Ecosystem Service Evaluation of the Zandvlei Estuary Nature Reserve, Cape Town, South Africa

By

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DECLARATION

I, Nicole Monique Little, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

N. Little ______________________.   16.10.2024

Signed   Date

ABSTRACT

Ecosystem services, encompassing both tangible and intangible benefits derived from natural processes, play a vital role in enhancing human well-being and environmental sustainability. Estuaries and wetlands, particularly those found in peri-urban areas, offer a unique blend of ecological services and are of paramount importance to our society. However, these crucial ecosystems face escalating threats due to urban expansion, resource exploitation, and pollution, underscoring the urgency for innovative management strategies. Ecosystem-based management (EBM) presents a holistic approach that integrates both ecological and human needs into decision-making processes.

Valuing ecosystem services is pivotal in guiding sustainable resource management and making informed policy decisions. Traditional valuation methods have predominantly relied on quantifying economic values, often neglecting the less tangible social and environmental dimensions of ecosystem services. This partial assessment fails to capture the comprehensive worth of ecosystems and their services, leaving a gap in our understanding of their true value to society.

This study investigated aspects of three ecosystem services of the Zandvlei Estuary Nature Reserve (ZENR):

1) Recreational Value: A comprehensive questionnaire survey, employing a travel-cost methodology, reveals that ZENR users contribute significantly to the local economy through expenditures on travel and recreational equipment and fees. Moreover, the study sheds light on the pivotal role that ZENR plays in enhancing the social and cultural well-being of its users, with a notable 95% of respondents acknowledging its value. Additionally, over half (56%) of respondents highlight the importance of ZENR to their livelihoods. Litter management emerges as a prominent concern, with 26% of respondents expressing apprehension. The user base varies, encompassing a wide range of activities from walkers and bird watchers to on-water enthusiasts like fishers, rowers, and canoeists. Notably, walking stands as the most

popular activity, while picnicking ranks the least frequented. Walkers and picnickers tend to spend less, whereas yachters and fishers are the highest spenders. A majority of respondents reside in neighbouring areas such as Marina da Gama, Muizenberg, and Lakeside, but ZENR draws visitors from across the Cape Town metropole.

2) Water Purification Service: The study delves into the regulatory ecosystem service of water purification which occurs via the natural filtration processes within the Zandvlei Estuary, where pollutants and excess nutrients are absorbed and broken down by aquatic vegetation, sediments, and microbial communities, thereby enhancing water quality and supporting the overall health of the ecosystem. This analysis was performed utilizing data from monthly water quality tests conducted by the City of Cape Town over a decade (2009 to 2018). The analysis uncovers spatial and seasonal trends, shedding light on the estuary's vital role in reducing concentrations of pollutants such as nitrogen, phosphorus, and *E. coli*, particularly in the aftermath of events like sewage spills. However, some chemical and biological pollutants have shown an increasing trend over the years, potentially jeopardizing the estuary's health and its capacity to provide safe recreational waters. The study pinpoints the river inlets, especially the Sand River Canal, as critical areas of concern due to reduced dilution capacity, canalization, and exposure to pollutants from industrial, agricultural, and residential sources. Stormwater drains further exacerbate the contamination issue, emphasizing the need for the rehabilitation and protection of these inlets.

3) Aesthetic Value: An assessment of property values in six areas surrounding ZENR provides insights into the cultural service of the estuary's aesthetic value using hedonic pricing methodology and general regression analyses. The findings highlight the positive influence of ZENR on the surrounding property market, contributing significantly to its economic value. The hedonic pricing approach indicates a surplus of up to R174 million generated by ZENR between 2014 and 2018 in the residential property market. General regression analyses reveal a positive correlation between house prices and proximity to the estuary, extending beyond a

200-meter range in three of the six surrounding suburbs. However, these analyses are influenced by other factors such as proximity to the beach, railway lines, or roads.

It is essential to recognize that the value of an ecosystem extends beyond its monetary contributions. Ecosystem services are interconnected, and a decline in one service can have cascading effects on others. To avoid double counting, it is imperative to distinguish final ecosystem service values from support services. Effective management is pivotal in maintaining the supply of ecosystem services, and decision-makers rely on research-based information and stakeholder engagement to make informed choices.

In conclusion, this study highlights the need for comprehensive valuations of ecosystem contributions to human well-being, moving beyond conventional economic metrics and embracing holistic approaches like the System of Environmental-Economic Accounting. The ZENR case study illustrates the multi-layered benefits provided by estuarine ecosystems and the importance of sustainable management to ensure their continued provision of vital services to society.

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- Lightstone Property (Pty) Ltd for access to additional property data.
- My husband and family for their unwavering love and support, throughout this study.

DEDICATION

This thesis is dedicated to:

Arn Durand

In times of despair and lack of motivation,

Cheering yet steering me from deviation.

As you always have for me since birth.

There are no words to describe that worth.

"Nature reaches out to us with welcoming arms, and bids us enjoy her beauty; but we dread her silence and rush into the crowded cities, there to huddle like sheep fleeing from a ferocious wolf."

¬ Kahlil Gibran

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

GLOSSARY

The terms defined below are direct quotes from the sources listed.

Terms/Acronyms/Abbreviations	**Definition/Explanation**	**Source**
Natural Capital	*"The world's stocks of natural assets which include geology, soil, air, water and all living things."*	Wackernage and Rees, 1997.
Value	*"The regard that something is held to deserve; the importance, worth, or usefulness."*	Ojea *et al.,* 2010.
Ecosystem Functions	*"A subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services."*	Daily and Matson, 2008.
Option Value	*"A willingness to pay a certain sum today for the future use of an asset."*	Turpie *et al.,* 2003.
Provisioning Ecosystem Service	*"Products obtained from ecosystems such as food, water, raw materials, genetic*	Town *et al.,* 2014.

	resources (including crop improvement genes, and medicines).”	
Regulatory Ecosystem Services	*”Benefits obtained from the regulation of ecosystem processes such as carbon sequestration and climate regulation, waste decomposition and detoxification, purification of water and air, pest and disease control ”*	Van Wilgen *et al.,* 2012
Cultural Ecosystem Service	*“Non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.”*	Turpie and Clark, 2007.
Support Services	*“Services needed to produce all other ecosystem services. These include services such as nutrient recycling, primary production and soil formation. These services make it possible for the ecosystems to provide services such as*	Daily and Matson, 2008.

	food supply, flood regulation, and water purification."	
Ecosystem Health	*"Describes the condition of an ecosystem. Ecosystem conditions can vary as a result of fire, flooding, drought, extinctions, invasive species, climate change, mining, overexploitation in fishing, farming or logging, chemical spills"*	Halper *et al.,* 2012; Turpie and Clark, 2007
Value System	*"A set of consistent values used for ethical or ideological integrity."*	Defra, 2007.
Ocean Governance	*"How affairs are governed, not only by governments, but also by local communities, industries, and other stakeholders, which includes national and international law, public and private law, as well as custom, tradition and culture, and the institutions and processes created by them."*	Borgese, 2001.

Ecological Governance	*"A process of informed decision-making that enables trade-offs between competing resource users to balance environmental protection with beneficial use in such a way as to mitigate conflict, enhance equity, ensure sustainability and allow accountability."*	Turton *et al.,* 2007.
Trade-Off	*"A balance achieved between two desirable but incompatible features; a compromise."*	Groot *et al.,* 2010.
Travel Cost	*"A technique of economic valuation used in a cost-benefit analysis to calculate the value of something that cannot be obtained through market prices."*	Wilson and Carpenter, 1999.
Contingent Valuation	*"The method of valuation used in cost-benefit analysis and environmental accounting. It is dependent on the creation of assumed*	Brouwer *et al.,* 1997.

	markets, illustrated in expressions of the willingness to pay for potential environmental benefits or the avoidance of their loss."	
Hedonic Pricing	*"A model identifying price factors according to the premise that price is determined both by internal characteristics of the good being sold and external factors affecting it."*	Wilson and Carpenter, 1999.
Market Value	*"The amount for which something can be sold on a given market."*	Howarth and Farber, 2002.
Non-Market Value	*"Many environmental goods and services, such as clean air and water, and healthy fish and wildlife populations, are not traded in markets. Their economic value - how much people would be willing to pay for them - is not revealed in market prices."*	Howarth and Farber, 2002.

Public Goods and Services	*"A public good (or service) may be consumed without reducing the amount available for others and cannot be withheld from those who do not pay for it."*	Howarth and Farber, 2002.
Ecosystem Services	*"Benefits humans gain from the environment either directly or indirectly."*	Ojea *et al.,* 2010.

CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Introduction

Ecosystem services are the conditions, processes and assets that ecosystems produce as the final goods and services from which humans benefit. These include provisioning services such as harvestable products, (food, building materials, medicine etc.) regulatory services such as nutrient assimilation or recycling, and the cultural services of often intangible aesthetics and cultural benefits (Chee, 2004). Ecosystem services also encompass supporting services from which humans do not directly benefit, but without which, the final benefits to humans would cease to exist. These include functions such as biodiversity maintenance, nutrient cycling, and primary productivity (Figure 1 below).

Catchment areas and river systems supply extensive water-related ecosystem services including the supply of clean water for consumption and recreation as well as flood-alleviation by wetlands. Wetlands and estuaries remain undervalued within policy and infrastructural planning and therefore continue to be degraded by anthropogenic threats such as increased nutrient inputs from farming, industrial and residential infrastructure and development, pollution and or poaching (Zhang et al., 2007),

To conserve the benefits that river and wetland ecosystems produce, policy and decision-makers need an integrated approach that incorporates not only the natural functioning of these ecosystems but the needs of the surrounding communities and local economy as well (Farmer, A., 2012). Ecosystem-based Management (EBM) is an inclusive approach to management that incorporates both human societal needs and ecological integrity and where ecosystem service valuations play a major role.

Costanza and Daly (1992) introduced the concept of “natural capital” illustrating the importance of natural systems by highlighting the various ecosystem services necessary for social and economic development. Costanza et al. (1997) estimated the total economic value for all ecosystem services on earth, by studying 17 different ecosystem services across 16 different biomes at US$ 3 trillion per year in 1997. Despite criticism of this broad approach (e.g. Seidl et al., 2000; Pagiola et al., 2004; Pimentel, 1998; Herendeen, 1998), the study raised awareness of ecosystems and their importance in the provision of natural capital to economic growth (Costanza *et al.* 1997).

De Groot *et al.* (2002) formed an ecosystem service classification system that links environmental processes to the goods and services they provide. In this paper, they classified a range of 23 ecosystem services and provided a checklist of the valuation method best for each of these functions (De Groot et al., 2002).

