.

Dean, W.E., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *Journal of Sedimentary Petrology*, 44, 242–248.

Dickens C., Kotze D., Mashigo S., Mackay H., and Graham M., 2003. *Guidelines for integrating the protection, conservation and management of wetlands into catchment Management Planning*. WRC Report No. TT 220/03.

Dini J., 2004. Restoring wetlands and healing a nation: South Africa’s Working for Wetlands programme. South Africa’s Working for Wetlands Programme. South African National Biodiversity Institute, South Africa.

Duarte, C.M., 1991. Seagrass depth limits. *Aquatic Botany*, 40, 363-377.

Duffus, J.H., 2002. Heavy Metals - A Meaningless Term? (IUPAC Technical Report). *Pure and Appied. Chemistry*, 74(5), 793-807.

Dyer, K.R., 1986. *Coastal and Estuarine Sediment Dynamics*. John Wiley and Sons, Chichester, Great Britain, 23-31; 231-247.

DWAF, 1995. South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment. Pretoria.

DWAF, 1996a. South African Water Quality Guidelines Volume 7 – Aquatic Ecosystems. Department of Water Affairs and Forestry, Pretoria.

DWAF, 1996b. South African Water Quality Guidelines Volume 3 – Industrial Use. Department of Water Affairs and Forestry, Pretoria.

DWAF, 1996c. South African Water Quality Guidelines Volume 2 – Recreational Use. Department of Water Affairs and Forestry, Pretoria.

DWAF. 1999. *Water resources protection policy*. Resource Directed Measures for Protection of Water Resources. Wetland Ecosystems, Version 1.1.

DWAF, 2002. Rapid determination of the Resource directed Measures of the Mdloti (including preliminary estimates of capping flows for the Mdloti and Mhlanga estuaries. Final Draft Report submitted to the Directorate Resource Directed Measures, February 2002.

DWAF. 2003. *A practical field procedure for identification and delineation of wetlands and riparian areas*. Department of Water Affairs and Forestry, South Africa.

DWAF, 2003b. Determination of the Preliminary Ecological Reserve on a Rapid Level for Mhlanga. Final Report submitted to Directorate Resource Directed Measures, DWAF, Pretoria.

DWAF, 2004. *Strategic framework for national water resource quality monitoring programmes, and guidelines for designing such programmes*. Draft document.

DWAF, 2006. *A practical field procedure for identification and delineation of wetlands and riparian areas.* Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF, 2008. *Updated manual for the Identification of Wetlands and Riparian Areas.* Prepared by: Rountree, M. Batchelor, MacKenzie, J. & Hoare, D. Stream Flow Reduction Activities, Department of Water Affairs and Forestry, Pretoria, South Africa.

Elliot, M. and Whitfield, A.K., 2011.Challenging paradigms in estuarine ecology and management.*Estuarine, Coastal and Shelf Science*, 94(4), 306-314.

Engelund, F. and Eggert, H., 1972. *A monograph on sediment transport in alluvial streams*, 3rd ed., Copenhagen: Teknisk Forlag.

Flindt, M.R., Pardal, M.A., Lillebo, A.I., Martins, I. and Marques, J.C., 1999. Nutrient cycling and plant dynamics in estuaries: A brief review. *Acta Oecologica*, 20, 237-248.

Folk, R.L. and Ward, W.C., 1957. Brazos River bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27, 3-26.

Fraser L.H., and Keddy P.A. (Eds), 2005. *The World's Largest Wetlands: Ecology and Conservation*. Cambridge University Press, Cambridge, U.K.

Friedman, G.M. and Sanders, J.E., 1978. *Principles of Sedimentology*. John Wiley & Sons, Chichester, 74-75.

Froneman, P.W., 2002. Response of the plankton to three different hydrological phases of the temporarily open/closed Kasouga Estuary, South Africa. *Estuarine, Coastal and Shelf Science*, 55, 535-546.

Ganesh, A., Lin, J. and Singh, M., 2014. Detecting Virus-Like Particles from the uMngeni River, South Africa. *Clean – Soil, Air, Water*, 42 (4), 393-407.

Georgiou S., and Turner K., 2012. *Valuing Ecosystem Services: The Case of Multi- functional Wetlands*. Routledge, London.

Glen R.P., Archer C. and Van Rooy J., 1999. Aquatic plants of South Africa. In: G.Cowan (Ed.). *Biota of South African wetlands in relation to the Ramsar Convention.* Department of Environmental Affairs and Tourism, Pretoria.

Gonzalez-Ortegan,E., Sabida, M.D., Caesta, J.A., Aries, A.M., Fernandez-Delgade, C. and Drake, P., 2010. The impact extreme turbidity events on the nursery function of a temperate European estuary with regulated freshwater inflow. *Estuarine, Coastal and Shelf Science*, 87(2), 311-324.

Greenfield, R., van Vuren, J.H.J. and Wepener, V., 2007. Determination of sediment quality in the Nyl River system, Limpopo Province, South Africa. *Water SA*, 33(5), 693-700.

Griffiths, J.C., 1967. *Scientific Method in Analysis of Sediments*. McGraw-Hill Book Co., New York.

Griggs G., 1975. An investigation of bottom sediments in a polluted marine environment upper Saromkos Gulf, Greece. Report of the environmental pollution control project, Athens, Greece, 1-30**.**

Hanekom, N., Baird, D. and Erasmus, T., 1988. A quantitative study to assess standing biomasses of macrobenthos in soft substrata of the Swartkops, South Africa. *South African Journal of Marine Science*, 6, 163-174.

Hassink J., 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. *Plant and Soil*, 191, 7-87.

Harrison,T.D., 2004. Physico-chemical characteristics of South African estuaries in relation to the zoogeography of the region.*Estuarine, Coastal and Shelf*, 61(1), 73-87.

Heiri, O., Lotter, A.F. and Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, 25, 101–110.

