A STUDY OF THE NATURAL AND ANTHROPOGENIC IMPACTS ON THE SEDIMENT AND WATER QUALITY OF THE MIDDLE AND LOWER MVOTI RIVER SYSTEM, KWAZULU NATAL, SOUTH AFRICA

by

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ABSTRACT

This dissertation focussed on the Mvoti River system in KwaZulu-Natal, an important resource for the numerous towns and villages along its course. Catchment activities are varied with agriculture being the predominant activity, and industrial activities common in the lower catchment. The Mvoti River is intensively utilized, especially in its lower reaches, to the extent that it is referred to as a 'working river'. Modifications of the chemical and physical characteristics of the system, and consequently the biological characteristics, have led to degradation of the system such that the functioning of the lower river has deteriorated in comparison to that of its pre-disturbance condition. There are three main aspects of the Mvoti system around which this dissertation is based, namely, water quality, geochemistry, and conservation of the system.

The results of the water quality survey of the estuary revealed that the system is presently experiencing water which is of an inferior quality. Compared against the South African water quality standards, a majority of the parameters exceed acceptable limits and are likely to present negative impacts on aquatic health and potentially human health. Comparison of current results, and water quality data for the system dating back to 1964, revealed that this degradation is not new to the system, and the Mvoti Estuary has in fact been experiencing continued deterioration over the years.

The second part of this study investigated heavy metal presence in the sediments of the lower system and elemental presence and distribution in the surface sediments of the middle and lower River respectively. Results indicated that even though selected heavy metals are present, they are of concentrations lower than those of two other South African and two other international systems they were compared with.

Enrichment and contamination assessments reveal that contaminants are in all probability present as a result of anthropogenic sources. However, distribution patterns which show highest levels just after effluent disposal sites suggest that the contamination is presumably human-induced and, the predominance of larger grained sediments that do not have high adsorption capacities, suggest that contaminants are readily remobilized into the water column.

The final part of this research investigates other environmental problems, and causes, both natural and anthropogenic, experienced by the estuary system. These stresses include poor water quality, reduced water quantity, sedimentation, alien vegetation invasions and loss of biodiversity. Strategies to address these issues are proposed, with the intention of improving the condition of the estuary. This is an attempt at ecological restoration, to restore the estuary to a condition as close to as possible, to its pre-disturbance condition. These strategies include controlling abstraction and discharge, eradicating alien vegetation, controlling sandmining, and improving the overall quality of the system. Also proposed is an estuary management plan (EMP) for the Mvoti system, as there is currently no plan of such a nature in place. The EMP will aid restoration attempts, increase public awareness, and *via* post-project monitoring and evaluation ensure the success and sustainability of any future projects. Significantly, the adoption of an EMP will be a major step towards the rehabilitation, conservation and protection of this already degraded system.

PREFACE

The experimental work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Durban, from March 2009 to March 2010, under the supervision of Dr. S. Pillay.

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.

DECLARATION 1: PLAGARISM

I, Prisha Sukdeo, declare that

1. The research reported in this thesis, except where otherwise 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 of other information unless specifically acknowledged as being sourced from other persons.
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DECLARATION 2: PUBLICATONS AND CONFERENCE PROCEEDINGS

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LIST OF ABBREVIATIONS

CF	Contamination Factor
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
EF	Enrichment Factor
EMP	Estuary Management Plan
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
KDM	Kwa Dukuza Municipality
MPA	Marine Protected Area
PLi	Pollution Load Index
SOER	State of Estuaries Report

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CHAPTER ONE

GENERAL INTRODUCTION AND THEORETICAL BACKGROUND

1.1. Introduction

The rapid expansion of human activities worldwide coupled with exponential population growth, has created immense stress on the environment and natural resources. These factors contribute to the diminishing status of a variety of resources including the global freshwater reserve. Water is a fundamental resource for all life on earth (Naidoo, 2005; Phiri *et al.,* 2005; Graham and Farmer, 2007). Despite its importance, water is often a victim of pollution and over-exploitation (DEAT, 2005). Accordingly, it is essential that this resource be efficiently and vigilantly managed and protected.

Adequate water is required in order for humans, and aquatic and terrestrial ecosystems to survive. For these systems to function at their optimum, it is important not only for appropriate amounts of water to be available (French, 1997), but also for this water to be fit in terms of its quality (chemical and physical), for usage by both human and non human consumers (DEAT, 2006).

South Africa is a semi-arid country (Naidoo, 2005; Bucas, 2006), receiving an average rainfall of approximately 450 mm per year (DEAT, 2006). The distribution of rainfall in the country is variable and uneven (Bucas, 2006), with the western and northern part of the country receiving substantially less rainfall than the southern and eastern regions (DEAT, 2006). The management and protection of water resources is particularly necessary in South Africa, which is considered a water-stressed country according to the United Nations definition, i.e. the availability of less than 1700 m^3/person/year (DEAT, 2005). In South Africa, rivers provide a vast majority of the exploitable water resource available (O' Keeffe, 1986). It has been predicted that fresh water will one day be the factor that limits South Africa's economic prosperity (O' Keeffe, 1986) and until then rivers will continue to be exploited.

Surface water bodies, especially rivers, are of particular importance in South Africa as they are the principle providers of water in the country (DEAT, 2006). Ground water is also utilized to an extent, more so in arid regions.

However, surface water is the preferred option, and the uneven distribution of water resources in the country is often overcome *via* inter-basin transfers of water from rivers (DEAT, 2006). South Africa's water resources presently exist within nineteen key water management areas (WMA), each comprising of individual tertiary catchments (DEAT, 2006; SOER, 2007). Apart from water, river systems are also important with regards to sources of food and sediments (building material), transport options, recreational areas, and disposal sites for irresponsible discharges of effluent.

Since the earliest days of civilization, rivers have always been and still are focal points for development, holding key roles in local and global economies (King *et al*., 2003). Globally, river-modifications have gradually changed the distribution and nature of surface waters (King *et al*., 2003). During the last few decades, manipulations of rivers have become increasingly extensive with the rapid development of dams and impoundments, inter-basin transfers, and catchment activities which affect the water resource (King *et al*., 2003). Other modifications include channelization, canalization, waste disposal, and the alterations of river courses to suit land use requirements (Viles and Spencer, 1995; King *et al*., 2003).

River systems and estuaries are important components of our physical environment as they play an integral role in the survival of a variety of life forms on earth (Munien, 2006). The use of water resources inland and in coastal areas affects the functioning of rivers, estuaries and coastal waters (French, 1997; King *et al*., 2003; DEAT, 2005). Activities occurring within the catchments of these river systems also affect the health and functioning of these rivers and estuarine ecosystems (Viles & Spencer, 1995; French, 1997; Davies and Day, 1998). This is mainly due to the fact that water in rivers is derived either from groundwater which has seeped though from the surface or directly from surface runoff (Dame and Allen, 1996), and eventually ends up in estuaries. Rivers therefore receive and serve as the conduit for the catchment's water and other material (in dissolved or solid state) which are conveyed in most cases to the marine environment *via* estuaries, especially urban rivers which are often considered as pollutant sinks and sometimes source (Scholes *et al*., 2008). Estuaries, therefore act as temporary sinks for materials, sediments, and nutrients derived from the catchment (Viles & Spencer, 1995; Lindsay and Bell, 1997), before these are eventually flushed out to sea.

The unlimited and convenient access to natural resources and water supply that most river systems and estuaries provide create ideal locations for industrial, agricultural and residential developments, making these environments vulnerable to degradation (Munien, 2006).

Furthermore, factors such as geology, vegetation and land use of the entire catchment all contribute in some way to quality of water entering rivers and consequently estuaries (O' Keeffe, 1986). Apart from water use, land use and other practices within the catchment, and natural processes such as weathering and erosion, climate change has been identified as a factor which may affect our water resources by influencing rainfall quantity and distribution, as well as evaporation rates (DEAT, 2006; Graham and Farmer, 2007).

Estuaries, being the interface between rivers and the sea (Anthony *et al.,*2002), are highly important and unpredictable areas along the coastline (Glennie, 2001) and provide us with a wide range of biological 'services' and goods such as, raw materials, areas for recreational activities and scenic views (Mander, 2001). Estuaries are also able to control flooding, to provide sediment to sustain beaches, and to control erosion by the growth of estuarine vegetation (Mander, 2001). Currently, estuaries are also popular sites for industrial and harbour development together with domestic and industrial effluent discharge (DEAT, 2001). Population growth and development in and around estuaries and river systems, in addition to exploitation of the resources they provide (Mander, 2001) are placing increasing pressure on the health and functioning of these ecosystems (DEAT, 2001).

According to Allanson (2001), in the last century human activities in South Africa have altered the natural progression of changes in riverine and estuarine geomorphology, accelerating it, by means of increasing impoundments on rivers and decreasing inflow into estuaries, or by over-abstraction of water. This in turn can result in destruction of the estuary, or consolidation of estuarine sediments and increased sandbar formations (Allanson, 2001).

1.2. Contextualization of the problem and motivation for the study

Globally, land and water developments and interrelations have brought many benefits to humankind, however, they have also resulted in a decrease in the ecological form and functioning of fluvial systems (King *et al.*, 2003). The implications of these declines are increasingly recognized, in terms of decreasing water quality, decreasing natural, aquatic resources available, sedimentation of storage bodies, loss of biodiversity, over and above the national costs associated with rectifying these issues (King *et al.*, 2003).
Consequently, river research concerned with these stresses, their causes, as well as mitigation measures are being progressively more attempted. However, constructive and meaningful river research of this nature is still relatively young in South Africa (King *et al.*, 2003).

The protection of water and aquatic resources is of vital importance in South Africa (Malan and Day, 2002). Rivers are capable of replenishing themselves via a self-cleansing function. However, when rivers are subjected to stresses like pollution and excessive water abstraction, their functioning as an ecosystem is compromised (Malan and Day, 2002), and this often affects their self-cleansing capabilities. With continued stress and impaired self-cleansing abilities, the quality of the system experiences further declines, and the use of the water resource becomes limited (Malan and Day, 2002). As noted by Malan and Day (2002), water is a limited resource in South Africa, and consequently pollutants cannot always be dealt with *via* dilution.

Effluent disposals and high abstraction rates coupled with high evaporation rates, have led to increased concentrations of pollutants in water bodies. Pollutants in the water column often reach toxic levels and present adverse effects on biota and human health (Orr, 2007). Pollutants also accumulate within sediments, and can be remobilised into the water column *via* various processes, re-contaminating the system (Chenhall *et al.,* 2004; Lin *et al.*, 2007; Harikumar and Jisha 2010). Common sources of pollutants of rivers include urban and agricultural activities (litter, various chemicals, organic waste, pesticides, fungicides and fertilizers), industrial effluents (various chemical and synthetic compounds, organic waste, dyes, and waste water used in washing/cooling processes), as well as natural processes (catchment geology, weathering and erosion). It is therefore of particular importance, that river systems be assessed and monitored, in terms of their water quantity and quality, sediment quality, as well as biotic integrity.

The Mvoti River is an intensively utilized system particularly in its lower reaches. Here the river is subjected to major influences from the local industries, in the forms of alterations of the main channel, water abstraction, together with milling and sewage effluent discharges which enter the river *via* the Mbozambo and Ntshaweni tributaries. These effluents enter the Mvoti River approximately 7 km upstream of the Mvoti Estuary, and have consequently presented a range of implications for this system over the years. The lower Mvoti River is severely degraded such that the river functioning is completely different to what it was in its pre-disturbance condition (MacKay *et al.*, 2000b).

Other influences on the system include extensive agriculture in the upper (forestry) and lower (sugarcane farming) catchment, sandmining, and diverse settlements ranging from urban, to rural, to informal. As catchment activities are a pivotal influence on river systems, these should also be considered in terms of their assessment and monitoring, i.e. a catchment approach should be implemented. The impacts of this myriad of activities and influences on the Mvoti has been investigated over the years (Tharme, 1996; Malherbe, 2006, Munien, 2006; Von Bratt, 2008, Chili, 2008). These studies have however been primarily concerned with the Mvoti Estuary and the lower reaches of the river. Preference has also been predominantly awarded to investigating the industrial effects on water quality and biotic characteristics of the system.

The primary focus of this study is therefore to view the system as a whole, encompassing the middle, lower and estuarine sections of the Mvoti River, in the assessment of both anthropogenic and natural effects, on the water quality and sediment contamination (of which there is little known) of the system. Despite its importance as a resource to a number of towns and industries, as well as its persistently deteriorating condition, there are currently no measures in place to monitor and manage the system, or to promote its conservation.

1.3. Aim and Objectives

The aim of this study is to asses the natural and anthropogenic effects on the water and sediment quality of the middle and lower Mvoti River system.

The main objectives of this study, set out to achieve the aim are as follows:

- To assess the current water quality of the Mvoti Estuary and appraise deteriorations in the system over the last four decades (Chapter 3).
- To determine the presence of selected heavy metals in the sediments of the lower Mvoti River and estuary in relation to other ecologically significant systems (Chapter 4).
- To assess the geochemical enrichment and pollution status of the middle and lower Mvoti River sediments (Chapter 5).
- To develop a proposal for the ecological restoration of the lower Mvoti River and estuary system (Chapter 6: Part I).
- To develop a potential estuary management plan for the Mvoti Estuary (Chapter 6: Part II).

1.4. Structure of the Dissertation

Chapters three to six of this thesis are based upon individual papers that have been submitted to peer-reviewed journals. The journals together with the title of the papers are presented at the beginning of each respective chapter.

Chapter One outlines briefly previous research conducted on the lower Mvoti system and their respective areas of focus. In addition, this section also discusses the various literature and theoretical concepts upon which this study is based. Key areas reviewed in this chapter include rivers, estuaries and their catchments, physico-chemical characteristics of aquatic systems, factors affecting them, as well as ecological degradation and restoration.

Chapter Two describes the physical characteristics of the study area and its regional setting, together with a brief description of the research methodology adopted in this study. It includes the selection of sample sites, field collection, descriptions of the chemical analysis conducted on the samples, other laboratory procedures including sediment analysis, as well as methods of data analysis. Chapter Three presents the results of the water quality analysis, to provide a description of the current conditions prevalent in the system. The implications the current water quality has for aquatic health and human use is also discussed, together with a comparison of existing data and present conditions to assess the deteriorations that have occurred in the system.

The fourth chapter discusses the results of the heavy metal analysis conducted on the sediments of the lower river and estuary. Varying land uses are catchment activities can have considerable detrimental effects on the levels of pollutants in freshwater systems. Of these pollutants, heavy metals are of particular concern due to their persistent and accumulative nature. The results are compared to data available for two South African, and two international systems. Chapter Five presents the findings of the geochemical assessment conducted on the sediments of the middle and lower Mvoti River. Here, elemental presence and distribution are discussed, along with pollution assessments of the system.

The sixth chapter (Part I) identifies environmental stresses imposed upon the lower Mvoti River and Estuary, the resultant impacts on the system, plus viable strategies to ecologically restore this degraded system. Part II of this chapter is a potential estuary management plan for the Mvoti Estuary, whilst the seventh and final chapter outlines the conclusions of the study, and recommendations for future research.

1.5. Introduction to the literature review

This remaining section of this chapter presents a review of the literature and theoretical concepts upon which this research is based. A review of previous research on the system is outlined, followed by a discussion of rivers, estuaries and catchment characteristics.

Furthermore, the subjects of water quality, geochemistry, and ecological restoration, which are important concepts governing this study, are detailed.

1.6. Review of past research on the Mvoti System

In South Africa, river and estuarine research is extensive, yet still in its infancy (King *et al.*, 2003). In recent years, the value of these aquatic systems has been increasingly recognized, and hence intensive research covering geomorphology, environmental stresses, environmental quality as well as rehabilitative efforts, has been conducted. These studies have considered individual systems on their own, as well as in relation to other systems, and their catchment or water management areas.

Regarding the Mvoti system, research has been somewhat fragmented in both time and content. Some of the earliest published work, includes that of Begg (1978; 1984), which are comprehensive studies of the biological, chemical, and physical characteristics of the Mvoti Estuary (Abed, 2009). Cooper (1994; 2001; 2002), explored in some detail, the geomorphology of the Mvoti Estuary.

The water quality of the lower river and estuary has been give priority over the last decade, with a number of research efforts investigating the impacts presented on the system from the industrial activities, together with the ecological integrity of the system (MacKay *et al.*, 2000a; Malherbe, 2006; Munien, 2006; Von Bratt, 2007; Carminati, 2008. The recent extensive work on the lower river system, regarding water quality and biological integrity, has allowed for comparisons to be made with current data.

However, despite the amount of research conducted, and the importance of the system, various aspects, most notably the sediment component has been neglected. To date, there are no published works concerning the sediment chemistry of the Mvoti River and Estuary system. Furthermore, despite the continued degradation of the lower Mvoti system (Tharme, 1996; Malherbe, 2006, Munien, 2006; Von Bratt, 2007 Chili, 2008), there is no estuary management plan in place for the estuary and, no attempts have been made to restore or rehabilitate the system to an ecological state resembling pre-disturbance. Therefore, these important knowledge gaps in data for the system have provided the motivation for this study.

1.7. River Systems

In the past few decades South African rivers have experienced extensive changes in terms of water quantity, quality and flow regimes (O' Keeffe, 1986). A river can be described as a dynamic, longitudinal ecosystem which is reflective of the type and condition of the land it drains (O' Keeffe, 1986). They are resilient systems, in the sense that given appropriate time and space, they can recover from perturbations provided that the disturbances have ceased, and both the biotic and abiotic characteristics were not damaged beyond recovery, i.e. the system has not been totally degraded (O' Keeffe, 1986).

Rivers usually consist of three broad sections, namely the headwaters, middle reaches, and lower reaches (O'Keeffe, 1986). The headwaters are usually fast flowing and erosive (O' Keeffe, 1986), cool and clean except for when in flood (Davies and Day, 1998). The substrate in this part of the river is usually hard and rocky, with very little silt and loose sand (Davies and Day, 1998). The headwaters are therefore usually oligotrophic, of good quality, with optimum levels of dissolved oxygen, and relatively low levels of nutrients and leached minerals. According to Davies and Day (1998), mountainous headwater streams are physically harsh environments, sculpting the channel as it flows over the landscape. Therefore instream vegetation is usually scarce, and aquatic inhabitants are adapted to living the in fast-flowing environment.

The middle reaches are slower flowing and partly erosive (O' Keeffe, 1986). The reduction in velocity is usually attributed to a gentler slope (Davies and Day, 1998). The river bed broadens and water and sediment are accumulated from tributaries. According to Davies and Day (1998), the water in this part of the river is of a poorer quality in comparison to the headwaters, owing to accumulated nutrients and leached minerals as well as possible anthropogenic inputs.
The water may also appear more turbid and less turbulent, as a result of an increasing sediment load. Oxygen levels are lower in the middle reaches of the river. However, aquatic inhabitants are more varied and productive, and instream vegetation is established (Davies and Day, 1998).

The lowest reaches are usually low lying (O' Keeffe, 1986) on coastal plains or plateaus (Davies and Day, 1998). The decrease in gradient reduces velocity and despite increases in discharge accumulated from tributaries, the river is slow flowing. Erosion here, is rare and deposition of materials eroded in the upper reaches occurs (Davies and Day, 1998; O' Keeffe, 1986). Siltation, nutrient and organic material accumulation and leaching occur continuously all the way down the river (Davies and Day, 1998). Hence, the lower reaches are often rich in nutrients and organic matter, accompanied by a decrease in oxygen levels.

Aquatic inhabitants in this part of the river are also more varied, yet adapted to a softer substrate and nutrient-rich water. Flora, both instream and along the banks are dense and developed (Davies and Day, 1998).

Despite this categorisation of rivers into different zones, rivers are not comprised of isolated systems. As documented by Davies and Day (1998), each river is a continuous system, with each section connected to each other *via* time, physical and chemical processes. "*Each river is a single four-dimensional entity with vertical, cross-sectional, longitudinal and temporal components*" (Davies and Day, 1998: 81). Within its own boundary, as noted by Davies and Day (1998) and King *et al*. (2003), from the source each river functions continuously as a coherent whole where processes and functions in the upper reaches of river influence processes and functions lower down the river until it reaches the sea. As noted by King *et al*. (2003), these unique linear ecosystems function in an inter-linked way from the source to the estuary, and are usually affected by most human activities occurring in the catchments they drain. Along this course, their abiotic and biotic nature also changes.

1.8. River Catchments and their influence on the river system

A catchment refers to all the land from the source to the sea drained by a single river system (Davies and Day, 1998). The nature of the catchment is an important factor in influencing the physical, chemical and biological characteristics of the river which drains it (Davies and Day, 1998), as a river is reflective of the landscape, climate and geological nature of its catchment.

Natural characteristics of the catchment, for instance the geochemistry, influences the water chemistry of rivers. In general, rivers utilized mainly for anthropogenic activities, are found to be of a poorer quality as opposed to those unperturbed by human influences (Bourg, 1995. In Allen *et al.,*1995). The latter system usually retains a healthier state.

This implies that anthropogenic activities and other processes in the catchment also play a major role in influencing river systems (Malan and Day, 2002). However, the extent to which upstream activities affect downstream characteristics is dependent upon factors such discharge and seasonality (Day *et al*., 1994). Decreases in river discharge often arise from upstream impoundments or abstractions, or from reduced catchment precipitation.

Land use practices within the catchment inevitably effect the water quality of the rivers which drain them (Malan and Day, 2002). For instance activities such as mining close to rivers increases the salinity, metal content, and sedimentation (DEAT, 2006) and also affect the pH of the water. Large scale clearance of land in the catchment for agricultural, industrial, and residential purposes increase surface runoff and consequently sedimentation of river systems. Agricultural and industrial activities often influence the water quality of rivers by contributing effluents and chemicals into the system, whist sometimes also directly modifying the watercourse to suite their abstraction needs. These are discussed further in Section 1.11 below.

1.11. Estuaries

A general definition of estuaries offered by Day (1981) and Breen and McKenzie (2001) is that an estuary is that part of a river system which meets and/or interacts with the sea. As a result of this, there exists a gradual change in the chemical, biological and physical properties from the fresh water to the sea (Begg, 1978). Begg (1978) mentions that estuaries are systems which are semi-closed and sometimes possess a free and open connection with the sea. According to Breen and McKenzie (2001), estuaries are valuable natural systems which support a wide range of biota, and are economically and aesthetically important (French, 1997; Scharler and Baird, 2005). Globally, estuaries are focal points around which a number of coastal communities settle and develop (Svensson *et. al,* 2007). Also, since estuaries form a large economic resource for the communities which develop around them, human disturbances and activities increase the pressure on these sensitive systems (Svensson *et. al,* 2007).

Estuaries are the end-users of water of the rivers catchment, and are therefore reflective of the activities and land use of the catchment. Consequently, estuaries are important traps for nutrients, chemicals and other pollutants before they are discharged into the ocean (Scharler and Baird, 2005). Most South African estuaries are not efficiently managed (Turpie, 2004) and this can be possibly attributed to the fact that the processes involved, and the complex interactions within these systems are not entirely understood.

1.12. Estuarine Classifications

Estuaries are not all uniform in nature, and exist as a number of different types (Day, 1981; Abed, 2009). Estuaries are hence classified according to a range of factors, i.e. physiographic measures, and tidal range, to name a few. A classification is provided by Cooper (2001) where estuaries are primarily categorized by whether or not they hold a connection to the adjacent ocean via a surface channel. Further subdivisions are based upon the presence of barriers, the level of the water in relation to sea level, and whether the outlet is maintained by fluvial or tidal discharge (Cooper, 2001).

Cooper (2001) mentions that aside from limitations occurring at the site of the estuary, the type of estuary at a particular site is influenced by the regional variability in climate, topology and sediment availability. For instance, tide dominated estuaries are common in coastal areas which have a low supply of fluvial sediment and a low gradient (Cooper, 2001). These systems are sometime known to close as a result of sea storms or following excessive sediment accumulation. In such an event, the outlet can only be reopened naturally with a flood event, or with human intervention (Cooper, 2001).

Contrary to tide dominated systems, river dominated estuaries or outlets maintained by fluvial discharge are common along the north eastern coast of South Africa (Cooper, 2001). Here the steep hinterland is responsible for a relatively high fluvial sediment contribution and a high fluvial discharge, which in turn are necessary for a river dominated estuary to remain so. Within the context of this chapter, only classifications which apply to the Mvoti Estuary are discussed.

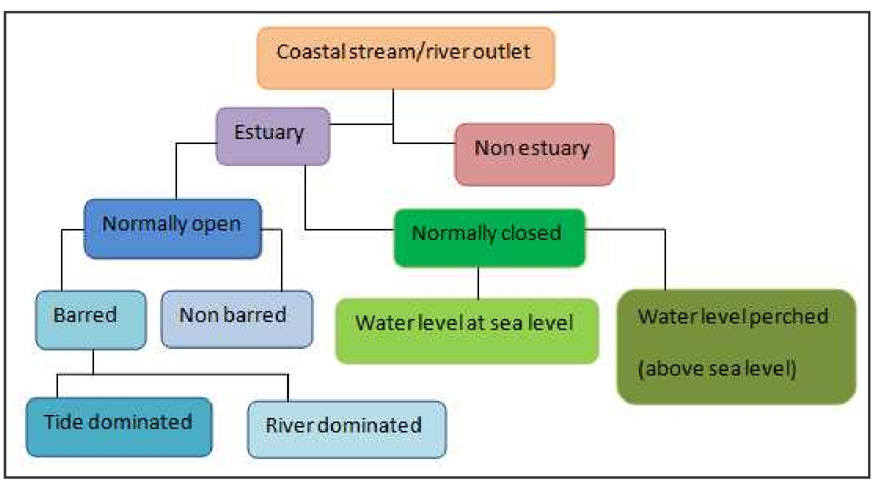

Figure 1.1. Conceptual morphodynamic classification of microtidal estuaries (After Cooper, 2001)

1.12.1. Permanently open estuaries

In South Africa, the most important variation among estuaries depends on their surface connection with the ocean (Cooper, 2001). This divides estuaries into two categories, 'normally open' estuaries and 'closed' estuaries (Cooper, 2001). As stated by Cooper (2001) and Chuwen *et al.* (2009), normally open estuaries have a surface connection with the sea, whilst closed estuaries are blocked by barriers or sand bars and achieve their fluvial discharge by means of barrier seepage or evaporation losses (Cooper, 2001).

Begg (1984) suggested that in KwaZulu-Natal, estuaries can be categorized into two groups: estuaries that are open for greater than 70% of the time, and estuaries that are open for less than 30% of the time. According to Cooper (2001), depending on the geomorphology and morphodynamics of the system, 'normally open' and 'normally closed' estuaries can be further subdivided within these two groups. The Mvoti Estuary is a permanently open or 'normally open' estuary (Cooper, 2001). Within this group, the Mvoti can be further categorized as a 'barred open, river dominated' estuary (Cooper, 2001).

1.12.2. Barred open estuaries

According to Mackay *et al.* (2000a) and Cooper (2001), the Mvoti is a 'barred open' estuary, as it possesses a supratidal barrier (an accumulation of sand that exists at the mouth region and is exposed even above high tide) and a surface drainage channel.

Furthermore, Cooper (2001) also mentions that open, barred estuaries may range from small, local systems, to huge systems which can drain parts of the subcontinent. The majority of the smaller systems cannot maintain large tidal prisms, and it is river discharge that maintains its open position (Cooper, 2001). Often, barred open systems have shorter barriers and this decreases the volume of discharge resulting from seepage via the barrier (Cooper, 2001).

1.12.3. River dominated estuaries

The Mvoti Estuary is also river-dominated, meaning that the flow is maintained by fluvial output and the tidal prism of the estuary is insufficient to maintain an inlet against wave and tidal action, from the nearshore environment (Cooper, 2001).

Even though some of these systems have relatively large surface areas, the steepness of the hinterland often restricts tidal penetration. Cooper (2001) suggests that river flooding in these systems play a major role in the erosion of accumulated sediment, temporarily deepening the channel.

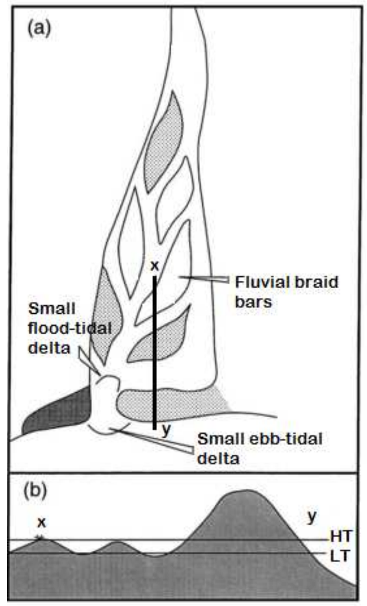

Figure 1.2. Generalised morphology of a river-dominated estuary in plan (a) and cross-section (b) (Adapted from Cooper, 2001)

1.12.4. Microtidal and Perched estuaries

Tidal range is often used to classify estuaries, as it controls a number of estuarine processes (Abed, 2009). The Mvoti Estuary is a microtidal estuary. This implies that it experiences a tidal range of less than 2 m. The Mvoti Estuary is also perched above sea level. This is a major contributing factor to its status as a 'river mouth system'. According to Lukey (2005), perched estuaries have an elevated berm barrier which results in the water levels within the estuary being higher than the levels of most high tides.

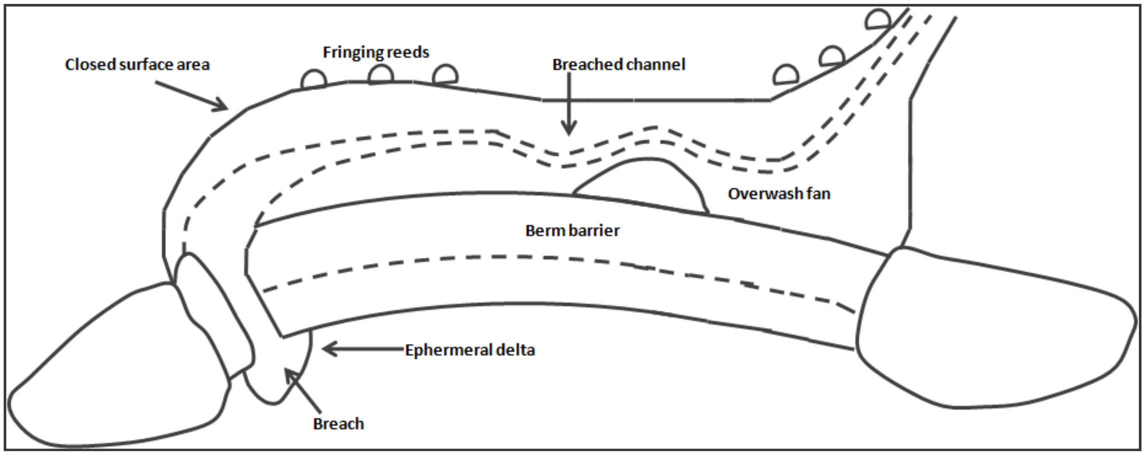

Figure 1.3. Generalised morphology of a perched estuary in plan

(Redrawn from Cooper, 2001)

1.13. Factors influencing aquatic systems

The abiotic aspects of aquatic systems are integral components of the system. Water which is to be used by human or other consumers needs to be of optimum quality for use, both in terms of its physical and chemical properties (DEAT, 2006). Different consumers usually have different fitness requirements (DEAT, 2006). Changes in these water quality properties can be affected by a range of factors attributed to either human induced factors or natural causes and can also have a range of impacts on the ecosystem. Aquatic sediments also experience various physical and chemical changes, and these changes in turn are capable of altering the above-lying water column.

1.13.1. Anthropogenic activities

Water pollution is a common consequence of irresponsible use of water resources for anthropogenic purposes. Pollution can be referred to as the introduction of substances into the environment, by direct or indirect human impacts, which is most likely to have negative impacts on the environment and its ecology (Hardman *et al.*, 1993). Pollutants can range from gases to organic and inorganic compounds, and can either be in the form of a natural compound or an artificial, synthetic one (Hardman *et al.,* 1993). According to Hardman *et al.* (1993), when the levels of these compounds are increased to levels that are unnaturally high or toxic, especially by anthropogenic activities, the environment within which it occurs experiences extreme pressure and consequently detrimental effects.

Generally, pollution is released from either a point or non-point source (Abed, 2006). Point source pollution is from a single, identifiable source (DEAT, 2006), and usually has a higher level of pollutants whereas non-point source, or diffused source pollution has lower levels of pollutants. In point source pollution, the concentrations of pollutants in the environment decrease with distance from the source. However this is not the case for diffused source pollution as there is no specific source. Furthermore, the environmental impacts are higher (Abed, 2006). According to Krantz and Kifferstein (1996), the quality of water in a country's rivers is linked strongly to water use and the state of the economic development of a country.

The economic sectors which have the most influence on river systems in South Africa are discussed below:

Urban sector

Urbanization, and the increase of non-permeable surfaces associated with development, has resulted in a decrease in the quantity of rain which penetrates the surface to contribute to groundwater. It has however, resulted in an increase in urban runoff. According to DEAT (2006), urban runoff can contain high amounts of organic compounds and other nutrients which in turn can be problematic for water courses. Urbanization and development are also associated with large amounts of waste and sewage (Bucas, 2006). Without proper disposal and treatment, these products can make their way into river systems, resulting in contamination and eutrophication of water resources (Bucas, 2006). The physical disposal of litter and other waste products into water bodies is also a common problem.

Expansion of urban areas and development has led to an increase in the demand for infrastructure and this has also placed pressure on rivers system (De Lange *et al*., 2009). Apart from the increasing need for water resources, a number of these systems are experiencing uncontrolled and often illegal sandmining, to accommodate for the growing need of sand material in the construction industry. A number of rivers in KwaZulu-Natal experience extensive sandmining (Demetriades, 2007). The clearing of riparian land for this practice, and the extraction of large amounts of sand has negative impacts on the river system. Sedimentation of the river channel is one the most common impacts. This reduces the river's capacity and affects instream fauna.