The Millennium Ecosystem Assessment (MEA, 2005) was initiated by the United Nations in 2001 to assess changes in ecosystems to strengthen the sustainable use of ecosystems and their associated benefits to the social and economic sectors (Millennium Ecosystem Assessment, 2005). The MEA developed a basic framework for the classification of ecosystem services into four main categories, namely, provisioning, regulating, cultural and supporting services (Figure 1 below).

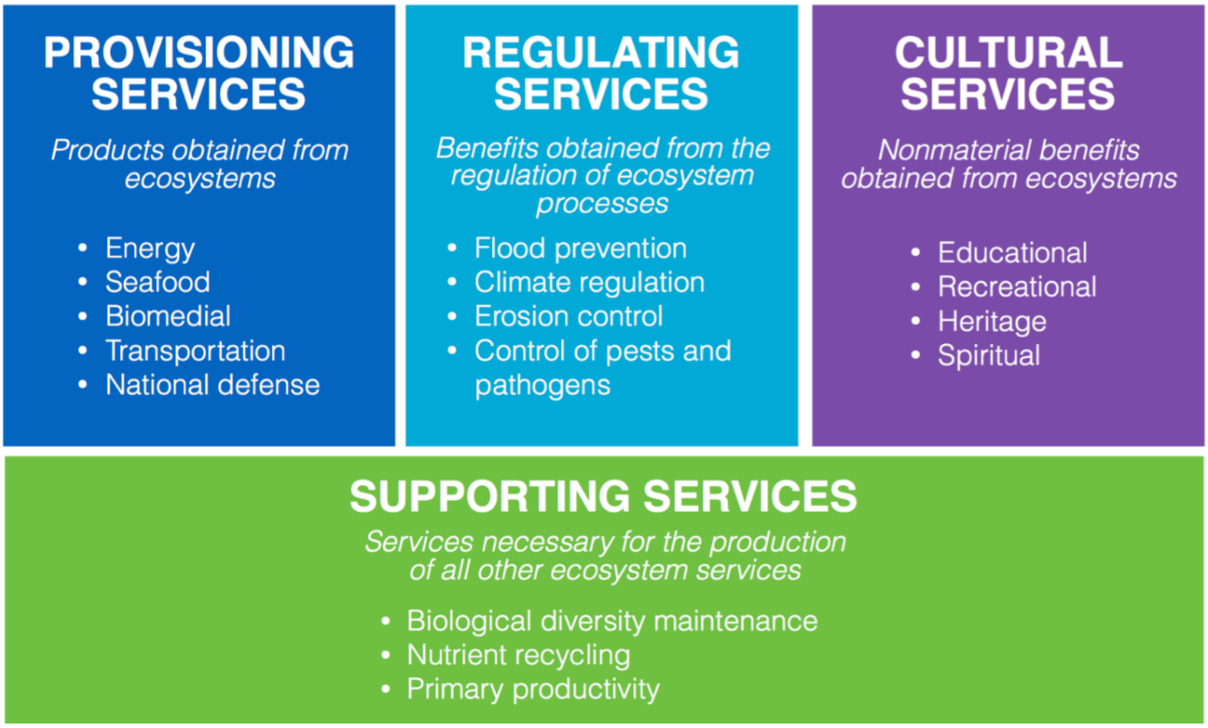

Figure 1 The classification of Ecosystem Services Millennium Ecosystem Assessment, (2005).

CICES was developed because of environmental accounting efforts and supports the revision of the System of Environmental-Economic Accounting (SEEA), which is currently being led by the United Nations Statistical Division (UNSD) (Haines-Young and Potschin, 2012). Dr. Robert Haines-Young and Dr. Melanie Potschin-Young are known for their contributions to the development of the Common International Classification of Ecosystem Services (CICES) framework. Haines-Young and Potschin-Young's work on the CICES framework has been influential in shaping how ecosystem services are categorized and assessed (Haines-Young and Potschin, 2012). CICES is more of a classification system than a specific framework like that of the MA. It provides a hierarchical structure for categorizing ecosystem services based on different levels of detail. CICES has three levels of classification:

Level 1: Divides ecosystem services into three main categories: provisioning, regulating and maintenance, and cultural services.

Level 2: Further breaks down these main categories into more specific groups of services.

Level 3: Provides detailed sub-categories of ecosystem services.

While all three frameworks share some common themes in their categorization of ecosystem services, the framework by De Groot *et al*. (2010) has similarities with both the MEA and CICES frameworks. The emphasis on categorizing ecosystem services based on their functions and benefits to humans is a common thread among these frameworks. However, the specifics of the categories and the organization of the classification levels might differ due to variations in terminology and evolving understanding of ecosystem services over time.

Haines-Young and Potschin-Young's CICES framework aligns with De Groot *et al*.'s (2002) and the Millennium Ecosystem Assessment (MEA) frameworks in terms of its attempt to provide a structured classification of ecosystem services. All three frameworks recognize the diverse contributions of ecosystems to human well-being and the need for a systematic approach to categorizing these services.

However, while De Groot *et al*. (2002) and MA frameworks provide a more general categorization of ecosystem services based on functions and benefits, the CICES framework offers a comprehensive and standardized classification system with multiple levels of detail. The CICES framework's hierarchical structure allows for finer granularity in classifying ecosystem services, which can be advantageous for different assessment needs and scales.

In summary, Haines-Young and Potschin-Young's work on the CICES framework contributes to the evolution of ecosystem service classification by providing a detailed and standardized system for categorizing ecosystem services. This classification system can be seen as an evolution of the ideas presented in De Groot *et al*.'s (2002) framework and is another approach to organizing ecosystem services similar to the MEA framework.

Since the MEA, the number of studies on the relationship between biodiversity and ecosystem services has increased although most have largely focused on provisioning or regulating services leaving little understanding of the socio-cultural values that are also essential to human well-being. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework has addressed this gap by defining the concept of "nature's contribution to people", which includes both material and non-material links between nature and people such as cultural ecosystem services (Tribot et al., 2018; Diaz et al., 2019).

The IPBES conducted one of the first critical assessments of ecosystem services since the MEA in 2005. This assessment aimed to evaluate available knowledge on the status and trends of biodiversity and ecosystem services around the globe and to provide an updated framework for policy and decision-makers within the environmental sector. One hundred and fifty experts assessed over 15 000 published articles, in addition to indigenous and local knowledge sources. Using the concept of nature's contribution to people to broaden the understanding of an ecosystem's value to societies' knowledge obtained from nature by indigenous and local communities was incorporated (Diaz et al., 2019).

Ecosystem accounting, also referred to as natural capital accounting, is a framework designed to integrate the values of ecosystem services into economic and policy decision-making by quantifying and valuing the benefits that ecosystems provide to human well-being. This approach involves systematically assessing and accounting for the contributions of ecosystems to the economy, allowing for a more holistic understanding of the relationship between the environment and the economy. Ecosystem accounting provides a structured way to incorporate the value of ecosystem services into national accounting systems, similar to how traditional economic activities are accounted for.

One of the prominent initiatives in ecosystem accounting is the System of Environmental-Economic Accounting (SEEA) framework, which is developed by the United Nations Statistics Division. SEEA includes the development of satellite accounts that capture the contributions of ecosystems and natural resources to the economy. These satellite accounts are integrated with the core national accounts to provide a comprehensive picture of economic and environmental interactions (Hamilton, 2016; European Commission. Eurostat. et al., 2014).

The relevance of ecosystem accounting to ecosystem service valuations lies in its ability to enhance the valuation of ecosystem services by providing a systematic framework to integrate these values into broader economic indicators. It enables decision-makers to recognize and consider the trade-offs and dependencies between economic development and environmental sustainability. By incorporating ecosystem services into national accounts, policymakers can make informed decisions that balance economic growth with the maintenance of natural capital and ecosystem services (van der Ploeg, 2010; Ring et al., 2010; Bherwani et al., 2020).

1.2 Study Site - The Zandvlei Estuary Nature Reserve (ZENR)

Background

The ZENR is one of three inland water bodies on the Cape Peninsula available to the city's population for inland water-based recreational purposes. South Africa's high-energy coastline means that many recreational activities are limited in the true marine environment so inland systems such as Zandvlei are vital for providing such opportunities in coastal areas. Regardless of the various changes that have occurred over the years, Zandvlei remains one of Cape Town's most popular recreational facilities as its natural features provide a variety of individual recreational activities throughout the year, including *inter alia* walking/hiking, canoeing, picnicking, birdwatching, yachting and fishing (Quick and Harding, 1994; Department of Environmental Affairs, 2018). To this end, the shores of Zandvlei are home to Sea Cadet and Sea Scout bases as well as sailing and canoe clubs.

Zandvlei furthermore plays host to numerous formal annual sporting events which further illustrates its importance as a recreation site. The annual International Kite Festival, which is the largest of such event on the continent, draws up to 20 000 people from all over the world into the area. Examples of other events include the 1998 World Canoe Championships and 2017, 2020 and 2021 National Canoe Championship Events (although the 2020 event was cancelled due to the COVID-19 pandemic), the Annual Provincial Kontikki Expedition, and various yachting events (Department of Environmental Affairs, 2018; Jackson et al., 2010)

A study by Thornton et al. (1989) found that Zandvlei hosts between 2 000 and 3 000 users per day during peak season between 1987/8. Considering the population of Cape Town has increased by 91.6% from 1995 to 2019 (from 2 400 000 to 4 600 000), an assumption of the same rate of increase for the users of Zandvlei would mean that the Estuary system could see up to 3 800 - 5 750 users per day during the peak season in 2019. However, there is certainly a saturation limit to what the system can tolerate. Furthermore, the state of degradation of the system over the last decade or so implies that popularity of the system may not have been constant over the same time period and therefore simply scaling up might not tell the true story of the actual peak utilisation.

The variety of recreational activities which Zandvlei provides can also be attributed to the geographic range from which users originate. This includes the local surrounding areas of Muizenberg, Marina da Gama, Lakeside and Lakeside North, lower-income suburbs such as Lavender Hills, Grassy Park, Strandfontein, and Mitchell's Plain as well as affluent areas such as Constantia and Tokai. The range illustrates the broad societal benefit that Zandvlei serves in providing people from diverse backgrounds with a natural space to participate in outdoor activities and lifestyles.

<u>Location</u>

Situated on the North-Western shore of False Bay and linked to entering the ocean at Muizenberg beach (Figure 2 below) (Harding, 1994), Zandvlei is the only fully functioning estuary on the False Bay coast (although its mouth is seasonally managed to alleviate winter flooding of residential properties and summer low water level challenges).