Hiddink, J.G., Jennings, S. and Kaiser, M.J., 2006. Indicator of the ecological impact of bottom trawl disturbance on seabed communities. *Ecosystems*, 9, 1190-1199.

Hoque E., Shehryar M., Nurul Islam K., 2013. Processing and Characterization of Cockle Shell Calcium Carbonate (CaCO3) Bioceramic for Potential Application in Bone Tissue Engineering. *J Material Sci Eng.*, 2, 132.

Hong, H., Qiu, J. and Liang, Y., 2010. Environmental factors influencing the distribution of total and fecal coliform bacteria in six water storage reservoirs in the Pearl river Delta Region, China. *Journal of Environmental Sciences*, 22 (5), 663-668.

Horowitz A., 1985. *A primer on trace metal-sediment chemistry*. U.S. Geological Survey Water Supply. Available at: http://pubs.usgs.gov/wsp/2277/report.pdf.

Horwitz A., Finlayson M., and Weinstein P., 2012. *Healthy wetlands, healthy people: a review of wetlands and human health interactions*. Ramsar Technical Report No.6. Secretariat of the Ramsar Convention on Wetlands, Gland, Switzerland, and the World Health Organisation, Geneva, Switzerland.

Howe C.P., Claridge G.F., Hughes R. and Zuwendra, 1991. *Manual of guidelines for scoping EIA in tropical wetlands*. PHPA/Asian Wetland Bureau, Sumatra Wetland Project Report No. 5, Bogor.

Huizinga, P., Taljaard, S., van Niekerk, L., Turpie, J.K. and Lamberth, S.J., 2001. The effects of water abstraction on the estuaries of the Eerste and Lourens rivers. *CSIR report ENV-SC* 2001-007.

Hyland, J.L., Balthis, W.L., Posey, M.H., Hackney, C.T. and Alphin, T.D., 2004. The soft-bottom macrobenthos of North Carolina estuaries, *Estuaries*, 27, 501-514.

Kamika, I. and Momba, M.N.B., 2013. Assessing the resistance and bioremediation ability of selected bacterial and protozoan species to heavy metals in metal-rich industrial wastewater. *BMC Microbiology*, 13(28), 1-14.

Kleynhans, C. J., Thirion, C., & Moolman, J. (2005). A level I river ecoregion classification system for South Africa, Lesotho and Swaziland. Pretoria: Department of Water Affairs and Forestry.

Kinjo, K. M. and Shimo, M., 2005. Characteristics of surface sediments along a creek in a Mangrove Forest. *Soil Science & Plant Nutrition*, 51(6), 809-817.

Kotze D.C., Hughes J.C., Breen C.M. and Klugg J.R., 1994. *The development of a wetland soils classification system for KwaZulu/Natal.* Report to the Water Research Commission by the Institute of Natural Resources and Department of Grassland Science, University of Natal, WRC Report No 501/4/94.

Kotze D.C. and Marneweck G.C., 1999. *Guidelines for delineating the boundaries of a wetland and the zones within a wetland in terms of the South African Water Act.* As part of the development of a protocol for determining the Ecological Reserve for Wetlands in terms of the Water Act Resource Protection and Assessment Policy Implementation Process. Department of Water Affairs and Forestry, South Africa.

Kotze D.C., Marneweck G.C., Batchelor A.L., Lindley D. and Collins N., 2004. *Wetland-Assess*. A rapid assessment procedure for describing wetland benefits. First Draft. Report prepared for Mondi Wetland Project.

Kotze D.C., Marneweck G., Batchelor A., Lindley D. and Collins N., 2005. *Wetland EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands*, Report submitted to the Water Research Commission, Pretoria.

Kotze D.C., Marneweck G.C., Batchelor A.L., Lindley D.S. and Collins N.B., 2007. *WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands.* WRC Report No TT 339/08, Water Research Commission, Pretoria.

Kotze, D,C., Morneweck, G.C., Butchelor, A.L., Lindley, D.S. and Collins, N.B., 2008. Wet - Ecoservices - A technique for rapidly assessing ecosystem services supplied by wetlands.WaterResearch Commision Report No TT 339/08. Pretoria, South Africa.

Kusanga, S., Warburton, M.L., van Garderen, E.A. and Jewitt, G.P.W., 2014. Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of the Earth*, 67-69, 47-54.

Lackey R.T., 2001. Values, policy and ecosystem health. *Bioscience*, 51, 437–443.

Leeder, M.R., 1982. *Sedimentology: Process and Product.* George Allen and Uwin, London.

Leopold, L.B., Wolman, G.M. and Miller, J.P., 1964. *Fluvial processes in geomorphology*. Freeman, W.H. and Co., San Francisco.

Manikum, T., John, W., Terry, S. & Hodgson, K., 2014. Preliminary study on the radiological and physicochemical quality of the uMngeni Water catchments and drinking water sources in KwaZulu-Natal, South Africa. *Journal of Environmental Radioactivity*, 137, 227-240.

Macdonald, D.D., Ingersoll, C.G. and Berger T.A., 2000. Development and evaluation of consensus-based sediment quality guidelines for fresh water ecosystems. *Archives Environmental Toxicology and Chemistry*, 39, 20-31.

Macfarlane D.M., Kotze D.C., Ellery W.N., Walters D., Koopman V., Goodman P., and Goge C., 2007. *WET-Health: A technique for rapidly assessing wetland health*. Water Research Commission, Pretoria.

Macfarlane D.M., Bredin I.P., Adams J.B., Zungu M.M., Bate G.C. and Dickens C.W.S., 2014. *Preliminary guideline for the determination of buffer zones for rivers, wetlands and estuaries.* Final Consolidated Report. WRC Report No TT 610/14, Water Research Commission, Pretoria.

Maltby E., and Barker T., (Eds) 2009. *The Wetlands Handbook*. Wiley-Blackwell, Oxford.

Marneweck G.C. and Batchelor A., 2002. Wetland inventory and classification. *Ecological and economic evaluation of wetlands in the upper Olifants River catchment*, 2.