Agricultural sector

The modification of land for agriculture also has implications for water quality. The clearance of natural vegetation for subsistence and commercial crop farming, as well as for forestry is often associated with high erosion rates and consequently high levels of sediment entering rivers (DEAT, 2006). This is particularly the case in places where riparian areas have been cleared for agricultural practices (Bucas, 2006). Overgrazing and other improper farming practices are associated with similar effects to water courses. Extensive abstraction of water from these water bodies for irrigation may also have negative effects on the functioning of theses systems by reducing the flow rates of rivers (Bucas, 2006).

Agriculture may also contribute chemicals derived from fertilizers, pesticides, and herbicides into rivers via runoff and seepage. Compounds associated with fertilizers include nitrates, phosphates, sulphates and potassium (Bucas, 2006). Water bodies affected by chemicals originating from agricultural activities often experience high salinities. Organic wastes from livestock and poultry farms have been known to contaminate water bodies (DEAT, 2006).

Industrial sector

Due to the benefits it presents for economical growth and human welfare, industrialization is considered to be an important contribution to development (Adebayo and Kehinde, 2008). However, as is the case with most human activities which present impacts on the environment, industrial activities often result in pollution and degradation of water resources and the environment in general (Adebayo and Kehinde, 2008). According to Adebayo and Kehinde (2008), water bodies are the primary disposal sites for industrial effluents and wastes. These noted, industrial wastes are considered to be the most common source of water pollution in the present day (Phiri *et al,* 2005).

Effluents, once in the water body initially alter the physical and chemical nature of the system, after which biological degradation becomes evident with regards to species diversity and organization in the water body (Adebayo and Kehinde, 2008). Rivers receiving untreated effluents are often unable to provide the dilution necessary to maintain themselves as quality water sources (Adebayo and Kehinde, 2008). These undesirable effluents are harmful to human and non human health and safety, and there is an increasing challenge in minimizing these hazards, and conserving water bodies.

1.13.2. Natural Processes

There are a number of natural factors which influence water chemistry and quality. These factors include chemical weathering, climate, soil and soil formation, sources of solutes, erosion and rivers themselves (Bucas, 2006). In terms of climate, temperature affects the reaction rates and extent of chemicals in the water (Davies and Day, 1998). High temperatures coupled with low rainfall affects the quantity of water in the system. Low flow rates affect the dilution of pollutants, and consequently increases pollutant concentrations in the river system (Davies and Day, 1998).

According to Bucas (2006), the chemical weathering of bedrock geology is the most important natural factor that controls the chemistry of water, particularly in unimpacted systems. This however, is dependant upon geological characteristics such as rock composition and texture, the purity and size of minerals, porosity, together with exposure time. Generally, weathering rates are known to increase with decreases in pH, and decrease within increases in pH (Bucas, 2006). With regards to climate, rivers in humid areas with higher temperatures experience higher solubility and dissolution rates of minerals as compared to cooler regions (Bucas, 2006). Biotic factors also impact upon the water quality of river systems (Davies and Day). For instance, photosynthesis and decomposition influences the oxygen and nutrient content in aquatic systems. However, to determine the effects of natural processes on individual systems, it is important for the natural, unimpacted condition of the system to be assessed. This allows for development of baseline data, which in turn can be used for comparisons (Bucas, 2006).

1.14. Water quality

Water quality is a term used to describe the physical, chemical, biological and aesthetic characteristics of a water resource which are responsible for determining how fit the water is for use by all its users (DWAF, 1996a; Malan and Day, 2002). These characteristics also govern the health and integrity of aquatic ecosystems (Malan and Day, 2002). According to Gower (1980), the assessment of water quality is an important tool in understanding and managing water as a resource. Gower (1980) and Naidoo (2005) also noted that factors and processes influencing water quality are best understood when the catchment is considered as an inter-related system, where catchment activities continuously influence naturally dynamic river systems.

Antonopoulos *et al*. (2001), noted that over the past last few decades the demand for water quality monitoring has increased, especially so in river systems. This monitoring is most commonly based upon the measurements of water quality variables, as a tool for detecting trends, problems, and causes, as well as for enforcing water quality standards.

1.14.1. Impacts of poor water quality

Water of poor quality affects its fitness for use (DEAT, 2006). Depending on the nature and extent of the pollution water resources become increasingly unsuitable for uses by man, and by aquatic systems.

Water related diseases

In water bodies contaminated by human and animal wastes, pathogenic microbes are often widely present (Naidoo, 2005). The main sources of these contaminants are raw sewage originating from local communities without proper sanitation facilities, or from insufficiently treated or untreated effluent from sewage treatment plants. Pathogenic organisms are the cause of water-borne diseases which can be fatal to humans and animals which come into contact with the infected water. Common water-borne diseases include cholera, bilharzia, polio, typhoid fever, meningitis, and hepatitis (Brijlal, 2005; Naidoo, 2005).

A number of the bacterial, viral, and protozoan organisms which cause water-borne diseases use aquatic invertebrates as hosts or vectors. For instance, *Schistosoma sp*., the liver fluke which causes bilharzia, uses a specific aquatic snail (*Biomphalaria sp*.) as an intermediate host (Fripp, 2004). Outbreaks of water-borne diseases are common in areas lacking proper water supply and sanitation (Naidoo, 2005). These outbreaks can sometimes become epidemic, resulting in a number of fatalities, and costing these communities a large amount of time and money to recover e.g. the current (November 2010) widespread of cholera in Haiti which is decimating communities across that country, causing international concern.

Eutrophication

The eutrophication of freshwater bodies is a problem associated with excessive amounts of nutrients, especially nitrogen and phosphorous present in the system (Graham and Farmer, 2007; Obeng, 2010). The enriched water usually encourages accelerated primary production and growth of algae and higher plants (Graham and Farmer, 2007; Obeng, 2010). According to Obeng (2010), this produces an undesirable disruption to the balance of organism in the system and to the water quality of the system.

Obeng (2010) also noted that even though natural processes also cause eutrophication of estuarine systems, human influences greatly accelerate the condition *via* the introduction of nitrogen and phosphorous compounds into the environment. Oxygen depletion is sometimes experienced in eutrophic conditions accompanied by turbid conditions, algal blooms, pathogens, and habitat loss (Obeng, 2010). Nitrogen and phosphorous in aquatic systems commonly originate from animal and human wastes, agricultural runoff, industrial effluents and municipal waste waters (Obeng, 2010).

Degradation of aquatic ecosystems

Aquatic systems are users of water resources, and poor water quality affects the health of these systems. It is only within the last decade or so that South Africa has given serious consideration to the relationship between poor water quality and aquatic biota (Malan and Day, 2002). The term ‘aquatic biota’ collectively applies to all biotic communities in an aquatic system, including fish, invertebrates, microorganisms, instream and riparian vegetation, and algae (Malan and Day, 2002).

Each species of aquatic inhabitant, has different physical and chemical requirements from the river system, therefore, any alterations to the physical and chemical characteristics of the watercourse will affect different species to greater or lesser extents (Davies and Day, 1998). Continued or extensive alterations may remove certain species while others may thrive, until no single species of the original assemblage remains (Davies and Day, 1998), and the water body experiences a decrease in its integrity as a habitat.

Davies and Day (1998) documented that some of the most common yet detrimental impacts of poor water quality upon aquatic inhabitants include:

- A physical movement of the riverine community away from the affected area (mobile organisms only.

- A reduction in key or original species, and sometimes an increase in exotic or troublesome species.
- A reduction in species diversity.

This results in a gradual shift in species composition and abundance (Malan and Day, 2002). Malan and Day (2002) also noted that with the disappearance of individual stress-sensitive species, and increases in diseases and parasitism, the system experiences decreases in species richness.

1.14.2. Water quality guidelines

During the last few decades there has been an increasing demand for monitoring the water quality of rivers based on measurements of water quality variables to detect trends, problems, causes and to enforce standards. The variability of flow rates of South African rivers due to seasonality and water abstraction, together with increasing changes in water quality are placing a range of different stresses on the users of the resource. In South Africa, water quality management is governed mainly by the requirements upon the water resource by the various users (DWAF, 1996a).

Water quality guidelines developed by the Department of Water Affairs and Forestry (DWAF, 1996a) differ in terms of standards, parameters and protection of the resource based upon activities for which the water will be used.
These guidelines provide acceptable limits of different water quality parameters, for marine water bodies, water to be used for domestic, industrial and recreational uses, and standards for aquatic ecosystems – the ultimate base of water resources (DWAF, 1996a).

1.15. Catchment Derived sediments

Fluvial sediments are derived from the catchments and the rivers themselves (Abed, 2009). The nature of these sediments is reflective of the catchment parent material and physiographic character. They are transported through the system *via* various modes, i.e. as wash load, suspended load, and bed load (Abed, 2009). This movement is dependent upon the size of the particle together with velocity and turbulence in the system. The finer fraction of sediments usually moves in suspension, whilst the larger particles are transported as bed load.

Sediments are transported through the system as a mixture of different sized and types of particles, and is characteristically comprised of fine sand, silt, clay, and the larger grained bed load (Abed, 2009). As the river encounters a gentler gradient, impoundment, or obstacle, the velocity and turbulence decreases, and a proportion of the suspended load is deposited. Finer particles usually remain suspended in the water column, until conditions inducing deposition occur.

Apart from sediments originating within the estuarine system itself, sediments are constantly being transported into and out of estuarine systems *via* fluvial and marine sources (Abed, 2009). Hence, estuarine sediments are also influenced by their catchments. Riverine and estuarine sediments are important with respect to this particular project. Physiochemical interactions between sediment (particularly fine sediment) and the water column influences the contaminant status of the water body and hence the quality of the aquatic habitat. Suspended sediments in the water column increases the density of the water (Abed, 2009), and depending on the load, increases turbidity. High levels of suspended matter in a water body often has negative impacts on aquatic biota, decreasing light penetration for flora, clogging gills and smothering bottom dwellers.

1.15.1. Granulometry

Granulometry is concerned with the physical nature of sediments, and considers the size, shape, surface features, and fabric characteristics of sediment grains.

Collectively, these characteristics which describe the sphericity and roundness of the grains, the packaging and orientation of the grains, as well as its porosity and permeability, are also referred to as texture (Lewis and McConchie, 1994). For the purpose of this study, only grain size will be considered, as grain size has significant influence on the concentration of contaminants within the sediment (Ram *et al.,* 2009).

Grain size is determined *via* various scales. A commonly used scale, and that employed in this study is the Udden-Wentworth scale (Blatt *et al.,* 1980; Lewis and McConchie, 1994). This scale is presented in Appendix A. Sediments are often divided into three broad divisions based on their size (Lewis and McConchie, 1994). The first group, gravel, has grains larger than 2.0 mm in diameter, and the second group, sand, has grains sized between 2.0 – 0.0625 mm in diameter. The last group is mud.

Here, grains are less than 0.0625 mm in diameter, but can further be divided into silt (between 0.0625 – 0.0039 in diameter), and clay (less than 0.0039 in diameter). The mud component is the finest product, derived from disintegration (silt and clay size detritus) and chemical decomposition (clay minerals).

1.15.2. Geochemistry

Geochemistry investigates the chemical elements of the earth's crust (Rosler and Lange, 1972), and can be used to assess the chemical properties of sediments. Furthermore, as the sediment type of an area is normally dependant on the geology, geochemistry is often used to assess the presence and distribution of chemical elements in the sediment of a system. Therefore, the degree of sediment contamination by chemical elements can be determined by geochemical methods (Martinez *et al*., 2007). Any rock or sediment can be considered as a chemical system which can experience chemical changes based on various factors (Rosler and Lange, 1972). In aquatic system these factors include oxidation-reduction potentials and ion exchange capacity.

Oxidation and reduction reactions are amongst the most important processes influencing sediment chemistry, because both oxidizing and reducing are common and as conditions change, or sediments are moved from one environment to another, changes in chemical composition also take place as equilibrium is established under the new conditions (Lewis and McConchie, 1994). Elements within sediments which experience a change in environmental conditions, or are transported from one environment to another, often experience a new set of redox conditions, different to the initial set.

This can strongly influence change in the chemical characteristics of sediments (Lewis and McConchie, 1994). Examples of this, as suggested by Lewis and McConchie (1994) are cadmium, where this element is more mobile under oxidizing conditions as oppose to reducing conditions, and iron, where this element is more mobile under reducing conditions.

According to Lewis and McConchie (1994), the smallest sediment particles, namely clays and colloids, have high surface area to volume ratios and may carry electrical charges. These charges and advantageous ratios allow these particles a higher capacity to adsorb ions from solution in comparison to larger particles.

These ions however are not permanently fixed to the sediment particles and can become desorbed with a change in conditions, or they may exchange with other ions in the surrounding solution (Lewis and McConchie, 1994). Adsorption, desorption and ion exchange *via* sediment-water interactions have a key influence on water chemistry and sediment composition (Lewis and McConchie, 1994).

1.15.3. Aquatic sediments as a sink for pollutants

Sediments can be used to describe the physical, chemical, and biological conditions of modern aquatic systems and predict the likely nature, rate, and extent of future natural and anthropogenic changes (Lewis and McConchie, 1994). In aquatic systems, the sediment component is often the larger accumulator, and potential sink for contaminants, due to its variable physical and chemical properties, (Sundarajen and Natesan, 2010).

According to Lewis and McConchie (1994), sediments are also useful in pollution control, as they can be used to assess chemical and contaminant transfers between sediments, water and biota, and they can also be used to predict the likely effects of anthropogenic changes to existing conditions. Aquatic sediments are also sometimes potential indicators of the sources of contaminants. For instance, the presence of high levels of heavy metals in the sediments of a system can be a suitable indication of human-induced pollution, derived from anthropogenic activities, as opposed to natural processes such as weathering and erosion (Klavins *et al*., 2000; Binning and Baird, 2001). Sediments are known to assimilate pollutants over time, and are therefore commonly used to determine the 'pollution-history' of a system (Binning and Baird, 2001; Landajo *et al*., 2004).

1.15.4. Contaminant - Sediment Relationship

The contamination of aquatic sediments is also influenced by sediment texture, more especially sediment grain size. Finer sediment particles, such as clays and silts are more likely to carry and accumulate heavy metal and organic contaminants in aquatic systems as opposed to the larger components of the sediments (Binning and Baird, 2001; Palanques *et al*., 2008) due to their relatively larger adsorption potentials (Chatterjee *et al*., 2006).

Adsorption, however, as mentioned above, is dependant upon physico-chemical factors of the system (Ghrefat and Yusuf, 2006). Contaminants do not necessarily remain fixed to sediments and, *via* various chemical, physical and biological processes are often remobilised into the water column becoming bio-available and potentially hazardous to living organisms (Landajo *et al*., 2004; Chatterjee *et al*., 2006; Jordao *et al*., 1997).

Estuaries are usually basins for fine grained sediments, which in turn are easily reactive to heavy metals and pollutants (Abed, 2006). Hence estuaries may often develop a high level of contamination in their sediments (Abed, 2006). According to Callow (1994) the highest levels of heavy metals occur within the initial 10 cm of undisturbed sediments. The distribution of contaminants in estuarine sediments is dependant on the sources of pollution, and the capability of the estuary to flush and disperse the pollutants (Abed, 2006). Estuaries or embayments that are partially enclosed are more susceptible to contamination (Abed, 2006). This is mainly due to the lower ability of such systems to flush out the pollutants to the sea, as opposed to systems that are fully open.

1.15.5. Background values

The importance of a reliable set of background values, or natural values for a specific region or sediment type has been well documented (Fergusson, 1990; Chenhall *et al.,* 2004; Martinez *et al.*, 2007). Background values for a specific region or geological type are often used to determine whether the presence and corresponding concentrations of contaminants in sediments are due to natural or anthropogenic sources, and whether it is indicative of acceptable limits or pollution (Chenhall *et al.,* 2004; Martinez *et al.*, 2007). Background values are especially valuable for enrichment detection where sediment quality guidelines have not yet been established or are not available.

In South Africa, such a set of guidelines governing sediment quality is not available (Orr, 2007), nor are specific background concentrations for the Mvoti catchment. Therefore, for the purpose of this study background or 'Clarke' values have been consulted. Clarke values serve as background values for the earth's crust (Rosler and Lange, 1972; Martinez *et al.*, 2007). Hawkes and Webb (1962), In Martinez *et al.* (2007), noted that this was acheived using 'geochemical backgrounds'. Geochemical backgrounds refer to the normal abundance of elements in barren earth material of a specific geological type or for a particular region. These background values assist in determining whether values of elements obtained are normal or are anomalies, which are deviations from the usual geological pattern for the region (Martinez *et al.*, 2007). Reliable background values are important guides for pollution remediation and control of sediments. The values are representative of mean elemental composition of all rock groups and, since the Mvoti catchment has a geology which is predominantly composed of sedimentary rocks, Clarke values of these rocks were used in the study.

As previously noted, background values are also essential tools in assessing the pollution of aquatic sediments. A number of methods which are used to determine the pollution status of a system require in some form the use of background values. These methods include contamination factors (CF), enrichment factors (EF) and the pollution load index (PLi), (Harikumar and Jisha, 2010).

1.16. Common physico-chemical parameters affecting aquatic systems

1.16.1. Physical characteristics

According to Tomar (1999), the physical characteristics of water refer to the palatability and aesthetic acceptability of water with regards to touch, sight, smell, or taste (Tomar, 1999). Physical characteristics of water include hardness, turbidity, temperature, conductivity and solids. However, within the context of this study, only conductivity of the water was assessed.

Conductivity (electrical conductivity) a term used to describe the ability of water to conduct an electrical current and is a measure of ion concentrations in the solution (Brijlal, 2005; Naidoo, 2005). According to DWAF (1996a) conductivity measures the ability of water to conduct an electrical current through ions that carry an electrical charge. The higher the conductivity, the higher the amount of ions present in the solution (Brijlal, 2005; Naidoo, 2005).

Conductivity is related to the presence of solids in the solution, and is a measure of the salts in the solution (Brijlal, 2005; Naidoo, 2005).

1.16.2. Nutrients and chemical characteristics

Aside from pathogens and organic matter, water contaminated by elements and inorganic compounds is often unfit for use. Consumptive and recreational use of such water may result in a number of health complications for both man and animals. Prior to usage, this water often requires some form of treatment (DEAT, 2006), even for industrial purposes where this water may have corrosive properties. However, treatment is often expensive.

pH

pH measurements are measures of the hydrogen ion activity in a sample (Brijlal, 2005; Naidoo, 2005), indicating the acidity or alkalinity of the solution. In a solution, as the concentration of hydrogen ions increases, pH decreases, and acidic conditions become prevalent (Brijlal, 2005; Naidoo, 2005). When hydrogen ions decrease, the pH increases, and the solution becomes basic (Brijlal, 2005; Naidoo, 2005). Between 0 and 14, 0-7 indicates acidic conditions, a pH of seven indicates neutral conditions, and 7-14 is indicative of basic conditions.

According to DWAF (1996a) the majority of naturally occurring fresh water in South Africa range between pH 6 and 8 (DWAF, 1996a). DWAF (1996a) also noted that the pH of water is an important factor affecting the solubility and availability of nutrients in the system, its utilization by aquatic organisms, plus the toxicity of trace metals, ammonium and other elements within the system (DWAF, 1996a).

Ammonium Ions

These are found in large amounts in runoff from agricultural areas which use ammonium salts as fertilizers (DWAF, 1996a). Ammonia present in low concentrations in drinking water does not pose major effects on human health (DWAF, 1996b). High levels of ammonia are also found in water bodies contaminated with organic wastes such as untreated sewage (DWAF, 1996b). Excessive ammonia ingestion has adverse effects on human health, particularly to children (DWAF, 1996b).
Effects on aquatic organisms include reduced hatching success, growth rates and development, in addition to respiratory problems (DWAF, 1996a).

Chloride

Chloride is often introduced into water bodies via irrigation and industrial return flows (DWAF, 1996b), especially from industries which use it as a bleaching agent or slimicide (Malherbe, 2006). At high levels, chloride is known to have implications on human health (DWAF, 1996b). It may result in electrolyte imbalances and nausea particularly in children. In aquatic systems, excessive exposure to chloride may affect growth rates and gill tissue of fish, and result in immobility and reduced reproduction rates in invertebrates (DWAF, 1996a).

Nitrate

Nitrate is introduced in water systems via organic pollution or untreated sewage (DWAF, 1996b). According to DWAF (1996b) nitrate is the product of oxidation of ammonia or nitrite. This is particularly dangerous, as once ingested, reduction in the digestive system may convert it to nitrite, a potentially toxic compound (DWAF, 1996b).

Sulphate Ions

In most natural waters sulphates ions exist in concentrations lower to those of chloride ions (Brijlal, 2005). According to DWAF (1996b), there are no health hazards for human consumption presented by low concentrations of sulphate, as sulphates themselves are not toxic (Brijlal, 2005). However at higher concentrations the likelihood of developing diarrhoea, if this water is consumed, increases (DWAF, 1996b). In excess, sulphates form sulphuric acid, a pH reducing acid which has harmful effects on humans and biota (Brijlal, 2005).

1.16.3. Heavy metals and other elements

According to Hardman *et al*., (1993), and Lenntech (2009) the term 'heavy metals' refers to those metallic elements which are low in the periodic table, and have atomic weights greater than 100, or a relative density greater than five. These elements are introduced into the environment either naturally from parent rock material, or anthropogenically from a wide range of human activities, or both (Harikumar and Jisha, 2010).

Despite being natural components of the earth's crust, the severity of elemental contamination in the environment has been drastically increased, primarily due to anthropogenic activities (Chen and Kandasamy, 2008; Harikumar and Jisha, 2010).

Heavy metals which are metallic elements and other elements are present naturally in the environment, and some such as iron and zinc, are essential for the functioning of cells within organisms and humans (Abed, 2006). However, once their presence exceeds natural concentrations, they may become potentially toxic to human and aquatic consumers. For instance, even at low trace levels cadmium and lead are highly toxic (Abed, 2006). The issue of metal toxicity and its negative impacts on human health can be traced back to about five millennia ago, when metal work originated (Abed, 2006).

In the present day industrial activities are also commonly responsible for heavy metal poisonings experienced by humans, and contamination of water resources (Hardman *et al.,* 1993). Heavy metals are persistent elements which do not biodegrade in systems. This coupled with the fact that they are transported through various mediums allows them the capability of bio-accumulating and bio-magnifying in aquatic organisms and consequently food webs. Due to their potential toxicity, this makes them particularly hazardous.

Bio-accumulation according to Ferguson (1990) is an increase in the concentrations of an element in a biological organism over time, in comparison to the element's concentration in the environment. These compounds accumulate in living tissues via ingestion or absorption from the environment, and are stored faster than they are metabolized or excreted (Fergusson, 1990). As these elements are often essential for the functioning of an organism, only the accumulation to levels higher than normal is potentially dangerous.

Bio-magnification occurs across food chains. The levels of these elements are magnified as they move up different trophic levels, where the higher the order of the consumer, the higher the level of element received.

Aluminium (Al)

Aluminium does not appear to be an essential nutrient to man (DWAF, 1996b). Industries which commonly use aluminium in their processes or products include paper, leather and textile industries (DWAF, 1996a). Aluminium is commonly used in water treatment processes and hence the metal is often present in large amounts in the final water (DWAF, 1996b).

Toxicity in fish relating to excessive aluminium levels includes respiratory problems resulting from mucus coagulation on their gills (DWAF, 1996a). Water birds which consume contaminated fish and invertebrates experience effects like eggshell thinning and hatchlings with low birth-weights. Implications of aluminium from aquatic sources on human health are yet to be conclusively identified (DWAF, 1996b).

Arsenic (As)

Arsenic is naturally present in both an organic and inorganic forms, of which the latter is considered more toxic (Hardy *et al*., 2008). It is usually present in low environmental concentrations due to its poor solubility (Boyd, 2000). Arsenic presents various adverse effects on the environment, with different organisms reacting differently based on the level and form of the element, and the organism's sensitivity (DWAF, 1996a). Some of the adverse effects include fatalities, reduced growth rate, reproductive failure, and low species diversity in aquatic systems.

Humans are more sensitive to arsenic than aquatic organisms, therefore, exposure to elevated levels of arsenic in drinking water has been known to cause hyperpigmentation, hyperkeratosis, and cancer of the skin and various internal organs (Ferguson, 1990; Harrison, 2007). Arsenic also causes ‘black foot disease’, liver cirrhosis, and renal problems (Ferguson, 1990).

Barium (Ba)

Barium is a metallic element, which occurs combined with other elements such as sulphur, oxygen or carbon. According to Lenntech (2009), it is capable of reacting with almost all non-metallic elements, forming poisonous substances. Water soluble forms of barium are harmful to health with severe effects like paralysis and death (Lenntech, 2009). Smaller exposures may cause increases in blood pressure, stomach irritation, and swelling of internal organs. Water-soluble compounds of barium are transported and transferred through systems easily. Bio-accumulation of barium is potentially toxic in aquatic organisms (Lenntech, 2009).

Boron (B)

Boron is a non-metallic element which in excessive levels of human exposure may result in liver, kidney, stomach and brain infections and consequently death (Lenntech, 2009). Boron is unlikely to bio-accumulate in organisms (Lenntech, 2009).

According to Chapman (1992), boron is released into water bodies *via* the natural processes of weathering (parent material), and leaching, and anthropogenically (Tomar, 1999) *via* industrial discharges and agricultural runoff containing pesticides.

Calcium (Ca)

Calcium is an important element as it is a vital constituent of the bony component of mammals (DWAF, 1996b). At relatively low levels calcium poses no threat to human health (DWAF, 1996b). It does however affect the efficiency and use of many household and industrial appliances.

Chromium (Cr)

Chromium in its naturally occurring state is highly insoluble, and most of the chromium found in soils is mainly the result of contamination by industrial emissions (Abed, 2006).

According to DWAF (1996a), its effects are variable depending on the concentration and are known to inhibit growth phases in fish and aquatic invertebrates. Chromium is a carcinogen, capable of causing lung and gastrointestinal cancer (DWAF, 1996b).

Cobalt (Co)

Cobalt is often present in mineral waters and mine drainage waters (Ackermann and Sommer, 1988). Relatively small amounts are often present in surface waters. Cobalt is beneficial for human health in moderate amounts, as it is part of vitamin B12, and its toxicity is relatively low (Lenntech, 2009). However, at excessive levels vomiting and nausea, vision impairments, heart problems and thyroid damage may present (Lenntech, 2009). Cobalt, like most other metals cannot be destroyed and bio-accumulates in environments.

Copper (Cu)

Copper is one of the most widely used metals in the world (DWAF, 1996a). It is also a micronutrient and is rapidly accumulated by plants and animals (DWAF, 1996a). High levels of copper present in aquatic environments and water sources have been known to have detrimental effects on biota and humans (Abed, 2006). These effects include brain damage in mammals (DWAF, 1996a), as well as gastrointestinal disturbances, kidney, liver and red blood cell damages (DWAF, 1996b).

Iron (Fe)

Iron is also an essential micro-nutrient for all organisms (DWAF, 1996a). It is important for chlorophyll and protein synthesis and for respiration (DWAF, 1996a). The ingestion of iron in excessive amounts may present adverse health effects in the form of tissue damage as a result of accumulation of the metal (DWAF, 1996b).

Lead (Pb)

The anthropogenic input of lead due to agricultural activities, industrial activities such as mining, vehicular emissions and land constructions, have resulted in an increased input of lead into the environment (Abed, 2006). This lead is often present in amounts greater than those due to natural sources (Abed, 2006). According to DWAF (1996a), lead is potentially toxic to most forms of life and often bio-accumulates in living tissues. In unborn and young children, extensive lead exposure may result in neurological disturbances (DWAF, 1996b).

Magnesium (Mg)

According to Chapman (1992), magnesium is an essential macronutrient for plants and animals and is naturally derived in water bodies through the weathering of rocks. Magnesium deficiencies often result in skeletal deformities and reduced reproductive capabilities in vertebrates (DWAF, 1996a). However, excessive levels are toxic and may result in disturbances to metabolism and the central nervous system. Potentially toxic sources of magnesium include various fertilizer and chemical industries (DWAF, 1996a).

Manganese (Mn)

Manganese is a toxic essential trace element, implying that it is necessary in certain amounts for human survival, and in excessive concentrations is detrimental to human health (Lenntech, 2009). Unusually high levels of manganese exposure may affect the brain and respiratory tract, with symptoms like hallucinations, forgetfulness, nerve damage, bronchitis, schizophrenia, headaches and insomnia (Lenntech, 2009).

Molybdenum (Mo)

Molybdenum is a rare element which is only naturally presently in aquatic systems in trace amounts (Savvin, 1988). Higher concentrations are usually a result of input of effluents from metallurgical, chemical, dye and varnish industries (Savvin, 1988). Molybdenum in high amounts has been known to affect the self-purification processes in aquatic systems by inhibiting biochemical self-purification processes and preventing the growth of the appropriate micro-organisms (Savvin, 1988) that aid this process.

Nickel (Ni)

As noted by David (2006) nickel is present at naturally high levels in the environment. Its anthropogenic sources include mining, refineries, nickel-cadmium battery manufacturing and fossil fuel industries (David, 2006). High levels of nickel within aquatic environments result in high mortality rates of the primary producers and consumers and the secondary consumers (David, 2006). According to Hardy *et al*. (2008), nickel is capable of diminishing the growth rates of algae in surface waters. Prolonged exposure at high levels may result in carcinoma of various organs (Lenntech, 2009).

Phosphorous (P)

Phosphorous, is not present as elemental phosphorous in the environment but instead occurs in several organic and inorganic forms of phosphate (DWAF, 1996a; Harrison, 2007). As noted by Boyd (2000), it is an essential macronutrient controlling plant growth in aquatic systems. Phosphorous is derived naturally from the weathering of phosphorous-bearing rocks and decomposition of organic matter. Anthropogenic inputs include domestic, industrial and agricultural effluent, all of which have the potential to cause eutrophication (DWAF, 1996a; Harrison, 2007).

Potassium (K)

Potassium is an essential dietary, metallic element, as it is the main intracellular cation in living organisms (DWAF, 1996b). Common sources of potassium in water courses include irrigation runoff, fertilizer production and waste water (DWAF, 1996b). According to DWAF (1996b), urine has high concentrations of potassium and sodium, and therefore potassium: sodium ratios are often used to as an indicator for sewage pollution. There are no health effects associated with excess levels of potassium in healthy adults. However, there is a risk of electrolyte imbalances and mucous membrane irritations in infants, and patients with kidney problems on a potassium-restricted diet (DWAF, 1996b).

Selenium (Se)

Selenium is also a rare element, and in excessive amounts its negative impacts include pathological changes, deformities, and death in fish, together with immobilisation, impaired reproduction and death in invertebrates (DWAF, 1996a). In aquatic birds, selenium toxicity includes embryonic deformities and death (Harrison, 2007). Selenium has the capacity to accumulate and bio-magnify across food chains.

Silicon (Si)

Silicon is one of the most abundant elements on earth (Rosler and Lange, 1972). Silicon is generally harmless when present in water, as it is naturally present in large amounts but abnormally high concentrations might limit algal growth (Lenntech, 2009).

Sodium (Na)

Sodium is an important dietary component for man as it is essential for the maintenance of electrolyte balances and other physiological processes (DWAF, 1996b). Sodium is common in industrial wastes, and irrigated runoff. Excessive intake of sodium is potentially hazardous to humans, especially infants and those with pre-existing health conditions such as hypertension and cardiovascular diseases (DWAF, 1996b).

Strontium (Sr)

As noted by Lenntech (2009), strontium compounds can move through the environment fairly easily, because many of the compounds are water-soluble. Strontium occurs in various rocks and minerals in the earth's crust but is found at low concentrations in most waters as a consequence of its relatively low abundance (Boyd, 2000).

Titanium (Ti)

Titanium is found naturally, bound to other elements (Lenntech, 2009). Titanium is the ninth most abundant element in the Earth's crust (Lenntech, 2009). Titanium poses no health hazards in water, unless present in a halogenated form. In this form, titanium is toxic to small water organisms and is capable of altering pH values (Lenntech, 2009).

Vanadium (V)

According to Lenntech (2009), vanadium is a metallic element which is rarely found naturally unbound. Vanadium is usually extremely soluble and is hence easily redistributed in the environment *via* rivers and water courses. In excess levels vanadium can induce the inhibition of certain enzymes in animals, causing several neurological effects (Lenntech, 2009). It is known to cause breathing disorders, paralysis and negative effects on the liver and kidneys (Lenntech, 2009).

Zinc (Zn)

Zinc is an essential micro-element due to the fact that it is involved mainly in metabolism and enzyme activity (DWAF, 1996a). Anthropogenic sources of zinc include the paper and pulp industries (Abed, 2006), fertilizer and insecticide (DWAF, 1996a). The impacts of exposure to high levels of zinc include growth deficiencies, decreased levels of reproduction and death in aquatic organisms (DWAF, 1996a) as well as gastrointestinal discomfort in humans (DWAF, 1996b).

1.17. Degraded systems and ecological restoration

In the past, low priority was given to the conservation and maintenance of river systems (King *et al.*, 2003). This was mainly due to a lack of environmental laws protecting them, as well as ideal that rivers were existed 'just to serve mankind'. Over the past few decades however, much consideration has been given to the degradation of rivers and estuaries in South Africa. With an ever growing increase in the demand for water and aquatic resources, coupled with the misuse of river systems by various users, a number of rivers in the country have experienced significant changes in their environmental condition.

The vast majority of these systems have experience some form of disturbance which has led to the degradation or deterioration of the natural system, where disturbance is an event in time which disrupts the ecosystem, community or population structure (King *et al.,* 2003). The lower Mvoti system is severely degraded and previous work has shown that the system has been this way for a number of years (Begg, 1978; Tharme, 1996; MacKay *et al.*, 2000a; Malherbe, 2006).

Degradation can be presented in a number of ways all of which are usually interlinked. It can be induced by a number of environmental stresses, which are either also interlinked, or, completely isolated from each other. Environmental disturbances which have led to degradation (within the boundaries of this study alone) include activities such as water pollution, excessive water abstraction, sandmining, and alien vegetation invasions. These activities have led to stresses like poor water quality, reduced flow rates, sedimentation, and loss of habitat and species diversity, being imposed on the system.