Figure 2 The ZENR and surrounding area (Source QGIS 3.22; City of Cape Town 2019).

Description of the ZENR

The catchment area for the ZENR lies within the Central Cape Peninsula. Although the estuary lies at the foothills of Muizenberg Peak, most of the rivers found in this part of the Table Mountain Range do not drain into the ZENR (Department of Environmental Affairs, 2018), and Zandvlei is fed largely from the north by flows from the Constantia and Wynberg hills, as well as from part of the Cape Flats. Inflow consists of its three primary rivers, namely: the Westlake River to the east, the Keyser's River and the canalised Sand River to the north totalling a catchment of only 92 km^2 in size (Thornton et al., 1995). The system comprises a degraded 60-hectare wetland area along its northern border, impacted by canalization and the railway line. Additionally, it features a primary body of 56 hectares. There is also a narrower serpentine channel and a 31-hectare constructed marina that lines the eastern margin of the estuary. The estuary waters exit via a narrow, canalised outlet on the north-western shore of False Bay, near Muizenberg Beach (Figure 2 above) (Jackson et al., 2010; Quick and Harding, 1994).

Ecology

The ZENR was officially proclaimed as a Nature Reserve in 1977. In October 2006 the Greater Zandvlei Estuary Nature Reserve was formally established with local authority nature reserve status under Section 7 of the Cape Nature Conservation Ordinance 19 of 1974. The proclamation placed greater priority on the importance of conserving the ZENR and has led to various changes in the system's management of water quality, drainage, flow and ecology (Viskich et al., 2016; Jackson et al., 2010). The management of the Zandvlei Estuary and the Zandvlei Estuary Nature Reserve is undertaken by the City of Cape Town (Department of Environmental Affairs, 2018). The ZENR or the management thereof has since been recognized under the NEM: Protected Areas Act 57 of 2003. Although the Zandvlei Estuary and catchment fall within the jurisdiction of the City of Cape Town (CoCT), responsibility for the management of the area, and activities that impact the reserve, is shared across multiple departments within the CoCT and are coordinated through the Zandvlei Action Committee

(Department of Environmental Affairs, 2018). The Zandvlei Estuary Advisory Forum is now incorporated as the Protected Area Advisory Committee.

Stuckenia pectinata (pondweed) occurs naturally in the ZES and is the most common aquatic plant here. A few alien invasive aquatic species also occur and include parrot's feather (*Myriopyllum aquaticum*), hornwort (*Ceratophyllum demersum*), red waterfern (*Azolla filliculoides*) and water hyacinth (*Eichornia crassipes*). Semi-aquatic plant species include large beds of *Phragmites australis* as well as *Typha capensis* and several sedges (*Scirpus spp* and *Juncus kraussii*) (Maurer, 2019)

Ficopomatus enigmaticus, a tube-forming polychaete better known as "coral worm", is another problematic species in Zandvlei. It is a highly invasive, non-indigenous reef-building polychaete. Ideal conditions resulting from oxygen and salinity stratification (arising in turn from the design of the Marina da Gama) have led to the rapid growth of its population (McQuaid, 2013).

Since the development of the Marina, the only remaining natural vegetation can be found along the northern section of the vlei, mainly consisting of low sparse shrubland and disturbed dune scrub. The area east of the railway line (the original Nature Reserve) consisted of wetland and Strandveld vegetation types, including 107 indigenous species. The current plant list for the ZENR includes 360 species, of which at least 36 are invasive aliens (Jackson et al., 2010). The reserve is also home to the critically endangered flowering plant, *Psoralea glaucina*.

The ZENR is also one of the very few protected areas in the Western Cape which provide suitable breeding habitats for the endangered western leopard toad (*Amietophrynus pantherinus*) (Jackson et al., 2010). One of the biggest threats to the western leopard toad is the introduced guttural toad *Amietophrynus gutturalis,* which has been found in both the Zeekoevlei and Zandvlei areas (McQuaid, 2013).

The ZENR is likely to be an important nursery area for many fish species such as leervis (*Lichia amia*), white steenbras (*Lithognathus lithognathus*), flathead mullet (*Mugil cephalus*), and cape stumpnose (*Rhabdosargus holubi*). However, after the development of a rubble weir at the mouth to retain water volume in the system, marine fish recruitment may have been reduced significantly as the weir prevented the movement of young fish in and out of the estuary (Jackson et al., 2010). Turpie and Clark (2007) attributed a fish nursery value of between R 1 – 5 million per year to Zandvlei. Lowering of this rubble weir over the years may have significantly increased fish movement in and out of the system (Jackson et al., 2010).

Regular bird counts have been undertaken at the ZENR since 1993. The ZENR was ranked 16th among coastal wetlands for the number of bird species in the South-Western Cape in 1979 (Ryan *et al*, 1988). There have been 166 bird species recorded at the ZENR, of which 39 are breeding species. There has been a general decline in the abundance and variety of waders for species associated with Pondweed. This is likely due to the harvesting of the Pondweed, dredging and resulting changes in habitat and increased urban development along the banks.

Thirty mammal species were recorded in the general area of Zandvlei by Morant and Grindley, (1982). These included a variety of rodents such as the Cape Golden Mole (*Chrysochloris asiatica*), cape dune mole rat *(Bathyergus suillus),* porcupine *(Hystrix africaeustralis),* stripped field mouse *(Rhabdomys pumilio),* pygmy mouse *(Mus minutoides),* vlei rat *(Otomys irroratus)*, forest fhrew *(Myosorex varius),* house mouse *(Mus musculus)*, brown rat *(Rattus norvegicus)*, cape molerat *(Georychus capensis)* and cape gerbil *(Tetra afra),* larger mammals such as the cape grysbok (*Raphicerus melanotis*), cape clawless otter (*Aonyx capensis)*, cape grey mongoose *(Galerella pulverulentus)*, water mongoose (*Atilax paludinosus)*, the cape fur seal *(Arctocephalus pusillus)*, large spotted genet *(Genetta tirina),* caracal or rooikat *(Caracal caracal*), *(Vulpus chama)* cape fox and domesticated species such as the domestic dog *(Canis domesticus) and* domestic cat (*Felis domesticus)* (Zandvlei Inventory and Monitoring Programme (ZIMP) (www.zandvleitrust.org.za).

History

During the 1950s, a rise in urban development around the ZENR resulted in an increased need for recreational use of the estuary. The canalization of the outlet channel, the construction of the promenade and Royal Road Bridge over the mouth and the rubble weir (which was initially built to protect a sewer line from erosion) also meant that water levels could be controlled for water sports such as yachting and boating during the summer months (Thornton et al., 1995). A residential development, the Marina da Gama was constructed along the Eastern Shore during the early 1970s. A large amount of sand had to be excavated and was used to create two islands (Park Island and Wildwood Island, Figure 2) in the middle of the water body which is now home to various fauna and flora (Jackson et al., 2010; Thornton et al., 1995).

1.3 Statement of the Research Problem

Regardless of the increase in ecosystem service valuation studies world world-wide (Carpenter et al., 2009; Sander and Haight, 2012; Reynaud and Lanzanova, 2017; Zhang et al., 2007; Bennett et al., 2009; Sylla et al., 2019; Howarth and Farber, 2002), research suggests that humans are exploiting the earth's ecosystems of their resources faster than these systems can replenish (Howard, 2000; Schramski et al., 2015; Harte, 2007; Sparks, 1999; Dustin et al., 2010). This reflects an inadequate value having been placed on natural capital and environmental assets in terms of sustainability (Wackernage and Rees, 1997). Governments and local authorities need to work with researchers, both locally and internationally, to implement the necessary policy plans and procedures to prioritise and conserve what little resources remain in our exploited ecosystems (Pimbert and Pretty, 1995).

The ZENR is one of only three estuarine systems in the Cape Peninsula that provides Cape Town residents with inland aquatic recreational opportunities (others including Zeekoevlei and Milnerton Lagoon and Rietvlei). The ZENR faces increasing pressures from the surrounding urban expansion including increased nutrient and pollutant loads arising through loadshedding and ageing infrastructure, canalisation, unnatural water level fluctuations, increased agriculture within the catchment area which increases sediment and nutrient inflows and increased infrastructure surrounding the vlei which has significantly increased effluent and litter inputs into the vlei. The Estuary's ability to supply ecosystem services such as suitable water for recreation and aesthetic values for the surrounding users and property market is at risk if these threats continue to rise. Very few valuation studies have been conducted at the ZENR (and none in the last 13 years). Therefore, updated information of the environmental, social and economic value of the Estuary, is needed for EBM to make informed and sound decisions.

The research area is defined as the ZENR, ending where tidal or salinity influences end and includes the surrounding natural habitat and urban development along the estuary's perimeter to a distance of 300m.

1.4 Research Objectives

This Study has the following Research Objectives:

- An investigation of the use-values and perceptions of different user groups of the ZENR as a recreation site.
- An assessment of the role the ZENR plays in the provision of clean water for recreational and aesthetic values.
- A determination of the influence of the ZENR on the surrounding property market as a proxy for its aesthetic value.

CHAPTER 2: RECREATIONAL USE VALUE OF THE ZANDVLEI ESTUARY SYSTEM

2.1 Introduction and Literature Review

After the Millennium Ecosystem Assessment (MEA) in 2005, Boyd and Banzhaf (2006) redefined ecosystem services by proposing standardized ecosystem service units for goods and services to be included within national welfare accounting. They proposed that ecosystem services are not the benefits humans obtain from ecosystems such as recreation, but rather the ecological components directly consumed or appreciated to contribute to human well-being. The ecosystem services that may help produce a recreational benefit could include components such as a waterbody, wetland, or forest (Boyd and Banzhaf, 2006).

Whilst several ecosystem service valuations have been carried out in South Africa (Quick and Harding, 1994; Town et al., 2014; Viskich et al., 2016), with many focusing on estuaries specifically (Cooper et al., 2003; Turpie and Clark, 2007; Marais et al., 2021; Hosking ed., 2010), the environmental values of estuarine systems are still largely undervalued within the social and economic sectors due to a lack of funding and associated research, and an understanding of value by local management authorities and government (Turpie and Clark, 2007).

Coastal and marine ecosystems including wetlands and estuaries supply an abundance of opportunities for recreational activities such as boating, fishing and swimming. Studies investigating cultural ecosystem services highlight recreation as one of the most valuable activities supported by these systems (Hynes et al., 2018; Hanley et al., 2015). Recreation is known to improve well-being and encourage public support for conservation practices (Daniel et al., 2012; Hanley et al., 2015; Hynes et al., 2018; Olden and Tamayo, 2014).