McCartney M.P., Neal C. and Neal M., 1998. Use of deuterium to understand runoff generation in a headwater catchment containing a dambo. *Hydrol. Earth System Science*. Vol 5, pp.65-76.

McCauley A., Jones C., and Jacobsen J., 2009. *Soil pH and Organic Matter*. Nutrient Management Module No. 8. Montana State University, 1-11.

McInnes R., 2010. Urban Development, Biodiversity and Wetland Management: Expert Workshop Report. Expert Workshop, 16-17 November 2009, Kenya Wildlife Service Training Institute, Naivasha, Kenya. Oxford, U.K.: Bioscan (U.K.) Ltd.

McLusky, D.S. and Elliott, M., 2004. The estuarine ecosystem, ecology threats and management, 214, Oxford University Press, Oxford.

Miles N. and Manson A.D., 1992. Considerations on the sustainability and environmental impacts of intensive pastures. J*ournal of the Grassland Society of Southern Africa*. Vol. 9, pp. 135-140.

Melwani, A. and Thompson, B., 2007. *The influence of chemical and physical factors on macrobenthos in the San Francisco Estuary*. San Francisco Institute Contribution No. 543.

Millenium Ecosystem Assessment, 2005. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. World Resources Institute, Washington D.C.

Mitsch, W.J. and Goselink, J.G., 1993. *Wetlands.* Van Nostrand Reinhold, New York, 88-469.

Mitsch W.J., and Goselink J.G., 2000. The value of wetlands:importance of scale and landscape setting. *Ecological Economics*. School of Natural Resources, The Ohio State University, Elsevier Science.

Monteiro, P.M.S. and Largier, J.L., 1999. Thermal stratification in Saldanha Bay (South Africa) and subtidal, density-driven exchange with the coastal waters of the Benguela upwelling system. *Estuarine, Coastal and Shelf Science*, 49, 877-890.

Morgan, R.P.C., 1995. *Soil Erosion & Conservation.* Longman, Essex, England.

Morgan, M.A. and Briggs, D.J., 1997. *Sources and Methods in Geography*. Butterworths, London, 14

Moss, A.J., 1962. The physical nature of common sandy and pebbly deposits. *American Journal of Science*, 260(1), 337-373.

Muchina L and Rutherford MC (eds.) 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia*. Vol 19. South African National Biodiversity Institute, Pretoria.

Mullins G., 2012. Copensation Flats Industrial Park- Wetland Rehabilitation Plan. Available: http://www.rhdhv.co.za/media/201210/CIBE/Addendum%201%20Appendix%20G3%20%20Wetland%20rehabilitation%20Plan.pdf.

Natural Resources Conservation Service, 1995. *Hydric soils of the United States*. In: cooperation with the National Technical Committee for Hydric Soils. U.S. Department of Agriculture, Washington, D.C.

National Research Council, 1995. *Wetlands: Characteristics and boundaries*. National Academy Press, Washington, D.C.

Naveedullah, M.Z.H., Chunna, Y., Hui, S., Dechao, D., Chaofeng, S., Liping, L. and Yingxu, C., 2013. Risk Assessment of Heavy metals Pollution in Agricultural Soils of Siling Reservoir Watershed in Zhejiang Province, China. *BioMed Research International*, 10.

Neal M, 1998. *An investigation of altered wetland inflow partitioning due to landuse change in the catchment of Alfred Park, New Germany*. BSc Honours thesis, Department of Geographical and Environmental Sciences, University of Natal, Durban.

Nelson, W. and Campbell, P., 1991. The Effects of Acidification on the Geochemistry of Al, Cd, Pb and Hg in Freshwater Environments: A Literature Review. *Environmental Pollution,* 71, 91-130.

Nel, J.L., Driver, A., Strydom, W.F., Maherry, A., Petersen, C., Hill, L., Roux, D.J., Nienaber, S., van Deventeer, H., Swartz, E. and Smith-Adao, L.B., 2011. Atlas of Freshwater Ecosystem Priority Areas in South Africa: Maps to support sustainable development of water resources. Water Research Commission, WRC Report No. TT 500/11.

Newman, B.K. and Watling, R.J., 2007. Definition of baseline metal concentrations for assessing metal enrichment of sediment from the south-eastern Cape coastline of South Africa. *Water SA*, 33(5), 675-692.

Ngetar, N.S., 2002. *Post-Dam Sediment Dynamics Below The Inanda Dam At The Mgeni Estuary, KwaZulu-Natal, South Africa.* Unpublished M.sc Thesis. Department of Geographical and Environmental Sciences, University of KwaZulu-Natal, Durban.

North Atlantic Treaty Organisation, 2006. *Environmental role of wetlands in headwaters.* Springer, Marienbad, Czech Republic.

Nyarko B.K., 2007. *Floodplain Wetland River Flow Synergy in the White Volta River Basin, Ghana*. Dissertation, ZEF University, Bonn, Germany.

Obasohan, E., Oronsaye, J. and Eguavoen, O., 2008. A Comparative Assessment of the Heavy Metal Loads in the Tissues of a Common Catfish (Clarias Gariepimus) from Ikpoba and Ogba Rivers in Benim City, Nigeria. *African Scientist*, 9 (1), 13-23.

Olaniran, A.O., Naidoo, S. and Pillay, B., 2012. Surveillance of Invasive Bacterial Pathogens and Human Enteric Viruses in Wastewater Final Effluents and Receiving Water Bodies – a Case Study from Durban, South Africa. *Clean – Soil, Air, Water*, 40(7), 681-691.

Ollis, D.J., Snaddon, C.D., Job, N.M., and Mbona, N. 2013. *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*. User Manual: Inland Systems. SANBI Biodiversity Series 22, South African National Biodiversity Institute, Pretoria.