According to King *et al.* (2003), when a system experiences disturbance, the natural process to follow would be gradual recovery to its pre-disturbance state *via* natural succession and self-purification aquatic systems. However, the capacity of the system to return to its pre-disturbance state is dependant upon the severity and persistence of the disturbance (King *et al.,* 2003). Systems which have become severely degraded often require some form of management/conservation intervention to aid its recovery (King *et al.,* 2003; Clewell and Aronson, 2007). Remediation, enhancement, restoration and rehabilitation, are some of the common methods regarding the management of aquatic systems currently.

Remediation and enhancement of aquatic systems are relatively similarly processes, where both have the intention of improving the current ecological state of the system but not necessarily to the extent of its original condition (King *et al.,* 2003).

These processes are often employed to mitigate disturbances to provide optimal conditions for valuable species of fish (King *et al.,* 2003). According to King *et al.* (2003) and Clewell and Aronson (2007), rehabilitation aims at making the ecosystem useful again after the degradation. It is concerned with a partial, not necessarily complete, return of the system to its pre-disturbance state. Rehabilitation describes the stabilization of a river system whilst taking into consideration existing catchment factors (King *et al.,* 2003). Restoration is similar to rehabilitation; however, restoration attempts to return the system to as close a level as possible, to its original, pre-disturbed condition (King *et al.,* 2003). Full restoration is not always possible, hence, restoration seeks to restore as much of the original ecological integrity as possible.

In this study strategies for the ecological restoration of the lower Mvoti River system, in response to the environmental distress experienced by the system, are proposed.

1.18. Policy and legislation relating to the protection of water and aquatic resources in South Africa

With regards to environmental governance, and in terms of South Africa's water resource, there are a number of policies and legislation which can offer protection to the country's water resources, if adequately implemented. Here legislation relating to water resources, particularly those relating to river and estuarine systems will be discussed.

The National Water Act (No. 36 of 1998) was introduced to offer protection to South Africa's water resources in terms of sustainability and equity of use, development, conservation and management (Malherbe, 2006; DEAT, 2006; NWA, 1998). It governs factors such as the supply of sufficient freshwater into the estuarine systems (Van Niekerk, 2007) as well as protecting the resource for present and future users (NWA, 1998). The law also attempts to provide water of suitable quantity and quality required to satisfy basic human needs and to protect aquatic ecosystems, so that ecologically sustainable development and usages of water resources can be attained (Malherbe, 2006).

The Marine Living Resources Act (No. 18 of 1998) is concerned with conserving the living resources which occur in marine ecosystems (RSA, 1998a), and below the high water mark of the system (Van Niekerk, 2007). Under this law marine protected areas can be established offering protection to the living resources.

The law attempts to ensure the equitable and long-term sustainable use of marine resources, and, to curb exploitation, so that all present and future citizens of South Africa may benefit (RSA, 1998a).

The Environment Conservation Act (No. 73 of 1989) governs a range of factors concerning the protection of the environment. Under this law provisions are made for environmental conservation policies and the establishment and requirements of protected areas (ECA, 1989). The law prohibited environmental pollution of any nature, and controlled and regulated waste management and activities which may present detrimental effects upon the environment. Amongst others, the Environment Conservation Act also addressed penalties and fines which may be awarded to perpetrators which did not comply with the law.

The National Environmental Management Act (NEMA) (No. 107 of 1998) notes that everyone has a right to an environment that is not harmful to their health and well-being (RSA, 1998b). Therefore under this act, these environments are offered protection from pollution and environmental degradation. This law provides for the promotion of conservation and the sustainable use of resources for the present and future generations to benefit ecologically, economically and socially (RSA, 1998b). The National Environmental Management Act is concerned with co-operative environmental governance, addressing environmental decision-making, and institutions and procedures involved.

The National Environmental Management: Protected Areas Act (No. 57 of 2003) is concerned with conserving the living resources which occur above the high water mark of the system (Van Niekerk, 2007). Under this law marine and terrestrial protected areas that exist with common or overlapping boundaries, are required to be managed as an integrated protected area by a single authority. The National Environmental Management: Biodiversity Act (No. 10 of 2004) is associated with the conservation of biodiversity, and the protection of species and ecosystems (Van Niekerk, 2007). This act is also concerned with regulating the sustainable use of resources.

1.19. Conclusion

Rivers and estuaries are important resources which are impacted upon by both natural and anthropogenic activities. These systems do not function in isolation and are inevitably affected by activities occurring within their catchments.

Together, these factors are responsible for altering the physical, chemical and biological states of these systems, leading to their degradation. Often, rivers are unable to naturally recover, as their deterioration is too advanced. It is in such circumstances that restorative attempts are necessary to prevent the complete loss of the integrity of the system and its use as a resource.

CHAPTER TWO

REGIONAL SETTING AND RESEARCH METHODOLOGY

2.1. Introduction

This section identifies and describes the study area of this project. It discusses the description of the study area in terms of its regional location and general regional and catchment characteristics. The physical location and characteristics of the study area are discussed, after which a description of the sample sites selected for this study is provided. Sampling procedures and laboratory analysis encompassing both various methods of chemical analysis and granulometric analysis are outlined, followed by details of data analysis which includes statistical methods and pollution assessments.

2.2. Regional physiographic description

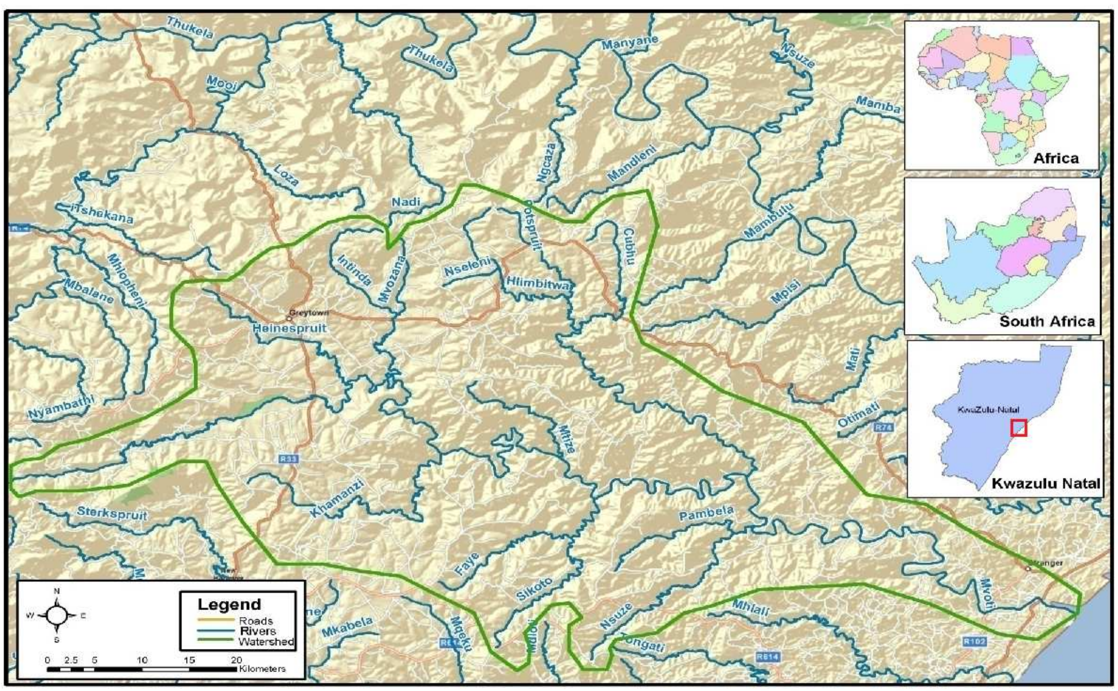

Figure 2.1 (a) The Mvoti River catchment (Produced by V. Devan, 2010)

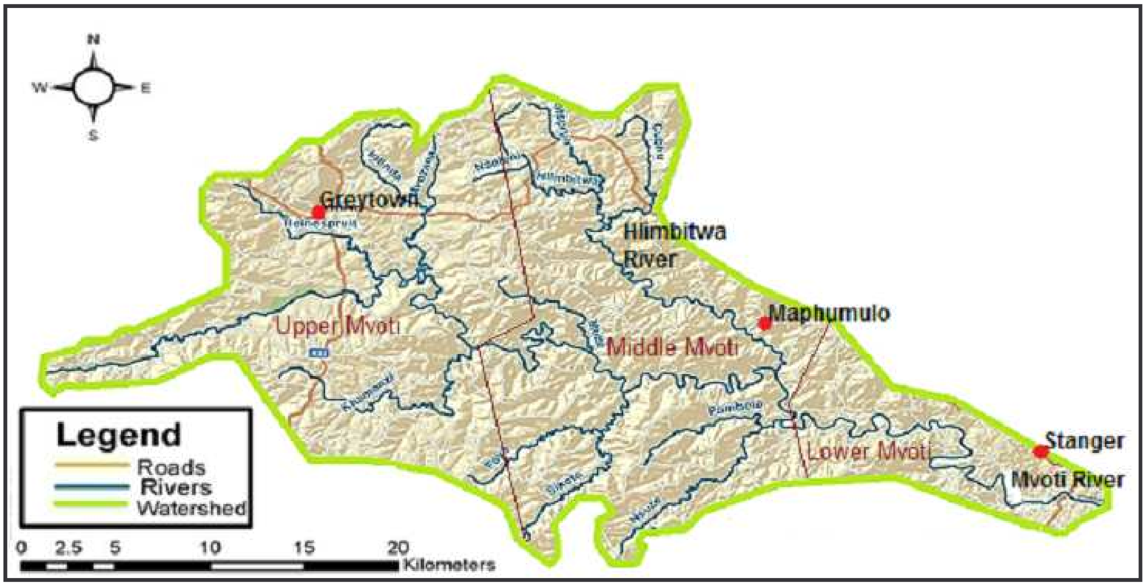

Figure 2.1 (b) The Mvoti River catchment and a representation of its division into the upper, middle and lower Mvoti regions (Produced by P. Sukdeo, 2010).

The Mvoti River is located entirely within the province of KwaZulu-Natal (KZN) along the eastern coast of South Africa. The Mvoti River system formed the study region for this project. The specific study area however, was confined to the middle and lower reaches of the Mvoti River, extending from the Maphumulo district down to and including the Mvoti Estuary and mouth. The rationale for limiting the study to this area was based on a reconnaissance study of the land uses in the catchment which revealed that the upper reaches of the catchment were fairly uniformly dominated by forestry and sugarcane agriculture. The effects due to this dominant activity are therefore represented in the samples collected in the mid-reaches of the catchment.

2.2.1. Topology of KwaZulu-Natal

The Drakensberg Mountain Range, located approximately 250 km away from the coastline, is a natural boundary for the province of KwaZulu-Natal (Abed, 2006). There is an abundance of rivers in the province (Cooper, 1993) and many of them originate within this region. Approximately fifty-five minor perennial rivers, ten secondary perennial rivers and nine major perennial rivers join the Indian Ocean *via* the KwaZulu-Natal coast (Abed, 2009).
The KwaZulu-Natal coastline is characterised by a steep hinterland and small coastal plain (Cooper, 1993; Abed, 2009).

In terms of drainage, the rivers flow through incised valleys (Pillay, 1996), as is also the case with a majority of South African estuaries (Cooper, 2001). Discharge in the province is perennial, though sometimes seasonal (Cooper, 1993), and sediment yields are often high (Cooper, 1993; Abed, 2009).

2.2.2. Hydrodynamics of the Kwa Zulu Natal coastline

Estuaries and tidal inlets along the South African coastline are divided into three biogeographical categories, namely cool-temperate, warm-temperate, and subtropical (Abed, 2009). The cool-temperate region extends from the Orange River mouth (Northern Cape) to the Krom Estuary (Cape Peninsula), and the warm-temperate region extends from the Silwermyn Estuary (False Bay) to the Mendu Estuary (Eastern Cape). The subtropical region, which encompasses the Mvoti Estuary, extends from the Mbashe Estuary (Eastern Cape) to Kosi Bay (KwaZulu-Natal). Cooper (1993) stated that the KwaZulu-Natal coast experiences semi-diurnal tides. The coastline is considered to be wave-dominated and an intermediate between microtidal and mesotidal, with the mean spring and mean neap tidal ranges being 1.72 m and 0.5 m respectively and an average tidal range being approximately 2 m (Cooper, 1993).

In term of oceanography, the Aghulas Current, which flows along the east coast of South Africa (Harrison, 2004) is the major influence on the water circulation of the Kwa-Zulu Natal coast (Cooper and Mason, 1987). According to Harrison (2004), the Agulhas Current is of a tropical origin and is generally warm in nature therefore the average surface sea temperatures off Durban usually exceed 22˚C. However, as it flows southward, it moves offshore, and the coastal sea temperatures drop (Harrison, 2004).

2.2.3. General climatology

The coast of KwaZulu-Natal has a warm, humid climate and experiences predominantly summer rainfall with an average annual rainfall that exceeds 1 000 mm (Harrison, 2004). The coast experiences morning sea breezes followed by evening land breezes (Tyson and Preston-Whyte, 2000). At the same time, local winds evolve and decay from one system into another (Tyson and Preston-Whyte, 2000).

According to Tyson and Preston-Whyte (2000), coastal lows and Berg Winds occur concurrently in KwaZulu-Natal. The coastal lows are restricted to coastal parts of the province. Very rarely do they move beyond the interior or midlands of KwaZulu-Natal. Coastal lows produce precipitation, and are generally associated with localized rainfall and drizzle (Tyson and Preston-Whyte, 2000). According to Tyson and Preston-Whyte (2000), the temperatures and winds of coastal lows are similar to those associated with cold fronts.

Berg winds may blow for a few hours to days and result in the warming of the air and higher temperatures as they descend from the interior of KwaZulu-Natal (Tyson and Preston-Whyte, 2000). As mentioned by Tyson and Preston-Whyte (2000), berg winds on the east coast of South Africa generate relatively high maximum temperatures being recorded in winter, and this phenomenon is irregular (Tyson and Preston-Whyte, 2000). The ridging anticyclones present on the KwaZulu-Natal coast cause high cloud cover and consequently good rainfall (Tyson and Preston-Whyte, 2000).

Periodically intense rainfall events, usually over a few days results in extensive flooding in the province (Cooper, 1993). The September 1987 flood was one such event, which had particularly drastic effects on the rivers of KwaZulu-Natal. This large magnitude flood occurred as a result of the formation of a cut-off low (Abed, 2009). During this event, the Mvoti River, one of the worst hit systems in the province, experienced flooding for up to 24 hours and consequently large scale erosion (Badenhorst *et al*., 1989). The width of river, normally approximately 35 m wide, extended to widths up to 900 m, and extensive sediment deposition occurred on the floodplains (Badenhorst *et al*., 1989).

During this devastating flood, a concrete pump house belonging to the Sappi pulp and mill and a bridge belonging to the Gledhow Sugar Estate, were washed away and never recovered (Badenhorst *et al*., 1989). Large areas of the sugarcane adjacent to the river were also washed away. Presently, however, the Mvoti River is experiencing some of the lowest flows recorded in three decades.

2.2.4. Geology

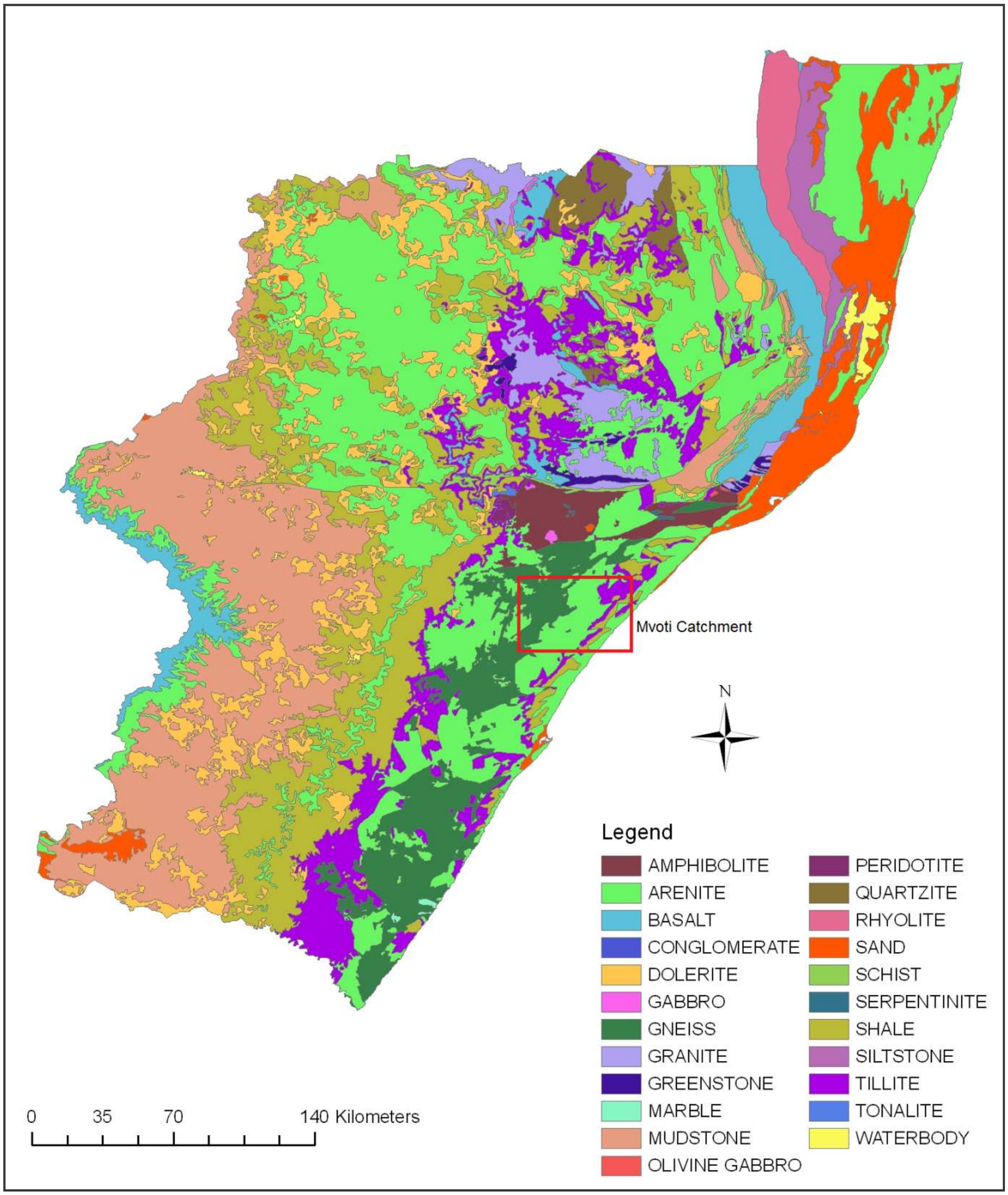

Figure 2.2. The geology of KwaZulu-Natal (Adapted from DEAT, 2000)

The catchment of the Mvoti Estuary is diverse with regard to rock type and geological characteristics (Begg, 1978). The catchment geology (Figure. 2.2) of the Mvoti River comprises of minor amounts of Natal coal measures, Ecca shales, Table Mountain sandstone (arenite), granite, gneiss and dwyka conglomerates (Begg, 1978). Sedimentary rocks dominate the central and lower sections of the catchment whilst igneous rocks are more prominent in the upper regions. This type of geology gives rise to highly erodible soils and consequently large amounts of sand and silt in the catchment (Von Bratt, 2007). The Mvoti Estuary itself is surrounded by Berea red sand, silt-stones and shale. There is also dolerite which forms rocky outcrops at the estuary mouth and along the adjacent coastline (Begg, 1978). This rocky outcrop tends to fix the south bank of the estuary, preventing southward migration of the mouth. The barrier environment is thus better developed north of the current, stable mouth position.

2.3. The Mvoti River System

The Mvoti River system is situated in northern KwaZulu-Natal. The river is commonly referred to as 'Umvoti', and was named after the leader of a local Zulu clan which settled on the banks of the river (Begg, 1978). The river itself is approximately 197 km in length (Wepener, 2007) and originates in the Natal midlands (Malherbe, 2006).

2.3.1. The Mvoti River and catchment characteristics

The Mvoti River drains a catchment with an area of approximately 2 730 km^2 (Wepener, 2007). The mean annual runoff within the catchment is 375 million m^3/annum (Malherbe, 2006). The catchment can be divided into two main sections, namely, the former Natal areas and the former KwaZulu homeland areas (Creemers and Pott, 2002). As illustrated by Figure. 2.1 (b), together, these two regions are further subdivided into the upper, middle and lower Mvoti regions, occupying 53%, 36%, and 11% of the Mvoti catchment respectively (Creemers and Pott, 2002). The only major impoundment on the river is Lake Merthley, a dam which supplies water to the area of Greytown (Malherbe, 2006).

The main tributary is the Hlimbitwa River (Begg, 1978) whilst in its lower reaches the Mbozambo and Nchaweni Rivers drain into the main river (Malherbe, 2006). As illustrated by Figure. 2.3, land use within the catchment varies across a range of different activities.

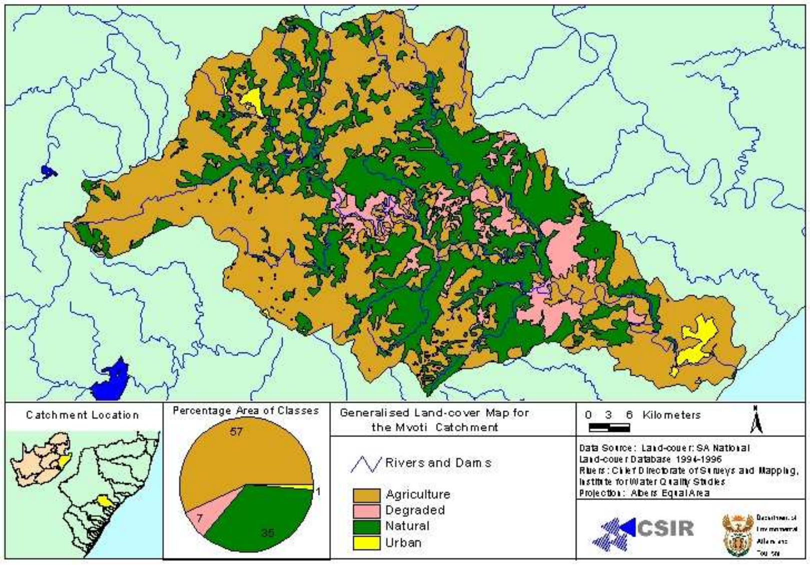

Figure. 2.3. The generalised land cover of the Mvoti catchment (SOER, 2001)

Of the 7% of degraded land, 79% of this land comprises of degraded thicket and bushland, while 21% is comprised of unimproved grasslands (SOER, 2001). Natural cover is also dominated by unimproved grasslands, thicket and bushland. The 1% of the catchment which is classified as urban is comprised of residential, commercial and industrial areas in the vicinity of Greytown and Stanger (SOER, 2001).

Agriculture is the predominant activity in the catchment. Approximately 57% of the total catchment area is under some form of agriculture, as presented by Figure. 2.3 (SOER, 2001). In the upper catchment forestry is dominant, and in the lower catchment sugarcane farming is extensive (Malherbe, 2006). Throughout the catchment, especially in the mid-reaches, where the inhabitants live in generally rural conditions, subsistence crop farming is present (Creemers and Pott, 2002).

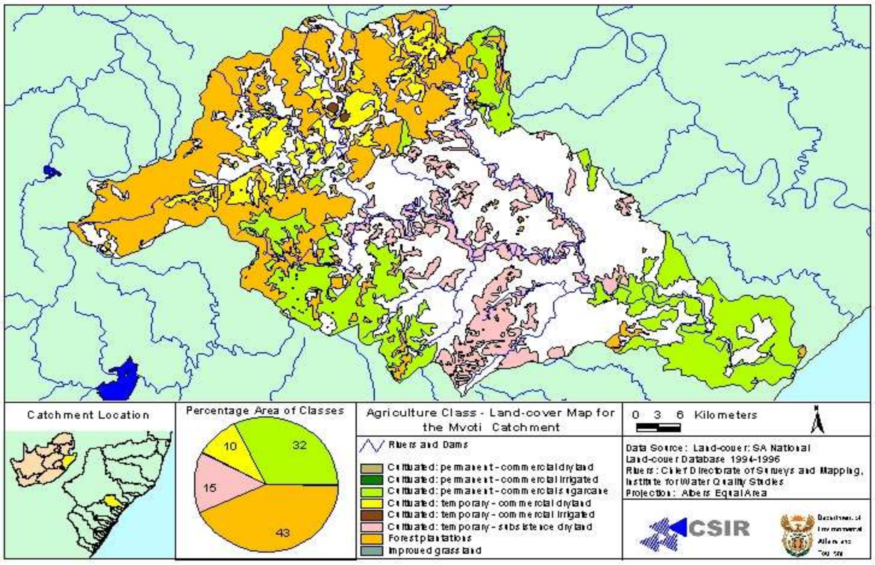

Figure. 2.4. Agricultural land cover in the Mvoti catchment (SOER, 2001)

2.3.2. The Mvoti Estuary

Figure 2.5. The location of the Mvoti Estuary on the KwaZulu-Natal coast

(Munien, 2006)

The Mvoti Estuary, located at (29˚ 24' S; 31˚ 21' E) occurs approximately 80 km north of Durban. In terms of accessibility, the estuary can be reached via a pathway from Blythedale beach on the northern bank, as the southern bank falls within private property. There are no bridges over the estuary (Begg, 1978). The estuary is river-dominated and experiences little or no significant tidal influence as it is perched above sea level. This is mainly due to the infilling of the original basin of the estuary with fluvial sand over the years which has risen the system above sea level (Begg, 1984). Hence, the predominantly freshwater system is referred to as a river mouth. A large sand barrier present across the estuary, prevents the river from taking a direct path to the ocean.

Morphometric characteristics

The estuary has an area of approximately 18.4 hectares (Chili, 2008). The system is relatively shallow as a result of severe siltation (Begg, 1984), with an average depth ranging between 1.5 m (Chili, 2008) and 1.8 m (Begg, 1978). As mentioned above, a sandbar exists within the estuary. This feature is approximately 1 km in length and causes the estuary to join the ocean at a southward position.

Nature of bottom materials

The bottom substrate of the lower river and estuary is predominantly comprised of sand, and the river channel is extensively braided (Von Bratt, 2007). The sand is widely of fluvial origin (Begg, 1984).The colours of the sand range from grey to yellow (Begg, 1978). This sand is uniformly distributed throughout the system except for backwater areas (Begg, 1984). Here, pockets of silt have accumulated as this area is usually out of the current. According to Begg (1984) the constant flow of water in the main channel of the estuary has resulted in the bottom material being fairly coarse and washed free of silt particles.

2.4. Site Selection

A total of 11 sample sites were selected for Chapter Five to seven. For chapter eight, 10 sample sites were selected. The sites extend from the Hlimbitwa and Mvoti Rivers in the Maphumulo District down to the Mvoti Mouth in the vicinity of Blythedale, near Stanger. However, within this range, different sites were used for different aspects of this study. Two types of samples were collected during field surveys, namely water and sediment samples.

2.4.1. The Riverine Sites

In the riverine section of the study area, a total of six sample sites were selected. In the chapters to follow, sample sites on the middle and lower Mvoti River will be referred to as R1, R2,...,R6, (where R= River). Site R1 is located in the lower reaches of the river, upstream of the estuary. The site is located directly under a bridge which forms part of the National Road (N2). It is accessible *via* the town of Stanger. This particular site is downstream of where the Mbozambo and Ntshaweni Rivers converge with the Mvoti River, contributing into its load treated wastewater from the town of Stanger, and effluent from the sugar and paper mills respectively. The site is characterised by clumps of alien vegetation along the disturbed banks, dark water with an unpleasant odour, and predominantly fine bottom sediments (97.8% of fine sand and smaller particles).

Sites R2 and R3 are located on the lower reach of the river within the settlements of Groutville and Glendale respectively. R2 is characterised by fast flowing water and the presence of rapids. This site is within close proximity to the Zululand palmveld which adorns the floodplain of the river. The substrate is much coarser than R1. The water is lighter in colour. Large tracts of the riparian area have been cleared for the cultivation of palm plants and subsistence agriculture. R3 is downstream of the Glendale Distillery. The distillery, approximately 400m away from the channel, extracts water from the Mvoti River for its cooling processes. The river here is fast flowing and clarity is low with the water displaying a reddish-brown colour, The river banks are completely covered with *Phragmites sp*., and the bottom sediments are comprised predominantly of larger sand and gravel particles.

Sites R4, R5 and R6 are situated in the middle reaches of the Mvoti catchment within the Maphumulo District. Mapumulo is located approximately 90 km inland from the town of Stanger. The area is predominantly rural and the river is an important source of water for the community. R4 is on the Mvoti River after its confluence with the Hlimbitwa River. R5 is on the Hlimbitwa River prior to its confluence with the Mvoti River, and R6 is on the Mvoti River before the Hlimbitwa River joins it. At R4, the riparian vegetation is dense and mainly exotic species. At both R5 and R6, the banks have been cleared for subsistence agriculture, and at R6, home-made water abstraction mechanisms have been constructed. All these sites are characterised by bottom substrates which are predominantly sand and gravel.

2.4.2. The Estuarine Sites

In the estuarine section of the study area five sites were selected (for the purpose of Chapter Four). Ten sites were randomly selected for chapter eight. The estuary is situated approximately 5 km from the town of Stanger. Public access is restricted to the northern banks via Blythedale Beach. In the chapters to follow, sample sites within the Mvoti Estuary will be referred to as E1, E2,..., E5, (where E= Estuary). Site E1 was the site closest to the Mvoti Mouth. Here, the river is reduced to a narrow channel with rocky outcrops. At E2, E3, and E4, the channel was wider, and opposite the large sand barrier. Lagoon-like conditions of slow flowing water were prevalent, and at E4 through to E5, *Phragmites sp.* covers the banks. Site E5 is located at the upper most reaches of the estuary. The ten sites randomly selected for chapter eight, also fall between sites E1 and E5. At all the estuarine sites, the water was darkly coloured during a majority of the site visits. Unpleasant odours also on some occasions emanated from the system.

The bottom sediments of the estuarine sites were unlike those of typical estuarine systems, i.e. mostly fine particles, but rather a mixture of coarse and fine sand and gravel with a very small proportion of finer sediments.

Figure 2.6. Aerial view of the sample sites on the Mvoti Estuary

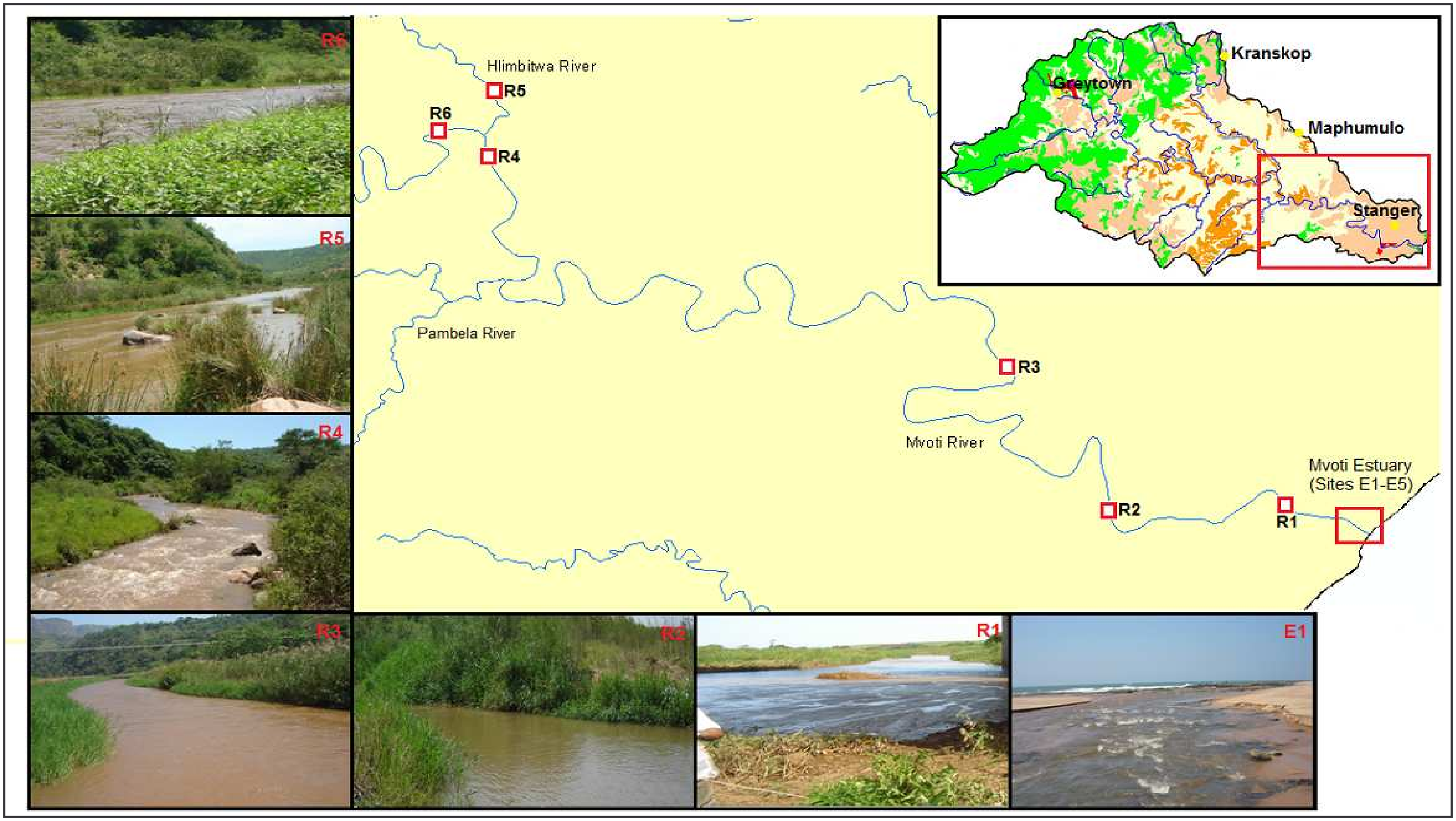

Figure 2.7. Sample sites selected along the middle and lower reaches of the Mvoti River (Produced by P. Sukdeo, 2010)

2.5. Sampling Protocol

Fieldwork for this study was carried out between March 2009 and March 2010. At each location, replicate samples were collected at three points: one at midstream, and the others midway between both banks and midstream. Water samples were collected within the estuary and lower section of the river in sterile 1L sample jars and stored at low temperatures for further analysis. Samples were collected biweekly for one month during each season. *In situ* readings were recorded for some of the parameters using a YSI (Yellow Sprigs Instrument) 6920 Multi-parameter Sonde and the 650 MDS (Multi-parameter Display System). Water samples were collected (for analysis), to determine the quality of water present in the estuary. The water quality parameters were selected based on previous studies in the system, for comparative purposes, and details nutrients and physical factors.