The number of studies investigating recreational values has increased globally in recent years. A 2010 survey of the United Kingdom estimated that 2 858 000 outdoor recreational visits were made across the country within that year, resulting in £20 billion for the economy (Natural England, 2012). A further UK ecosystem assessment in 2014 of the cultural value of marine protected areas and associated ecosystem services, found that recreational users were willing to pay up to £1.3 billion for the protection of such areas in addition to their user expenses (Jobstvogt et al., 2014; Hanley et al., 2015). Carlsen and Wood, (2004) conducted a valuation assessment of the national parks (marine and terrestrial) in Western Australia and estimated the annual direct tourist expenditure within two regions. Visitor expenditure attributable to the Southern Forest Region was estimated at up to 70 million Australian dollars annually, while up to $138 million was spent by users of the Gascoyne Coast Region each year (Carlsen and Wood, 2004). Using the travel cost method, Shrestha et al., (2007) investigated the value of recreation in the Apalachicola River region of Florida, USA and found that users spent on average $74.18 per visit-day, resulting in a total value of $484,560,000 to the economy (Shrestha et al., 2007) per annum.

Whilst recreation can promote revenue and social upliftment, exceeding the visitor carrying capacity of a natural environment can have detrimental effects on the area. Several United States National Parks have had to implement a visitor permit system after studies revealed that annual visitors were negatively impacting the natural environment due to trampling fragile foliage and soils, increased litter, light and noise pollution, as well as hampering visitor experience through overcrowding (Neuvonen et al., 2010; Van Wagtendonk, 1981; Manning, 2002). The management strategies to mitigate these impacts involved limiting visitor use through permits (limiting visitor numbers), restricting visits to areas/zones as well as visitor education on appropriate behaviour and the importance of environmental conservation.

In South Africa, Turpie and Clark (2007) conducted a large-scale study for all 149 larger estuaries in the country, which included the estimation of the tourism value of these estuaries by investigating visitors' expenses on travel and accommodation to the surrounding areas. However, they found that only a portion of this expenditure can be attributed to the estuary itself through recreation. They estimated that the majority of estuaries had a recreational value of between R10,000 and R1 million per annum and a total value of up to R2 billion per annum through tourism.

Cooper *et al.* (2003), investigated the recreational value of four major South African estuaries. Total annual recreational value (consisting of travel, accommodation, and meal costs) was estimated at R331,503,403 for the Berg Estuary, R414,455,094 for the Breede Estuary, R6,870,264 for the Richard's Bay Estuary and R53,964,106 for the Keiskamma Estuary.

Using travel, accommodation, and meal costs of visitors of the Knysna Estuary during 2002, along with visitor number data from the local travel associations, the Knysna Estuary was estimated to induce R1 billion of visitor expenditure per annum and 60% of the town's economy during 2002 (Cooper et al., 2003). The Kromme Estuary was accountable for R25 million in visitor expenditure as well as seventeen per cent of the attraction for the surrounding areas (Akoto and Hosking, 2009). The Seekoei Estuary was accountable for R3 million in visitor expenditure and 10% of the attraction for the surrounding areas (Turpie et al., 2009). The Goukamma Estuary induced up to R350,000 per annum in visitor expenditure (Turpie, 2006). The Kleinemonde Estuary was valued at up to R3.4 million per annum. The relatively small proportion of economic input from this estuary was due to other high-value use areas nearby such as beaches (Turpie et al., 2009).

Few recreational value studies have been conducted on the ZENR. Turpie and Joubert (2001) used the travel cost method to investigate the willingness of recreational users to pay a consumer surplus (an amount over and above what they spend to partake in their relative recreational activity) for conservation at the ZENR and found that users were willing to pay an average R15 per visit above their activity costs towards the preservation of the ZENR. This was a total surplus value of R713,500 per annum.

In 2006 the ZENR was proclaimed into the ZENR which Jackson et al., (2010) suggested would have a positive effect on this value. The following year, the recreational value of the ZENR was estimated at between R 1 and 5 million per year (Turpie and Clark, 2007).

Ecosystem service valuation studies that rely solely on an economic (monetary) value-based approach offer valuable insights for policymaking and budgeting by quantifying the measurable economic benefits of ecosystems. However, it is essential to acknowledge their limitations. While monetary valuation is adept at assigning a price tag to goods and services provided by ecosystems, it often falls short in capturing the broader significance of ecosystems to social wellbeing, livelihoods, and the perceptions and attitudes of visitors. Ecosystems offer an array of non-market benefits, including cultural and aesthetic values, which are challenging to quantify in monetary terms yet are vital for human flourishing. Moreover, ecosystems support social wellbeing and livelihoods in various ways beyond their economic contributions, such as providing cultural resources and recreational spaces. Visitor perceptions and attitudes toward ecosystems can significantly influence their use and management, often shaped by cultural factors and personal experiences that may not align neatly with economic valuations. Thus, while monetary valuation is a crucial tool, it should be complemented by a holistic, multidisciplinary approach that incorporates both economic and non-economic indicators and takes into account the rich tapestry of human values and relationships with ecosystems. This approach ensures that ecosystem management decisions are informed by a comprehensive understanding of the multifaceted role of ecosystems in supporting human wellbeing and environmental sustainability. Therefore, a more holistic management approach has been undertaken to broaden the understanding of an ecosystem's value to society.

Visitor perceptions and attitudes towards management

Effective management of recreational ecosystem services relies on understanding how they are perceived by the individuals who benefit from them (Daily, 1997). Therefore, it is essential to explore user perceptions (Schnurr & Holtz, 1998; Daily et al., 2000) to guide management strategies and decisions within adaptive policy frameworks (Petrosillo et al., 2007). Investigated tourist perception in a marine protected area (MPA) in Italy and found that a visitor's socio-economic status, level of education, place of residence, cultural ties, and past experiences all influenced their perception of the quality of the environment and its management. Their results highlighted the importance of profiling the visitors to protected areas to better manage their concerns, perceptions, attitudes, and requirements.

Within this study, users of the ZENR were questioned on their perceptions and attitudes on several management issues and the perceived efficacy of management approaches across the issues introduced below.

Litter Management

For the last 70 years, the production, consumption, and consequent disposal of plastics (and microplastics) in our natural environments have increased exponentially (Löhr et al. 2017). Schmidt *et al.* (2017) found that river outputs accounted for up to four million tonnes of plastic pollutants in the world's oceans per annum, estimating that the top 10 ranked rivers deposited up to 95% of the plastic pollutants into the world's oceans.

Litter pollution and microplastics can have negative social, economic and environmental impacts. United Nations Environment Programme (2014) estimated the cost to activities such as recreation and tourism due to litter at around $8 billion per year. Furthermore, there is growing evidence regarding the effects of microplastics on the organisms that we consume and therefore overall human health through ingestion (Derraik, 2002; Löhr et al. 2017).

Ryan and Turpie, (2000) investigated the effect of litter on beach users along the Cape Peninsula, and the consequent effect on the economy. Using the travel cost method, the recreational value of beaches within this area was estimated at between R3 million and R23 million per annum. The large range is due to several assumptions associated with the Travel Cost Method, as well as the limited data available. In a survey interview, beachgoers (especially foreign tourists) stated that cleanliness was the most influencing factor when choosing a beach. Almost 50% were willing to spend seven times their average travel cost to visit clean beaches. They estimated that a decline in cleanliness could result in a drop in the recreational value of these beaches of up to 97% (Ryan and Turpie, 2000).

Zandvlei Mouth Conditions, Water Levels, Salinity and Sedimentation

Controlling the volume of water within the ZENR has occurred since the mid-19th century when an attempt was made to drain it for agricultural purposes. When this failed, higher water levels were maintained for sport and recreation. Shortly after the outlet channel was canalized in the 1950s, a concrete weir was built underneath the Royal Road Bridge (see Figure 2). This weir disintegrated and shortly after a rubble weir was built in its place to prevent corrosion and damage to the main sewer line which crosses the estuary mouth in this area. This rubble weir now serves to control the water levels for the system. In addition, the mouth at Muizenberg beach is mechanically closed using a bulldozed sand berm at the end of the winter rainfall season and then opened periodically through the summer to maintain water quality and levels in the estuary and again at the beginning of the following winter.

Both the rubble weir and the berm increase the water turnover/retention time within the main vlei area of Zandvlei, possibly increasing pollutant, sediment and nutrient retention in the system. Sediment deposits within the ZENR occur from natural erosion and sediment input upstream and anthropogenic sources from land. Canalization of the outlet channel means that the mouth of the estuary does not flow along the coast as it did naturally, allowing it to deposit this sediment on the beach (Jackson et al., 2010). The sediment is currently forced to collect within the main body of the vlei and the outlet channel which results in reduced water flows, and regular dredging has to take place to remove the build-up of sediment (Quick and Harding, 1994).

Natural water levels were likely to have been between 0 and 3 m above mean sea level (amsl). The present water levels are maintained between 0.6 and1.4 m amsl for several reasons:

- To protect concrete revetments in the Marina da Gama
- To mitigate flooding of properties at 1.4 m.
- To protect houses at risk of erosion when water levels are lower than 1.4 m
- A depth of 1m is needed for boating activities
- A depth of 0.8 m is needed to operate the weed harvester (Department of Environmental Affairs, 2018).

The limited water circulation within the canals of the Marina has contributed to the anoxic conditions for prolonged periods of calm and is worsened as the canals are deeper than the main water body and therefore act as traps for decaying matter (Jackson et al., 2010; Morant and Grindley, 1982).

Safety and Law Enforcement

In addition to a private security company whose rangers are stationed at the ZENR to cover basic safety and compliance tasks on behalf of the Estuary's Management authority, a Coastal Compliance and Law Enforcement Task Team, as well as a Marine and Environmental Law Enforcement Unit for the City of Cape Town, have been established. These local and provincial marine units have conducted several successful operations in the ZENR area to date, however, regulation compliance and visitor safety are still a major priority for managers (Department of Environmental Affairs, 2018).

Water Quality Management

Regardless of their ability in water filtration, estuaries are susceptible to the build-up of nutrients and pollutants (Russell and Greening, 2013). This is a major concern for ZENR management which, at times is pressured to reduce its natural breaching conditions to allow for the many recreation activities, and other pressures thus preventing pollutants from being flushed from the system. This is further intensified within the canal system of the Marina where the water is deeper and therefore reduces the flow, preventing nutrient flow.