Pelletier, M.C., Campbell, D.E., Ho, K.T., Burgess, R.M., Audette, C.T. and Detenbeck, N.E., 2011. Can sediment total organic carbon and grain size be used to diagnose organic enrichment in estuaries? *Environmental Toxicology and Chemistry*, 30, 538-547

Perissinotto, R., Blair, A., Connell, A., Demetriades, N.T., Forbes, A.T. Harrison, T.H., Lyer, K., Joubert, M., Kibirige, I., Mundree, S., Simpson, H., Stretch, D., Thomas, C., Thwala, X. and Zietsman, I., 2004. *Contribution to information required for the implementation of Resource Directed Measures for estuaries (Volume 2). Responses of the biological communities to flow variation and mouth state in two KwaZulu-Natal temporarily open/closed estuaries.* Water Research Commission Report No. 1247/2/04.

Potter, I.C., Chuwen, B.M., Hoeksema, S.D., Elliot, M., 2010. The concept of an estuary: A definition that incorporates a system which can become closed to the ocean and hypersaline. *Estuarine, Coastal and Shelf Science,* 87(3), 497-500.

Przybysz, A., Saebo, A., Hanslin, H.M. and Guwronski, S.W., 2014. Accumulation of particulate matter and trace elements on vegetation as affected by pollution level, rainfall and passage of time. *Science of The Total Environment*, 481, 360-369.

Ramanchandra, T.V., Kiran, R. and Ahalya, N., 2002. *Status, Conservation and Management of wetlands*. New Dehli: Alied Publishers.

Ramachandra, T.V.and Kumar, U., 2008. Wetland of Greater Bangalore, India: Automatic Delineation through Pattern Classification. *Electronic Green Journal*, 1(26), 1076-7975.

Ramsar COP 7, 1999. 7th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971).

Raudkivi, A.J., 1976. *Loose boundary hydraulics*. 2nd ed., New York, Pergamon Press.

Reddy K.R., and Gale P.M., 1994. Wetland processes and water quality. A symposium overview. *Journal of Environmental Quality*, 23, 875-877.

Renwick M.E., and Eden S., 1999. *Minnesota Rivers a primer*. The Water Resources Centre, University of Minnesota, United States of America.

Rosenberg, R., Blomqvist, M., Nilsson, H.C., Cederwall, H.and Dimming, A., 2004. Marine quality assessment by use of benthic species-abundance distribution: a proposed new protocol within the European Union Water Framework Directive, *Marine Pollution Bulletin*, 49(9-10), 728-739.

Roulet NT, 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: prospects and significance for Canada. *Wetlands*. Vol.20, pp. 605-615.

Roux, D.J. and Nel, J.L., 2013. Freshwater conservation planning in South Africa: Milestones to date and catalysts for implementation. *Water SA*, 36(1), 151-164

Sahu N.C., and Choudhury A.K., 2005. *Dimensions of Environmental and Ecological Economics*. Universities Press, India.

SANBI and DWS, 2016. *WETLAND OFFSETS: A Best Practice Guideline for South Africa.* WRC Report No. TT 660/16.

Schumann, E., Largier, J. and Slinger, J., 1999. Estuarine hydrodynamics. In Allanson, B.R and Baird, D (eds.) *Estuaries of South Africa*, Cambridge University Press, 289-321.

Schnurrenberger, D., Russell, J. and Kelts, K., 2003. *Classification of Lacustrine sediments based on sedimentary components,* 29(2), 141-154.

Schlacher, T.A. and Wooldridge, T.H., 1996a. Axial zonation patterns of subtidal macrozoobenthos in the Gamtoos, South Africa. *Estuaries*, 19, 680-696.

Schlacher, T.A. and Wooldridge, T.H., 1996b. How accurately can retention on benthic macrofauna by a particular mesh size be predicted from body size of organisms? *Hydrobiologia*, 33, 149-154.

Schlacher, T.A. and Wooldridge, T.H., 1996c. How sieve mesh size affects sample estimates of estuarine benthic macrofauna. *Journal of Experimental Marine Biology and Ecology*, 201, 159-171.

Schulze RE, Lynch SD, Angus, GR and George WJ, 1989. ACRU: User Manual. University of Natal, Pietermaritzburg, Department of Agricultural Engineering. *ACRU Report 36*.

Schwirzer A., 2006. *Geomorphic attributes of palustrine wetlands in the upper Boesmans river catchment, KwaZulu Natal*. Unpublished Masters Dissertation, University of Pretoria, South Africa.

Schwirzer A., 2006. *Geomorphic attributes of palustrine wetlands in the upper Boesmans river catchment, KwaZulu Natal*. Unpublished Masters Dissertation, University of Pretoria, South Africa.

Scodari, P.F., 1997. *Measuring the Benefits of Federal Wetland Programs*. Washington D.C., Environmental Law Institute.

Sekabira, K., Origa, H., Basamba, T., Mutumba, G. and Kakudidi, E., 2010. Assessment of Heavy Metal Pollution in the Urban Stream Sediments and its Tributaries. *International Journal of Environmental Science and Tech*nology, 7 (3), 435-446.

Selley, R.C., 2000. *Applied Sedimentology.* Academic Press, San Diego, USA, 50-52.

Shozi, M., 2011. A *Study of the Chemical and Pathogenic Status of Umgeni Estuary, Durban*. BSc. Honours Thesis). Department of Geographical and Environmental Science. University of KwaZulu Natal, Durban.

Simboura, N. and Zenetos, A., 2002. Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index. *Mediterranean Marine Science*, 3, 77-111.

Simons, D. and Sentürk, F., 1992. *Sediment Transport Technology: Water and sediment dynamics.* Water Resource Publications.

Singh, A. and Lin, J., 2015. Microbial, coliphages and physic-chemical assessments of the uMngeni River, South Africa. *International Journal of Environmental Health Research*, 25(1), 33-51.

Skoog, D.A., West, D.M., Holler, F.J. and Crouch, S.R., 2004: *Fundamentals of Analytical Chemistry*, 8th ed., Thomson Books, 155, 845–855.