Sediments were collected in a similar manner, i.e. replicate at three points per transect, at all of the riverine sites, and two of the estuarine sites (E2 and E5). The samples were collected at monthly intervals using a Polyvinylchloride (PVC) Pipe Sediment Extractor, and stored in polyethylene jars at low temperatures for further analysis.

(a) **(b)**

Figure 2.8. (a) The 650 MDS Multiparameter Display System and (b) The 6920 Multiparameter Sonde (http://www.ysihydrodata.com/products.htm)

2.6. Chemical Analysis

Following collection, all samples were transported to the analytical laboratory at the School of Chemistry, University of KwaZulu-Natal (Westville Campus), where all chemical preparation and analyses were conducted. Prior to chemical analysis, sediment samples underwent granulometric analysis. Water samples were analysed for pH and conductivity measures, and level of dissolved oxygen, nitrates, ammonium ions, chloride, sulphate ions, sodium and calcium. Sediment samples were analysed for the presence and concentrations of a range of elements, namely, aluminium, arsenic, barium, boron, calcium, cobalt, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorous, selenium, silicon, strontium, titanium, vanadium, and zinc.

2.6.1. *In Situ* Recordings

Onsite measurements for dissolved oxygen, pH, ammonium ions and conductivity, were recorded using the YSI 6920 Multi-parameter Sonde and the 650 MDS Multi-parameter Display System.

2.6.2. Ion Chromatography

The concentrations of chloride, nitrate and sulphate ions were measured using ion chromatography. This is an instrumental method which is widely used to determine common cations and anions (Ngila, 2009). During this procedure, the aqueous sample is first injected into a stream of carbonate/bicarbonate eluant, after which this eluant is pumped through an ion-exchanger (Ngila, 2009).This ion-exchanger is a resin-packed column, for which ions in the sample have different affinities. Hence, they are separated. As the original eluant and these separated ions pass through the ion-exchanger, the conductivity of the eluant is curbed to enhance the detection and conductivity of the ions (Ngila, 2009). The ions as transformed into a highly conductive form, and are consequently measured by their conductivities. They are then identified using respective retention times, and quantified *via* a comparison between calibration standards and their peak areas (Ngila, 2009).

2.6.3. Flame Photometry

Flame photometry was used to determine the levels of sodium and potassium in the samples. This is done using a flame photometer, an instrument used to quantify Group I and Group II metals (Ngila, 2009). This procedure involves aspirating metallic ions in solution into a low flame in aerosol form. Their electrons proceed to higher energy states, become unstable, and then quickly return to ground state (Ngila, 2009). This loss in energy is displayed as a discrete wavelength of visible light, detected by a photo-detector, and distinguished from other wavelengths with an optical filter (Ngila, 2009). Within the flame photometer, the electrical signal from the photo-detector is amplified and presented as a digital readout. Flame photometry presents numerous advantages over techniques, two of which are cost effectiveness, and freedom from spectral interferences (Ngila, 2009).

2.6.4. Inductively-coupled plasma optic emission spectrometry

Inductively-coupled plasma optic emission spectrometry (ICP-OES) was used to measure the concentrations of calcium in both the water and sediment samples and the concentrations of aluminium, arsenic, barium, boron, cobalt, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorous, selenium, silicon, strontium, titanium, vanadium, and zinc in the sediments.

According to Robin (1988) of the many analytical techniques available for trace metal determination, ICP-OES is one of the most useful. Inductively-coupled plasma techniques allow for several different elements to be simultaneously determined. The emission source transforms the sample into atomic vapours to ‘excite’ the constituent elements. Thereafter, these ‘excited’ elements emit characteristic radiation, which by optical emission spectrometry is qualitatively and quantitatively analysed. Generally, the excitation energy is applied to an inert yet flowing plasma gas (often argon is the recommended choice) by means of an inductor, which is part of a circuit supplied by a high-frequency current. The plasma gas, then partially ionised by the excitation energy displays a simple spectrum of atomic lines.

The various elements emit both atomic and ionic spectra at the same time, by which they are identified. There are four key features associated with this method, which makes it favourable over other procedures, i.e. the detection limits are low, there are few inter-element effects, the analytical range is large, and the method is precise, accurate and fast.

2.7. Granulometric analysis

Textural analysis on sediment samples was carried out in the soil laboratory in the School of Environmental Sciences (Westville Campus), to determine their particle size distribution. This was achieved using a standard dry sieving technique (Gordon *et al.*, 1992; Abed, 2009). Equal proportions of the samples (approximately 500 g) were homogenised and oven-dried at 110ºC for 48 hours. The samples were disaggregated with a pestle and mortar (Gordon *et al.*, 1992), and split using a riffle box sample splitter. One portion of the split samples were used to determine particle size using a Retsch® sieve shaker, and the remaining portion was reserved for chemical analysis. Particle size was determined according to the Udden-Wentworth sediment grade scale (Blatt *et al.*, 1980).

2.8. Data Analysis

2.8.1. Statistical analysis

Statistics allows the researcher to interpret data in a scientific setting (Naidoo, 2005). In this study, descriptive statistical techniques, which are techniques for displaying, interpreting and summarizing sets of data, and significance statistical techniques, which are techniques that allows the researcher to determine whether observed trends, relationships and differences are significant or due to chance (Naidoo, 2005).The statistical programme SPSS (version 15.0 for Windows) was used to analyze the water quality and sediment data. The descriptive statistic calculated in this study was the mean of recorded values. The t-test was the significance test used, to ascertain differences between the means (Bryman and Cramer, 2001) of recorded values and previous data, background data, and data recorded at other sites.

2.8.2. Pollution assessments

A range of methods exist which can be used to determine different measures of pollution in aquatic sediments or aquatic systems in general, require in some form the use of background values. Contamination factors (CF), enrichment factors (EF), and the pollution load index (PLi) are just a few of some of the indicators of the existence and extent of pollutants in a system (Harikumar and Jisha, 2010).

Contamination Factors (CF)

Contamination factors are used to determine the level of contamination of the sediment by a particular element (Harikumar and Jisha, 2010) and are calculated using the following equation:

$$CF = \frac{[\text{Concentration of element in the sediment}]}{[\text{Background value of element}]} \quad (1)$$

Enrichment Factors (EF)

Enrichment factors are used to evaluate the magnitude of contamination of the sediment (Harikumar and Jisha, 2010). Enrichment factors are calculated using a reference element or element for normalisation (Harikumar and Jisha, 2010). One of the most commonly used elements is iron, as it is a naturally abundant element in the earth's crust (Rosler and Lange, 1972). Enrichment factors indicate the extent to which measured concentrations of elements exceed the reference background values for the particular site or sediment type (Martinez *et al.*, 2007). Furthermore, these values can assist in evaluating geochemical trends and comparisons between sites (Harikumar and Jisha, 2010). The following equation is used to determine an enrichment factor:

$$EF = \frac{[\text{Concentration of element}] / [\text{Concentration of reference element}]}{[\text{Background of element}] / [\text{Background of reference element}]} \quad (2)$$

Pollution Load Index (PLi)

Pollution load index is used to measure the extent of pollution at a specific site (Harikumar and Jisha, 2010). The pollution load index for a specific system is calculated *via* the follow equation:

$$PLi = n\sqrt{(CF1 \times CF2 \times \ldots \times CFn)} \quad (3)$$

Where, CF refers to the contamination a factor at each site and n refers to the number of elements.

2.9. Conclusion

Numerous methods have been used to collect and analyze data in this study. The fieldwork comprised of both water and sediment sample collections, together with *in situ* water testing for certain parameters. The laboratory work encompassed two main types of analysis, namely grain-size determination, and chemical analysis. Chemical analysis comprised of three different procedures, depending on the ion/element being tested for. The data was the analyzed using statistically techniques, and pollution assessments.

CHAPTER THREE

THE WATER QUALITY OF THE MVOTI ESTUARY

This chapter is based on:

Sukdeo, P., Pillay, S., Bissessur, A., Chili, N. S., and Desai, A. *In Review.* Deteriorations in the water quality of the Mvoti Estuary: implications for aquatic ecosystems and domestic use. *Water SA*.

(Submitted 01 November 2010)

3.1. Abstract

The Mvoti Estuary located on South Africa's eastern seaboard is notorious for its poor water quality and overall degraded state. Measurements of dissolved oxygen, ammonium ions, nitrate, chloride, sulphate ions, sodium ions, calcium, conductivity and pH, were assessed to determine the current quality of water passing through the estuary. Comparisons were made to previously published data sampled in 1964 and 2000 to assess the deterioration in the system over time. The current state of the water was assessed against water quality guidelines for aquatic ecosystems and domestic use provided by the Department of Water Affairs and Forestry.

The results indicate that this degradation is not new to the system. The Mvoti system has been experiencing deteriorations in its water quality over the past few decades, with the current concentrations of nutrients exceeding those recorded in 1964. Only calcium and dissolved oxygen levels have decreased over this period. Presently, ammonium ions, nitrate and chloride exceed the acceptable limits proposed by the water quality guidelines and dissolved oxygen levels are extremely low, implying that the biotic integrity of the system is seriously compromised and may result in detrimental effects to all other users if the quality of water is not improved.

Key Words

Mvoti Estuary, water quality, deterioration, aquatic ecosystems, domestic use

3.2. Introduction

The South African coastline boasts approximately two hundred and fifty estuarine systems (Pillay *et al*., 2003) and are relatively small by global standards (Breen and McKenzie, 2001). More than seventy estuarine systems occur within KwaZulu-Natal on the eastern seaboard of South Africa (Pillay *et al*., 2003), many of which have been intensely developed (MacKay *et al*., 2000a). River dominated estuaries, estuaries or outlets maintained by fluvial discharge, are especially well developed in the province and a large number of the open estuaries are dominated by fluvial discharge (Cooper, 2001).

The Mvoti Estuary geographically located at 29˚ 24' S; 31˚ 21' E, is one of the smaller (Begg, 1984), river dominated estuaries on the subtropical, microtidal coast of KwaZulu-Natal (Cooper, 2001). Despite being fairly small, the approximately 197km long Mvoti River which feeds the estuary, serves as a principal resource for many towns and various informal settlements along its course, together with a sugar mill, a pulp and paper mill, and a distillery in its lower reaches (Malherbe, 2006). Approximately 1% of the 2730km^2 Mvoti catchment (Wepener, 2007) is urbanized and approximately 57% has been modified from its original state for agricultural purposes, predominantly commercial sugarcane farming and forestry (SOER, 2001). Subsistence agriculture is common practice throughout the catchment.

Geologically, the catchment is varied containing Ecca shale, granite and gneiss. The estuary itself is surrounded by Berea red sand, silt-stones and shale, and has some dolerite outcrops towards the coastline (Begg, 1978). A spit extending southwards is present at the estuary making it a typical bar-built estuary (Chili, 2008; Begg, 1978). This sand barrier is over 1 km long and is capable of detaching the estuary from the marine environment during low flow periods (Chili, 2008). A northward extending spit is sometimes formed during winter closing off a section of the estuary and leading to the formation of a lagoon (Munien, 2006). This spit is often breached to prevent flooding of the adjacent sugarcane fields (Munien, 2006). Breaching is sometimes necessary as the lagoon formation leads to a minimal outflow rate and consequently a rapid accumulation of pollutants within the estuary (Chili, 2008). With time, further degradation of the estuary, which is already in a poor condition, is imminent.

The river is presently experiencing a number of environmental problems resulting from poor catchment practises and irresponsible utilization of the river itself (Sukdeo *et al.,* 2010).

Sukdeo *et al.* (2010) identified some of these environmental concerns as modifications of the river channel and riparian zones to facilitate water abstraction and sandmining activities, excessive siltation of the river and estuary, together with industrial and municipal discharges into the system. As noted by Russell (1996) these factors inevitably influence the water quality of a system.

The large number of functions and services that the estuary provides relative to its size, and the fact that it is severely degraded and fed by a 'working river' (Malherbe, 2006) emphasizes the urgency with which it needs to be prioritized in terms of protection, conservation and rehabilitation. According to Tharme (1996) the habitat integrity of the Mvoti River has been reduced to a very low level with the river ecosystem being severely modified. While previous studies into the water quality of this system have been documented, a number of them have been fairly brief and short-term. Hence, despite concerns of the peril the river has been facing, intensive investigations into the water quality of the Mvoti Estuary has been limited.

Given the importance of this system and the extent to which it has been impacted upon largely by anthropogenic activity within the catchment, the aim of this study was to assess the present quality of water within the Mvoti Estuary (2009 and 2010), and compare these results against South African Water Quality Guidelines, and available water quality data for the estuary dating back to 1964 and 2000. Processed results were used to assess the implications presented by poor water quality upon aquatic ecosystems and domestic users. As a result, changes in the water quality and degradation of the estuary can thus be tracked to the present status.

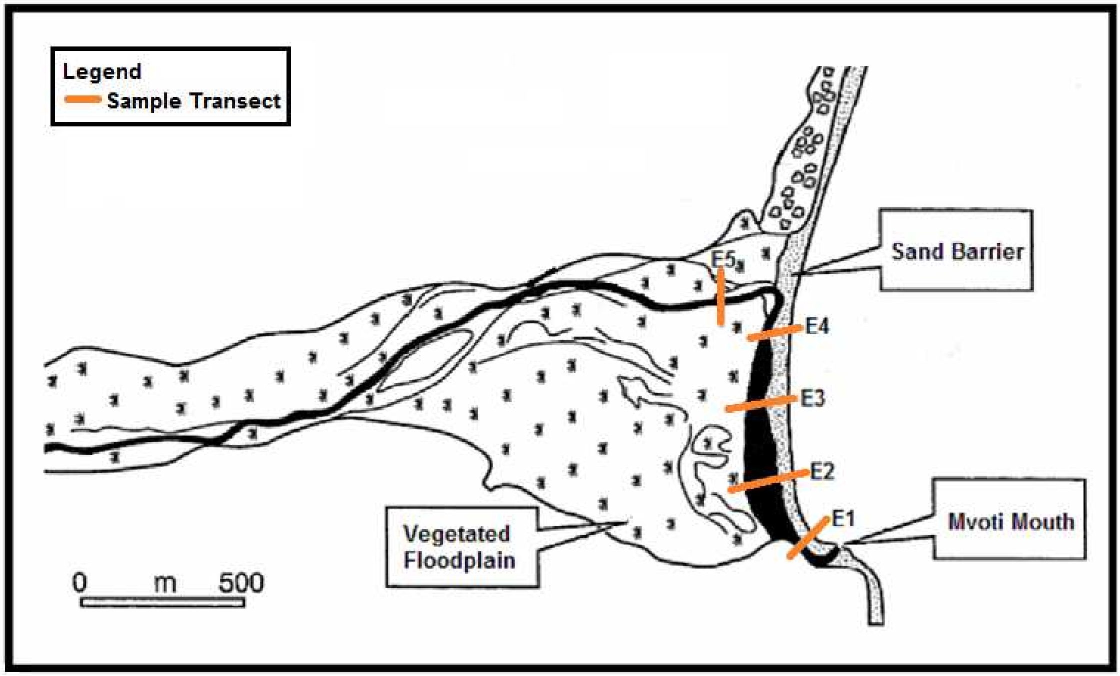

Figure 3.1. Schematic representation of the Mvoti Estuary and sampling transects (Adapted from Cooper, 2001)

3.3. Methodology

3.3.1. Sample Collection and Chemical Analysis

Levels of dissolved oxygen, un-ionised ammonia, nitrate, chloride, sulphate, sodium, calcium, conductivity and pH values in the surface waters of the Mvoti Estuary were recorded between 2009 and 2010. As the Mvoti Estuary itself is fairly small with an area of approximately 18.04 ha and length of approximately 2.40 km (Chili, 2008), only five sample sites were selected for this study (refer to Figure. 3.1). The sites are within close proximity to sample sites of the previous studies for comparative purposes.

Onsite recordings were carried out for dissolved oxygen, pH, ammonium ions and conductivity, using the YSI 6920 Multi-parameter Sonde and the 650 MDS Multi-parameter Display System, after which water samples were collected in sterile sample jars and stored at low temperatures till further analysis. Concentrations of chloride, nitrate and sulphate ions were measured using an Ion Chromatography method, whilst calcium and sodium ion concentrations were measured *via* Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Flame Photometry methods respectively.

3.3.2. Statistical Analysis and Comparisons

A comparison of the results from this research to that from previous work conducted on the estuary in 1964 (Begg, 1978) was *via* t-tests. The results were graphically compared to data collected on the estuary in 2000 (MacKay *et al.,* 2000a). Data obtained in this work was evaluated against guidelines as set out by the Department of Water affairs and Forestry (DWAF, 1996a; DWAF, 1996b). The objective of this was to highlight the implications the current estuarine water quality presents for aquatic ecosystems and domestic use. To achieve this, the levels of contaminants and pollutants present serves as an indicator of the degree of hazard that the water poses to flora and fauna, as well as humans as a result of consumption and domestic use.

For the purpose of this study guidelines for Aquatic Ecosystems (DWAF, 1996a) were used. As yet, no such comprehensive guidelines governing estuarine contaminants have been developed for estuarine environments in South Africa (MacKay *et al*., 2000a). The Mvoti Estuary displays the potamonic characteristics of a river mouth. It therefore seemed viable to compare the results against standards provided by the guidelines for aquatic ecosystems (DWAF, 1996a).

The results of the water quality analysis were also evaluated in accordance with guidelines stipulated for Domestic Use (DWAF, 1996b). All statistical analysis was conducted using SPSS 15.0 for Windows.

3.4. Results and Discussion

Waters of the Mvoti River are used for a variety of activities from the agricultural, industrial and domestic sectors, resulting in a range of impacts on the water quality (Malherbe, 2006). The results presented in Table. 3.1 indicate statistically significant differences in the water quality parameters between 1964 and 2010.

Table 3.1. Measurements of the Water Quality parameters recorded at the Mvoti Estuary in 1964 (after Begg, 1978), 2000 (MacKay *et al.,* 2000a), and 2010. The *p*- values associated with the T-Tests between 1964 and 2010 are also presented

Parameter	*1964*	*2000*	*2010*	*p- value**
Dissolved Oxygen (mg/L)	2.70	5.03	1.11	0.000
Conductivity (µS.cm)	409.00	960.67	674.33	0.000
Nitrate (mg/L)	0.125	0.22	1.04	0.006
Ammonium (mg/L)	0.10	0.24	498.69	0.041
Chloride (mg/L)	34.75	200.58	119.31	0.000
Sulphate (mg/L)	2.75	21.07	49.99	0.000
Sodium (mg/L)	26.30	138.00	60.62	0.010
Calcium (mg/L)	50.80	22.00	18.77	0.000
pH	7.05	7.55	7.80	0.02

******p***-Value refers to the significant value obtained for the statistical procedure.**

Where $p < 0.005$, results are deemed significant.

By comparison, the concentrations of contaminants present in the system have shown increases over this period, with certain exception shown for calcium levels (Figure 3.9). This overall increase in contaminant levels has been accompanied by a decrease in dissolved oxygen. Levels of contaminants closer to the Mvoti mouth (E1) were lower than those recorded in the lagoon-like section of the estuary (E2, E3 and E4). Those recorded at E5, the upper reaches of the estuary were on average higher than the rest of the sites. The results from Table 3.1 also indicate that the estuary currently experiences a relatively poor quality of water. The distribution of contaminants in relation to the distance from the mouth indicates that the pollution is most likely originating upstream of the estuary, and not emanating from the estuary itself.

3.4.1. Dissolved Oxygen

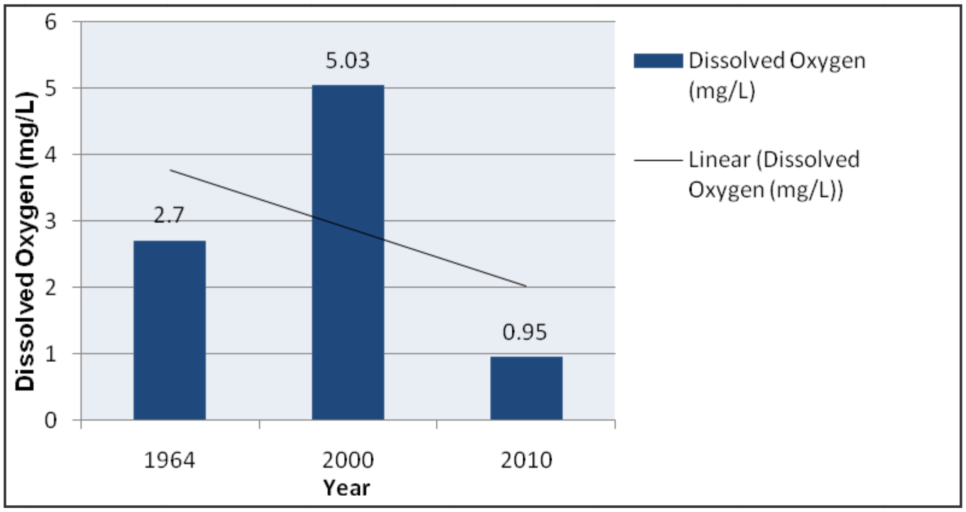

Figure 3.2. Changes in the levels of dissolved oxygen in the Mvoti Estuary between 1964 and 2010

Extremely low levels of dissolved oxygen were recorded in the estuary averaging at 1.11 mg/L. Comparisons of dissolved oxygen levels show significant differences in the estuary over the past decade. The Mvoti Estuary can be described as hypoxic, as dissolved oxygen levels are below 2.0-3.0 mg/L (Obeng, 2010). There is a marked decrease in the levels of dissolved oxygen by approximately 22% between 2000 and 2010, and approximately 41% between 1964 and 2010.

In unpolluted surface waters dissolved oxygen concentrations are close to saturation (DWAF, 1996a). Levels of dissolved oxygen in this study were extremely low in comparison to these standards and are therefore unacceptable. The amount of dissolved oxygen present within a system is negatively influenced by the suspension of anoxic sediments, excess amounts of suspended material, and the presence of organic matter. The latter being either detritus or originating from waste, and increasing the biochemical (BOD) and chemical (COD) oxygen demand during its breakdown.

Sewage effluents reduce DO in aquatic systems by introducing into the system organic matter which, as noted by Russell (1996) requires oxygen for its breakdown. The Mvoti system receives treated sewage effluent from the adjacent town of Stanger *via* the Mbozambo River.

Shortages of dissolved oxygen could be lethal for aquatic aerobic organisms which depend upon this for respiration. One of the many effects of dissolved oxygen depletion is the reduction in growth and development of some fish species. Photosynthesis in green plants and algae can also be inhibited, often favouring the growth of blue algae which may become a nuisance (DWAF, 1996a).

Obeng (2010) noted that the prevalence of anthropogenic activities along coastal areas is a huge contributing factor to the increasingly common occurrence of hypoxic conditions in estuaries. The Mvoti system is known to be very polluted with effluents from formal and informal settlements, and the town of Stanger and several industries located on its floodplain causing major degradation. It is therefore not surprising that very low levels of diffused oxygen were encountered in the system. From dissolved oxygen levels alone, it is clear that the Mvoti Estuary is in need of attention and proper future management.

3.4.2. Conductivity

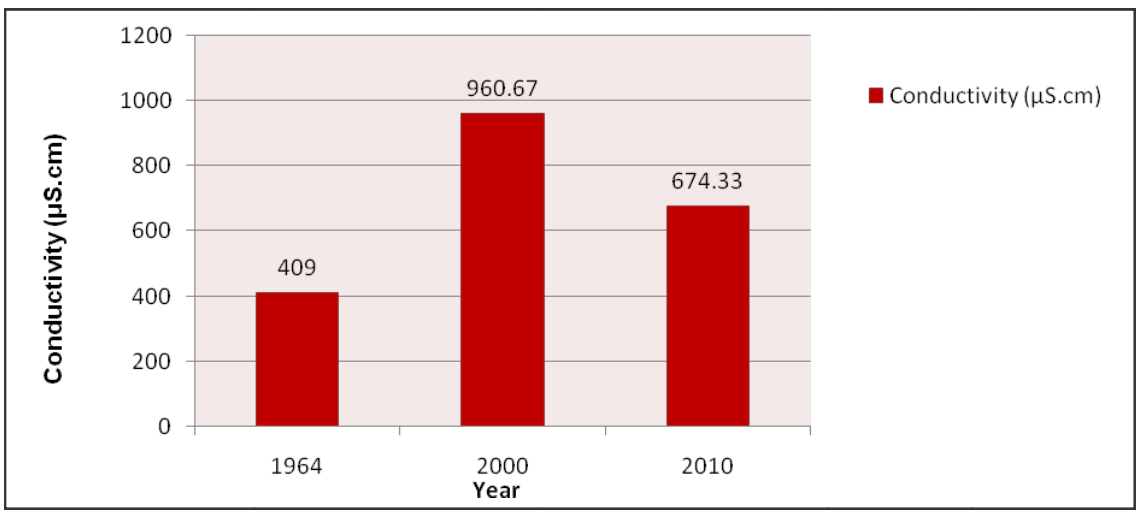

Figure 3.3. Changes in the levels of conductivity in the Mvoti Estuary between 1964 and 2010

The conductivity of the estuarine water has increased over the years as seen in Figure 3.3. There are no target water quality ranges for conductivity, for domestic uses or aquatic systems.

The waters of the Mvoti Estuary are known to contain high levels of nutrients, particularly chloride and nitrates, increasing electrical conductivity levels (Chili, 2008). This is further enhanced by the presence of other nutrients such as sulphate ions and sodium. The Mvoti Estuary is not generally utilized for recreation purposes, and therefore the variations in conductivity levels are most likely a reflection of the changing nutrient inputs from anthropogenic activities in the catchment.

3.4.3. Nitrate

Illustrated by Figure 3.4, significant increases in nitrate concentrations have been observed between 2000 and 2010. A 472% increase in concentration occurs during this period and is attributed to increased industrial development in the lower catchment. Some of this increase may be attributed to leaching from fertilizers used on commercial sugarcane farms, and another possible source is the faecal pollution emanating from informal settlements in the lower catchment. Nitrate levels present a range of effects on aquatic ecosystems. There are no specific target water quality ranges for aquatic ecosystems, however optimum levels for ecosystem functioning are below 0.5 mg/L (DWAF, 1996a). At these levels the system experiences oligotrophic conditions, and at levels between 0.5 – 2.5 mg/L mesotrophic conditions prevail (DWAF, 1996a). It is the latter condition that now prevails at the Mvoti Estuary.

In oligotrophic conditions, such as those occurring in 2000, there are moderate species diversity, low productivity and rapid nutrient cycling. There is no excessive growth of aquatic plants or algal blooms. In mesotrophic conditions there is high species diversity and high productivity. There is also nuisance growth of aquatic plants and blue - green algal blooms. However these are seldom toxic.

In eutrophic conditions, nitrate levels are between 2.5 – 10.0 mg/L. Here, species diversity is low and productivity of the system is high (DWAF, 1996a). Excessive growth of aquatic plants and blue - green algal blooms, some species of which are toxic to man, livestock and wildlife may also occur. The same effects can be noticed for hypertrophic conditions, such as those experienced in 2010 where nitrate levels are > 10mg/L (DWAF, 1996a).

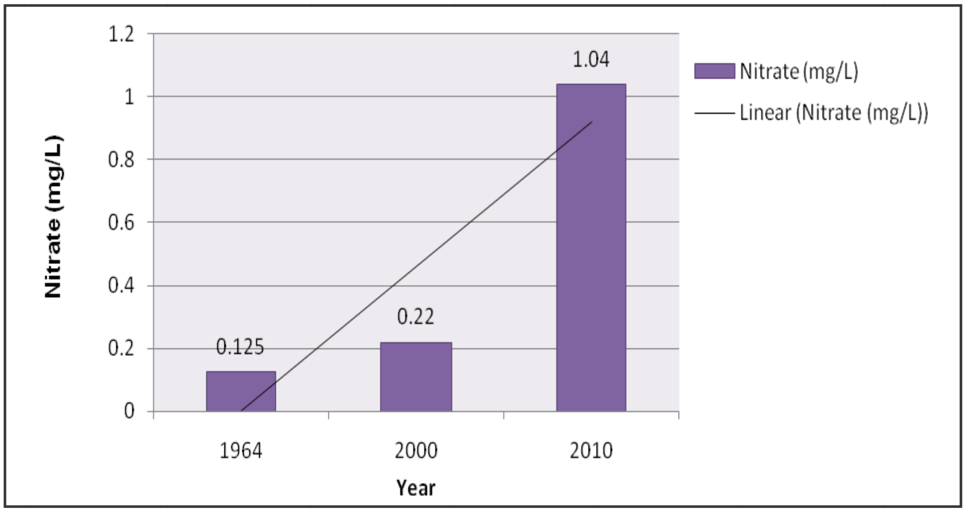

Figure 3.4. Changes in the levels of nitrates in the Mvoti Estuary between 1964 and 2010

The target water quality range of nitrate for domestic purposes where there are no adverse health effects is < 6.0 mg/L (DWAF, 1996b). Concentrations between 6.0 – 20.0 mg/L have no effects on adults but in infants, may induce methaemoglobinaemia, a condition where haemoglobin is converted to a form incapable of carrying oxygen (DWAF, 1996b). Levels of nitrates > 20.0 mg/L also induce methaemoglobinaemia in infants and cause mucous membrane irritation in adults (DWAF, 1996b). Major sources of nitrates in aquatic systems are effluent containing human and animal excreta, organic industrial wastes and agricultural fertilizers (DWAF, 1996a). Unimpacted surface waters in South Africa usually have levels of nitrate that are below 0.5 mg/L (DWAF, 1996a). Hence, since much of the Mvoti catchment and river system is utilized, nitrate enrichment of the estuarine waters can be expected.

3.4.4. Ammonium ions

Levels of ammonium ions in the Mvoti Estuary have increased considerably between 1964 and 2010 (refer to Figure 3.5). The recorded values have exceeded the target water quality range of ≤ 7.0 *µg*/L for aquatic ecosystems (DWAF, 1996a) making these values unacceptable according to DWAF guidelines. Whilst concentrations were barely detectable in earlier measurement, they are now at toxic levels (439.9 mg/L). Concentrations between 7.0 – 15.0 *µg*/L often result in a reduced growth and morphological development rate for aquatic organisms, and impairment of hatching success.

There is also the possibility of pathological changes in the tissues of gills, liver and kidneys. At levels of >100.0 mg/L ammonia affects the respiratory systems of many animals and often results in fish death (DWAF, 1996a).

In terms of domestic use, high ammonia levels have rendered the estuarine water unfit for domestic use. Levels between 2.0 – 10.0 mg/L are likely to compromise the taste and odour of the water, and levels > 10.0 mg/L are completely unacceptable (DWAF, 1996b). At these levels there is a high possibility of nitrite formation, which is potentially toxic to humans, and the death of fish in domestic aquaria is common.

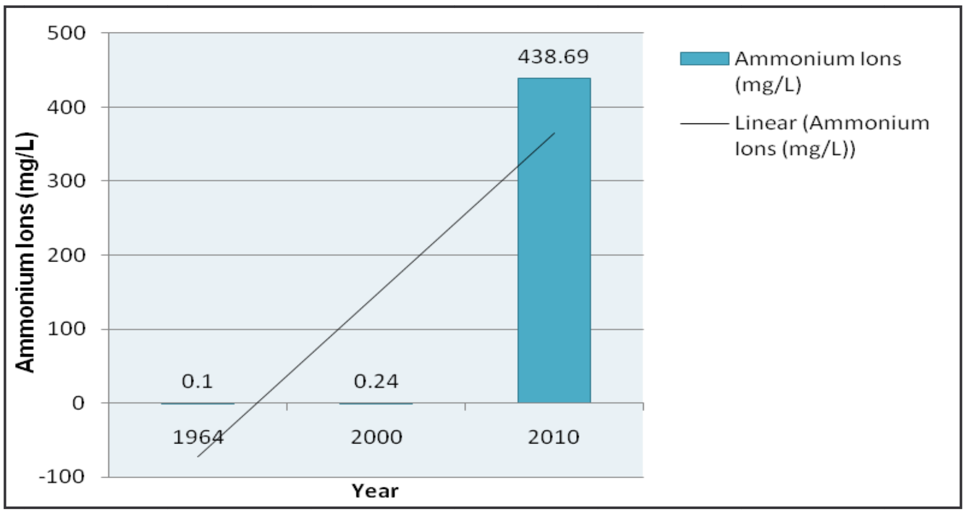

Figure 3.5. Changes in the levels of ammonium ions in the Mvoti Estuary between 1964 and 2010

3.4.5. Chloride

Levels of chloride in the estuary have experienced an overall increase over the years. There is a decrease is noted between 2000 to 2010 (refer to Figure 3.6). This however, does not have much significance for overall the health of the estuary as the levels have exceeded the target water quality range of 0.2 μg/L for aquatic ecosystems (DWAF, 1996a). Exposure to chloride levels > 0.35 μg/L may result in gill damage, changes in blood chemistry, hampered growth rates, loss of equilibrium and death in fish, whilst in invertebrates, immobility and reduced reproduction and survival have been noted (DWAF, 1996a).

This is currently the situation at the Mvoti Estuary and care should be taken that no further increases occur. With regards to fauna, aquatic plants may become chlorotic, and photosynthesis and respiration are hindered in phytoplankton (DWAF, 1996a).

The target water quality range for domestic use is 100.0 mg/L (DWAF, 1996b). When chloride values range between 100.0 – 200.0 mg/L, there are no health or aesthetic effects but there is an increase in the corrosion rate of domestic appliances. At levels between 200.0 – 600.0 mg/L, as observed in 2000 and 2010, the corrosion rate would increase with no health effects but the water develops a distinct salty taste (DWAF, 1996b). Levels within the range of 600.0 – 1200.0 mg/L would display an unpleasantly salty taste and rapid corrosion rate in domestic appliances. Above 1200.0 mg/L saltiness is still present, and nausea and electrolyte imbalances are common. In children this may result in death caused by dehydration (DWAF, 1996a).