Thornton and McMillan (1989) conducted a comprehensive questionnaire survey involving over 3000 water-based recreational users within the regions of Cape Town and Pretoria, including the Zandvlei Estuary System. The primary objective of their survey was to gather insights into the perspectives and concerns of individuals engaged in water-based recreational activities. Notably, the participants expressed significant apprehensions regarding issues related to water quality, specifically citing excessive plant growth and visual factors affecting water quality. These findings shed light on the environmental quality concerns associated with recreational water bodies. The large sample size (3000) was employed to ensure robust and representative results. Such surveys serve as essential tools for engaging the public in environmental management, helping to identify areas of concern and inform policies and actions aimed at enhancing the quality of recreational experiences in these natural settings. The results from surveys of this nature often play a pivotal role in guiding management decisions, encouraging further research, and influencing environmental policies and practices.

Various sources of pollutants can be identified within the Zandvlei catchment which can be detrimental to its value as a recreation site and water filtration system. These include direct deposits from settlements along the lower reaches to run-off of agricultural herbicides and pesticides in the upper reaches which run through the farmlands of Constantia and Tokai. Rivers within the catchment also flow through a large industrial area (Department of Environmental Affairs, 2018). Further water-quality threats to the ZENR include sewage spills (most common), high levels of phosphorus and low levels of oxygen as well as algal blooms which can cause fish to die off (Department of Environmental Affairs, 2018).

The ageing sewer system surrounding the ZENR is subject to vandalism due to theft of the metal pumps and associated cables, accidental and active blockages that cause overflows, and age and severe weathering, resulting in the bulk sewer lines collapsing, all contributing to the frequent severe sewage inflows into the ZES. The ZENR management has put in place mitigation procedures and protocols in the event of a sewage spill to alleviate the effects of *E. coli* and pollutants on the estuary system and human health. Monitoring of the water quality is carried out via analyses of the monthly water samples taken throughout the system.

It is important to note that after this study, in 2021, the vlei was closed to recreational water use due to high *E. coli* levels for over nine months, resulting in significant losses to user groups. This closure was exacerbated by the co-incident closure of both Zeekoeivlei and Rietvlei due to similarly high levels of *E. coli* in the systems.

Education, Awareness-Raising and Communications

Public awareness and education on the importance of estuaries and wetlands are crucial for the effective implementation of management programs both in the Nature Reserve and in surrounding areas. This is particularly true in the case of the ZENR where there is both a high level of recreational use, surrounded by high and low-income residential areas in relative proximity to the reserve and the rivers flowing into it.

At present, there is a well-established environmental education program run by the Reserve staff with support from the Zandvlei Trust (ZT) as well as a community-based salinity monitoring program. The current ZENR management plan (Department of Environmental Affairs, 2018) identifies the need for continuing education programs with the surrounding schools, the creation of environmental clubs and holiday programs, relationships with the youth groups (scouts and sea cadets); sports groups such as the canoe club, an adult-based community program, a poster-based marketing campaign, and an “adopt-a-patch” program to attract investors to the area (Department of Environmental Affairs, 2018).

Pondweed Management

Pondweed has been an ongoing maintenance issue in the ZES for decades and excessive growth can occur due to increased nutrients creating a major problem for the ZENR management as it forms dense mats which restrict recreational activity such as boating and further increases in nutrients as it decomposes. To date, pondweed has been mainly managed through the use of one or two mechanical floating weed-harvesters. However, excessive growth continues despite the development of harvesting guidelines to achieve adequate levels of pondweed for both ecological and recreational purposes. The guidelines include clearing all recreation areas of pondweed (canals and main water body) whilst keeping a 30% reserve for ecological purposes, maintaining adequate flow regimes within to prevent stagnation and improving the understanding of pondweed dynamics in Zandvlei.

Public Areas Maintenance

Most of the ZENR is open access to the public with several public facilities including braai and picnic areas along the eastern and western waterbody banks, public toilets and children’s playgrounds, and a pedestrian bridge over the canal to the South, to name a few. The City Parks Department ensure the maintenance of these public-use areas and facilities however, many users have complained about the lack of attention to their maintenance and day-to-day cleaning (Department of Environmental Affairs, 2018).

2.2 Methods and Materials

Both face-to-face (in-person) and electronic-based survey questionnaire (Appendix A) approaches were utilised to determine the visitor use and expenditure of Zandvlei as a recreation site over a year-long period (July 2018 – August 2019). Ethics approval was obtained in 26.04.2018 by the research ethics committee. Questions included in the survey were determined to calculate the users' monetary and time expenditure on particular recreational activities as well as any value of the system to their livelihood, social and cultural wellbeing and their perception of the management and health of the system. Question areas included the reason for visiting Zandvlei (activity); demographic details (age and gender, etc.), broad gross monthly income; distance/time travelled to use the facility; frequency of visits; duration spent per visit; expenses for their activity (travel, equipment and membership for respective activity, if any); perceived concerns with management approaches and proposed resolutions of these; the value of Zandvlei to their livelihood and or social wellbeing and the perceived health of the system.

In-person surveys were conducted monthly, at random sites and on random days and times throughout the Nature Reserve around the picnic sites and areas, the Zandvlei sports club and fishing areas. Surveys conducted during off-peak hours or in the quieter areas of the reserve were performed in the presence of one or two rangers for safety (three times). No conflict was experienced in any questionnaire sampling attempts.

Electronic surveys were submitted by respondents throughout the year after being distributed via various online sources such as social media (Facebook groups) and bulk E-mails to various user groups (such as the Peninsula Canoe Club, the Zandvlei Forum, the surrounding Residents' association, the South African Scouts Association, and other activity-user groups). Whilst online surveys have the advantage of greatly increasing the sample size, limitations and biases include limiting the survey to those who have access to the internet.

A total of 1078 questionnaire survey returns were achieved, 410 of which were performed in person (38%) and 667 (62%) were submitted electronically. The data were stored and analysed using Microsoft Excel 2019 (Microsoft Corporation, 2019). Pivot charts and tables were created in IMB SPSS 20.0 to analyse trends and differences between user groups for each survey question. The average expenditure per user activity group was calculated by using the sum of travel costs, equipment costs and membership fees thereof.

Statistical analyses:

The Chi-square test (Mehta and Patel, 2011) was used to assess whether the distribution of one categorical variable differed across the levels of another categorical variable. Specifically, we explored whether recreational activity was independent of factors such as gender, suburb of residence, the importance of the ZENR to the respondent's livelihood, social and cultural well-being, perceived health of the ZENR, and use of public transport. The Kruskal-Wallis H test (Mehta and Patel, 2011) was employed to determine if there were statistically significant differences in numeric variables, such as user age, gross monthly income, time spent at the ZENR, and annual expenditure on their recreational activities, across different recreational user groups.

2.3 Results

No absolute user numbers could be ascertained during this study, as there were no access control points or permit fees at the time, making access to the ZENR almost impossible to quantify at any time. As a result, the total value of the recreational benefit of the system remains inconclusive as total use remains unknown. The 1078 users within the questionnaire survey spent a total of R3,129,224.43 collectively on recreation through travel, membership fees, and equipment at the ZENR over one year.

2.3.1 Activities and Visitor Profile at the ZENR

Of the 1078 questionnaire responses, 720 respondents stated that they utilised the system for multiple recreational activities including those shown in Figure 3 below. All respondents identified their activities.

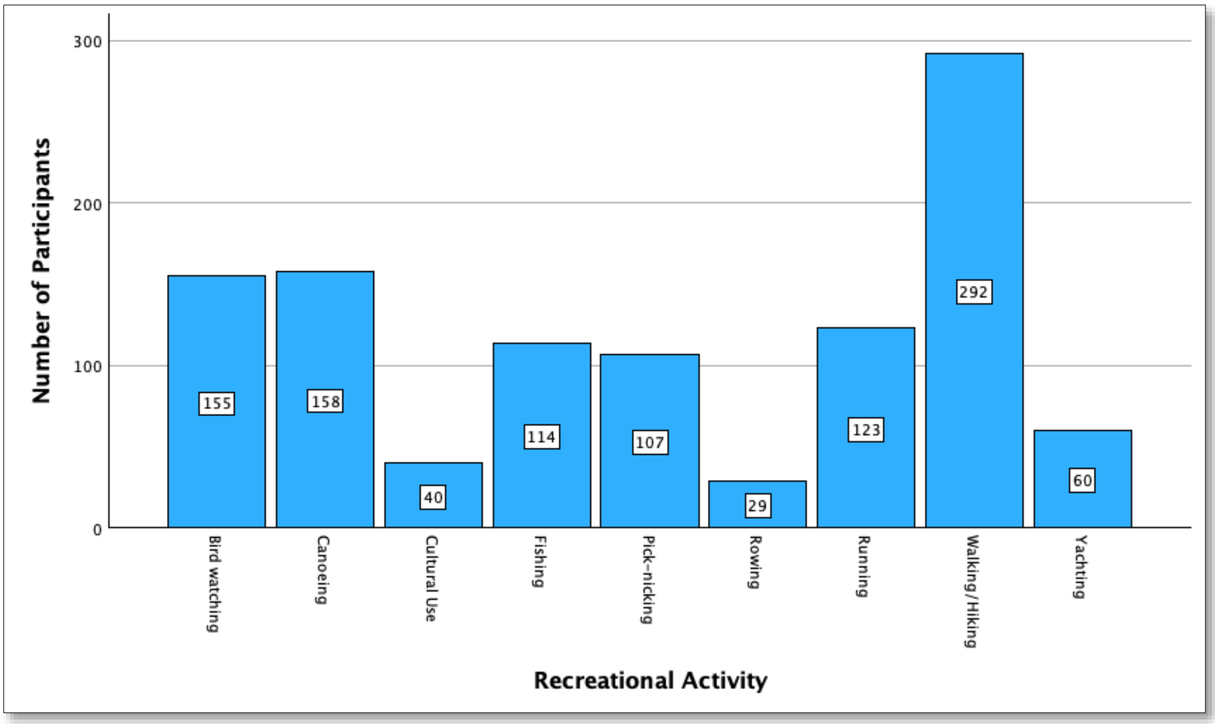

Figure 3 The number of recreational users participating in identified activities during the duration of the study period (July 2018 – August 2019).

Walking/hiking was the largest activity of the nine most popular identified recreational activities and accounted for a quarter (27%) of recreational users of the ZENR within the study period. Canoeing was the second largest user group (15%) and the largest of the on-water activities.

Bird watching was the third-largest activity (14%), while meditation and rowing had the lowest percentage of participants with only 4% and 3% respectively (

Figure **3**). Others identified such as photography, windsurfing and pedal boating were not included in the study due to their small sample size (less than 8 respondents each).