Sprecher S.W., 2001. Basic Concepts of Soil Science. In: Richardson J.L., and Vepraskas M.J. (Eds). *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification*. Lewis Publishers, Boca Raton, FL., 3-18.

Sukdeo, P., 2010. *A study of the natural and anthropogenic impacts on the sediment and water quality of the middle and lower Mvoti River System, KwaZulu Natal*. M.sc Thesis. Department of Geographical and Environmental Science, University of KwaZulu Natal, Durban.

Sukdeo, P., Pillay, S. and Ballabh, H., 2016. Ecological Restoration and Remediation of a Degraded Estuary: The Case of the Mvoti Estuary, KwaZulu-Natal, South Africa. *Journal of Human Ecology*, 55(1-2), 69-79.

Taljaard, S., De Villiers, S., Fricke, A.H. and Kloppers, W.S., 1992. Water quality status of the Rietvlei/Milnerton Lagoon system (Diep River Estuary) – 1988/89. *CSIR Data Report EMAS-D* 92007. Stellenbosch.

Taljaard, S. and Slinger, J.H., 1993. Investigation into the flushing efficiency of 1. A freshwater release and 2. Seawater overwash in the Great Brak Estuary. *CSIR Research Report* 713. Stellenbosch.

Teklehaimanot, G.Z., 2013. *Faecal water pollution loads as a function of population growth in Sedibeng and Soshanguve, South Africa*. Magister Technologiae: Water Care. Department of Environmental, Water and Earth Sciences. Tshwane University of Technology.

Teske, P.R. and Wooldridge, T.H., 2001. A comparison of the macrobenthic faunas of permanently open and temporarily open/closed South African estuaries. *Hydrobiologia*, 464, 227-243.

Teske, P.R. and Wooldridge, T.H., 2003. What limits the distribution of subtidal macrobenthos in permanently open and temporarily open/closed South African estuaries? Salinity vs sediment particle size. *Estuarine, Coastal and Shelf Science*, 57, 225-238.

Teske, P.R. and Wooldridge, T.H., 2004. Affinities of some common estuarine macroinvertebrates to salinity and sediment type: empirical data from Eastern Cape estuaries, South Africa. *African Zoology,* 39, 183-192.

Theron, A.K., 2000a. Durban beach monitoring progress report: July 1998 to June 1999, Volume I. *CSIR Report ENV-S-C 2000 – 022A.* Environmentek, Stellenbosch.

Theron, A.K. 2004a. SA estuarine hydro- and sediment dynamics: Marine sediment yields. Goukou fieldwork and workshop proposals. *CSIR Internal Report ENV-S-I 2004-022*. Environmentek, Stellenbosch.

Theron, A.K., 2004b. Sediment transport regime at East London. M.Eng. thesis, University of Stellenbosch, Stellenbosch.

Tiner R.W., 1999. *Wetland Indicators*. A guide to wetland identification, delineation, classification and mapping, Lewis Publishers, New York.

Tucker, M., 1998. *Techniques in Sedimentology.* Blackwell Scientific Publications, Oxford, 65-68, 76-78.

Turner R.K., 1991. Economics and Wetland Management. *Ambio,* 20, 59-630.

Turpie, J.K., Adams, J.B., Colloty, B.M., Joubert, A., Harrison, T.D., Maree, R.C., Taljaard, S., van Niekerk, L., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taylor, R., Morant, P., Awad, A., Weston, B. and Mackay, H., 2002. Classification and prioritization of South African estuaries on the basis of health and conservation priority status for determination of the estuarine water reserve. *Department of Water Affairs and Forestry*, Pretoria.

Umgeni Water and WRP Consulting Engineers (Pty) Ltd., 2009. Water Resources Operational Planning Analysis of the Mooi-Mgeni River System. Pietermaritzburg: Umgeni Water.

USEPA, 1995. Economic Benefits of Runoff Controls, Office of Wetlands, Oceans and Watersheds. Environmental Protection Agency. Available at: http://www.epa.gov/nps/runoff.html.

USEPA. 2001. *Nutrients. Factsheet: Methods for evaluating wetland condition*. Office of Water, U.S. Environmental Protection Agency, Washington D.C. EPA-822-F-01-008.

USEPA, 2002. *Methods for evaluating wetland condition: Using vegetation to assess environmental conditions in wetlands*. Office of Water, W.S. Environmental Protection Agency, Washington D.C.

USEPA. 2008. *Methods for Evaluating Wetland Condition: Biogeochemical Indicators*. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-08-022.

Uys M.C., 2004. Development of a framework for the assessment of wetland ecological integrity in South Africa. Phase 1: Situation Analysis, Department of Water Affairs and Forestry, Pretoria.

van der Valk A.G., 2012. *The Biology of Freshwater Wetlands*. Second Edition, Oxford University Press, Oxford, U.K.

van Niekerk, L., Huizinga, P. and Theron, A., 2002. Semi-closed mouth states in estuaries along the South African coastline. In: Environmental Flows For River Systems Proceedings. *Fourth International Ecohydraulics Symposium*, 31, 1 (ISSN 0378-4738)

van Niekerk, L., 2005. Desktop assessment of the Wild Coast Estuaries: Sensitivity to Flow reduction. *CSIR Report ENV/S-C* 2005-042.

van Niekerk, L., van der Merwe, J.H. and Huizinga, P., 2005. The hydrodynamics of the Bot River revisited. *Water SA*, 31, 73-85.

van Wyk, E. and Van Oudtshoorn, F. 2009. Guide to Grasses of southern Africa (2nd edition). Briza Publications, Pretoria.

Vepraskas M.J., and Faulkner S.P., 2001. Redox Chemistry of Hydric Soils. In: Richardson J.L., and Vepraskas M.J. (Eds). *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification*. Lewis Publishers, Boca Raton, FL., 85-105

Walker, D.R., Perissinotto, R. and Bally, R.P.A., 2001. Phytoplankton/protozoan dynamics in the Nyara estuary, a small temporarily open system in the Eastern Cape (South Africa). *African Journal of Aquatic Science*, 26, 31-38.