Chlorides are often used to remove unwanted tastes and odours, and to disinfect water. Large amounts of chloride containing compounds are commonly present as bleaching agents and slimicide in the textile, and pulp and paper industries. One of the most prominent industries on the lower Mvoti floodplain is a large pulp and paper mill. This paper mill had recently upgraded part of its chemical treatment process to reduce odour emissions (Chili, 2008). A water quality survey by Chili (2008) before and after the implementation of the new process, showed a considerable increase in the levels of chlorides present in the estuary after the implementation of the new process.

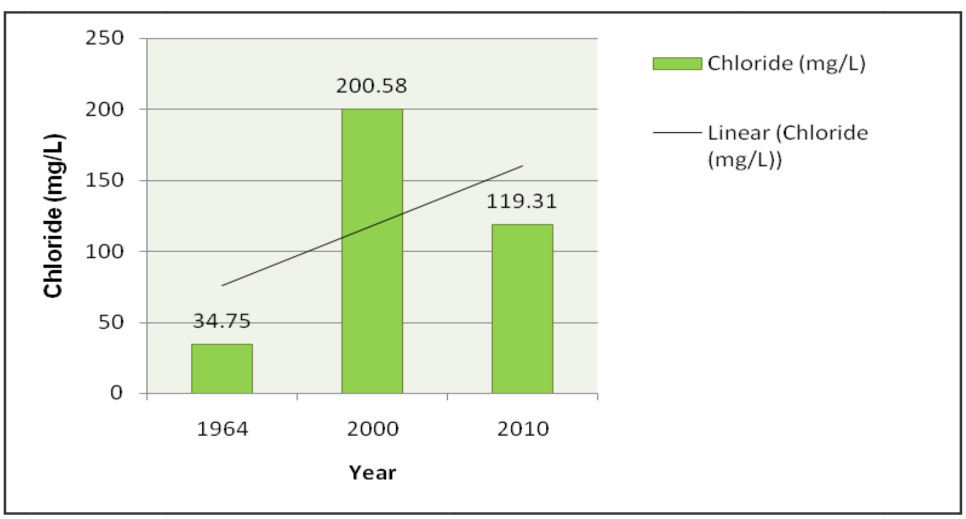

Figure 3.6. Changes in the levels of chloride in the Mvoti Estuary between 1964 and 2010

3.4.6. Sulphate

Increases in sulphate ions have been noted within the system between 1964 and 2010 (Refer to Figure. 3.7). According to DWAF (1996b), there are no health hazards for human consumption presented by concentrations of sulphate between 0 – 200.0 mg/L. However as this concentration increases, so to does the likelihood of developing diarrhoea, if this water is consumed (DWAF, 1996b). Measured levels are currently well within the acceptable limits, but the fact that steady increases from 1964 to 2010 have occurred, portends serious concerns for the future.

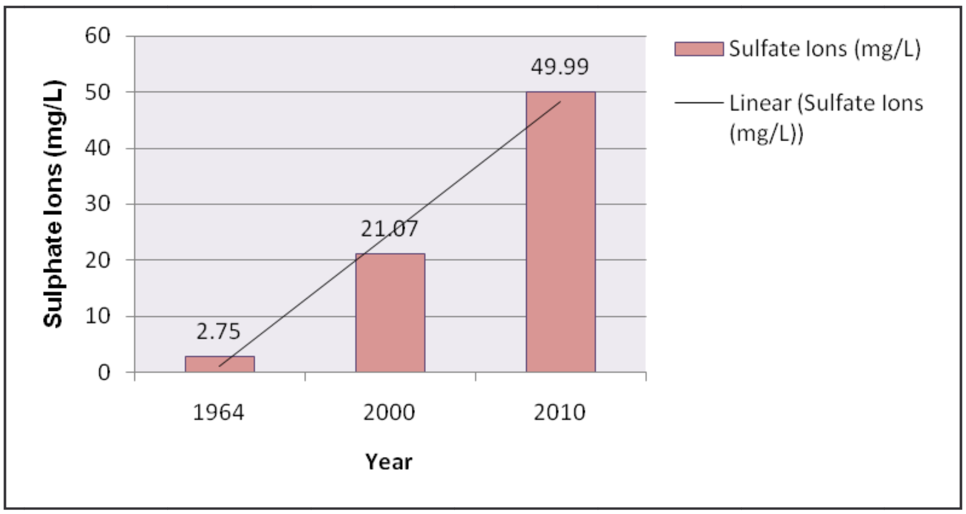

Figure 3.7. Changes in the levels of sulphate ions in the Mvoti Estuary between 1964 and 2010

3.4.7. Sodium

The concentrations of sodium recorded in the estuary for 2010 have increased by approximately 230% in comparison to 1964 (Figure 3.8). With regards to domestic uses there are no health effects associated with use for domestic purposes in water containing sodium levels <200.0 mg/L (DWAF, 1996b). However, concentrations between 200.0 – 400.0 mg/L are not suitable for consumers on a sodium-restricted diet, and levels exceeding this range are also not suitable for infants (DWAF, 1996b).

Consumption of water containing between 1000.0 – 5000.0 mg/L of sodium may induce nausea and vomiting, while concentrations > 5000.0 mg/L are associated with severe electrolyte imbalances which can be fatal (DWAF, 1996b).

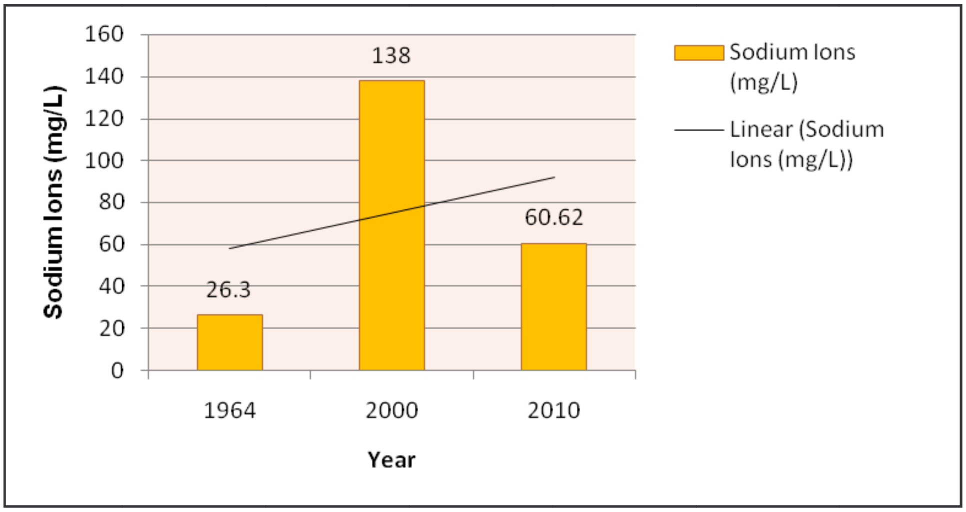

Figure 3.8. Changes in the levels of sodium ions in the Mvoti Estuary between 1964 and 2010

3.4.8. Calcium

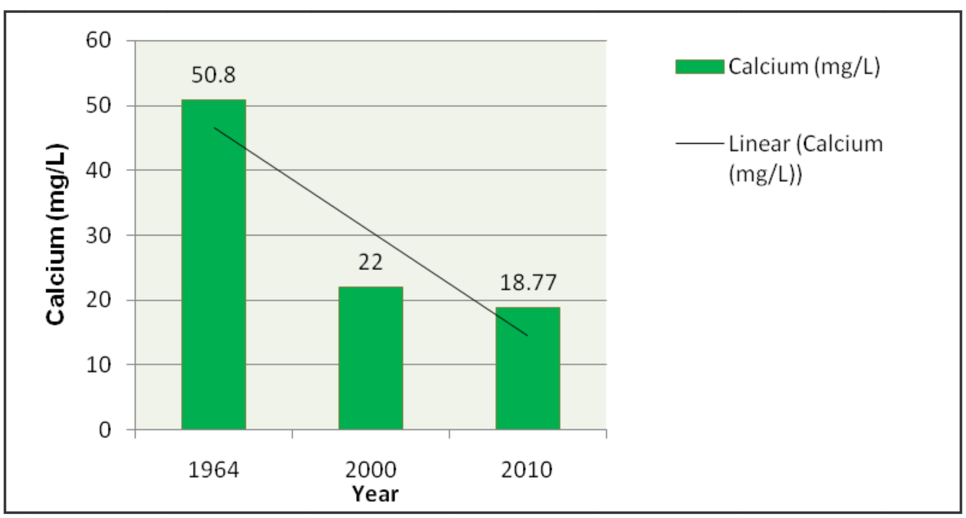

Figure 3.9. Changes in the levels of calcium in the Mvoti Estuary between 1964 and 2010

As presented by Figure 3.9, calcium levels have decreased within the estuarine waters. There are no health effects associated with higher levels of calcium in water to be used for domestic purposes (DWAF, 1996b). However high levels of calcium when present with magnesium (usually in the forms of magnesium carbonate and calcium carbonate may render the water hard. This hard water introduces industrial problems of clogged pipes due to precipitation and the formation of 'scum'- a mixture of calcium, magnesium and contaminants.

3.4.9. pH

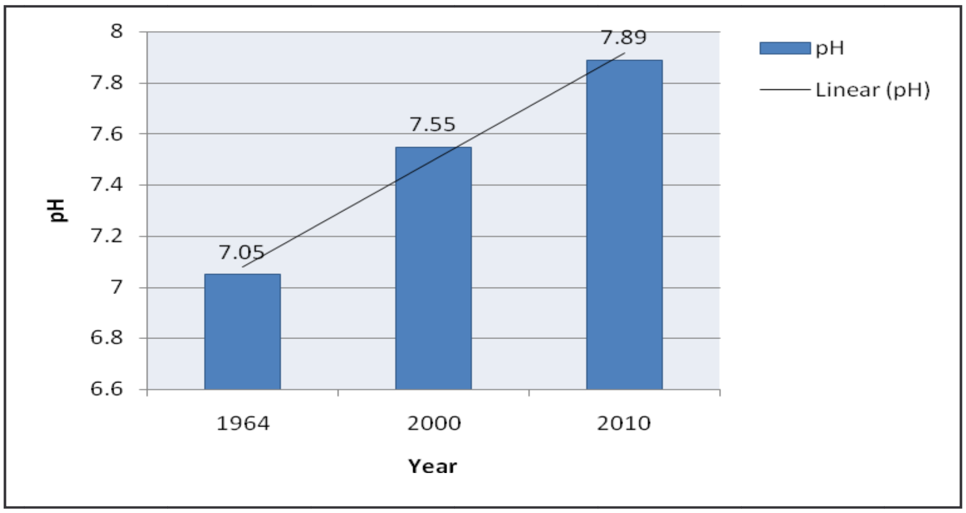

Figure 3.10. Changes in the pH levels of the Mvoti Estuary between 1964 and 2010

As illustrated by Figure 3.10, while the pH of the estuary water has experienced very small variations over the years, these differences are statistically significant (Refer to Table 1). The waters have remained more or less neutral, while in some instances reaching mildly alkaline and mildly acidic conditions. Acidification of water, according to DWAF (1996a), is commonly attributed to effluents from the pulp and paper, tanning and leather industries.

The Mvoti Estuary is a typical South African freshwater system which remains predominantly neutral, with pH values ranging between 6.0 and 8.0 (DWAF, 1996a). In terms of the target water quality range for domestic use, all values fall within the acceptable limits of 6.0 – 9.0 pH units.

Within this range there are no significant effects on human health due to toxicity of protonated species or dissolved metal ions (DWAF, 1996b). At pH <6.0 there is danger of toxicity associated with dissolved metal ions, and a sour water taste (DWAF, 1996b). Water has a bitter taste at pH > 9.0 and a soapy taste at pH >11.0 (DWAF, 1996b). If one considers that the Mvoti system has had a history of high pollutant levels from anthropogenic sources, it is important that regular flushing of the system occurs to reduce the potential for long term damage to the biota of the system.

3.5. Conclusion

The Mvoti is currently in a degraded state in terms of its water quality. It is also evident that this deterioration is not new to the system. The pollution in this disturbed estuary has been increasing on an ongoing basis over the years, consequently deteriorating the water quality. Despite the fact that pH values are within acceptable limits, the estuary has very high levels of nutrients present and corresponding low levels of diffused oxygen. The Mvoti system is known to be very polluted with effluents from formal and informal settlements, the towns and industries located on its floodplain causing major degradation. This is enforced by the distribution of pollutants in the estuary, where the highest concentrations were recorded at the upper reaches of the system, indicating that pollution sources are most likely upstream of the estuary and not within the estuary itself. It is not surprising therefore that very low levels of diffused oxygen were encountered in the system.

Since a majority of the values did not comply with the target water quality ranges, there are serious negative implications for estuarine biota and human health. Hence, the system is in urgent need of monitoring, rehabilitation and management. Whilst at times, visually the estuary may appear to look aesthetically pleasing, alarming signs of pollution abound on closer examination. There appears to be signs of eutrophication in the system signalled by significant algal growth, the water and visible underlying sediments appear discoloured, and unpleasant odours continuously emanate from the system. Other visible signs of pollution, particularly along the river banks, include flocculation and foaming of the water at numerous sites.

CHAPTER FOUR

HEAVY METALS IN THE SEDIMENTS OF THE LOWER MVOTI RIVER SYSTEM

This chapter is based on:

Sukdeo, P., Pillay, S., and Bissessur, A. *In Review*. A study of the presence of heavy metals in the sediments of the lower Mvoti River system and its comparison to other ecologically important systems. *South African Geographical Journal*.

(Submitted for publication 15 November 2010).

4.1. Abstract

Excessive levels of heavy metals present in aquatic systems are often a result of anthropogenic activities. Sediment analysis for this type of contamination is often preferred over the dynamic water column. Due to accumulation of these elements over time, sediment analysis can provide a pollution-history for the site. Heavy metals at elevated levels are potentially toxic to aquatic life and, because they bio-accumulate in food webs, are also potentially detrimental to human life. This study assesses the presence of heavy metals in the lower Mvoti River and estuary. Levels of aluminium, arsenic, chromium, copper, iron, lead, magnesium, manganese, nickel, titanium, vanadium and zinc were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

The results show that the riverine and estuarine sites closest to industrial effluent discharge sites and informal settlements displayed the highest levels of heavy metal contamination. The results of the estuarine analysis were compared to current levels of heavy metals present in two other South African estuaries: the St. Lucia estuary, also located on the north of KwaZulu-Natal and the Swartkops estuary in the Eastern Cape, as well as two international estuaries. Even though the lower Mvoti River and estuary does experience some heavy metal sediment contamination, the above-mentioned comparisons illustrate that the level of contamination is relatively low in comparison to other ecologically significant South African estuaries and, selected international estuaries. With respect to heavy metals, these results bode well for the Mvoti, a system historically reported to be in serious ecological degradation from other pollution sources.

4.2. Introduction

Coastal seas inevitably receive much of the effluent of the world. Rivers are responsible for transporting a range of both dissolved and particulate matter from land into the sea (Klavins *et al*., 2000). These contaminants most often derived directly from human activities, are sometimes harboured in estuaries and other coastal embayments before being flushed out to sea. Contaminants such as potentially toxic metals are introduced into the environment either naturally or anthropogenically, or both (Harikumar and Jisha, 2010). Despite being natural components of the earth's crust, the severity of contaminants like heavy metals in the environment has drastically increased, primarily due to anthropogenic activities (Chen and Kandasamy, 2008; Harikumar and Jisha, 2010).

Due to its variable physical and chemical properties, the sediment component of aquatic systems is often the larger accumulator, and acts as potential sinks of contaminants, (Sundarajen and Natesan, 2010). The presence of high levels of heavy metals in the sediments of a system is a possible indication of human-induced pollution, derived from anthropogenic activities, as opposed to natural processes like weathering and erosion (Klavins *et al*., 2000; Binning and Baird, 2001). According to Nriagu and Pacyna (1988) in Chen and Kandasamy (2008), human induced inputs of metals like arsenic, nickel and zinc into the environment are often more than twice the input of the same metals from natural sources. The presence of these elements when investigating heavy metal contamination can be detected by analysing water, sediments or biota.

However, analysis of sediments are often more reliable and advantageous than the water column, as sediments assimilate these pollutants over time, while the water column on the other hand, is fairly dynamic and experiences significant changes over space and time (Binning and Baird, 2001; Landajo *et al*., 2004). The absence or very low levels of contaminants in the water column may be due to the accumulation of heavy metals by the sediment component of the system over time. As a result of this sediment accumulation, some indication of the history of pollution in a system may be understood (Binning and Baird, 2001; Landajo *et al*., 2004; Chatterjee *et al.,* 2006).

In aquatic systems the most common sources of heavy metals are usually industrial effluent discharge (Topalián *et al*., 1999). As noted by Martin and Whitfield (1983), in Binning and Baird (2001), in addition, around 90% of the particulate material carried by rivers settles in estuaries and coastal areas.

Another important factor to consider when investigating heavy metal contamination of aquatic sediments is the relationship between pollutant contamination and sediment texture. The finer components of sediment, such as clays and silts are more likely to carry and accumulate heavy metal and organic contaminants in aquatic systems as opposed to the larger components of the sediments (Binning and Baird, 2001; Palanques *et al*., 2008). This is due to their relatively high adsorption ability (Chatterjee *et al*., 2006). This adsorption is dependant upon physico-chemical factors of the system such as pH, dissolved oxygen, and oxidation-reduction potential (Ghrefat and Yusuf, 2006).

However, contaminants are not necessarily fixed to sediments and are often re-mobilised *via* various chemical, physical and biological processes (Landajo *et al*., 2004). Sometimes, they are released into the water column and become available to living organisms (Landajo *et al*., 2004). There is also potential for the bio-accumulation of these contaminants in food webs (Chatterjee *et al*., 2006; Jordao *et al*., 1997) resulting in possible detrimental effects to biota and humans (Harikumar and Jisha, 2010).

This study focuses on the heavy metal characterization of the lower reaches of the Mvoti River, located approximately 70 km north of Durban on the KwaZulu-Natal coastal zone. The lower Mvoti River flows through a highly modified region of northern KwaZulu-Natal. Much of the catchment is under agriculture, and sugarcane farming is extensive in the lower regions.

Despite being one of South Africa’s relatively smaller systems, the Mvoti River is an important resource for a number of towns, settlements and industrial developments along it’s approximately 197km long course (Wepener, 2007). The river is subjected to a range of effects and influences associated with human activities. In the upper and middle catchment of the river, agricultural, rural and informal users dominate, whilst in the lower catchment a distillery, sugar mill, pulp and paper mill together with the sewerage works associated with the coastal town of KwaDukuza (formerly known as Stanger) are the principal users of the Mvoti.

Two large tributaries, the Ntshaweni and Mbozambo rivers enter the Mvoti in the lower reaches (Malherbe *et al.,* 2010). Prior to its confluence with the Mvoti River, the Ntshaweni river receives effluent discharge and return flow from milling processes located in the area, and the Mbozambo river is the recipient of treated sewage and waste water from the town of Stanger. A short distance downstream, the river-dominated Mvoti Estuary receives this water before it eventually drains into the Indian Ocean.

As estuarine systems receive and frequently accumulate these catchment-derived pollutants, and considering the relatively poor water quality the lower Mvoti River system experiences (Sukdeo *et al.,* 2010), the Mvoti Estuary is a potential contaminant sink for heavy metals with possible adverse biotic effects.

Although there has been significant research conducted regarding heavy metal contamination within estuarine sediments, and despite the vast anthropogenic influences within the study region, a significant assessment of such contamination within the Mvoti Estuary has not previously been attempted. Considering these factors, an evaluation of the abundance of heavy metals in this river system would be beneficial for future management of the system.

Hence the purpose of this study is to provide an assessment of the heavy metals present in the sediments of the lower Mvoti River and estuary, and to compare these results with levels of heavy metals present in the St. Lucia estuary, another ecologically significant system also on the northern coast of KwaZulu-Natal but one that is regarded to be in fairly pristine condition.

4.3. Materials and Methods

4.3.1. Sampling Sites

A total of eight sample sites in the lower Mvoti River system were selected of which five were located within the estuary itself. The remaining three sites were within the lower reaches of the river, but upstream of the estuarine reaches. The extraction of samples was carried out using a Polyvinylchloride (PVC) Pipe Sediment Extractor.

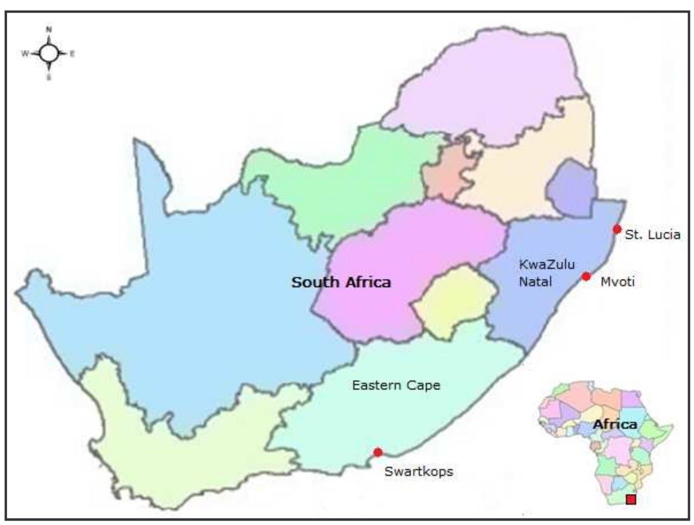

Figure 4.1. Location of the Mvoti Estuary in relation to the St. Lucia and Swartkops Estuaries along the South African coastline

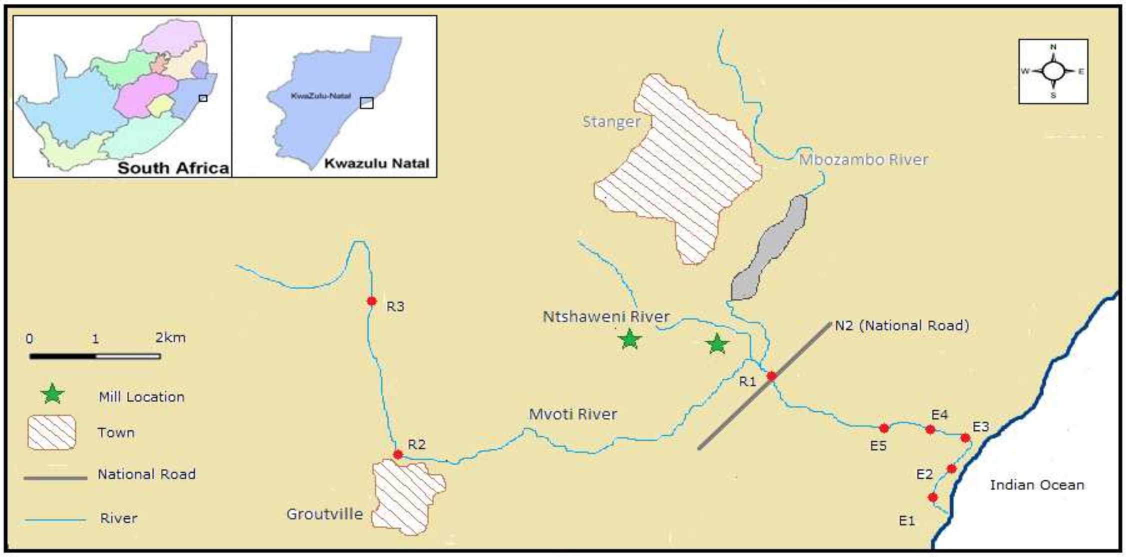

Figure 4.2. Map of the lower Mvoti River and estuarine system indicating the sampling sites selected for the study

At each site, replicate samples were collected at three different points: one midstream and others midway between the midstream point and either bank. As this study aimed to assess the most recent heavy metal pollution due to increased anthropogenic activity, the upper 30 cm of the river and estuarine bed sediments were specifically sampled. Following collection, samples were sealed in polyethylene jars, stored at low temperatures, and sent for chemical analysis within 24 hours.

4.3.2. Sediment particle size analysis

Textural analyses to determine the particle size distribution of the samples was conducted in the soil science laboratory by using a standard dry sieving technique (Abed, 2009). Equal proportions of the three samples weighing approximately 500 g for each site were homogenised and oven-dried at 110ºC for 48 hours. Samples were then disaggregated using a pestle and mortar, and split using a riffle box sample splitter. One portion of the split samples were used to determine particle size using a Retsch® sieve shaker, and the remaining portion was reserved for chemical analysis.

Chemical analysis to determine the heavy metal concentrations was carried out using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES). ICP-OES measures atomic spectra of the elements being determined. Analysis by ICP offers a greater advantage in terms of sensitivity and freedom from interference. For the purpose of this study the following metals, namely, aluminium (Al), arsenic (As), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), titanium (Ti), vanadium (V) and zinc (Zn) were measured by the ICP-OES method.

4.3.3. Statistical analysis

The T-test was used to ascertain any differences between heavy metal concentrations in the sediments of the Mvoti and St. Lucia estuaries. Data for the St. Lucia estuary from a prior study (Agjee, *et al*., 2010) was made available to this study for comparative purposes. All statistical analyses were completed using SPSS version 15.0 for Windows.

4.4. Results and Discussion

The mean concentrations of heavy metals determined at each site are illustrated Table 4.1.

The upper reaches of the estuary, site E5 (Figure 4.1) displayed the highest levels of all the metals tested for within the estuarine section of the study area, with the exception of arsenic. This is the closest estuarine site where the Mvoti River experiences industrial discharge and utilization of the river for domestic purposes by informal settlements. At this point and at site E4, the estuary widens and decreases in depth due to excessive sedimentation and hence velocity decreases with a resultant reduction in the fluvial competence and capacity. The lagoon-like characteristics of E4 and E5 facilitate the settling of contaminants in this region. There is a general decrease in the concentrations of the heavy metals (except for aluminium, which has a higher concentration at E3 than at E4) for the remaining estuary sites, approaching the Mvoti mouth. This decrease is significantly evident at site E1, closest to the Mvoti mouth, where levels of contaminants are at its lowest.

The highest concentration of heavy metals tested for, with the exception of manganese, was experienced at sample site R1 across both the riverine and estuarine sites. Site R1 was strategically chosen as it is directly under an N2 (national road) bridge and downstream of the confluences of the Mbozambo and Ntshaweni rivers (tributaries) with the Mvoti.

According to Malherbe (2006), effluent from the pulp and paper mill, the sugar mill, and the Stanger sewage works enter into the Mvoti River slightly upstream of this site.

In addition the site is significantly influenced by informal communities, located upstream and adjacent to the river that use the river mainly for domestic purposes. In the vicinity of site R2 (located where the Mvoti River intersects the town of Groutville) the river is used extensively for domestic purposes and subsistence agriculture by the local community. This is possibly why the majority of heavy metal concentrations at this site were relatively higher in comparison to site R3. The lowest concentrations of heavy metals was recorded at site R3 (adjacent the Glendale Distillery). However, in contrast, the highest concentration of manganese was recorded at this site. The main use of the river at this point is the abstraction of water by the distillery, for use in its cooling processes thereafter in the irrigation of the surrounding sugarcane fields.

Table 4.1. Heavy metal concentrations (ppm) and mean at each sample site												
Sample Site	Heavy metal concentrations (ppm) in the sediments of the estuarine section											
	Al	As	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Ti	V	Zn
Site E1	29.10	0.03	0.50	0.00	65.66	31.89	0.98	0.00	0.11	2.47	0.02	0.00
Site E2	50.60	0.37	0.11	0.00	64.99	40.23	1.27	0.00	0.00	5.80	0.10	0.07
Site E3	67.53	0.00	0.19	0.07	74.33	41.28	1.32	0.08	0.76	9.87	0.24	0.00
Site E4	58.69	0.17	0.00	0.22	123.96	42.05	0.98	0.11	0.97	16.14	0.39	0.10
Site E5	75.76	0.20	0.43	1.23	181.50	51.99	2.25	0.16	1.13	21.17	0.55	0.97
Mean	56.34	0.15	0.16	0.30	102.09	41.49	1.36	0.07	0.59	11.09	0.26	0.23
Sample Site	**Mean heavy metal concentrations (ppm) in the sediments of the riverine section of the study area**											
	Al	**As**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Ni**	**Pb**	**Ti**	**V**	**Zn**
Site R1	365.70	0.9	1.27	0.21	603.60	54.24	7.60	1.14	4.23	48.48	1.91	1.65
Site R2	57.01	0	0.92	0.03	211.14	22.44	1.34	0.06	0.13	26.79	0.44	0.54
Site R3	67.95	0	0.17	0.00	117.80	11.80	10.45	0.00	0.05	10.17	0.26	0.03
Mean	163.55	0.3	0.79	0.08	310.85	29.49	6.46	0.4	1.47	28.48	0.87	0.74

According to Ram *et al.* (2009), the grain size effect has significant bearing on the concentration of contaminants present within the sediment, therefore to compensate for this; the results were normalized for textural variations in sediment. The dependency of contaminant accumulation on sediment grain size is well documented (Binning and Baird, 2001; Palanques *et al.*, 2008). This is clearly observed in both estuarine and riverine sections of the study area where increases in contaminant concentrations are more likely associated with finer sediments.

Estuarine site 5 has a higher concentration of heavy metals than the remaining estuarine sites which show decreases in concentration toward the river mouth. In addition site 5 possesses higher amounts of fine sand and fines (very fine sand, silts and clays) compared to the other estuarine sites. Higher proportions of fine sediments located at sites away from the river mouth, imply a proportional relationship between finer sediment and contaminant accumulation.

The sediment composition of the Mvoti system is not typical of documented estuarine sediments, where the highest proportion of fines is found within the estuary. This is possibly due to the fact that the Mvoti is a perched, river-dominated system, with little or no significant marine influences. Hence there is a low accumulation of mud and fine sediments due to reduction in flocculation affected by low salinity. As a consequence, regular scouring of fine material with fluvial outflows is common.

The site R1 with the highest percentage of fine sediment within the riverine section contains a high concentration of heavy metals. This unusually high proportion of finer sediment at the riverine sites (R1 in particular), most likely, is a contribution from the Mbozambo and Ntshaweni rivers. Excessive siltation of the Mvoti River system according to Sukdeo *et al.* (2010) is due to extensive and uncontrolled sandmining, riparian zone disturbances and agriculture along the river.

A similarly study on the properties of sediments in the St. Lucia Estuary was conducted by Agjee *et al.* (2010). This system also located on the north coast of KwaZulu-Natal (Figure. 4.2), is one of the most ecologically significant systems in South Africa due to its rich biodiversity. St.Lucia, a natural heritage site, is regarded as a fairly pristine environment but has recently been under threat of that status due to pressures from increased tourism and catchment activities. This is evident from the fact that five of the eight heavy metals analysed in a study by Agjee *et al.* (2010) correspond to those assessed in this study. Sample techniques and chemical methods of analysis are similar in both studies, thus enabling a comparison between of the two estuaries. A comparison of heavy metals between the St Lucia (data from Agjee *et al.,* 2010) and Mvoti estuaries (this study) is presented in Table 4.2. The concentrations of heavy metals are higher within the sediments of the St. Lucia estuary, in comparison to the Mvoti Estuary and this is confirmed by the statistical comparison of the two data sets.

Table 4.2. Heavy metals (ppm) within the sediments of the St. Lucia Estuary (Agjee *et al,.* 2010) and the Mvoti Estuary

Estuary	**Heavy metal concentrations (ppm)**				
	Cr	**Cu**	**Ni**	**Pb**	**Zn**
St. Lucia	123.89	47.00	63.44	16.00	46.89
Mvoti	0.16	0.30	0.07	0.59	0.28
Mean	62.025	23.65	127.02	8.295	23.59
Std. Deviation	0.168	0.525	0.586	0.511	0.417
***P*- values**	<0.05	<0.05	<0.05	<0.05	<0.05

***p*-Value refers to the significant value obtained for the statistical procedure. Where *p* < 0.005, results are deemed significant**

The results of the statistical analysis reveal that significant differences exist between the concentrations of heavy metals present in the sediments of the St. Lucia system, and the concentrations of the corresponding metallic elements in the Mvoti system.

These concentrations along with the significant values obtained from the T-tests, confirming these differences (i.e. p>0.005), are given in Table 4.2. The high concentrations of chromium and nickel of the St. Lucia system according Agjee *et al,* (2010), may be attributing to catchment geology. It has been suggested that these elements were mobilised and transferred into the system *via* weathering and leaching of minerals from the catchment area. Tributaries have also been known to be a potential source of these elements, and a protracted drought in the area has accelerated the accumulation of metals in the system (Agjee *et al.,* 2010). The Mvoti Estuary has, by comparison, relatively lower levels of heavy metals (contaminants) than the other systems as shown in Table 4.3. Shown also in Table 4.3. are the mean concentrations of selected heavy metals present in two international estuaries, namely Galvesto Bay in Texas (Morse *et al.,* 1993, *in* Binning and Baird, 2001), and the Hudson-Raritan Estuary in New York Hence (Wolfe *et al.,* 1996, *in* Binning and Baird, 2001) and, the Swartkops Estuary in South Africa (Binning and Baird, 2001).

Table 4.3. Comparative amounts of heavy metals (ppm) within the sediments of two international and two South African estuaries

	Heavy metal concentrations (ppm)			
Heavy metal	**Galvesto Bay (Texas)**	**Hudson-Raritan Estuary (New York)**	**Swartkops Estuary (South Africa)**	**Mvoti Estuary (South Africa)**
Cr	37.00	122.00	20.30	0.16
Cu	8.00	142.00	6.80	0.30
Mn	605.00	No data available	115.00	1.36
Pb	25.00	160.00	33.00	0.59
Ti	No data available	21.70	99.00	11.90
Zn	55.00	299.00	36.00	0.23

***Galvesto Bay in Texas (Adapted from Morse *et al.,* 1993. In Binning and Baird, 2001)**

***Hudson-Raritan Estuary in New York (Adapted from Wolfe *et al.,* 1996. In Binning and Baird, 2001)**

***Swartkops Estuary in South Africa (After Binning and Baird, 2001)**

Hence, despite its reported polluted water quality status and the numerous other environmental problems which the estuary experiences (Sukdeo *et al.,* 2010), the sediments of the Mvoti Estuary demonstrates fairly low levels of heavy metal contamination in comparison to other important South African, and international systems. Despite the data from these studies having been collected more than a decade ago it has been used as a comparator to show the relatively better pollution status of current South African estuaries over its American rivals. This may be attributed to relatively low metal contributions from catchment geology and fewer point anthropogenic sources of contamination. In addition, the Mvoti Estuary itself as a perched estuary possess strong fluvial outflow that allows for continual flushing of sediments especially at the estuary mouth.