The percentage breakdown for various profile characteristics (age, gross income, suburb of residence, gender etc.) for the nine most popular activities at the ZENR for the duration of the study period (July 2018 – August 2019) is displayed in Figure 4 below.

<u>Age</u>

A Kruskal-Wallis H test showed that there was a statistically significant difference in age between the different recreational user groups at the ZENR, ($H = 117.01$, $p < 0.001$, d.f = 8). The average age rank of respondents was 50-59. Bird watchers were the oldest user group with an average age of 57 whilst rowers were the youngest with an average age of 43.

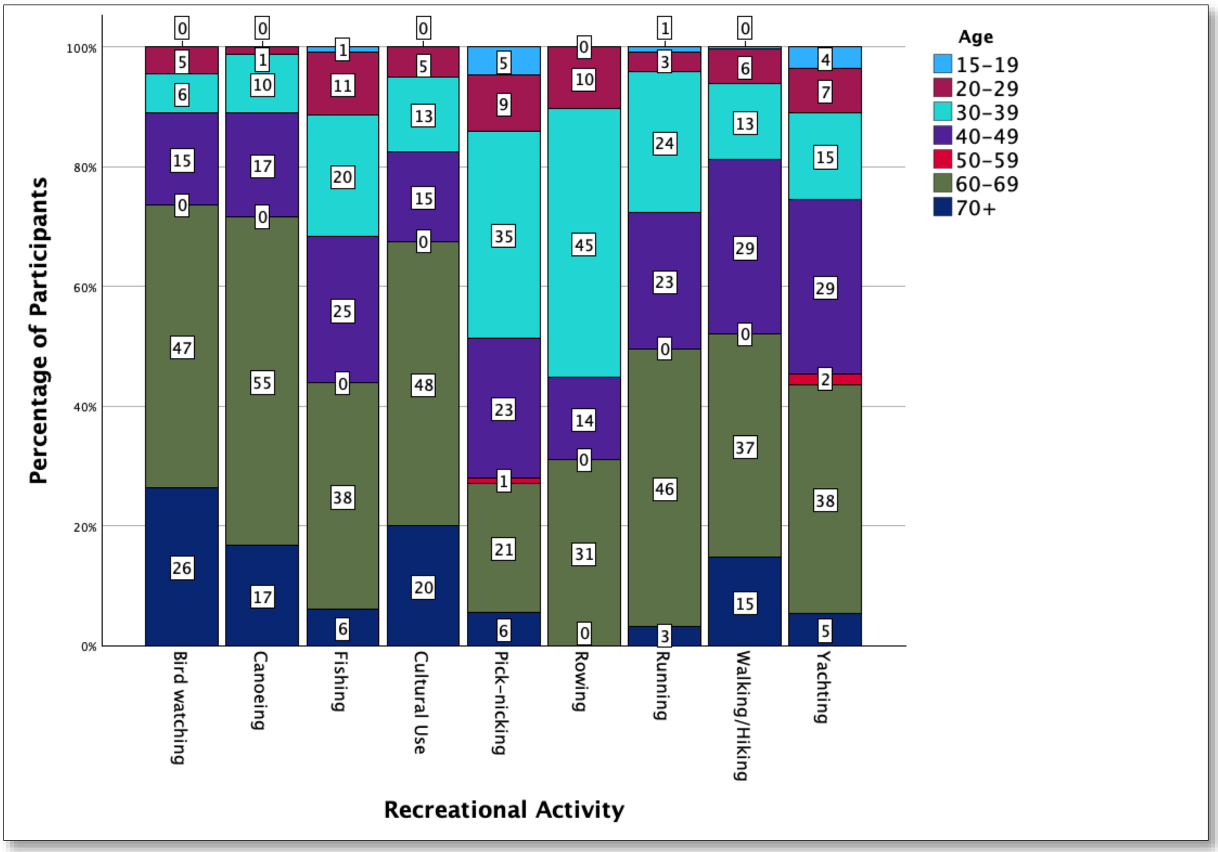

Figure 4 The distribution of age categories among recreational users at the ZENR between July 2018 and August 2019 with actual numbers displayed within the bars.

Gender

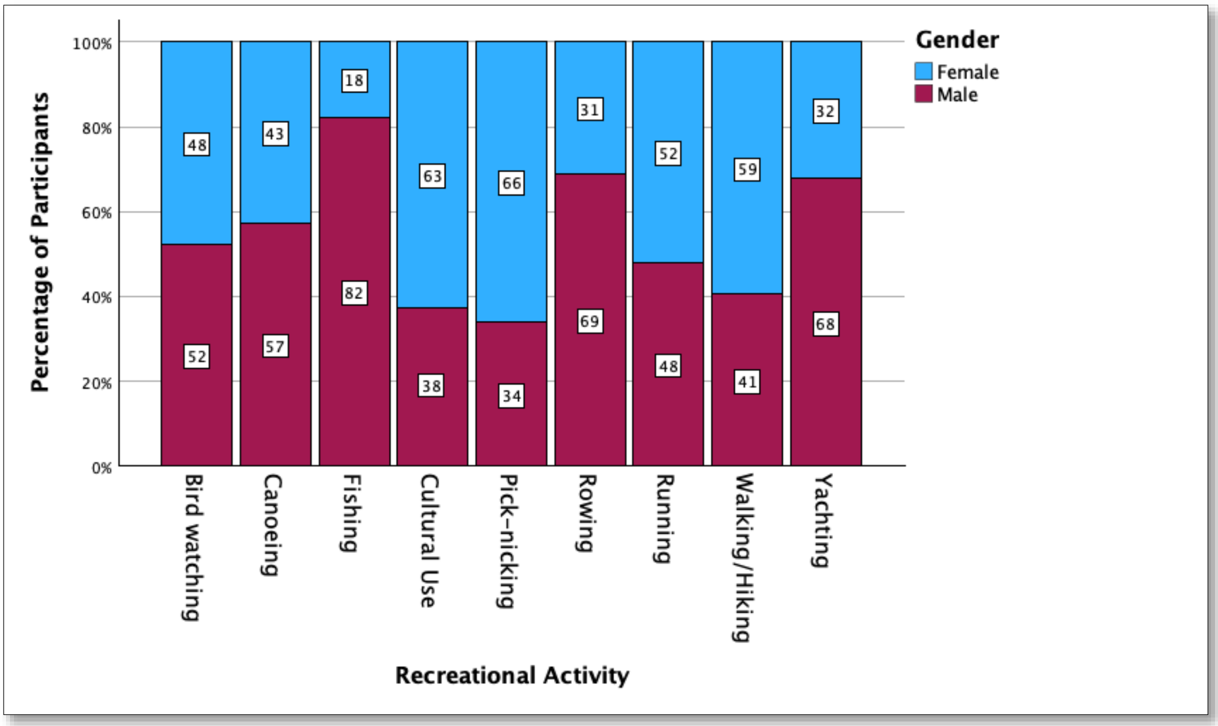

Figure 5 Proportional gender breakdown between recreational user groups at the ZENR between July 2018 and August 2019. Actual user numbers are displayed within the bars.

There was a significant association between gender and recreational activity of choice among users, (Chi-square = 1078, $p < 0.001$, df = 8). Respondents were 56% male and 44% female overall during the study period. Walking and picnicking were the only activities whose participants were majority female (52% and 64% respectively). Fishing and rowing were the most male-dominant activities (88% and 71% respectively).

Suburb of residence

The majority of recreational users resided in the adjacent neighbourhoods of Marina da Gama (30%), Muizenberg (19%) and Lakeside (14%) to the Cape Winelands (20 to 30km away). There was a significant association between the suburb of residence and recreational activity of choice among users, (Chi-square = 1122.50, $p < 0.001$, df = 224). Picnickers came from the broadest range of residential areas and most on-water or reserve-dependant activities such as rowing, yachting and canoeing predominantly consisted of residents from the nearest suburbs such as Marina da Gama, Muizenberg and Lakeside (Figure 6).

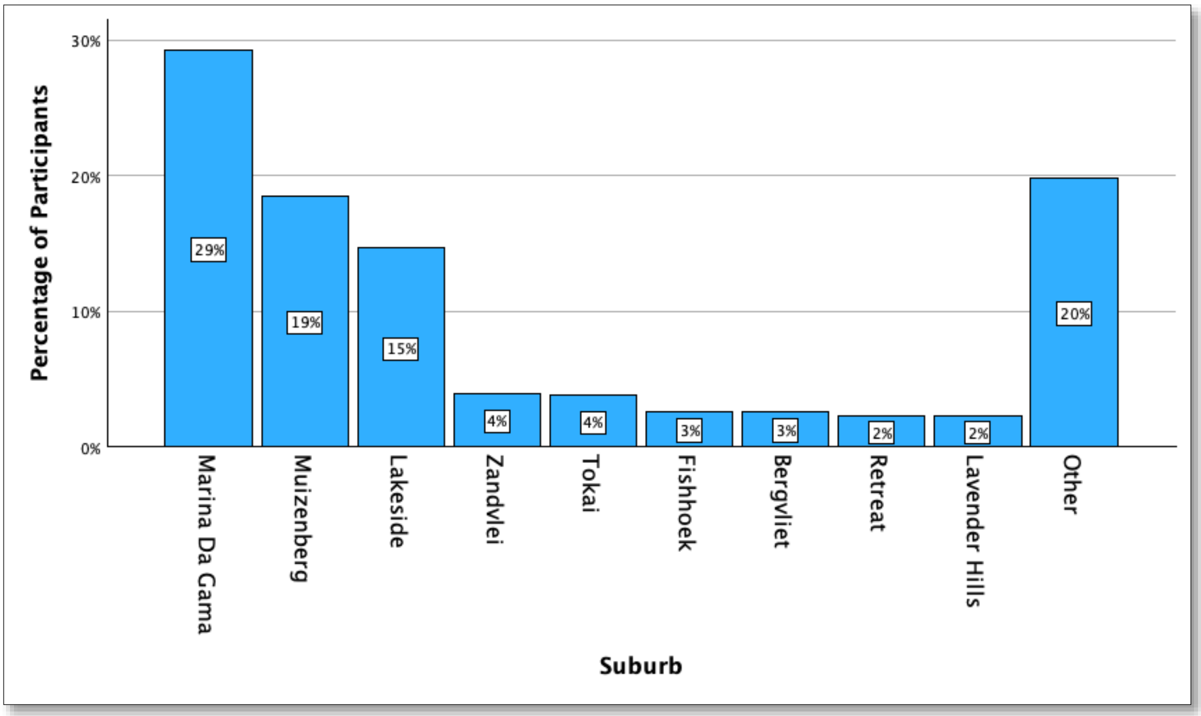

Figure 6 Percentage break-down of residential origin of recreational user groups using the ZENR between August 2018 and July 2019. Categories less than 2% were grouped as "Other". X^2 (224, n = 1078) = 1122.50, $p < 0.001$

Although not captured in the questionnaire returns, the system is at times utilised by broader communities that would involve a greater travel distance (for example, the holding of the national canoe marathon championships in 2021 resulted in users from across the country).