Weisser, P.J., Whitfield, A.K. and Hall, C.M., 1992. The recovery and dynamics of submerged aquatic macrophyte vegetation in the Wilderness lakes, southern Cape. *Bothalia*, 22, 283-288.

Wentworth, C.K., 1922. A Scale of Grade and Class Terms for Clastic Sediments. *The Journal of Geology*, 30(5), 377-392.

Weaver C.E., 1976. The nature of TIO_2 in kaolinite. *Clays and Clay Minerals*,24, 215-218.

Whitfield, A.K., 1992. A characterisation of southern African estuarine systems. *Southern African Journal of Aquatic Sciences*, 12, 89-103.

Whitfield, A.K., 1998. Biology and Ecology of Fishes in Southern African Estuaries. *Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology*, 2**,** 1-223.

Whitfield, A.K. and Bate, G., 2007. *A Review of Information on Temporarily Open/Closed Estuaries in the Warm and Cool Temperate Biogeographic Regions of South Africa, with Particular Emphasis on the Influence of River Flow on these Systems* (Unpublished doctoral thesis). Nelson Mandela Metropolitan University, Port Elizabeth, South Africa.

Wilcox D.A., Meeker J.A., Hudson P.L., Armitage B.J., Black M.G. and Uzarski D.G., 2002. Hydrological variability and the application of Index of Biotic Integrity metrics to wetlands: A great lakes evaluation. *Wetlands*, 22, 588-615.

Zedler J., 2004. Compensating for wetland losses in the United States. *IBIS,* 46(S1), 92-100.

9. APPENDIX

Table 9.1: Data sheets and sediment cores at sampling stations

SAMPLE NO: 1 – HGM 1	**LOCALITY DESCRIPTION:** Presence of vast array of alien vegetation and dryland sugarcane plantation (*Saccharum oficinarum*)	
LATTITUDE: 30°25'0.21"S	**LONGITUDE:** 30°40'12.79"E	
VEGETATION: *Phragmites australis*		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: high**
	COLOUR: orange	**ABUNDANCE: high**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 2**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: high**
	COLOUR: orange	**ABUNDANCE: high**
MATRIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 2 -HGM 1	**LOCALITY DESCRIPTION:** Presence of dirt road, alien vegetation and dryland sugarcane plantation (*Saccharum oficinarum*)	
LATTITUDE: 30°24'58.51"S		**LONGITUDE:** 30°40'19.83"E
VEGETATION: *Phragmites australis*		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**
	COLOUR:	**ABUNDANCE:**
MARTIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 2**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: intermediate**
	COLOUR: orange	**ABUNDANCE: low**
MATRIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 3 – HGM 1	**LOCALITY DESCRIPTION:** Presence of dirt road and a large stand of dryland sugarcane plantation (*Saccharum oficinarum*)	
LATTITUDE: 30°40'19.17"E	**LONGITUDE:** 30°40'15.60"E	
VEGETATION: *Phragmites australis*		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: high**
	COLOUR: orange	**ABUNDANCE: high**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 2**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT / NONE**	**CONTRAST: high**
	COLOUR: orange	**ABUNDANCE: high**
MATRIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 4 – HGM 2	**LOCALITY DESCRIPTION:** Area was predominantly natural with a large stand of macrophytes	
LATTITUDE: 30°24'38.94"S	**LONGITUDE:** 30°40'19.17"E	
VEGETATION: *Phragmites australis*		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: intermediate**
	COLOUR: orange	**ABUNDANCE: low**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: Intermediate**
	COLOUR: Orange	**ABUNDANCE: low**
MATRIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 5 – HGM 3	**LOCALITY DESCRIPTION:** Presence of hardened surfaces and vast array of alien vegetation.	
LATTITUDE: 30°24'19.23"S		**LONGITUDE:** 30°40'11.75"E
VEGETATION: *Cyperus papyrus*		
	SOIL MORPHOLOGY (0-10cm):	
MOTTLING:	**PRESENT / NONE**	**CONTRAST: intermediate**
	COLOUR: orange	**ABUNDANCE: low**
MARTIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 2**
	SOIL MORPHOLOGY (30-40cm):	
MOTTLING:	**PRESENT / NONE**	**CONTRAST: Intermediate**
	COLOUR: orange	**ABUNDANCE: moderate**
MATRIX HUE:	**MATRIX VALUE: 5**	**MATRIX CHROMA: 1**
	HYDROLOICAL ZONE:	
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 6 – HGM 3	**LOCALITY DESCRIPTION:** Presence of dirt road and vast array of alien vegetation	
LATTITUDE: 30°24'20.69"S	**LONGITUDE:** 30°40'11.80"E	
VEGETATION: *Cyperus papyrus*		
SOIL MORPHOLOGY (0-10cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: intermediate**
	COLOUR: orange	**ABUNDANCE: high**
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**
SOIL MORPHOLOGY (30-40cm):		
MOTTLING:	**PRESENT** / **NONE**	**CONTRAST: Intermediate**
	COLOUR: orange	**ABUNDANCE: High**
MATRIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 2**
HYDROLOICAL ZONE:		
PERMANENT	**SEASONAL**	**TEMPORARY**

SAMPLE NO: 7 – HGM 3	**LOCALITY DESCRIPTION:** Presence of dirt road, culvert and bridge and, vast array of alien vegetation		
LATTITUDE: 30°24'24.09"S		**LONGITUDE:** 30°40'12.19"E	
VEGETATION: *Cyperus papyrus*			
SOIL MORPHOLOGY (0-10cm):			
MOTTLING:	**PRESENT** / NONE	**CONTRAST: intermediate**	
	COLOUR: orange	**ABUNDANCE: low**	
MARTIX HUE:	**MATRIX VALUE: 4**	**MATRIX CHROMA: 1**	
SOIL MORPHOLOGY (30-40cm):			
MOTTLING:	**PRESENT / NONE**	**CONTRAST:**	
	COLOUR:	**ABUNDANCE:**	
MATRIX HUE:	**MATRIX VALUE: 3**	**MATRIX CHROMA: 1**	
HYDROLOICAL ZONE:			
PERMANENT	**SEASONAL**	**TEMPORARY**	