4.5. Conclusion

In this study it was found that even though heavy metal contamination is present in the Mvoti system, it is relatively lower than those experienced by other selected estuaries. The distribution of heavy metals within the system is a possibility of primarily industrial effluent discharge into the system and domestic utilization of the river. However, further, in-depth analysis is required to confirm that these results are either due to domestic and industrial use in isolation, or it is the cumulative effect of improper catchment practices and management. The increased contamination and accumulation of heavy metals in riverine and estuarine sediments is a major cause for concern, as these elements are often remobilised into the water column and accumulate in food webs with detrimental end-results.

It is therefore imperative to monitor the Mvoti sediments thus preventing increasing levels of potentially toxic contaminants. This will assist with improving the overall health condition of the system that is currently in an extremely poor condition.

CHAPTER FIVE

A GEOCHEMICAL ASSESSMENT OF THE SURFACE SEDIMENTS OF THE MIDDLE AND LOWER MVOTI RIVER SYSTEM

This chapter is based on:

Sukdeo, P., Pillay, S., and Bissessur, A. *In Review.* A geochemical assessment of the middle and lower Mvoti River system, KwaZulu-Natal, South Africa. *Environmental Earth Sciences*.

(Submitted for publication 17 November 2010).

5.1. Abstract

This paper presents one the first investigations into the geochemical enrichment of the middle and lower Mvoti River system. Chemical elements are naturally present in aquatic sediments, but their concentrations tend to rise to potentially toxic levels *via* both natural and anthropogenic processes. This study evaluated the concentrations of aluminium, arsenic, boron, barium, cadmium, calcium, cobalt, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorous, selenium, silicon, strontium, titanium, vanadium and zinc, using inductively coupled plasma optical emission spectroscopy . The levels of elements present were used to assess their spatial distribution within the system and to determine the *contamination factors (CF)* and *enrichment factors (EF)* for each element. The *pollution load index* (PLi) was calculated to determine the degree of pollution at each site. Results indicate that the sediments of the Mvoti system is low to moderately polluted and deteriorating with time (average PLi value of 5.19), and that a major contributing factor to this contamination is natural sources. However, due to their relatively coarse nature, it can also be assumed that the Mvoti sediments are potential sources of re-contamination into the system as opposed to contaminant sinks.

Key Words: geochemistry, contaminant, enrichment, sediment, pollution, Mvoti River

5.2. Introduction

Chemical elements are present in various quantities and forms in river systems, as a result of either natural or human inputs (Lin *et al.,* 2007; Chen and Kandasamy 2008; Harikumar and Jisha, 2010), and are influenced by factors like the underlying parent material (natural), the chemistry of the water column above (natural / anthropogenic), as well as the physiographic characteristics of the catchment (Chenhall *et al.,* 2004). Within certain limits these elements often pose little or no treat to both human and other life. However once the levels some of these elements are exceeded due to natural or human-induced processes, they may become potentially hazardous and toxic (Orr, 2007).

Within aquatic systems the associated biota and sediment component also tend to accumulate contaminants (Chatterjee *et al.,* 2006; Lin *et al*., 2007), such as trace metals that do not biodegrade (Jordao *et al.,* 1997) and remain in the system for considerable periods of time. Such contaminants have an affiliation for finer grained sediments such as silts and clays which have high adsorption capabilities (Chatterjee *et al*., 2006; Lin *et al*., 2007). Hence, sediments often act as sinks for contaminants (Chenhall *et al*., 2004; Lin *et al*., 2007) which are increasingly being used to assess the pollution history of such specific systems (Chatterjee *et al.,* 2006; Chen and Kandasamy, 2008), as opposed to using the overlying, highly dynamic water column. These elements, however, are not permanently fixed in the sediment. They may be remobilised into the water column through various physical and chemical processes, and consequently contaminate the system (Chenhall *et al.,* 2004; Lin *et al*., 2007; Harikumar and Jisha 2010).

To establish whether the presence and corresponding concentrations of contaminants in sediments are due to natural or anthropogenic sources, and fall within acceptable limits it is imperative to compare results with standard background values for a specified region or geological type (Chenhall *et al*., 2004; Martinez *et al*., 2007). As the type of sediment in an area is normally dependant on the geology, geochemical methods are often used in determining the degree of sediment contamination (Martinez *et al*., 2007). This, according to Hawkes and Webb (1962, In Martinez *et al*., 2007), is acheived using 'geochemical backgrounds' which is the normal abundance of such elements in barren earth material. Geological standard background values assist in determining whether concentrations of elements obtained are anomalous, which are representative deviations from the usual geological pattern (Martinez *et al.,* 2007). Standard background values serve not only as important guides in pollution remediation and but also as assessments of the changes occurring within the sediments.

The Mvoti River is situated on the east coast of the province of KwaZulu-Natal in South Africa. This 197 km long river (Wepener, 2007) is utilized fully, to the extent that it is often classified as a 'working river' (Malherbe, 2006). The catchment geology comprises predominantly of sandstone and shale (Von Bratt, 2007). Much of the catchment is modified to accommodate for agriculture, while forestry, sugarcane farming and subsistence farming continue as main practices here. The Mvoti in its lower reaches is an important resource for industrial activities.

This study was aimed at investigating the geochemistry of the middle and lower Mvoti River system by assessing its spatial distribution of elements within the sediments. In this study, the enrichment status of the sediment to determine its potential as a source of contamination was evaluated as outlined in Figure 5.1 below.

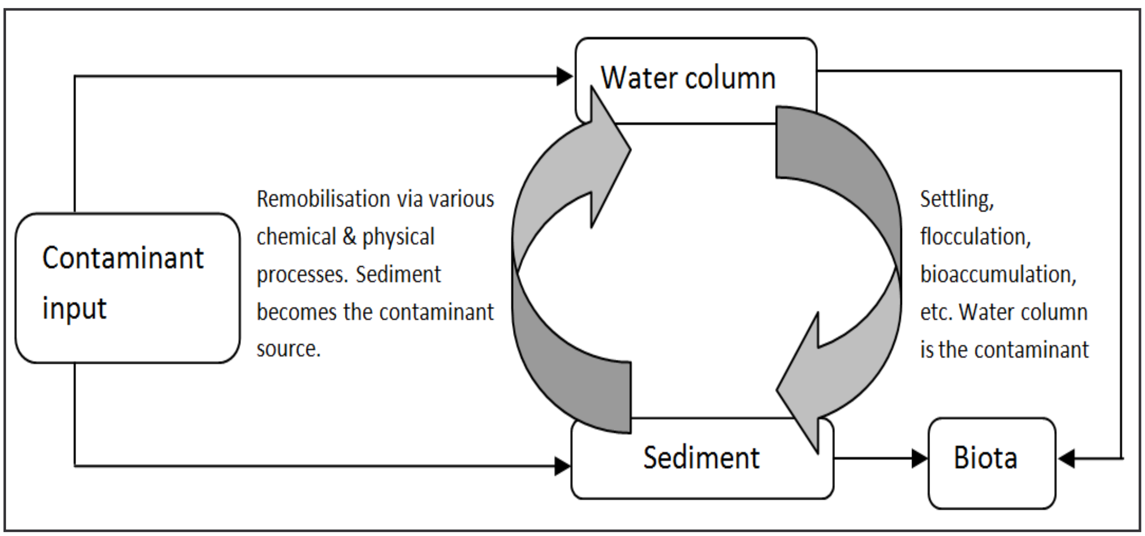

Figure 5.1. The fate of non-degradable elements in aquatic systems (Adapted from Harikumar and Jisha, 2010).

5.3. Materials and Methods

5.3.1. Sampling sites and sediment collection

The samples for the geochemical and grain size analysis were collected between March 2009 and March 2010. Seven sampling sites (E1-E2, R1-R5) as illustrated by Figure 5.2 (below) within the Mvoti River system, starting at the estuary and extending upstream to the middle reaches of the river were selected.

Two sites were located within the estuary, two within the lower reaches of the river, but upstream of the estuarine reaches, and while three sites were located in the middle reaches of the rivers course. The latter three sites (R3, R, and R5) were in the vicinity of the rural settlement of Maphumulo (Figure 5.2), where the river is not subjected to significant industrial pollution, but is subjected to agricultural pollution from the upper catchment area. Site R5 was located along the lower part of the Hlimbitwa River, a major tributary of the Mvoti in its middle reaches.

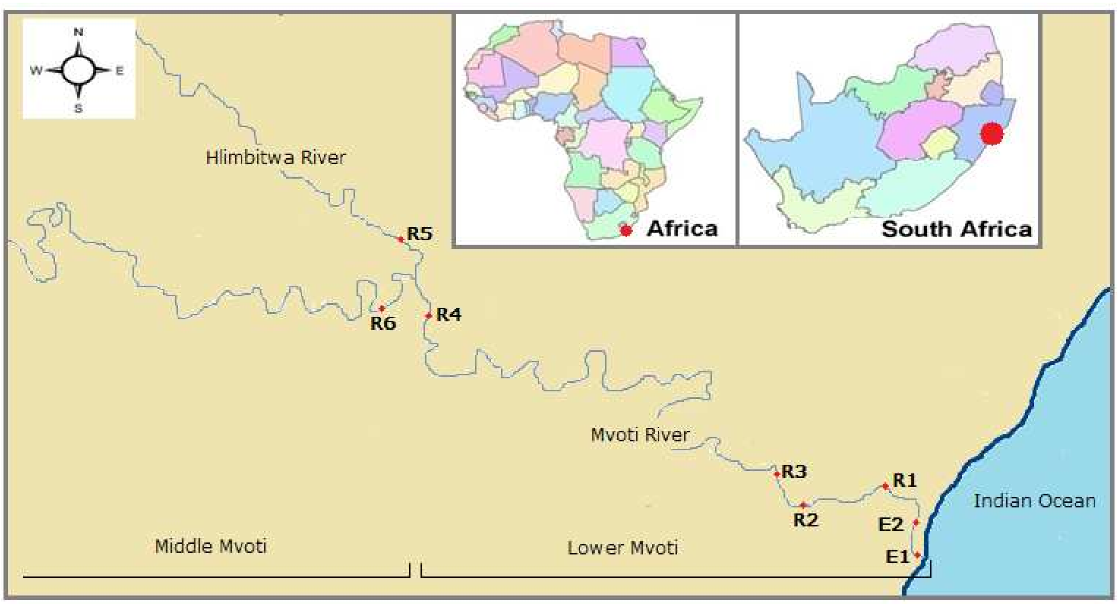

Figure 5.2. Schematic representation of the sampling sites (E1-E2, R1-R5) for geochemical and grain size analysis

Sediment samples from the lower river sites were collected using a polyvinylchloride pipe sediment extractor. In the Mapumulo region, where the river is significantly deeper, sediment samples were collected using a hand-held sediment grab. Replicate samples were collected at three points at each site, *viz.*, at midstream, and two others midway between this point and either bank of the river. Samples were sealed in polyethylene jars and stored at low temperature (usually below 5^{o}C).

5.3.2. Grain-size determination and Chemical analysis

According to Ram *et al.* (2009), the grain size has significant (E1-E2, R1-R5) bearing on the concentration of contaminants within the sediment. Textural analyses of samples were conducted using a standard dry sieving method (Abed, 2009). In this method 500 g of sample from each site was homogenised and oven-dried at 110ºC for 48 hours. Samples where then manually disaggregated using a mortar and pestle grinder, after which samples were separated using a riffle box sample splitter. One-half of the sample was used to determine particle size using a Retsch® sieve shaker, and the remaining portion was reserved for chemical analysis.

The elemental concentration of the sediment was determined using inductively coupled plasma - optical emission spectroscopy (ICP-OES). From a geochemical perspective the following elements were analysed for: aluminium (Al), arsenic (As), boron (B), barium (Ba), calcium (Ca), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), Phosphorous (P), selenium (Se), silicon (Si), strontium (Sr), titanium (Ti), vanadium (V) and zinc (Zn).

Determination of Contamination Factors

To establish whether the presence of metal ions are natural or due to human-induced activities, data obtained were compared against standard background concentrations, or sediment quality guidelines. There are currently no sediment quality guidelines available for South African sediments (Orr, 2007), and no specific background concentrations for the Mvoti catchment, hence, for the purpose of this study “Clarke values” (Rosler and Lange 1972; Martinez *et al*., 2007) which serve as background values for the average elemental composition of earth’s crust were applied.

Clarke values are representative of the mean metal composition of sedimentary rocks. The use of Clarke values is primarily due to the fact that the geology of Mvoti catchment is predominantly sedimentary rock.

Aqueous solutions of metals and metalloids are potentially toxic to human and aquatic life. Contamination of sediments, according to Harikumar and Jisha (2010), by such elements can be expressed in terms of a *contamination factor* (CF). A contamination factor for each element was calculated using equation 1 (Harikumar and Jisha 2010), shown below:

$$\mathrm{CF} = \frac{[\text{Concentration of element in the sediment}]}{[\text{Background value of element}]} \quad (1)$$

Where, [Concentration of element in the sediment] = parts per million (ppm; mg/kg) and, [Background value of element] = ppm.

Determination of Enrichment Factors

An *enrichment factor (EF)* for each site was calculated based on the abundance of the element present in the sample relative in the earth's crust average concentration or background values (Harikumar and Jisha 2010). The computation of the EF, using equation (2) (Martinez *et al*., 2007) is given below:

$$\mathrm{EF} = \frac{[\text{Concentration Element}] / [\text{Concentration Fe}]}{[\text{Clarke Element}] / [\text{Clarke Fe}]} \quad (2)$$

Where, EF is the enrichment factor, [Concentration element] is mean concentration of element analysed (ppm), [Concentration] is mean concentration of Fe in sediment (ppm), [Clarke Element] is Clarke value of element (ppm), and [Clarke Fe] is Clarke value of Fe (ppm).

Enrichment Factors were calculated using iron as a reference or element for normalisation (Harikumar and Jisha 2010) as iron is an abundant element in the earth's crust (Rosler and Lange 1972), and its natural input into a system often exceeds 'unnatural inputs' (Harikumar and Jisha 2010). This mean concentration of Fe, according to Taylor (1964), in Rosler and Lange (1972), is approximately 5.6 %. The EF values displayed in Table 5.3 indicate the extent to which measured concentrations of elements exceed the reference Clarke values (Martinez *et al.*, 2007).

These values were used to evaluate the extent of contamination in the river sediment. In addition it also served as an efficient method for evaluating geochemical trends and comparisons between sites (Harikumar and Jisha 2010).

Determination of the Pollution Load Index

The pollution load index (PLI) developed by Thomilson *et al.* (1980) in Harikumar and Jisha (2010) has been applied to evaluate the extent of pollution by an element. The pollution load index was determined at each site using equation (3) (Harikumar and Jisha, 2010).

$$\mathbf{PLI = n\sqrt{}\,(CF1\ X\ CF\ 2\ X...X\ CFn)} \qquad (3)$$

Where, CF refers to the contamination a factor at each site and n refers to the number of elements.

5.4. Results and Discussion

5.4.1. Geochemical distribution: grain size analysis and elemental presence

Grain size analysis revealed that sediments on the bed of the river channel are sand dominated with the presence of larger sized particles, except at site R1, where finer particles dominate. In addition the slow water flow at this site produces ideal conditions for the settling of suspended finer particles together with other materials entering the channel *via* its tributaries. The concentration of these elements observed within the sample sediments are presented in Table 5.1.

Several of the metals tested for and expected to be present within the estuarine section of the study area especially, are absent. These include Co, Cu, Ni, and Pb. It was observed that metals Mo, Sr, V, and Zn are only present at site E1. Most metals identified and tested for, with the exception of As, were present at site R1 with higher concentrations prevalent than at site R2. Site R1 is situated directly downstream from the point where the Ntshaweni and Mbozambo rivers join the Mvoti system. These rivers contribute into the Mvoti system effluent from the pulp and paper mill and, waste water from the Stanger sewage works.

R1 recorded the highest concentration of elements which is possibly attributed to being the only site that is directly affected by industrial discharges. At site R2, elements As, Co, Cu, Ni and Se were absent. It can thus be presumed that granulometry has important influences upon elemental concentrations in sediments (Chatterjee *et al.*, 2006). The concentration of elements around finer sediments as a result of their high adsorptive capability may possibly be the reason why site R1, in addition to possessing the highest proportions of finer sediments also contained high elemental presence (refer to Table. 5.1).

The elements Co, Cu and Pb are conspicuously absent from all the sample sites in the middle reaches of the river. Site R5 was the only site where Se was detected with the absence of As which presents an ideal scenario for healthy plant development. The highest concentration of Fe was recorded for sites R3, R4 and R5. The presence of Ni was recorded at Site R3 while Mo at the same site was absent.

5.4.2. Contamination Factors (CF)

Table 5.2 presents the CF calculated for each study site. As previously mentioned, CF are commonly used to express the contamination of sediments by particular elements. According to Harikumar and Jisha (2010), CF values less than 1 imply low contamination, and values between 1 and 3 imply moderate contamination. Considerable contamination is expressed by CF values between 3 and 6, and greater than 6 indicates very high contamination. Across all sample sites, contamination is fairly low, not exceeding 1, with the exception of Se which, where present, exceeds preferred limits. Within the estuary, at site E1 contamination is considerable and at site 2 is very high. In the riverine section of the study area, contamination varies between moderate and considerable. To prevent any future pollution risks, monitoring levels of Se in the system is important.

Table 5.1. Mean concentration (ppm) of elements present within the sediments of the sample sites

Element	**Clarke Value**	**E1**	**E2**	**R1**	**R2**	**R3**	**R4**	**R5**
Al	81300.00	50.63	75.76	365.7	67.95	179.8	112.3	128.2
As	5.00	0.37	0.20	0.00	0.00	0.02	0.08	0.00
B	10.00*	0.45	0.69	1.41	0.45	0.61	0.45	0.67
Ba	260.00	0.37	0.49	4.66	2.63	1.83	1.51	2.30
Ca	36300.00	1021.00	1404.00	50.54	16.62	26.83	41.18	29.66
Co	23.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Cr	200.00	0.11	0.43	1.27	0.17	0.56	0.35	0.50
Cu	70.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00
Fe	50000.00	74.99	181.50	603.60	117.80	265.90	220.10	288.70
Pb	16.00	0.00	0.00	0.23	0.05	0.00	0.00	0.00
Mg	20900.00	45.23	59.99	54.24	11.80	29.28	17.93	16.13
Mn	1000.00	1.37	0.25	7.60	10.45	3.91	5.67	3.89
Mo	15.00	0.03	0.00	0.05	0.03	0.00	0.04	0.03
Ni	80.00	0.00	0.00	0.14	0.00	0.03	0.00	0.00
P	1180.00	13.12	33.35	58.62	8.97	16.28	15.65	18.93
Se	0.05*	0.13	0.84	0.05	0.00	0.00	0.00	0.21
Si	281500.00*	11.55	13.18	10.62	13.37	10.68	11.90	13.23
Sr	300.00	16.97	0.00	1.24	6.48	0.67	0.66	0.67
Ti	4400.00	5.80	21.17	48.48	10.17	21.03	17.01	19.00
V	150.00	0.10	0.55	1.91	0.26	0.98	0.58	0.92
Zn	132.00	0.07	0.00	0.65	0.03	0.17	0.13	0.11

Clarke Values after: *Rosler and Lange, 1972 (B, Se and Si), and Martinez *et al.* (2007)

Table 5.2. Contamination factors of elements present within the sediments of the sample sites

Element	Clarke Value	E1	E2	R1	R2	R3	R4	R5
Al	81300.00	0.001	0.001	0.01	0.001	0.002	0.001	0.002
As	5.00	0.074	0.04	0.00	0.00	0.004	0.02	0.00
B	10.00*	0.045	0.07	0.141	0.045	0.061	0.045	0.067
Ba	260.00	0.001	0.002	0.018	0.01	0.007	0.006	0.01
Ca	36300.00	0.03	0.04	0.001	0.001	0.001	0.001	0.001
Co	23.00	0.00	0.00	0.002	0.00	0.00	0.00	0.00
Cr	200.00	0.001	0.002	0.006	0.001	0.003	0.002	0.003
Cu	70.00	0.00	0.00	0.003	0.00	0.00	0.00	0.00
Fe	50000.00	0.002	0.004	0.012	0.002	0.005	0.004	0.006
Pb	16.00	0.00	0.00	0.014	0.003	0.00	0.00	0.00
Mg	20900.00	0.002	0.003	0.003	0.001	0.002	0.001	0.001
Mn	1000.00	0.002	0.00	0.01	0.01	0.004	0.006	0.004
Mo	15.00	0.002	0.00	0.003	0.002	0.00	0.003	0.002
Ni	80.00	0.00	0.00	0.002	0.00	0.00	0.00	0.00
P	1180.00	0.01	0.03	0.05	0.008	0.014	0.013	0.02
Se	0.05*	2.60	16.80	1.00	0.00	0.00	0.00	4.20
Si	281500.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr	300.00	0.06	0.00	0.004	0.02	0.002	0.002	0.002
Ti	4400.00	0.001	0.005	0.011	0.002	0.005	0.004	0.004
V	150.00	0.001	0.004	0.013	0.002	0.007	0.004	0.006
Zn	132.00	0.001	0.00	0.005	0.00	0.001	0.001	0.001

Clarke Values after: *Rosler and Lange, 1972 (B, Se and Si), and Martinez *et al.* (2007)

Table 5.3. Enrichment Factors of elements present within the sediments of the sample sites

Element	Clarke Value	E1	E2	R1	R2	R3	R4	R5
Al	81300.00	0.42	0.26	0.37	0.35	0.42	0.31	0.27
As	5.00	49.34	11.02	0.00	0.00	0.75	3.63	0.00
B	10.00*	30.00	19.01	11.68	19.10	11.47	10.22	11.60
Ba	260.00	0.95	0.52	1.48	4.29	1.32	1.32	1.53
Ca	36300.00	18.75	10.66	0.16	0.19	0.14	0.26	0.14
Co	23.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
Cr	200.00	0.37	0.59	0.53	0.36	0.53	0.40	0.43
Cu	70.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
Fe	50000.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pb	16.00	0.00	0.00	1.19	1.33	0.00	0.00	0.00
Mg	20900.00	1.40	0.79	0.21	0.24	0.26	0.19	0.13
Mn	1000.00	0.02	0.07	0.01	4.44	0.74	1.29	0.67
Mo	15.00	1.33	0.00	0.28	0.85	0.00	0.61	0.35
Ni	80.00	0.00	0.00	0.15	0.00	0.07	0.00	0.00
P	1180.00	7.41	7.79	4.12	3.23	2.59	3.01	2.78
Se	0.05*	1733.56	4628.10	82.84	0.00	0.00	0.00	727.40
Si	281500.00*	0.03	0.01	0.003	0.02	0.01	0.01	0.01
Sr	300.00	37.72	0.00	0.34	9.17	0.42	0.50	0.39
Ti	4400	0.88	1.33	0.91	0.98	0.90	0.88	0.75
V	150	0.44	1.01	1.05	0.74	1.23	0.88	1.06
Zn	132	0.35	0.00	0.41	0.10	0.24	0.22	0.14

Clarke Values after: *Rosler and Lange, 1972 (B, Se and Si), and Martinez *et al.* (2007)

5.4.3. Enrichment Factors

Enrichment factors (Table 5.3) are useful indicators for geochemical trends and similarities or differences between sites (Harikumar and Jisha 2010). Martinez *et al*. (2007) suggested that an EF value greater than 2 implies contamination and concentrations of elements that are twice the magnitude than the background values which is a direct implication of anthropogenic pollution. However, according to Harikumar and Jisha (2010), EF values greater than 5 implies contamination, values between 0.5 and 1.5 are indicative of elemental input from natural sources, and high EF values suggest anthropogenic sources of elemental input. Furthermore, Harikumar and Jisha (2010) noted that study sites with EF values less than 1 for particular elements, should be approached with caution as these are potentially capable of releasing these elements into the environment hence rendering them bioavailable.

Apart from those sites where certain elements were not detected within the sediment, EF values less than 1.5 were observed for most of the sites thus implying that elemental input is most likely a result of natural sources. In addition as most of the EF values are less than 1, a possibility of a re-release of these elements into the system exists. This possibility is reinforced by the predominance of larger grained sediment particles in the system, implying that the Mvoti sediments are also potential sources of contamination into the system. Enrichment values for arsenic and calcium are unusually high within the estuary, and such is the case of boron in all the sample sites. Enrichment values exceeding five for As, Ca and B are indicative of contamination which at some sites can possibly be attributed to anthropogenic sources. The enrichment values of phosphorous and selenium exceed the limits for natural input at all sites while strontium limits are exceeded only at site E1. Due to the exceptionally high enrichment factors by Se and Sr promotion of contamination can be attributed to anthropogenic influences.

The highest EF values exceeding the limits for natural input values displayed within the estuarine sites were recorded for As, B, Ca, P, Se, and Sr,. The highest EF values in the lower section of the river, were recorded for As, B, Ca, P, and Se. In the middle reaches of the river, B, P, and Se produced some of the highest EF values.

EF values for Fe obtained at all the sample sites indicated natural input. However, since Fe was used as a reference element and EF=1 at all sites, this may not be indicative of what actually happens in the system. The high EF values exceeding 10.5 for all sites observed, especially for Se, As and P, is sufficient evidence to assume that a very high proportion of contamination in the Mvoti sediments is due primarily to anthropogenic sources.

As the bioavailability and potential toxicity of elements in a system depends on the concentration of the element, sediments with high EF values and accompanying fine grained sediment particles, are often sources for mobilising these elements in aquatic systems and making them bioavailable (Harikumar and Jisha 2010).

5.4.4. Pollution Load Index

According to Harikumar and Jisha (2010), PLi values of zero indicate pristine environments; values between zero and one indicate baseline levels of the pollutants; and values greater than one indicate deteriorations in the system. However as the PLi values increase the condition of the environment decreases. Within the Mvoti system, the PLi values exceeded a value of one at all sites, implying deterioration in the condition of the system.

The highest PLi value of 8.83 was recorded for site E2. From the average recorded PLi value of 5.19 for sample sites it can be strongly inferred that sediments are undergoing some form of pollution. This index also serves as an efficient tool for assessment and monitoring of pollution. It is also a convenient measure to assist decision makers and the general public to understand the condition of this particular aquatic environment (Harikumar and Jisha, 2010).

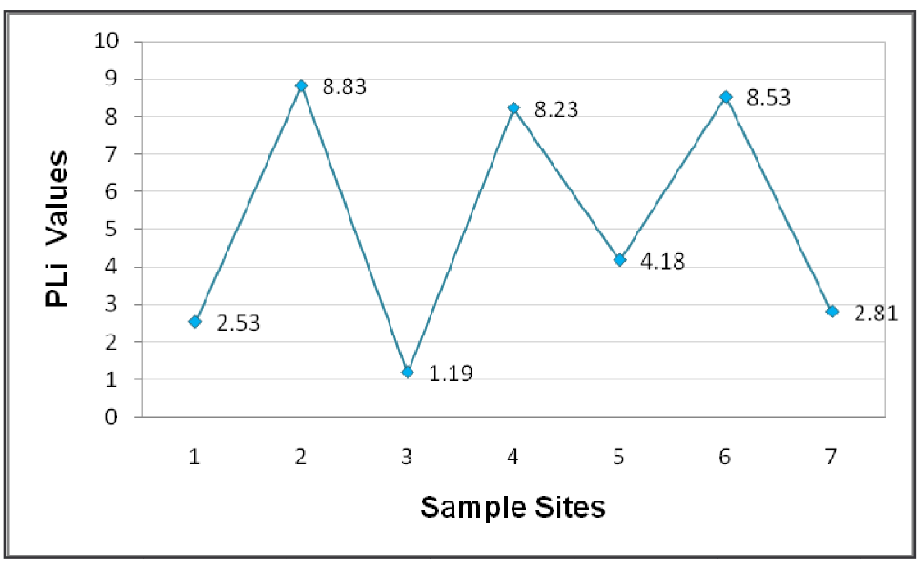

Figure 5.3. PLi values at the different sample sites along the Mvoti River

5.5. Conclusion

An investigation into the granulometry of the Mvoti system played a key role in highlighting the presence of elements within the sediment. It was evident from the results obtained that the site with the highest proportion of finer sediments (97.21%) contained the highest concentration of potential contaminants. The results reveal that the Mvoti system experiences relatively low to moderate levels of contamination, and enrichment of these contaminants is most probably due to natural sources at most sites. However, with the PLi values implying deterioration and pollution of the system occurring at all sites, it is highly probable that contaminants within the sediments are constantly remobilized into the water column. Accumulation of contaminants in the sediments is most likely hindered by the prevalence of a matrix of finer and larger sized particles allowing for the sediments of the Mvoti to become sources of pollutants in the system.

CHAPTER SIX
ECOLOGICAL RESTORATION AND MANAGEMENT OF THE MVOTI ESTUARY

Part I of this chapter is based on:

- Sukdeo, P., Pillay, S., and Bissessur, A. (2010). *A proposal for the restoration and management of the lower Mvoti River and Estuary, KwaZulu-Natal, South Africa.* Research Paper presented at the InSym-SUSL 2010, Sabaragamuwa University of Sri Lanka. 26^{th} – 28^{th} August 2010.

- Sukdeo, P., Pillay, S., and Bissessur, A. *In Review.* Ecological Restoration of a Degraded Estuary: The Case of the Mvoti Estuary, KwaZulu-Natal, South Africa. *Environmental Conservation.*

  (Submitted for publication 15 November 2010).

Part II of this chapter is based on:

- An Estuary Management Plan for the Mvoti Estuary

PART I: RESTORATION AND REHABILITATION OF THE MVOTI ESTUARY

6.1. Abstract

Excessive modification and utilization of the Mvoti catchment, located on the eastern seaboard of South Africa, has caused severe degradation of the Mvoti Estuary. Sandmining, agricultural and industrial pollution, excessive water abstraction and, wetland and riparian vegetation disruption have led to environmental problems such as poor water quality, sedimentation, alien vegetation invasions and, loss of habitat integrity and species diversity. This study outlines these environmental concerns by drawing on past and current research. Despite numerous surveys on the state of the estuary and its importance as a natural heritage site, no significant attempts have been made to restore or manage this estuary. This paper provides a first attempt at restoration; at devising a realistic set of strategies to redress the situation and, proposes some viable management initiatives. The latter include enforcing relevant environmental protection laws and building partnerships between the users of the river resources and the authorities responsible for conserving its' health status; abating, controlling and monitoring of anthropogenically derived pollution to improve water quality; re-introduction of indigenous instream and riparian vegetation and eliminating alien vegetation; measures for reducing the high sediment levels in the river and, improving water flow particularly during 'low-flow' periods.

Key words: estuary, degradation, rehabilitation, restoration, management

6.2. Introduction

Estuaries are ecologically important systems (Buggy and Tobin, 2008) as they sustain and support a wide range of flora and fauna, and provide humans with a unique variety of services (Breen and McKenzie, 2001). This places them amongst the most sensitive and productive ecosystems known, despite occupying a small percent of global waters (Glennie, 2001). Estuaries are affected directly by actions and processes occurring within them and within close proximity of them (Breen and McKenzie, 2001). They are also affected by activities which do not occur within their bounds, for instance in their catchment hinterland, in the upper reaches of the river feeding them and, in their tributaries.

The degradation of the state of South African estuaries had been identified as a cause for concern more than two decades ago (Brownlie, 1988), and without human intervention, damages to estuarine systems due to escalating population growth and development will most likely increase and eventually become irreparable. Fortunately, the value of estuaries has been recognized and efforts to rehabilitate and manage them have been made. In doing so they may retain their valuable characteristics and continue to provide the services on which we depend (Wiseman and Sowman, 1992).

In South Africa (KwaZulu-Natal in particular), efforts have been made to rehabilitate the Siyaya and Sezela estuaries (Wiseman and Sowman, 1992) and, proposals have been put forward for the rehabilitation of the Isipingo estuary (Kalicharran and Diab, 1993). The Mvoti Estuary is one of the most severely degraded systems on the north coast of KwaZulu-Natal and despite numerous surveys on the state of the estuary, and its importance as a bird sanctuary, no significant attempts have been made to restore or manage this estuary.

This paper provides the first attempt at restoration in estuarine degradation, investigating management initiatives and devising a realistic set of strategies to redress the current situation.

6.3. Study Area

The Mvoti River drains into the Indian Ocean at 29°24' S; 31°20' E (SOER, 2001), off the east coast of South Africa. The catchment occupies an area of approximately 3035 km^2 (DWAF, 2004) and occurs entirely within the province of KwaZulu-Natal (Creemers and Pott, 2002).

The 197 km long river begins in the midlands of KwaZulu-Natal (Malherbe, 2006), and ends in the Mvoti Estuary, located approximatelyt 90km north of the economically significant port city of Durban. The approximately 2 km^2 estuary (Wepener, 2007) is commonly regarded as a river mouth (Begg, 1984) dominated by fluvial discharge (Cooper, 2001). As is typical of such systems there are no considerable tidal influences, and the system remains almost entirely comprised of freshwater (Begg, 1984) except for marine water contributions from wave overwash during spring high tides. The Mvoti River falls within the Mvoti to Mzimkulu Water Management Area and under tertiary catchment U40 (DWAF, 2004).

A sandbar approximately 1 km in length (Figure 6.1), separates the estuary from the adjacent ocean, causing the river to deflect at the coast and open at a slightly southerly position (Wepener and MacKay, 2002). Wepener and MacKay (2002), note that the Mvoti mouth has been fairly stable, rarely closing since the mid 1990's. However, when necessary, the sandbar was artificially breached to prevent inundation of the adjoining sugarcane fields, or to prevent anoxic conditions of the estuary caused by effluent disposal with inadequate river flow for dilution (MacKay *et al.,* 2000a).