The 'Other' category made up 20% of the respondents, but each individual location within this group, including Claremont, Constantia, Strandfontein, Rondebosch, Grassy Park, Sun Valley, Mitchell's Plain, Noordhoek, Ottery, Zeekoevlei, Durbanville, Hout Bay, Philadelphia, Athlone, Green Point, Somerset West, and Simon's Town, accounted for less than 2% of the total.

Gross monthly income

The Kruskal-Wallis H test revealed that a user's gross monthly income differed significantly across user groups ($H = 49.64$, $p < 0.001$, $df = 8$). The average visitor to Zandvlei during this study earned a monthly salary range between R20,000 to R35,000 which was higher than the average South African wage (within the formal sector) for 2019 (R22,500 / Month). Runners had the highest average gross monthly salary range of R30,000 – R39,999, whilst picnickers earned the lowest monthly salary range of R10,000.00 to R19,999 per individual.

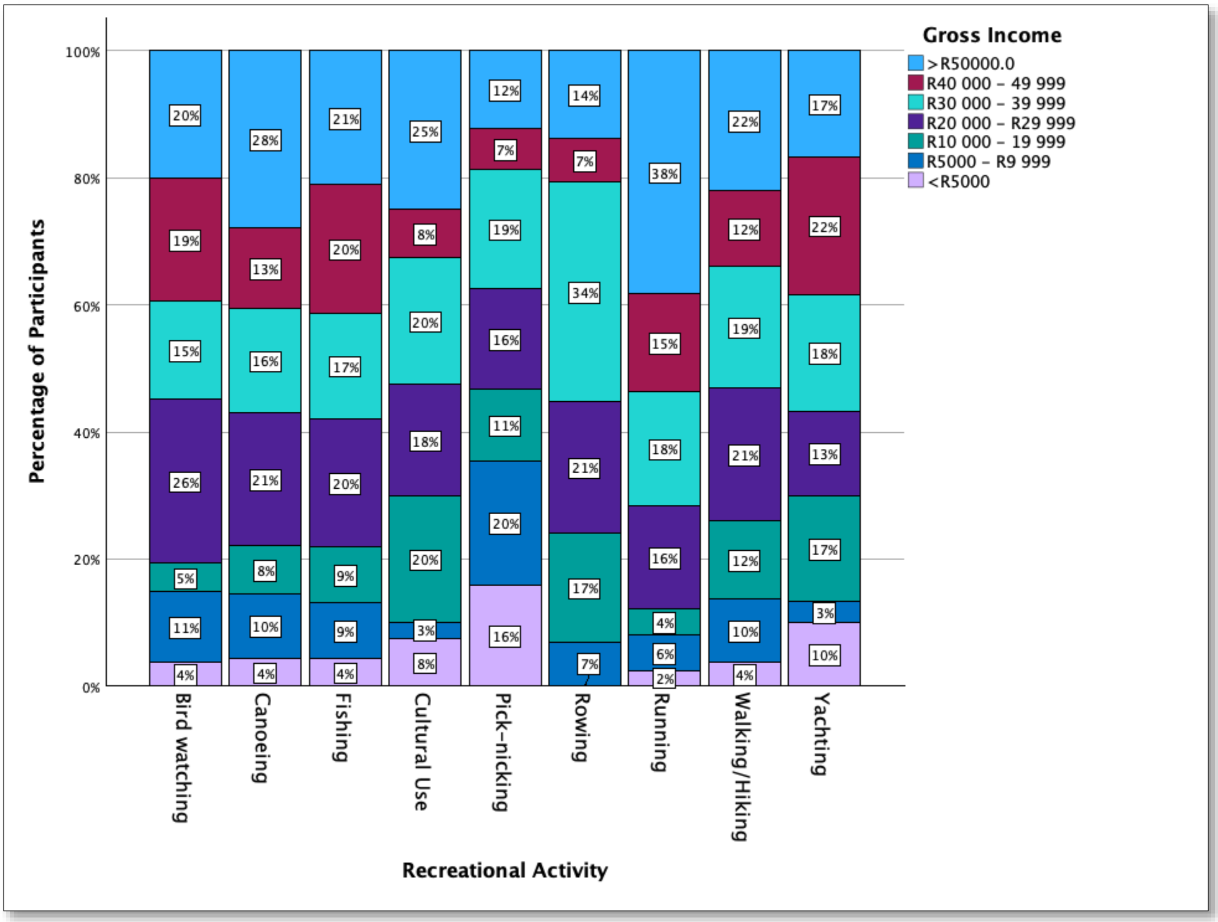

Figure 7 Percentage break-down of gross monthly income range across recreational user groups at the ZENR between July 2018 and August 2019 with the count in each category. $H = 49.64$, $p < 0.001$, d.f. = 8, N = 1078.

2.3.2 Visitor's Time and Expenditure for Recreation

The expenditure (by time and money) for the individual recreational user respondents is displayed in Table 1 below.

Table 1 Time spent and expenditure (in rands) by individual respondents to partake in their respective activities at the ZENR for the duration of the study period (July 2018 to August 2019).

Activity	Number of users	Individual/total	Number of visits per year	Hours spent annually	Annual Membership Costs	Annual Transport Costs	Annual Equipment Costs	Total Annual Costs	Average Cost per visit
Walking / Hiking	292	Average by Individual	222	519	R204.79	R872.22	R762.09	R1,837.21	R8.29
		Total	64824	151548	R43,826.00	R188,400.00	R164,612.00	R396,838.00	
Canoeing	158	Average by Individual	174	433	R567.19	R1,330.43	R2,284.93	R4,167.75	R24.01
		Total	27492	68414	R89,616.02	R210,207.94	R361,018.94	R658,504.50	
Bird watching	155	Average by Individual	198	530	R224.37	R878.57	R1,331.92	R2,430.85	R12.26
		Total	30690	82150	R34,777.35	R136,178.35	R206,447.60	R376,781.75	
Picknicking	107	Average by Individual	66	153	R150.97	R953.68	R577.71	R1,682.37	R25.40
		Total	7062	16371	R16,153.79	R102,043.76	R61,814.97	R180,013.59	
Running	123	Average by Individual	155	380	R317.09	R1,391.49	R1,270.46	R2,975.66	R19.15
		Total	19065	46740	R39,002.07	R171,153.27	R156,266.58	R366,006.18	
Fishing	114	Average by Individual	143	478	R342.90	R1,851.22	R3,078.20	R5,268.13	R36.93
		Total	16302	54492	R39,090.60	R211,039.08	R350,914.80	R600,566.82	
Yachting	60	Average by Individual	72	272	R859.21	R1,592.31	R3,105.31	R5,526.78	R76.75
		Total	4320	16320	R51,552.60	R95,538.60	R186,318.60	R331,606.80	
Meditative / Spiritual	40	Average by Individual	243	666	R182.59	R1,480.00	R773.12	R2,429.62	R10.01
		Total	9720	26640	R7,303.60	R59,200.00	R30,924.80	R97,184.80	
Rowing	29	Average by Individual	90	314	R97.52	R3,000.00	R1,099.79	R4,197.31	R46.46
		Total	2610	9106	R2,828.08	R87,000.00	R31,893.91	R121,721.99	
Total	1078	Average Total Individual	151	416	R327.40	R1,483.32	R1,587.06	R3,390.63	R28.81
		Average Group Total	20232	52420	R36,016.68	R140,084.56	R172,245.80	R347,691.60	
Grand Total	1078	Total	182085	471781	R324,150.11	R1,260,761.00	R1,550,212.20	R3,129,224.43	

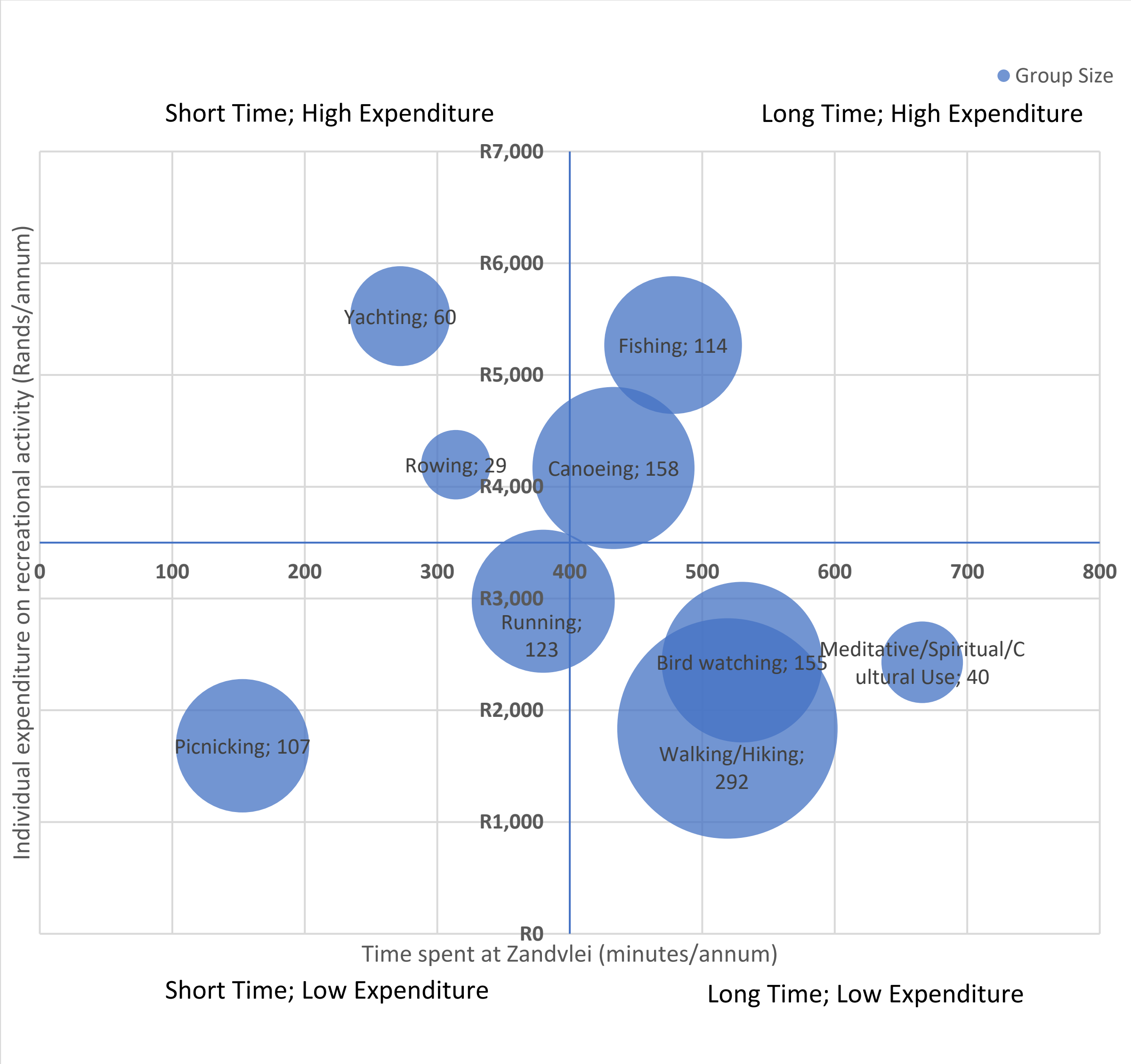

Figure 8 Proportional annual time (hours) and money (rands) spent on recreation by relative group size by users of the ZENR between July 2018 and August 2019. Numbers in the circles represent sample sizes.