Table 9.2: List of plant species found in Site SW5

Taxon	Family	Growth Form	Conservation Status
Ageratum conyzoides	Asteraceae	Herb	Alien – 1b
Asystasia gangetica	Acanthaceae	Herb	Indigenous - LC
Bidens pilosa	Asteraceae	Herb	Alien - NDec[WIP]
Cassia didymobotrya	Fabaceae	Shrub/Tree	Alien - NCA
Centella asiatica	Apiaceae	Herb	Indigenous - LC
Chromolaena odorata	Asteraceae	Shrub	Alien – 1b
Colocasia esculenta	Araceae	Shrub	Alien - NDec[WIP]
Commelina erecta	Commelinaceae	Herb	Indigenous - LC
Conyza sumatrensis	Asteraceae	Herb	Alien - NDec[WIP]
Cyperus dives	Cyperaceae	Sedge	Indigenous - LC
Eichhornia crassipes	Pontederiaceae	Herb	Alien – 1b
Eragrostis curvula	Poaceae	Graminoid	Indigenous - LC
Erythrina lysistemon	Fabaceae	Tree	Indigenous - LC
Ficus natalensis	Moraceae	Tree	Indigenous - LC
Gomphrena celosioides	Amaranthaceae	Herb	Alien - NDec[WIP]
Ipomoea indica	Convolvulaceae	Creeper	Alien – 1b
Lantana camara	Verbenaceae	Shrub	Alien – 1b
Musa acuminata	Poaceae	Herb	Alien - NCA
Oxalis purpurea	Oxalidaceae	Herb	Indigenous - LC
Panicum maximum			Indigenous - LC
Pennisetum purpureum	Poaceae	Graminoid	Alien - 2
Phoenix reclinata	Arecaceae	Palm	Indigenous - LC
Plectranthus spp.	Lamiaceae	Herb	Indigenous - LC
Ricinus communis	Euphorbiaceae	Shrub/Tree	Alien - 2
Solanum elaeagnifolium	Solanaceae	Herb	Alien – 1b
Trema orientalis	Cannabaceae	Tree	Indigenous - LC

Alien Status

Cat.1b^{NN} =	Category 1b according to NEMBA national criteria
Cat. 1b^{NKZN}=	Category 1b in KZN according to NEMBA provincial criteria
Cat. 1b^{NN} *Cat. 3 in urban areas =	Category 1b according to NEMBA national criteria but Category 3 in urban areas
Cat. 1b^{NN} *in riparian & grassland biome^{NN} =	Category 1b according to NEMBA national criteria in riparian habitats and grassland biome
Cat. 1^{WIP} =	Category 1 according to WIP website
Cat. 2^{NN} =	Category 2 according to NEMBA national criteria
Cat. 2^{WIP} =	Category 2 according to WIP website
Cat. 3^{NN} =	Category 3 according to NEMBA national criteria
NCA =	Non-Categorized Alien
NDec^{WIP} =	Non-Declared alien according to WIP website
NEx^{SANBI} =	Naturalized Exotic according to the SANBI red list website

Figure 9.1: An area of site SW5.

Table 9.3: List of plant species found in site SE3.

Taxon	Family	Growth Form	Conservation Status
Centella asiatica	Apiaceae	Herb	Indigenous - LC
Colocasia esculenta	Araceae	Shrub	Alien - NDec^{WIP}
Commelina erecta	Commelinaceae	Herb	Indigenous - LC
Eragrostis capenis	Poaceae	Graminoid	Indigenous - LC
Ipomoea indica	Convolvulaceae	Creeper	Alien – 1b
Musa acuminata	Poaceae	Herb	Alien - NCA
Panicum maximum	Poaceae	Graminoid	Indigenous - LC
Phragmites australis	Poaceae	Reed	Indigenous - LC
Syzygium cordatum	Myrtaceae	Tree	Indigenous - LC

Alien Status

Cat.1b^{NN} =	Category 1b according to NEMBA national criteria
Cat. 1b^{NKZN}=	Category 1b in KZN according to NEMBA provincial criteria
Cat. 1b^{NN} *Cat. 3 in urban areas =	Category 1b according to NEMBA national criteria but Category 3 in urban areas
Cat. 1b^{NN} *in riparian & grassland biome^{NN} =	Category 1b according to NEMBA national criteria in riparian habitats and grassland biome
Cat. 1^{WIP} =	Category 1 according to WIP website
Cat. 2^{NN} =	Category 2 according to NEMBA national criteria
Cat. 2^{WIP} =	Category 2 according to WIP website
Cat. 3^{NN} =	Category 3 according to NEMBA national criteria
NCA =	Non-Categorized Alien
NDec^{WIP} =	Non-Declared alien according to WIP website
NEx^{SANBI} =	Naturalized Exotic according to the SANBI red list website

Figure 9.2: An area of site SE3.

Table 9.4: List of plant species found in site SE2.