During flood conditions the sandbar is naturally breached and the river enters the ocean in a more northerly position (Wepener and MacKay, 2002). Such was the case during the floods experienced by KwaZulu-Natal in September 1987 (Badenhorst *et al.*, 1989). During this particularly harsh flood, large areas of sugarcane adjacent to the lower Mvoti were destroyed as the entire valley flooded, and the river scoured the sandbar and established a direct course to sea. Despite its relatively small size, the Mvoti River supports a number of towns, villages, and both rural and informal settlements along its course.

According to Creemers and Pott (2002) in the middle and lower regions of the Mvoti, water supply for the local populace is almost solely dependant on this river. In addition, the Mvoti catchment is a crucial resource for agricultural practices throughout the catchment, and industrial activities in its lower reaches. In terms of commercial agriculture, forestry and sugarcane farming are the two most extensive practices within the catchment, occupying approximately 576 km^2 and 370 km^2 of the total catchment area respectively (Malherbe, 2006). As these are both alien species to KwaZulu-Natal (Malherbe, 2006), this can have serious implications for the catchment. The Glendale distillery, Ushukela sugar mill and Sappi Stanger paper mill are responsible for the bulk of the industrial uses of the Mvoti water.

The Mvoti is described as a 'working river' as a result of the high utilization of the catchment and river (Malherbe, 2006). The river is severely degraded particularly in its lower reaches after its intersection with Stanger and onwards as it flows onto the coastal plain, with the current condition differing completely to the original (MacKay *et al.,* 2000a). The objectives of this study are to describe the past and present environmental concerns that have led to the progressive decline in the health status of the lower Mvoti and to formulate recommendations for the effective restoration and management of the system.

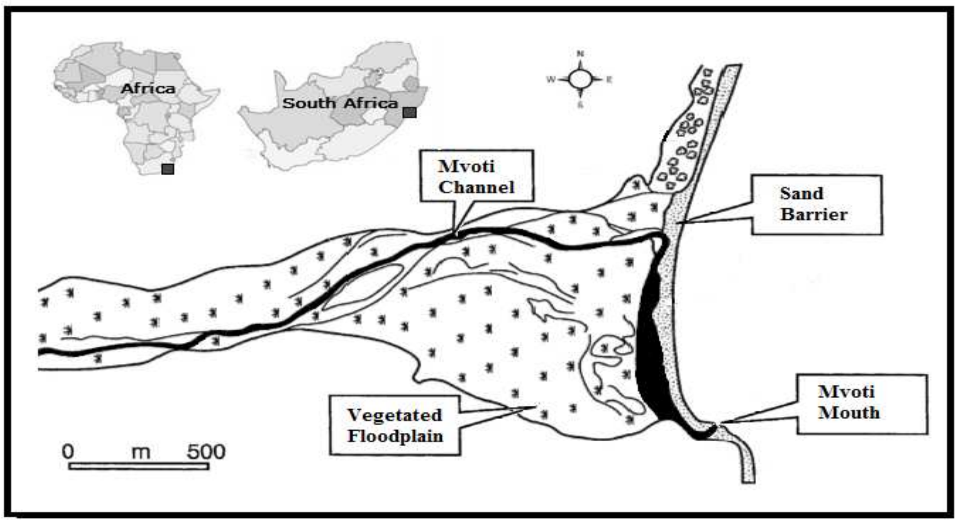

Figure 6.1. Schematic representation of the Mvoti Estuary along the South African coastline (Adapted from Cooper, 2001).

6.4. Current Environmental Problems

According to Begg (1978) estuarine degradation in the Mvoti can be attributed to impacts from the agricultural and industrial sectors, more specifically the problem comprises of issues such as incoming sand and silt, cropland and industrial pollution, disruption of wetlands, and, disruption of riverine vegetation.

The major issues of concern are discussed below:

6.4.1. Water Quality

The water quality entering the Mvoti Estuary has been recognized as a major problem for a considerable period of time. Begg (1978) described the condition of the estuary as ‘grossly polluted’, and now, more than four decades later, it is apparent that conditions have generally worsened. About forty years ago the major sources of pollution in the estuary were treated sewage effluent and sugar and paper mill effluents (Wepener and MacKay, 2002). These were discharged into the lower sections of the river from the town of Stanger, and from the Gledhow Sugar Mill and Sappi Stanger Paper Mill respectively. Currently, effluent is still discharged on a large scale into the river.

Agricultural practices and domestic uses also contribute to the poor condition of the estuary. Over the years, a number of assessments (Malherbe, 2006; Chili, 2008; Wepener and MacKay, 2002; Mackay *et al.,* 2000a) have affirmed the inferior quality of water entering the estuary, and its overall modified and degraded state (Wepener and MacKay, 2002).

During a field survey of the water quality in the river, ten sites along the lower length of the river were sampled. Dissolved oxygen concentrations at all ten sites were extremely low decreasing to values of 0.71 mg/L within the estuary. On the other hand, dissolved ammonia levels were also high at all ten sites. These concentrations exceed the target water quality ranges provided by DWAF (1996a; 1996b) of 7 mg/L and 10 mg/L for aquatic ecosystems and domestic use respectively.

Concentrations of potassium ions at all the sites also exceed the target water quality range for domestic use of 50 mg/L. In the estuary itself concentrations of chloride and nitrate ions are higher than the proposed water quality ranges of 0.2 µ*g*/L and 0.5 mg/L respectively.

6.4.2. Water Abstraction and Siltation

The Mvoti River experiences a mean annual runoff of approximately 375 million m^3/annum (Malherbe, 2006). Malherbe (2006) noted that the lower Mvoti River, particularly near Stanger, experiences a large scale water abstraction for industrial, agricultural and domestic purposes. Considering that this area is only 5 km upstream of the estuary, large scale water abstraction affects flow rates and natural functioning of the estuary.

The paper and sugar mills are the main water abstractors on the lower Mvoti (Von Bratt, 2007). To facilitate their water requirements, these industries have been largely responsible for modifications to the river channel and extensive water abstraction from the Mvoti (Von Bratt, 2007).

Furthermore, the Mvoti Estuary is subjected to extensive effluent discharge which underscores the vitally important role that river flow plays in dilution and flushing of pollutants. If the fluvial discharge is insufficient for effective flushing and dilution, there would be potentially serious impacts on the estuarine biota (MacKay *et al.,* 2000a).

According to MacKay *et al.* (2000a), water abstraction the sugar and paper mills is directly linked to this, especially during winter, when low flow conditions are experienced. Extensive, continuous water abstraction can also lead to modification of the stream banks and alteration of the channels (MacKay *et al,.* 2000a). King *et al*. (2003) suggested that water abstraction often results in a reduction in quantity of the remaining streamflow. This is currently experienced in the Mvoti River (Von Bratt, 2007), and consequently affects its integrity as a habitat and its ecology (MacKay *et al.,* 2000b, In Malherbe, 2006).

Previously, the single most important factor impacting negatively on KwaZulu-Natal's estuaries has been siltation (Begg, 1978). Over the years the Mvoti Estuary has experienced levels of sedimentation such that elevation of the bed level has occurred, resulting in a very limited tidal influence (Begg, 1978). Hence the estuary is predominantly river dominated and referred to as a river mouth (Begg, 1984). Von Bratt (2007) noted that the catchment geology of the Mvoti River is such that the region is characterized by highly erodible soils. This, together with the high rainfall, runoff experience in the lower Mvoti region, and anthropogenic activities has led to the Mvoti River experiencing high sediment loads (Von Bratt, 2007). Figure 6.2 illustrates the impacts of sugarcane farming and sugar milling, on watercourses upon which they depend.

6.4.3. Habitat Integrity and Species Diversity

Habitat plays a crucial role in the survival of a species in an ecosystem, and any decrease in habitat sustainability or availability will result in a decrease in the diversity of species (DWAF, 1999, In Malherbe, 2006). The habitat integrity of the lower Mvoti River is poor in that it has very little habitat of adequate quality to support the biotic communities (Malherbe, 2006). A reduced river flow, its poor water quality, and its predominantly sandy substrate have resulted in a decrease of diversity in the system. Invertebrate diversity and abundance within the estuary is poor, and so is fish diversity (MacKay *et al.,* 2000a).

In both cases tolerant and hardy species dominate and very few sensitive species are noted (Malherbe, 2006). According to MacKay *et al.* (2000a), the Mvoti Estuary is known to support a variety of birdlife. It is frequented by many Red Data species such as the *Pelecanus onocrotalus, Ciconia episcopus*, and *Glareola pratincola*, some of which utilize the sandbar as a nesting area. However, over the years these numbers have decreased (MacKay *et al.,* 2000a).

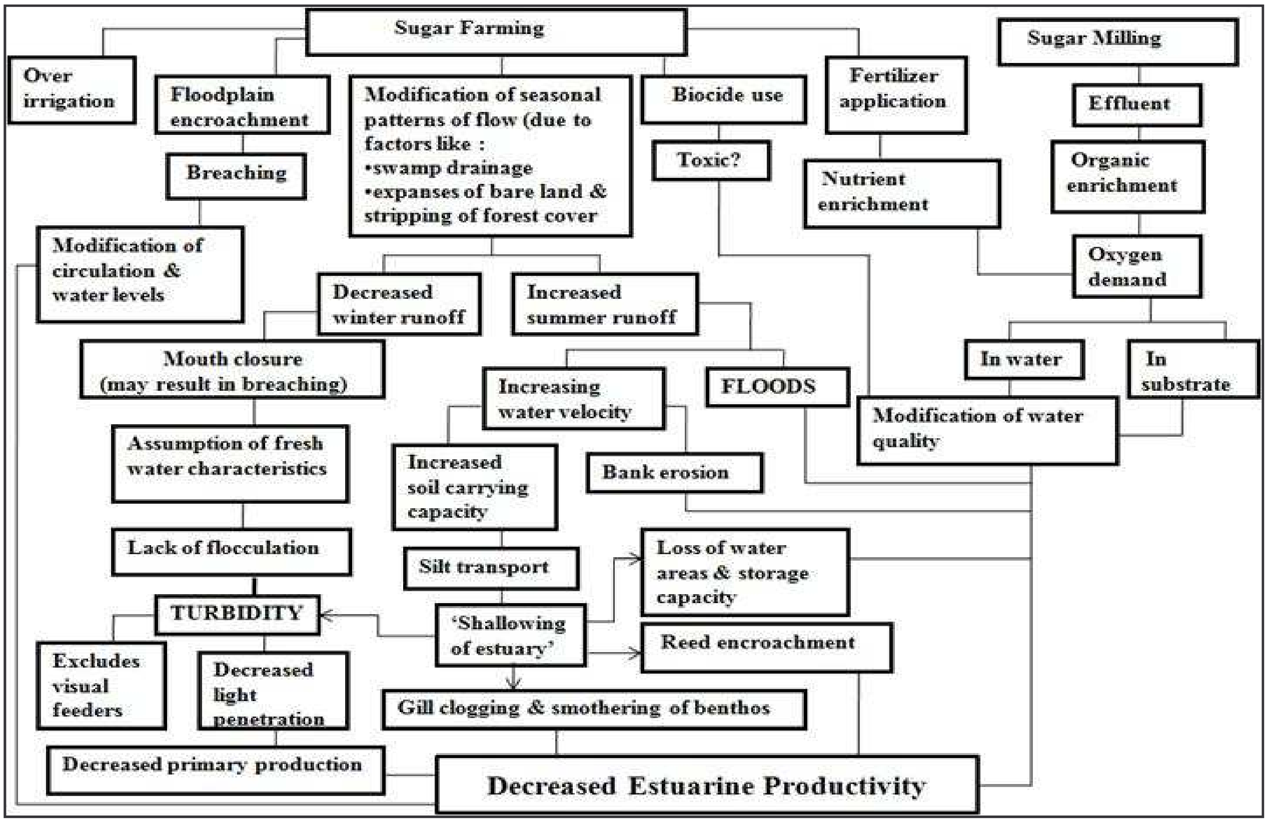

Figure 6.2. Impacts of sugarcane farming and sugar milling on estuarine productivity (Adapted from Begg, 1978)

6.4.4. Sandmining

The increasing demand for infrastructure and housing in South Africa has made building sand an important resource in the industrial and construction sectors. Large scale removal of alluvial sand is associated with negative effects on rivers and estuaries and consequently negative impacts on local sectors such as tourism and fisheries (De Lange *et al.,* 2009).

According to Demetriades (2007), some of the stream characteristics affected by sandmining include depth, velocity, turbidity, sediment transport, discharge and temperature.Changes in these characteristics often result in flow changes, excessive amounts of suspended sediments and, changes in riparian and instream habitats, all of which may impact adversely on biota, both instream and in the riparian zone (Demetriades, 2007). Refer to Table 6.1 for the effects of sandmining on the Mvoti Estuary. Demetriades (2007) identified several distinct sandmining operations on the lower Mvoti River.

Table 6.1. The activities and consequent impacts associated with sandmining on the lower Mvoti River (Adapted from Demetriades, 2007)

Observed activities	***Resultant impact***
Sandmining operations in very close proximity and to each other, each with separate access route(s) from the road down to the river bank.	This intensifies the possibility of erosion, and the negative effects of heavy vehicles and machinery on the floodplain.
Wide scale disturbance and removal of large areas of unconsolidated sediments. Vast removal of riparian vegetation around these operations	This is associated with adverse effects on the estuary including: sedimentation, changes in sediment composition, disturbance of benthic communities, and, a direct decrease of estuarine habitat integrity and productivity as well as floodplain productivity. These also impact negatively on estuarine community especially fish.

6.4.5. Alien Vegetation

Aside from instream characteristics such as water quality and sedimentation, degradation of habitats can be a result riparian zone disturbance and the dominance of alien vegetation (Malherbe, 2006), usually in the form of reeds and shallow-rooted grasses (Von Bratt 2007).

Riparian vegetation is responsible for a number of ecological functions that assist in maintaining a healthy ecosystem (Malherbe, 2006). These include retaining channel form, bank stabilization, erosion control and providing a habitat for biota.

Along the lower Mvoti River the riparian zone is almost entirely modified (MacKay *et al.,* 2000a) where places are completely cleared for agriculture, usually sugarcane, with the prevalence of subsistence agriculture. The invasion of the riparian zone by alien vegetation species also poses a problem. Areas of natural vegetation exists are usually dominated by either *Phragmites. sp,* reeds or exotic species. Alien plants species commonly invade disturbed areas as the new condition of the area enables the plants to establish themselves (Von Bratt, 2007). Hence, the disturbed riparian zone of the lower Mvoti River is an ideal habitat for alien vegetation.

6.5. Restoration and Management of the Mvoti Estuary

In response to the increase in the cases, causes and severity of estuarine degradation over the years, there has been advancement in approaches to estuarine restoration and management. For instance, Brownlie's approach (Brownlie, 1988. In Wiseman and Sowman, 1992) to estuarine restoration adopted four main principles:

- Identifying the 'symptoms' or signs of degradation
- Identifying the probable or definite causes of this degradation
- Selecting a suitable 'restored state' for the estuary
- Assessing the different options possible to achieve the 'restored state'.

Currently, rehabilitation approaches have expanded to an extent where estuaries are not just considered in isolation. Their interactions with other systems are recognized, and post rehabilitation management of the estuary is essential. An outline of the rehabilitation plan proposed in this study is presented in Figure 6.3.

Almost two decades after Brownlie (1988 In Wiseman and Sowman, 1992), Van Niekerk (2007) looked at a current and more detailed approach, which considered restoration and management on regional and local scales. However, despite the evolution of approaches and their underlying principles, there are still numerous factors which hinder effective estuarine rehabilitation and management in South Africa. Factors such as policies and legislation often have overlapping and sometimes conflicting contributions.

According to Van Niekerk (2007), there are approximately 16 international conventions, 10 white papers, 40 national acts, and provincial and local by-laws which govern estuarine management. Often there is confusion surrounding the government and local institutions that are responsible for estuarine management.

The Department of Environmental Affairs and Tourism is largely responsible for environmental management in South Africa, and *via* Marine and Coastal Management, they play a major role in the management of riverine and estuarine biodiversity, and consequently estuarine management (Nawn, 2004), together with land use and infrastructure (Van Niekerk, 2007). The Department of Water Affairs and Forestry is responsible for all water bodies in South Africa including estuaries (Nawn, 2004). They are also responsible for the management of water quantity and quality in estuaries and executing the National Water Act, Act 36 of 1998, which requires the formation of a catchment management authority to control activities and actions upstream that negatively affect estuaries. The local authority responsible for the Mvoti Estuary is the Kwa Dukuza Municipality.

However, the current state of the estuary indicates that there is a lack of enforcement of policies and legislation which protects this water resource. There is also a lack of action taken against perpetrators who have exploited the resource. This was particularly noticed during a pilot survey of the study area, where local authorities had erected signs warning the public against fishing and swimming in the estuary, as inferior water quality posed a health hazard. However, no known attempts have been made to improve any aspect of the system, and it remains in a poor condition.

The ultimate goal of rehabilitation of the Mvoti estuarine system is to restore the value of the system by improving the overall environmental health of the system and its riparian zone. Currently, access to the lower estuary is restricted. Admission to the northern banks can only be gain via a trail from Blythedale Beach, about 1km away, and the southern banks fall under private property owed by Jex Estate. Hence, the lower estuary is seldom under large scale recreational use, and, restoring it for recreational purposes is not a main priority. However, should this be later considered as an option, then recreational activities should ideally be nature-based and should not degrade the estuary in any way (Kalicharran and Diab, 1993).

To achieve this goal it is necessary for the causes of degradation, as opposed to its effects be addressed (Kalicharran and Diab, 1993). For the purpose of this study, the main environmental problems which have been identified in the Mvoti Estuary are poor water quality, sedimentation, invasion of alien plants, and, loss of habitat integrity and species diversity. Reduced water flow rates are also a concern.

It is highly recommended that an estuarine management committee be formulated to oversee the implementation of rehabilitation strategies and management of the estuary. Short term goals following the formulation of a committee would be to identify the current environmental problems that have led to the degradation of the estuary, and determine suitable remediation strategies for the systems. These have already been assessed within the context of this study. The establishment of such a committee for the Mvoti is long overdue. The committee should include relevant national government departments, para-statals and non government organizations.

With respect to the problems faced by the Mvoti, the Department of Water Affairs and Forestry and the Department of Environmental Affairs and Tourism have major roles to play in remediating water quality and controlling water abstraction. The Department of Water Affairs and Forestry and the Department of Agriculture have authority over alien plant eradication, and the Department of Mineral and Energy Affairs has a huge role to play in controlling sandmining. Regional and local authorities, local users of the estuary and other interested or affected parties should also be involved. At a local level, the KwaDukuza Municipality has jurisdiction over the estuary. However this is one of four Municipalities which make up the Illembe District Municipality. Hence these municipalities in unison have an active role to play in the estuary's remediation and management.

Other users of the river, namely local communities, the SAPPI and Ushukela mills and the Glendale Distillery, together with affected parties like the owners of Jex Estate play a vital role in rehabilitating the river and ensuring it is efficiently managed. Academic institutions should be involved by assisting with research and offering scientific recommendations or proposals. The rehabilitation of the estuary, once initiated, also requires, efficient management which needs to be an ongoing, and constantly monitored process in order to achieve completion and success.

6.5.1. Water Quality

Prevention of further decline in water quality of the estuary requires compliance with existing legislation and enforcing legal action against perpetrators who are responsible for this decline (Wiseman and Sowman, 1992; Kalicharran and Diab, 1993). The main pollutants in the Mvoti Estuary are industrial effluents released from the paper and sugar mills upstream.

If the levels of pollutants exceed limits set by the Department of Water Affairs and Forestry, legal action should be initiated against the perpetrators (Wiseman and Sowman, 1992; Kalicharran and Diab, 1993). If point-source pollution can be traced back to the source, a polluter-pays principle should also be applied.

Brownlie (1988) In, Wiseman and Sowman, 1992) suggested that development of management agreements between local municipalities and industries responsible for using the estuary. In the past, artificial breaching has been practiced in the Mvoti Estuary to prevent inundation of the adjacent sugarcane fields. This practice would possibly flush out the estuary. However, according to Allanson and Baird (1999), this is not a viable option, as in the long term, it only makes the original problem more complex. Artificial breaching may lead to excessive accumulation of marine sediments in the estuary, and, may also disrupt estuarine habitats.

Biologically, introducing more indigenous vegetation to the riparian zone can assist in the improvement of water quality by acting as a sink for nutrients and sediments (Lowrance *et al.,* 1984). The presence of these plants along the banks of the river play a role in controlling nutrients and sediments derived from agricultural practices and runoff from the catchment, from entering the river channel. This might be especially viable for the Mvoti as much of the catchment is under agriculture. The presence of agriculture in the lower regions is so extensive that cultivation often ends on the river banks.

Establishing instream plant communities may also offer some assistance in improving the river water quality. Some of these macrophytes are capable of extracting nutrients such as nitrogen and phosphorous from both the water and sediment in the system (Clarke, 2002). Aside from improving water chemistry, the physical structure of these plants offer resistance to the flow of water and its sediment load (Clarke, 2002), also helping the siltation problem.

The Mvoti Vlei is a natural wetland present on the upper reaches of the river (Begg, 1989). Artificial wetlands in the lower reaches can be beneficial by acting as a filter and decreasing the nutrient load of the river (Uys, 2003).

The Mvoti Estuary is a relatively shallow system (Begg, 1984), and therefore vegetation such as reeds and sedges will be more suitable for the system as opposed to submerged plants which require deeper waters (Whitfield and Bate, 2007). Reed beds can also be used to reduce any excessive bacterial levels (Kalicharran and Diab, 1993).

6.5.2. Reducing Sedimentation

To control and prevent sedimentation in the estuary, the issues of sandmining and riparian zone disturbance needs to be addressed. Sandmining operations on the lower river are extensive to the extent that individual boundaries between the operations cannot be identified.

There is an urgent need for responsible authorities to control sandmining, and to conduct a survey of current sandmining activities along the river, so that all illegal and uncontrolled operations can be identified and stopped. Legal action must be enforced against guilty operators. A comprehensive survey of the sand resources along the Mvoti is essential for enabling informed decisions on the part of the Department of Mineral and Energy Affairs in issuing sandmining permits for the area in question. In addition, the quota for each permit should be limited, so that the river banks and the river bed have sufficient time to rehabilitate in terms of gravel and alluvial material accumulation. This can avoid drastic impacts on the morphology of the stream, and improve its potential as a habitat.

Re-vegetation of the riparian area is recommended, as this decreases the time necessary for natural restoration and prevents erosion. This is also beneficial in that invasions by alien species, which thrive in disturbed conditions, can be controlled. Alternatively, the Department of Mineral and Energy Affairs can identify and provide access to an alternative, suitable source of sand material for extraction. The presently high levels of sediment can be reduced by the implementation of sediment traps. King *et al.* (2003) suggested that such traps should be located in accessible areas where the sediment can be removed by machinery.

6.5.3. Minimizing Water Abstraction

Lake Merthley is the only major impoundment on the Mvoti River. Therefore, unlike some of the larger rivers in South Africa where dams are a common feature, and the release of water from these impoundments during low flow periods can increase water levels down stream, the seemingly only suitable option for any improvement in water flow to occur, is water abstraction at a controlled rate.

The paper and sugar mills are the major abstractors of water from the river. Even though, some proportion of this water re-enters the river via return flow, it is often insufficient to cancel the effects caused by over extraction. The return flow is of inferior quality (Von Bratt, 2007) and has harmful effects on the health of the stream. Alternatively diversion of water from another river may be considered.

6.5.4. Eradicating Alien Vegetation

The development of an alien eradication programme would be beneficial in the removal of alien vegetation species from the riparian zone. This however requires man power, is time consuming and requires the removal of these plants upstream to prevent reinvasion (Wiseman and Sowman, 1992). Enlisting the assistance of local communities in these programmes may prove to be beneficial.

Assistance may involve educating community members on identification and removal methods of alien species in the region, in return for a fee or services they may require from local authorities. These programmes need to be ongoing and constantly monitored for them to be successful. Such a strategy implemented in South Africa is the 'Working for Water' programme, which sets out to eradicate both alien invasive plants, and unemployment (Uys, 2003). The Department of Environmental Affairs and Tourism, the Department of Water Affairs and Forestry and the Department of Agriculture were the governmental departments involved in this mission (Uys, 2003). As mentioned above, river banks and riparian zones that have been cleared either via disturbance or alien removal can be rehabilitated by reintroducing suitable indigenous vegetation.

This method stabilizes the banks and adjacent area preventing erosion and consequently siltation of the river. This method is efficient in preventing reinvasion of the disturbed area by alien vegetation.

6.5.5. Improving Habitat Integrity

To address the loss of habitats and instream integrity, the pollution problem in the river needs to be addressed. Biodiversity can only improve with an improvement in water quality. With a decrease in siltation of the river benthic communities and macrofauna less tolerant to turbidity may be able to re-establish themselves.

A decrease in pollutants in the river will allow re-establishment and flourishing of less tolerant macrofauna. It would seem that environmental education will play an important role in influencing the attitude of users of the river to the environment (Kalicharran and Diab, 1993). This would apply in particular to domestic users of the Mvoti, a majority of who hail from informal settlements and rural areas.

6.6. Conclusion

The causes of degradation in the lower Mvoti River and estuarine system, and suitable potential restoration strategies have been identified. It has been established that the primary cause of environmental degradation within the lower Mvoti River and estuary is the inferior quality of the water entering the system. Sedimentation within the estuary is also a major problem, coupled with low water flow rates caused by over-abstraction of water by industries upstream, and alien plant invasions along the riparian zone. All these factors contribute to the current loss of habitat integrity and species diversity experienced by the system. There is a lack of enforcement of the laws protecting this water resource by the relevant authorities, and a lack of action against the perpetrators abusing the resource. These are the issues which have been considered in this proposal for the restoration of the lower Mvoti River and estuary system. Until an attempt is made to improve the current condition of the system, and effective management strategies are in place, the system will continue to move toward a more in a severely degraded state than its present condition.

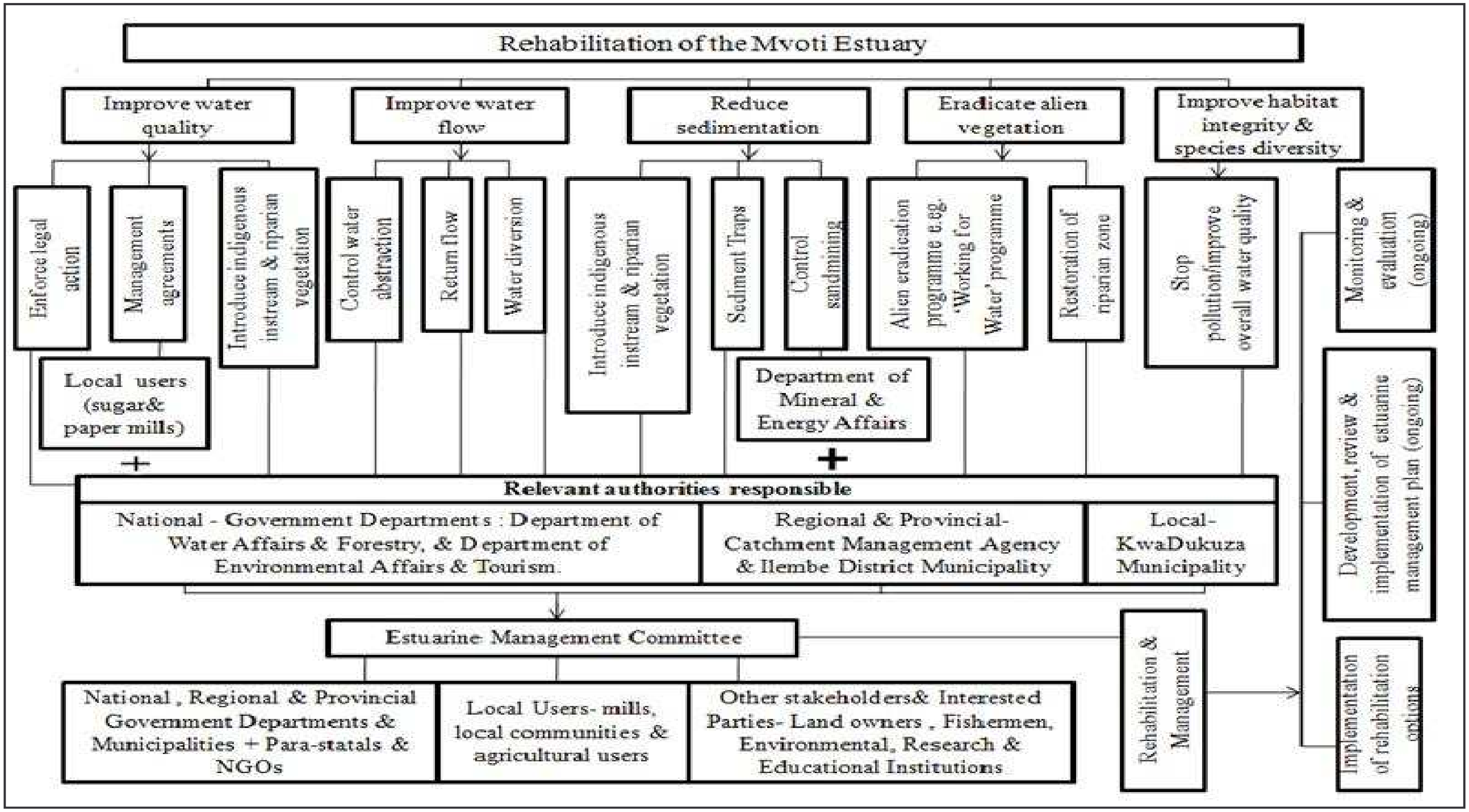

Figure 6.3. The proposed rehabilitation and management plan for the lower Mvoti River and Estuary

(Adapted from Kalicharran and Diab, 1993)

PART II: AN ESTUARY MANAGEMENT PLAN FOR THE MVOTI ESTUARY

6.7. Introduction

The overall protection of South Africa's estuaries is relatively low (DEAT, 2006). According to Van Niekerk (2007), the governance and management of estuaries in South Africa occurs on an 'ad hoc basis'. Here, decisions regarding important characteristics of estuaries, including water quantity and quality, and estuarine biodiversity, together with conservation, are taken non-strategically and without prior planning. As a result issues are considered as they occur, and estuarine interactions are often not properly addressed (Van Niekerk, 2007). Van Niekerk (2007) notes that mismanagement of catchments or areas surrounding estuaries has resulted in a vast number of degraded systems, and it is important to prevent any further deteriorations in the health of South Africa's estuaries.

Over the years the Mvoti Estuary has become known as an important bird sanctuary, supporting a diverse range of avian fauna, including important red data and migratory species (Mackay *et al.*, 2000a). Begg (1978) notes that the estuary is not botanically significant, and currently the dominant flora in the system is the *Phragmites species,* also known as the common reed.

Despite being an importance resource for a relatively large part of the KwaZulu-Natal midlands and north coast (Malherbe, 2006), there is currently no EMP, or even estuarine management committee in place to protect or monitor the Mvoti Estuary (Mackay *et al.*, 2000a). Without proper management, the current state of the Mvoti estuarine system signals that the estuary is likely to experience a further deterioration in health and functioning. The purpose of this chapter therefore, is to provide a potential/hypothetical EMP for the Mvoti River estuary.

6.8. Situational assessment

As there is currently no situational assessment in place for the Mvoti Estuary, a provisional situational assessment for the Mvoti Estuary, for the purpose of this study, was conducted by the researcher.

The assessment is based upon the terms of reference provided for the development of EMPs for the Mbashe and Mtentu estuaries (Eastern Cape Parks, n.d) on South Africa's eastern coast, and the Olifants' River EMP (Anchor Environmental, 2009) on the western coast. The Mbashe and Mtentu estuaries occur within the same subtropical, biogeographical region as the Mvoti Estuary. The situational assessment provides a platform upon which the EMP will be based.

6.8.1. Goods and services provided by the estuary

Currently the lower Mvoti River and estuary are critical sources of water for the local towns and industries. A large amount of water is abstracted by the sugar and paper and pulp mills for operational activities like cooling and dilution.

The river is a release point for effluent from these mills and from the sewerage works in the lower regions. Local communities use water for domestic purposes. The estuary was previously a favourable fishing area, but fishing has since been prohibited due to contamination. Over the years, local fishermen have noted a significant decrease in fish populations. The Mvoti Estuary is renowned for its bird population, and has been proposed as a bird sanctuary. It supports a wide variety of indigenous and migrating aquatic birds, including numerous red data species.

6.8.2. Issues relating to the exploitation of living resources

Fishing and bait harvesting are not extensive within the estuary. This is possibly due to the fact that contamination has reduced the number of less-tolerant fish and other aquatic species populations in the estuary, and the danger to human health posed collecting existing contaminated resources.

6.8.3. Assessment of the water quality and quantity requirements

The quality of water entering the Mvoti Estuary is of extremely poor quality. This study, as well as previous assessments of the estuary have recorded inferior water quality for a number of years. The inferior water quality entering the Mvoti Estuary can be attributed to treated sewage effluent and sugar and paper mill effluents.

These are discharged into the lower sections of the river from the town of Stanger, and from the sugar Mill and Pulp and Paper Mill respectively. Agricultural practices and domestic uses also contribute largely to the poor condition of the estuary. With regards to water quantity, the water level of the Mvoti Estuary is relatively low. The Mvoti River experiences a mean annual runoff of approximately 375 million m^3/annum (Malherbe, 2006).

Malherbe (2006) notes that the lower Mvoti River, particularly near Stanger, experiences large scale water abstraction for industrial, agricultural and domestic purposes. As this area is only a few kilometres upstream of the estuary, water abstraction affects flow rates and functioning of the estuary.

6.8.4. Priority restoration actions

The current state of the estuary is severely degraded. Restoration actions as proposed by Sukdeo *et al.* (2010). Aside from issues such as poor water quality and reduced water quantity, the estuary experiences numerous other environmental problems, many of which are caused either directly or indirectly by anthropogenic activities. As noted in Chapter Seven, the most prevalent issues experienced by the estuary are poor water quality and quantity, sedimentation, uncontrolled extensive sandmining, loss of habitat and alien plant invasions. Restoration action actions proposed in Chapter Seven are outlined in Figure 6.3.