Taxon	Family	Growth Form	Conservation Status
Amaranthus spp	Amaranthaceae	Herb	Indigenous - LC
Anredera cordifolia	Basellaceae	Creeper	Alien – 1b
Cardiospermum grandiflorum	Sapindaceae	Creeper	Alien – 1b
Cyperus dives	Cyperaceae	Sedge	Indigenous - LC
Ipomoea indica	Convolvulaceae	Herb	Alien – 1b
Phoenix reclinata	Arecaceae	Palm	Indigenous - LC
Phragmites australis	Poaceae	Reed	Indigenous - LC
Ricinus communis	Euphorbiaceae	Shrub/Tree	Alien - 2
Solanum lycopersicum	Solanaceae	Herb	Alien - NCA
Stenotaphrum secundatum	Poaceae	Graminoid	Indigenous - LC
Strelitzia nicolai	Strelitziaceae	Shrub	Indigenous - LC
Tropaeolum majus	Tropaeolaceae	Herb	Alien - NDec^{WIP}

Alien Status

Cat.1b^{NN} =	Category 1b according to NEMBA national criteria
Cat. 1b^{NKZN}=	Category 1b in KZN according to NEMBA provincial criteria
Cat. 1b^{NN} *Cat. 3 in urban areas =	Category 1b according to NEMBA national criteria but Category 3 in urban areas
Cat. 1b^{NN} *in riparian & grassland biome^{NN} =	Category 1b according to NEMBA national criteria in riparian habitats and grassland biome
Cat. 1^{WIP} =	Category 1 according to WIP website
Cat. 2^{NN} =	Category 2 according to NEMBA national criteria
Cat. 2^{WIP} =	Category 2 according to WIP website
Cat. 3^{NN} =	Category 3 according to NEMBA national criteria
NCA =	Non-Categorized Alien
NDec^{WIP} =	Non-Declared alien according to WIP website
NEx^{SANBI} =	Naturalized Exotic according to the SANBI red list website

Figure 9.3: An area of site SE2.

Table 9.5: List of plant species found in site SE1.

Taxon	Family	Growth Form	Conservation Status
Phragmites australis	Poaceae	Reed	Indigenous - LC

Alien Status

Cat.1b[NN] =	Category 1b according to NEMBA national criteria
Cat. 1b[NKZN]=	Category 1b in KZN according to NEMBA provincial criteria
Cat. 1b[NN] *Cat. 3 in urban areas =	Category 1b according to NEMBA national criteria but Category 3 in urban areas
Cat. 1b[NN] *in riparian & grassland biome[NN] =	Category 1b according to NEMBA national criteria in riparian habitats and grassland biome
Cat. 1[WIP] =	Category 1 according to WIP website
Cat. 2[NN] =	Category 2 according to NEMBA national criteria
Cat. 2[WIP] =	Category 2 according to WIP website
Cat. 3[NN] =	Category 3 according to NEMBA national criteria
NCA =	Non-Categorized Alien
NDec[WIP] =	Non-Declared alien according to WIP website
NEx[SANBI] =	Naturalized Exotic according to the SANBI red list website

Figure 9.4: Site SW5 Dominants: Eichhornia crassipes, Erythrina lysistemon, pennisetum purpureum, Phoenix reclinata (from top to bottom).

Figure 9.5: Site SE3 Dominants: *Syzygium cordatum* and *Ipomoea indica (*from left to right).

Figure 9.6: Site SE2 dominants: Ipomoea indica, Anredera cordifolia, Ricinus communis, Tropaeolum majus, Cyperus dives (from top to bottom).

Figure 9.7: Site SE1 dominant: *Phragmites australis*

Table 9.6: Sezela estuarine and river sampling co-ordinates

Sampling site	Co-ordinates
SE1	30°24'51.75"S 30°40'35.32"E
SE2	30°24'34.06"S 30°40'16.16"E
SE3	30°24'33.13"S 30°40'4.22"E
SW5	30°24'1.15"S 30°39'17.30"E

Table 9.7: WET-EcoServices scores for HGM's 1, 2 and 3.

		HGM 1			HGM 2			HGM 3	
Hydro-geomorphic setting		VC			F			VC	
Size		9.57			22.2			2.43	
		Overall score	Confidence rating		Overall score	Confidence rating		Overall score	Confidence rating
Flood attenuation		2,3	3,4		2,4	3,4		2,3	3,4
Streamflow regulation		2,3	3,8		1,8	3,7		2,3	3,8
Sediment trapping		2,9	3,5		2,5	3,3		2,9	3,5
Phospahte trapping		2,7	3,2		2,1	3,0		2,7	3,2
Nitrate removal		3,0	3,1		2,1	3,0		2,9	3,1
Toxicant removal		2,8	3,3		2,3	3,2		2,8	3,3
Erosion control		2,4	2,7		2,3	2,6		2,5	2,7
Carbon storage		2,0	3,3		2,7	3,3		2,0	3,3
Maintenance of biodiversity		2,3	3,4		3,3	3,5		1,5	3,4
Water supply for human use		0,9	3,8		1,0	3,8		1,1	3,6
Natural resources		1,6	3,8		1,6	3,8		1,6	3,8
Cultivated foods		2,0	3,8		1,8	3,8		2,0	3,8
Cultural significance		1,0	4,0		1,0	4,0		1,0	4,0
Tourism and recreation		1,4	3,6		1,9	3,8		1,1	3,4
Education and research		0,8	3,8		1,0	4,0		0,8	3,8
Threats		2,0	3,0		2,0	3,0		2,0	3,0
Opportunities		3,0	3,0		3,0	3,0		3,0	3,0

VC-valley bottom with a channel, F-Floodplain, all scores out of a total of 4

Table 9.8: Physico-chemical parameter water chemistry results.

Sampling stations	DO (mg/L)		pH		EC		TDS		Salinity	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
SE1	3.9	2.7	7.76	8.57	355	1341	1889	312	22.6	1.5
SE2	4.2	2.9	8.86	8.50	210	1446	305	535	0.1	0.4
SE3	3.7	3.0	9.16	8.87	238	1202	552	517	0	0.4
SW5	3.4	2.9	8.68	8.78	352	657	156	283	0	0.1

Table 9.9: Metal water chemisty results.

Sampling stations	Copper (mg/L)		Cadmium (mg/L)		Lead (mg/L)		Mercury (mg/L)		Zinc (mg/L)	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
SE1	-	-	-	-	-	-	-	-	-	-
SE2	-	-	-	-	-	-	-	-	-	-
SE3	-	-	-	-	-	-	-	-	-	-
SW5	-	-	-	-	-	-	-	-	-	-