6.8.5 Protected area potential

The Mvoti Estuary falls within a natural heritage site (SANHS 166) that is located on privately owned property. There are no other proclaimed nature reserves in the vicinity. A protected area, namely the Mvoti Community Protected Area and Marine Protected Area, has been proposed for the area by the Kwa Dukuza Municipality (KDM, 2003), but is yet to be established. It extends from the Mvoti River mouth upstream towards the settlement of Groutville, and is proposed to cover the area between the Mvoti River mouth and the Mnyundwini River as it passes through Groutville (KDM, 2003). The protected region encompasses both a terrestrial and marine protected area. The marine protected area offers a sanctuary for sensitive juvenile and spawning fish, sensitive invertebrate species, as well as for birds and waterfowl that use the estuary. The terrestrial protected area offers protection to the last remnants of coastal forest close to the coast, and to the Zulu Palmveld, wetlands and moist grasslands in the Groutville region (KDM, 2003).

6.8.6. Awareness raising and public participation/ stakeholder involvement

A programme should be developed to increase public awareness of the importance of the Mvoti Estuary and estuaries. This programme should involve the development of an onsite visitor centre and the facilitation of field trips to the area. The provision of educational material relating to the estuary should form part of this programme.

With respect to public participation and stakeholder involvement, processes must be implemented to ensure this. Processes must the formation of an estuary management forum/ committee for the Mvoti Estuary. This development needs to be advertised via public meetings, advertisements in local media, via word of mouth, and via the above-mentioned awareness campaigns, which will inform the public and various stakeholders of the proposal to establish such a forum. Interested parties will in turn have to attend meetings or inform organizers of their interest in the committee, to become part of it, and have their views and interests reflected in the decisions taken by the forum. Provision should be made to facilitate other stakeholders, for instance members from local communities that do not have means to attend.

6.9. Estuarine Management Plan

This will be completed by broadly incorporating the National Estuarine Management Protocol (NEMP) framework (Van Niekerk, 2007), previous research, and this study.

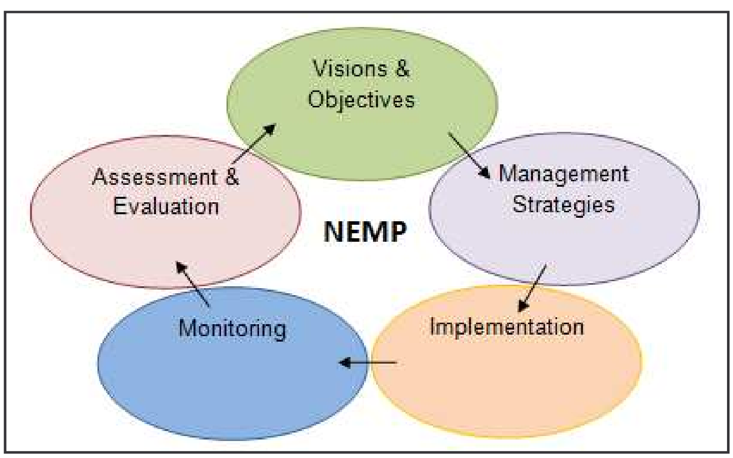

Figure 6.4. The Proposed National Estuarine Management Protocol

(After Van Niekerk, 2007)

The National Estuarine Management Protocol is an adaptive approach. It entails the development of a vision, resources objectives, and strategies to meet these objectives. It requires implementation, monitoring and assessment of results. This integrated approach is beneficial in that it encourages a more balanced use of resources, better management, and better environmental protection.

6.9.1. Vision statement for the Mvoti Estuary

A vision statement displays the intention of a management attempt or intervention. Generally, a vision statement is developed and agreed upon by relevant stakeholders and users, prior to the completion of the management plan (Dent and Breen, 2001. In Breen and McKenzie, 2001). As there is currently no estuarine committee for the area in question, for the purpose of this study, available information was used to develop a potential vision statement.

> *The Mvoti Estuary is a sanctuary for aquatic fauna, and water fowl, which should provide for all its users water of an acceptable quality; It should also benefit local users in terms of sustainable natural resources use.*

6.9.2. Management Objectives

Management objectives for the Mvoti Estuary should be proposed and agreed upon by relevant stakeholders and authorities. Building on the first part of this chapter, potential, viable management options and objectives are provided below:

Pollution control

Sound management of the estuary should ensure that pollution, both in the form of physical litter and from industrial effluent, is curbed. This will lead to an improvement in the water quality of the system, and consequently will result in an improvement in biodiversity and estuarine health.

Restoration of the estuary

Once restoration of the estuary is initiated, efficient estuarine management should help facilitate the remainder of the restoration processes. An estuary undergoing restoration is a step closer to its original condition and vulnerable. Management of the area should also help prevent the estuary from relapsing back into the degraded condition.

Conservation of biodiversity

Management of the estuary incorporating conservation efforts should help protect the area's flora and fauna, especially with the current, poor state of the estuary. Biodiversity needs to be protected, to prevent any further loss. Improvements in the water quality will improve the biodiversity which is presently dominated by more-tolerant fish and invertebrate species. Following restoration efforts, indigenous populations of fish and invertebrates which have been lost, and other less-tolerant species may re-establish themselves within the estuary. Management of the estuary may help these communities remain in the estuary. Floral communities within the estuary are not diverse. *Phragmites species* are extensive, together with sugarcane along the river banks. Reintroducing indigenous riparian and instream vegetation require sound management for these macrophytes to survive and flourish.

The above-mentioned objectives are interlinked and share a common goal of improving the health and functioning of the estuary. Once these objectives are implemented, the overall condition of the estuary should experience improvement. This in turn will require suitable management for improvements to continue and to prevent the estuary from returning to its severely degraded condition.

Increase public awareness

Visitors, residents and other users of the estuary need to know the importance of the estuary and the services it provides to both people and the environment. They also need to be aware of the legislation and processes that protect the estuary, and the consequences of not abiding by these rules. A sound management plan should allow for all this information to made available to the public, in various forms so that all users will be able to understand the information, the reason for the EMP, and they will also have no reason not to comply.

Increase economic potential without exploiting resources

Currently, the estuary is not heavily used for recreation and access is controlled, with the south bank falling under private property. Activities and services which will increase the economic potential of the estuary need to be nurtured and established, without creating any unnecessary pressure on the estuary or causing it harm in any way.

6.10. Strategies to meet key management objectives

Some of the main strategies proposed to meet the key management objectives are presented in Figure 6.4. Each of the main objectives has a number of suggested strategies which can be implemented in the management of the estuary. Some objectives have a role as a key strategy for other objectives, and a number of strategies overlap for different objectives.

6.10.1. Key strategies for restoration of the estuary

As discussed earlier, restoration of the estuary is a key objective for the management of the estuary. This incorporates implementing strategies such as alien vegetation eradication, reducing sedimentation, improving the habitat integrity, water quality and quantity. Alien eradication programmes have already proven successful in other parts of the country (Uys, 2003; Sadan, 2005).

For instance, the 'Working for Water' programme introduced by the Department of Water Affairs and Forestry and the Department of Agriculture list the help of local communities to remove alien plants. This has two-fold benefits, whereby the communities gain an income, improving their livelihoods, and alien plants are removed and their reinvasions are prevented (Uys, 2003; Sadan, 2005).

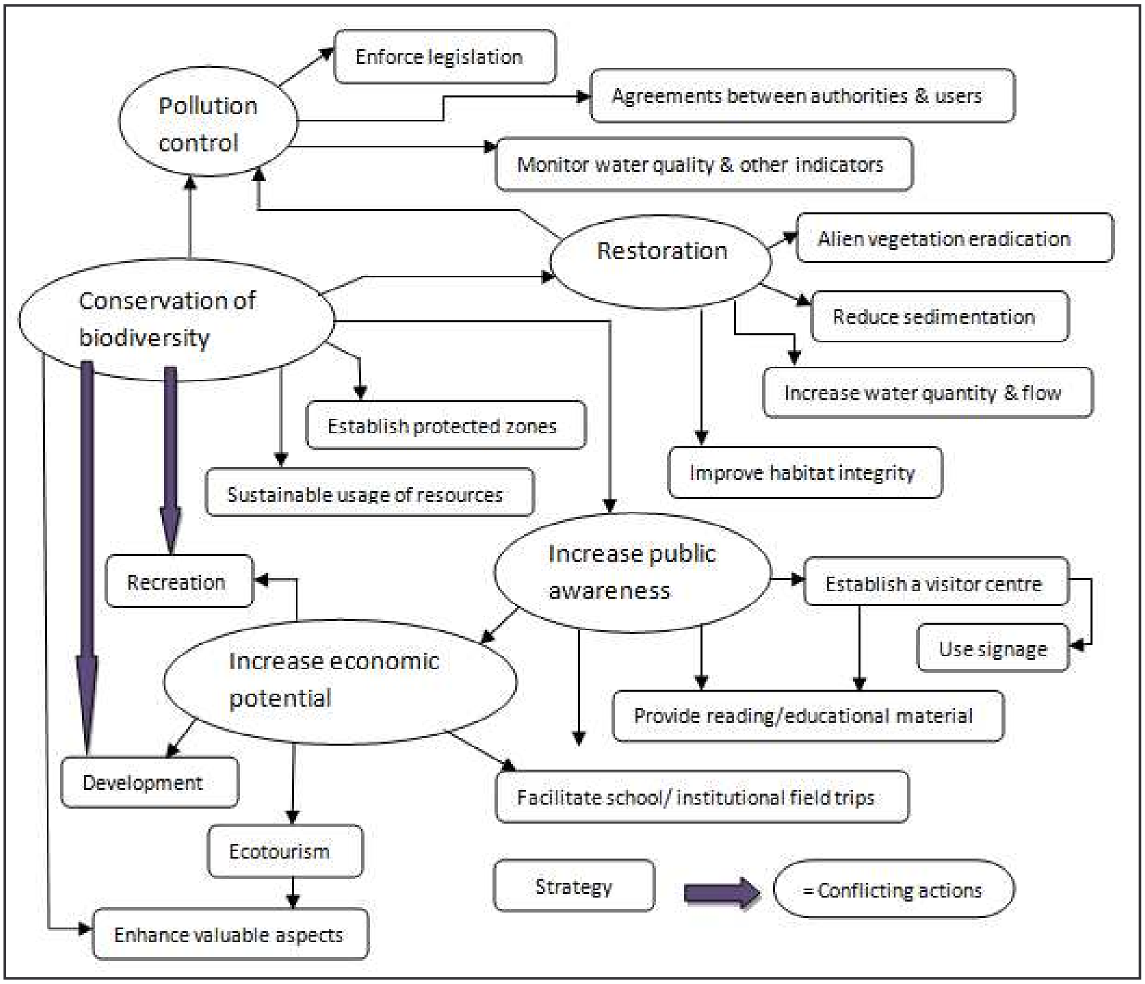

Figure 6.5. Key strategies to meet management objectives for the estuary

6.10.2. Controlling pollution in the estuary

Pollution control, a management objective, forms part of the strategy for achieving restoration. Similarly to pollution control, securing a better quality and quantity of water requires the involvement of groups larger than just the estuarine management agencies. These objectives require assistance from catchment management agencies which manage the greater part of the catchment. However, as there is no catchment management agency established as yet for the Mvoti to Mzimkulu water management area, the Department of Water Affairs and Forestry is left responsible for the greater part of the river (DWAF, 2004). Noting the laws and legislations which protect South Africa’s water resource, legal action should be enforced against perpetrators guilty of misusing the water.

In the case of the Mvoti, misuse is primarily in the form of over-abstraction and pollution. Legal agreements between these users and the authorities may be able to avoid this.

6.10.3. Conserving biodiversity

The conservation of biodiversity is another management objective which encompasses other objectives as part of its strategy. It is one of the main objectives proposed in this study. Together with pollution control and restoration, other important strategies include ensuring the sustainable use of resources, and establishing protected zones.

The establishment of a protected zone will be effective if protection is provided for at least 50% of all biodiversity. Protected zones will help prevent excessive sand mining and riparian zone disturbance. The protected zones will control the harvesting of fish and invertebrates for bait and consumption. It will limit the harvesting of reeds and indigenous plants which contribute to bank stabilisation. These measures are in concord with the other strategy of ensuring the sustainable use of resources. The control imposed by protecting the biodiversity should prevent exploitation of theses resources and result in the resources being used at a sustainable rate.

6.10.4. Strategies to increase public awareness

Increasing public awareness on the importance of the estuary is vital. This is mainly because the degraded condition of the Mvoti Estuary is primarily due to anthropogenic negligence. This is also a key strategy to conserving the estuary and its biodiversity. After initiating the estuarine management plan, facilitating field trips for schools and other institutions will be valuable for educating the public on the importance of the Mvoti Estuary and estuaries. A visitor centre onsite will be beneficial. Making available educational material on the estuary, especially at these centres will prove to be beneficial. Material can be in the form of posters, signage and booklets, with pictures and illustrations, and presented in local languages, so that the message can be understood and spread.

6.10.5. Increasing the economic potential of the estuary

The last objective, the most controversial, involves increasing the economic potential of the area. This can be achieved by facilitating field trips into the area, which overlaps with increasing public awareness. Promoting the Mvoti Estuary for ecotourism may be beneficial, especially with a concentration on the most valuable aspects, which in this case is the rich avian fauna present. The results can be two-fold, both bringing an income into the area and helping conserve biodiversity. Even though public access to the estuary is currently restricted, promoting the estuary for recreational purposes will increase income into the area. However this may present negative impacts on the estuarine health and pose problems for conserving the biodiversity.

Another factor which is conflicting with biodiversity conservation is development. This would most definitely increase the economy of the area, especially with the extensive housing developments that have been established along the coastal areas of Kwa Dukuza in recent years. However this would disrupt valuable ecosystems and habitats, and add increasing negative pressure to an already stressed system.

For these objectives to be met, a number of organizations together have a role to play by forming an estuary management forum to oversee the management and monitoring of the estuary. These include estuary management agencies, catchment management agencies, relevant local, regional and national government departments, conservation agencies, property owners and other involved stakeholders.

6.11. The proposed Mvoti Estuary protected area and zonation

The Mvoti Estuary is one of the most stressed systems in northern KwaZulu-Natal, with water requirements exceeding the availability of the resource. The estuary and much of the lower river fall within the jurisdiction of the Kwa Dukuza Municipality. There are no proclaimed nature reserves within this area, however the Mvoti Estuary falls within a natural heritage site (SANHS 166) that is located on privately owned property. According to MacKay *et al.* (2000a), the Avian Demography Unit from the University of Cape Town has declared this area as one that is in desperate need of conservation.

Of the numerous laws that govern South Africa's water resources, there are three key laws that will be considered for the protected area aspect of this study. The Marine Living Resources Act, 1998 is associated with conserving the living resources which occur below the high water mark of the system. This law allows for a marine protected area to be zoned, implying that it can offer varying levels of protection to different parts of the marine protected area. The Protected Areas Act, 2003 is associated with conserving the living resources which occur above the high water mark of the system. A beneficial aspect of this law is that if marine and terrestrial protected areas exist with common or overlapping boundaries, the law requires that both areas be managed as an integrated protected area by a single authority. The third law, the National Water Act, 1998, governs the supply of sufficient freshwater into the estuarine system.

The Kwa Dukuza Municipality, together with Ezemvelo KZN Wildlife, the Department of Environmental Affairs and Tourism, and various other stakeholders have identified the need for, and proposed a protected area (marine and terrestrial) for part of the lower Mvoti River and estuary (KDM, 2003). This, together with other potential sites along the river will be briefly discussed below.

6.11.1. The proposed protected area

The proposed protected area, the Mvoti Community Protected Area and Marine Protected Area extends from the Mvoti River mouth upstream towards the settlement of Groutville. It is proposed to cover an area of approximately 300 ha, between the Mvoti River mouth and the Mnyundwini River as it passes through Groutville. However, the Kwa Dukuza Municipality revised Integrated Development Plan (2003) only pays significant attention to certain aspects within this area, for instance the Zulu Palmveld in Groutville. The protected area proposed in this study will looks at other areas and assets in the region, and will also consider the interests of the various users of the river. This proposed protected area will be zoned where necessary, as allowed for by the Marine Living Resource Act, 1998. This may help prevent coexisting activities from imposing upon each other.

Figure 6.6. *Aristida junctiformis* grasslands in the Zulu palmveld (Groutville). Note also patches of *Phoenix sp. and Cussonia sp.* (KDM, 2003)

The activities which are most likely to conflict with each other include aspects such as fishing and biodiversity conservation. The prevention of fishing in this zone, should comply with biodiversity conservation attempts, especially the capture of juveniles and spawning adults. Additionally, with the release of particularly noxious effluents into the Mvoti channel, the collection of fish for human consumption may not necessarily be a wise decision.

The lower estuary as noted by Mackay *et al.* (2000a) is dominated by mullet. This species of fish commonly feeds upon algae, meio- and micro invertebrates and plant matter. During surveys between 1999 and 2000 within the estuary, Mackay *et al.,* (2000a), have noticed a lack of fish species which feed upon invertebrates.

This has been attributed to the lack of these invertebrates within the estuary. Only one species of prawn and one amphipod were collected in this area. The prevention of bait harvesting here will allow for invertebrate populations to re-establish themselves and consequently will allow for the reestablishment of the fish populations which feed upon them. Between the period of the survey by Mackay *et al.,* (2000a) a decrease in the number of birds at the estuary was also noted, possibly as a result of a decrease in food. Similarly, zoning this area as a 'bait sanctuary' should also prove beneficial to the bird population.

Begg (1978) mentioned that the sandbar at the Mvoti mouth was often used to launch ski boats. In more recent years, the sandbar has also become a common spot for all-terrain vehicles, and the estuary itself has become popular for jet skiing. A ban should be imposed upon such activities within the estuary. Motorised boats will disturb the waders and other birdlife, and will also disturb the water column. This may have significant effects upon fish in the estuary, particularly during spawning and hatching. The bottom sediments of the estuary may also be unnecessarily disturbed which may in turn have some negative impacts upon bottom dwellers and benthic communities, together with the rest of the food chain which depends upon them. The use of vehicles on the sandbar may have negative consequences for the birdlife which use the sandspit as a roosting and nesting place.

6.11.2. Boundaries of the proposed marine protected area

The lower Mvoti River and estuary will be separated into four distinct zones, each with its own restrictions. The different zones are presented in Figure 6.7. It is important that the different zones be clearly demarcated onsite. This can be done using signage and posts at boundaries between the different zones. It is also important that legal action be enforced against perpetrators that do not comply with the rules of the different zones.

Zone A

This is the 'estuarine' reaches of the river including the mouth. The area displayed in blue in the zonation plan. In this zone, fishing and bait collection are not allowed. Disturbance of the bird community is also not allowed. The use of motorised boats is prohibited (though the channel may be too shallow for this activity in this section of the estuary).

Zone B

This zone encompasses the uppermost reaches of the estuary and is demarcated in pink. Here fishing and bait collection are not allowed. The use of motorised boats is still prohibited. Water extraction for non-domestic uses is prohibited.

Zone C

This is a 'riverine' section of the river. It is displayed in green on the zonation plan. As this area is directly downstream of the release of effluent and treated water (from the paper and pulp mill) into the Mvoti main channel via the Mbozambo River, it is suggested that fishing for human consumption be banned here.

The water in this section is of poor quality and this often has negative effects on the fish quality making them unfit for consumption. Water extraction for non-domestic uses, especially industrial and agricultural uses, is not allowed.

Zone D

This zone, the uppermost reaches of the protected area is displayed in yellow. Multiple uses of this area are allowed. There are no major restrictions in this zone, with the exception of major disturbances to the system, over-abstraction of water, and exploitation of the natural resource.

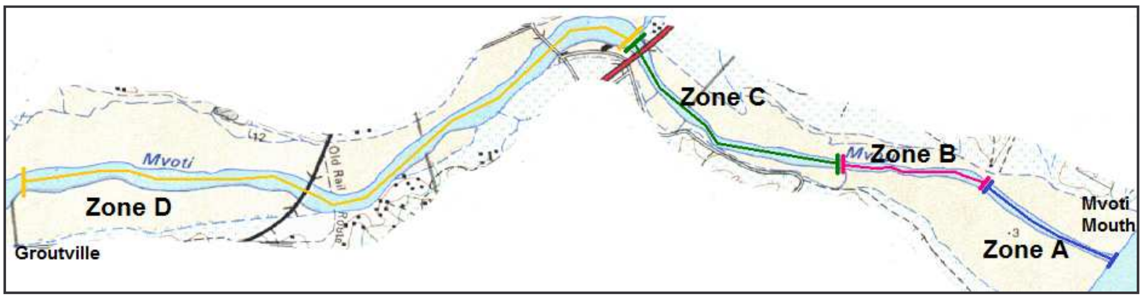

Figure 6.7. Zonation plan for the proposed Mvoti marine protected area (Adapted from 1:250 000 Topographical Map of South Africa)

6.11.3. Development set back zone around the estuary

According to the Integrated Coastal Management Act, local municipalities are required to develop a ‘setback zone’ around their estuaries. This protection zone should be at least 1km around the estuary for all the land dedicated to agriculture or of undetermined use, and excluding all land zoned for legal townships, urban areas or other human settlements. A zone of 100 m should be established for all other areas. Thereafter, any future development in this zone will require an environmental impact assessment (EIA) and will have to be compatible with the best interests of the estuary. Hence, these setback zones offer protection from uncontrolled and incompatible development, to estuaries.

6.11.4. Establishment of a terrestrial protected area.

The remaining valuable aspects of the estuary lie above the high water mark and are protected by the Protected Areas Act, 2003, the Biodiversity Act, 2004 and the Environment Conservation Act, 1994. The suggested areas for protection are the Mpande Forest which grows along the riparian zone of the estuary, extending from Jex estate, a private estate on the southern bank of the Mvoti mouth, to a neighbouring estate. There is also a primary dune forest growing along the coast, extending from Tinley Manor to Jex estate. The forest is relatively well preserved and therefore requires protection from the management plan, to prevent any future disturbance.

Slightly inland of the estuary, on the Mbozambo River, a tributary of the Mvoti is the Mbozambo swamp, an artificial wetland created by the Sappi Stanger Paper Mill. This wetland was created to temporarily harbour wastewater from the mill, before returning it into the Mvoti River. The swamp is particularly rich in birdlife, and together with the Mvoti mouth has played host to a number of birds over the years. Even though the water is of particularly poor quality, these bird sanctuaries require adequate protection.

Upstream, bordering on the edge of the protected area exists the Zulu Palmveld, another site which requires protection. The area has been described as 'unique' because of its species diversity which is unlike any other area in South Africa (KDM, 2003). Some of the plants present at the palmveld include palm trees (*Phoenix reclinata*), Bride's bush (*Pavetta sp.*) and Cabbage trees (*Cussonia sp.*). There are open wetlands and moist grasslands which occur in the Groutville /Tembeni regions.

According to Mackay *et al.* (2000a) the natural vegetation of the lower Mvoti should be grasslands, with coastal forests close to the coast. Hence, it is important for the last remnants of this vegetation to be protected. The protected area is shown in Figure 6.8. In the potential protected area plan, the area demarcation 'A', is dedicated primary to the protection of the Mpande and coastal dune forests. Section 'B' is concerned with the protection of the Mbozambo swamp, and section 'C' is dedicated primarily to the protection of the palmveld, wetlands and grasslands.

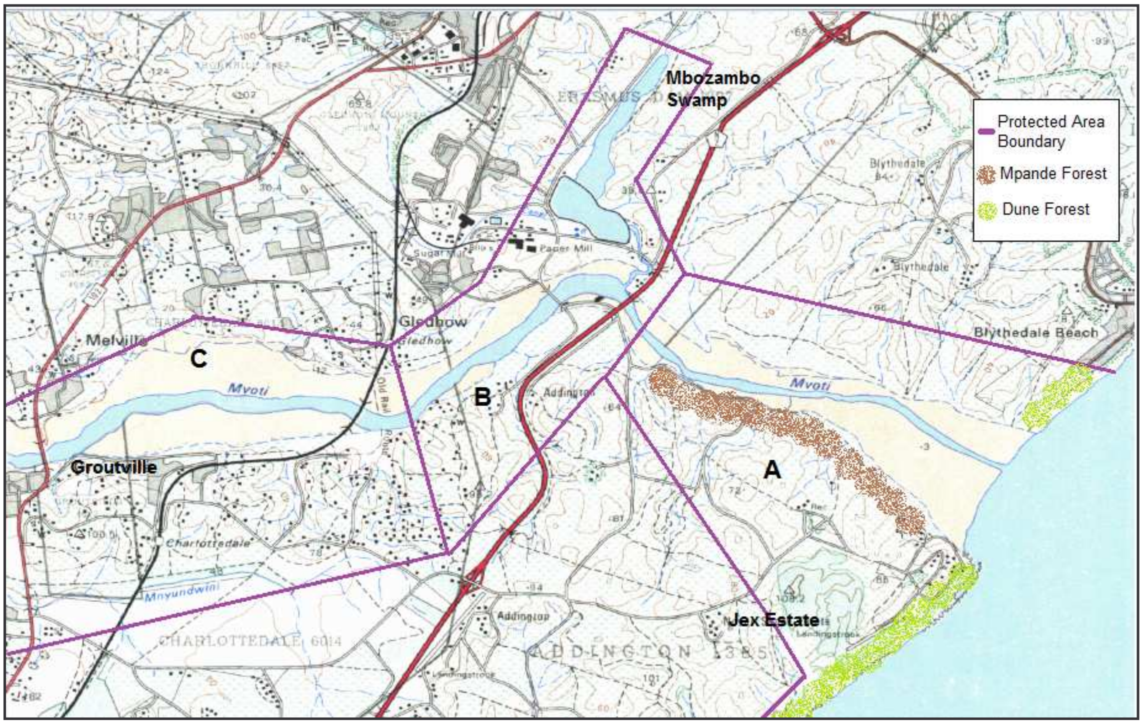

Figure 6.8. The proposed Mvoti terrestrial protected area (Adapted from 1:250 000 Topographical Map of South Africa)

6.12. Co-operative Governance and estuary management forums

Different users of estuaries often have different requirements from estuaries, hence they have different views of what constitutes a healthy estuary, or how the system should be managed (Dent and Breen, 2001). These differences can only be resolved where and when all users groups appreciate and accommodate the reasonable needs of all others (Dent and Breen, 2001). Therefore all the interested groups need to come together in managing estuaries so that they can provide the maximum sustainable benefits to society (Dent and Breen, 2001).

Estuaries are ultimately the responsibility of the government, and it is the duty of the government to promote relationships between the regulators of the system (government agencies) and the regulators (users of the system). The strength of these partnerships is a reflection of the extent to which stakeholders are able to constructively contribute to improving and managing the estuary (Dent and Breen, 2001. In Breen and McKenzie, 2001).

Estuary management forums are useful organizational bodies which stakeholders can form or join, to facilitate engagement with government. These forums can either be formal organizations like to sub-committees of local authorities or coastal forums, or they can be citizens' action groups (Dent and Breen, 2001. In Breen and McKenzie, 2001). Either way, these forums should promote appropriate management of the estuaries, as well as contribute to monitoring and reporting (Dent and Breen, 2001. In Breen and McKenzie, 2001).

6.13. Post-project monitoring and evaluation

It is assumed that once rehabilitative measures have been initiated in a river system, that part of the system will be improved with a situation better than what it was prior to rehabilitation. However, whether or not this is really the case, is seldom evaluated (King *et al*., 2003). According to King *et al*. (2003), this is due to a number of reasons, namely:

- Rehabilitation of a dynamic self-maintaining system is difficult to measure.
- Techniques for monitoring vary between systems, as each system requires individual, site-specific assessment.
- Poor project design and lack of advance planning, where post-project evaluation is only considered after the project is designed and implemented.
- Funding is often a problem, as preference is given to the main project, and post-project activities are not always considered.
- The project loses momentum – a disadvantage to later activities.

Monitoring refers to a continuous assessment of the activities within a project, and evaluation deals with assessing the appropriateness, effectiveness and efficiency of the activities with regards to achieving the desired objectives (King *et al*., 2003). When used concurrently, monitoring and evaluation are effective tools in natural resource management, allowing for the efficient design and implementation of projects (King *et al*., 2003).

Monitoring is site and project-specific, however the post project evaluation process as suggested by King *et al*. (2003), is outlined in Figure 6.9.

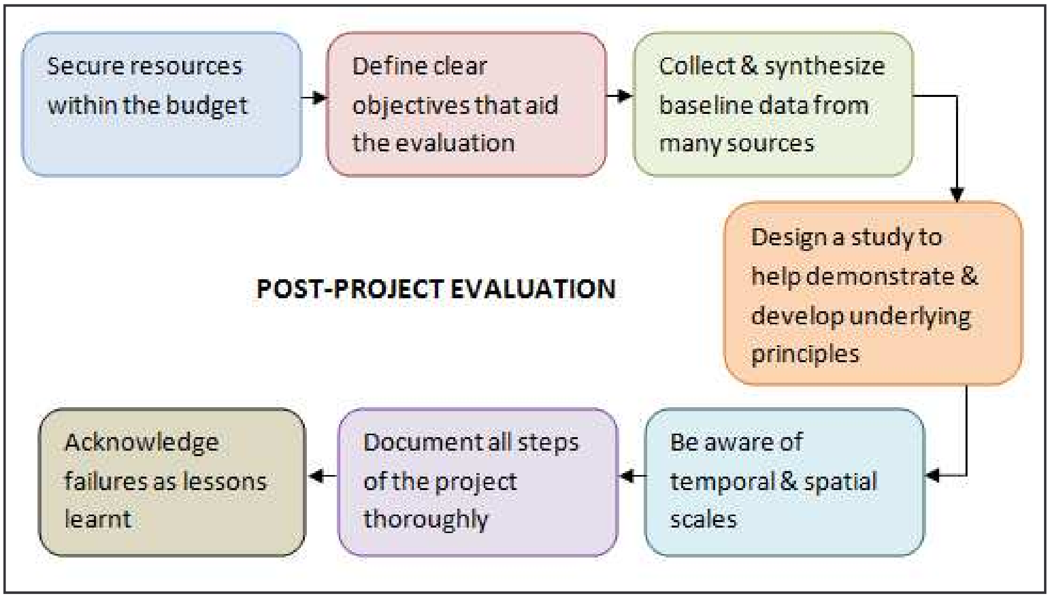

Figure 6.9. Seven key steps to post-project evaluation (King *et al.*, 2003)

6.14. Conclusion

This section aims at constructing a potential estuary management plan for the Mvoti Estuary, as there is currently no such plan in place. With the immense value of the estuary (determined only within the context of this study), and the number of pressures it has to endure, it is imperative that a management plan be adopted. This should be done not only to improve its present condition, but also to encourage aquatic and terrestrial conservation, and increase awareness of such issues amongst local users. It is therefore of extremely importance that logistical and financial aspects be secured by authorities, and such a project be planned and implemented to offer protection to the Mvoti Estuary, before its functioning is completely lost.

CHAPTER SEVEN
CONCLUSION

7.1. Conclusion and key findings of this study

The aim of this study was to assess the impacts, both natural and anthropogenic, on the sediment and water quality of the Mvoti system. The results of the research indicate that:

- The water quality of the Mvoti Estuary is extremely poor and has been experiencing deteriorations for a number of years. This water is unfit for most domestic usage and is likely to present negative impacts on aquatic health, as per South African water quality guidelines.
- Contaminants present in excessive levels in the samples are consistent with those typically associated with agricultural runoff and industrial (pulp and paper mill) discharges. This implies that it is most likely anthropogenic factors which have contributed to the degradation of the system.
- Heavy metals and other elements are present in the surface sediments of the middle and lower Mvoti system. However, the heavy metals that are present are still in lower concentrations in the Mvoti as compared to two other South African systems and two American systems and do not pose a threat.
- The elemental distribution is not similar across the lower river study sites. Concentrations were higher at sites located just below effluent disposal outlets (e.g. paper and sugar mills, sewage works etc) again, confirming anthropogenic influence.
- Even though levels of metal concentrations and enrichment were generally low and suggestive of natural sources, a moderately high pollution load index indicates that contamination is most likely due to anthropogenic input. It also suggests that due to the predominance of coarse sediments, contaminants are likely to be easily remobilised into the water column. Therefore, the sediment component of the system is potentially a contaminant source as opposed to a contaminant sink.
- Stresses imposed on the lower Mvoti system are mainly human induced, i.e. effluent disposal, water abstraction, sandmining, and riparian area clearance. These activities

have resulted in negative implications for the system in the sense that, the disturbances are ongoing and extensive and the river's ability to recover from the degradation is impaired. It therefore seems necessary that the recovery of the Mvoti Estuary is assisted by restorative and rehabilitative measures to ensure that the total functioning of the system is not lost.

Consequently, it is clear that human activities are accountable for much of the poor condition and functioning of the lower Mvoti River and Estuary. The main problems in the system are pollution and sedimentation, the latter of which is associated with land clearance. The Mvoti system is currently in distress, and without human intervention the river may soon completely lose its role as a reliable water resource, and sanctuary for aquatic fauna and vegetation and the rich diversity of bird species.

7.2. Recommendations

Numerous studies on the Mvoti system have proposed recommendations to be complied with for the estuary in terms of biological, chemical, and physical aspects of the system (MacKay *et al*., 2000a; Malherbe, 2006). However, the present study, together with that of Malherbe (2006), have both determined that the state of the estuary provides little evidence that the recommendations were implemented. This study details a number of options which could be considered to improve the condition of the system, and these include:

- Implementing the numerous laws which offer protection to the system, to control and monitor effluent disposals, water abstraction, and sandmining;
- Prevention of any further riparian zone clearance, irrespective of the activity, and the rehabilitation of this zone (with the use of indigenous vegetation);
- The users of the lower river system, to all make an effort to reduce their impacts upon the system;
- Developing and implementing a management plan for the system such as the one presented herein;
- Monitoring the system on a continued basis to ensure that it is maintained in an optimum condition.

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APPENDIX A

The Udden-Wentworth grade scale for grain size (Lewis and McConchie, 1990)