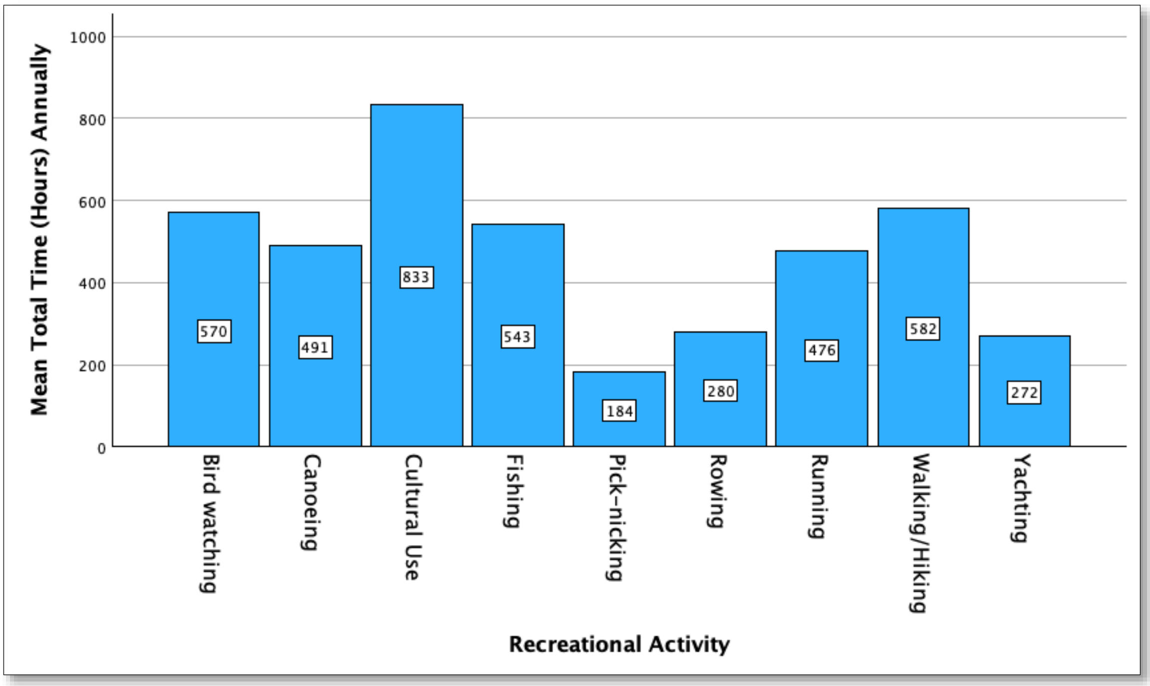

Figure 9. Average time (hours) spent on activity by individual respondents at the ZENR data H = 112.78, d.f, = 8; p = 0.001, n = 1078.

Significant differences were found between the time spent on activity among user groups at the ZENR using the Kruskal-Wallis H test; H = 112.78; df = 8; p < 0.001; n = 1-78.

Meditative/Spiritual/Cultural users and walkers/hikers had the largest visit frequency per individual per annum (222), whereas picnickers visited the least (66). Walkers/Hikers spent the least time per visit (109 minutes), whereas rowers spent the most time per visit (191 minutes). Meditative/Spiritual/Cultural users had the shortest travel time of fewer than 30 minutes to the ZENR whereas Yachters has the longest of more than 60 minutes

Meditative/Spiritual/Cultural users and bird watchers spent the greatest number of hours per annum (666 and 530 respectively), whereas picnickers spent the least (153 hours). Each respondent spent an average of 416 hours (17 days) throughout the year and collectively, respondents visited the ZENR 20232 times during the year (151 times per user) (Table 1).

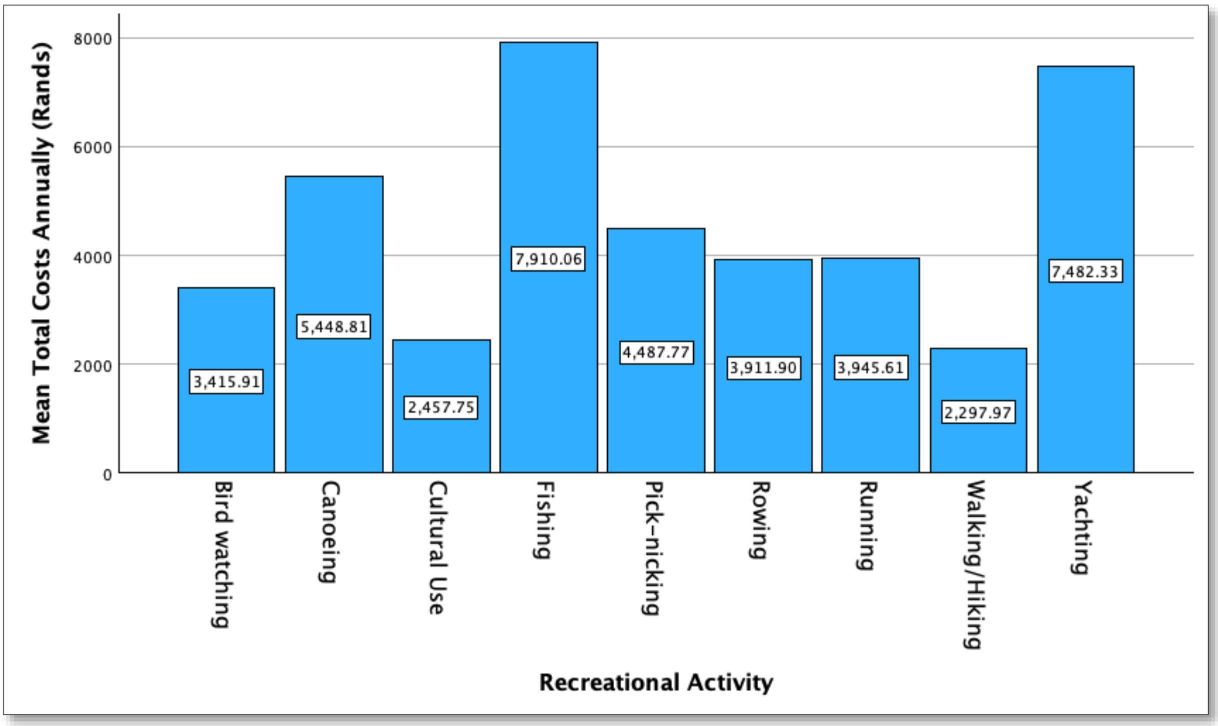

Figure 10 Expenditure across recreational user groups at the ZENR (with standard error of the mean). Small circles indicate outliers and stars indicate extreme outliers. H = 146.93, df = 8; p = 0.001, n = 1078.

The Kruskal-Wallis H test revealed a significant difference in annual expenditure for several activity groups at the ZENR (H = 146.93; df = 8; p = 0.001; n = 1078). The average respondent spent R28.81 per visit or R3,390.63 annually to partake in their activity during the study (Table 1) and spent 1% of their gross monthly income on their activity.

Rowers and picnickers had the lowest annual membership fees whereas canoeists and yachters had the highest. Rowers and fishers had the highest annual transport costs whereas walkers and bird watchers had the least. An individual picnicker had the lowest equipment costs of R577.71 per year, whereas fishers and yachters had the highest (R3,078.20 and R3,105.31 respectively). Picnickers also had the lowest total annual cost of R1 682.37 per individual whereas fishers and yachters paid the most (R5,268.13 and R5,526.78

respectively). Walking/hiking had the lowest cost for each visit but was not the lowest cost annually as they visited more frequently than picnickers. Yachters had the most expensive activity per visit (R76.75).

2.3.3 Attitudes and Perceptions Towards Management

Table 2 Areas of concern by respondents at the ZENR during 2018-2019. Yellow highlighted cells represent the largest area of concern for each user group. ($X^2 = 214.86$, df = 48 $p < 0.001$)

Activity	Litter Management	Mouth Conditions, Water Levels.	Safety and Law Enforcement	Water Quality Management	Environmental Education	Pondweed Management	Public Areas Maintenance
Bird watching	34%	18%	16%	15%	4%	10%	4%
Canoeing	31%	20%	11%	18%	6%	13%	2%
Fishing	10%	37%	26%	11%	2%	11%	2%
Meditative/ Spiritual/Cultural Use	26%	9%	17%	9%	19%	13%	17%
Picnicking	24%	3%	24%	6%	3%	2%	38%
Rowing	35%	9%	9%	13%	0%	35%	0%
Running	29%	19%	16%	14%	1%	12%	0%
Walking / Hiking	32%	18%	17%	11%	5%	6%	13%
Yachting	13%	28%	0%	44%	0%	16%	0%
Grand Total	**26%**	**18%**	**15%**	**16%**	**4%**	**13%**	**8%**

There was a significant association between a respondent's activity of choice and their area of concern at the ZENR (Chi-square = 214,86; df = 48; $p < 0.001$; n = 1078). Litter was the largest area of concern among most user groups except for Fishers, Picnickers, and Yachters who were more concerned with mouth and water level management, and public area maintenance.

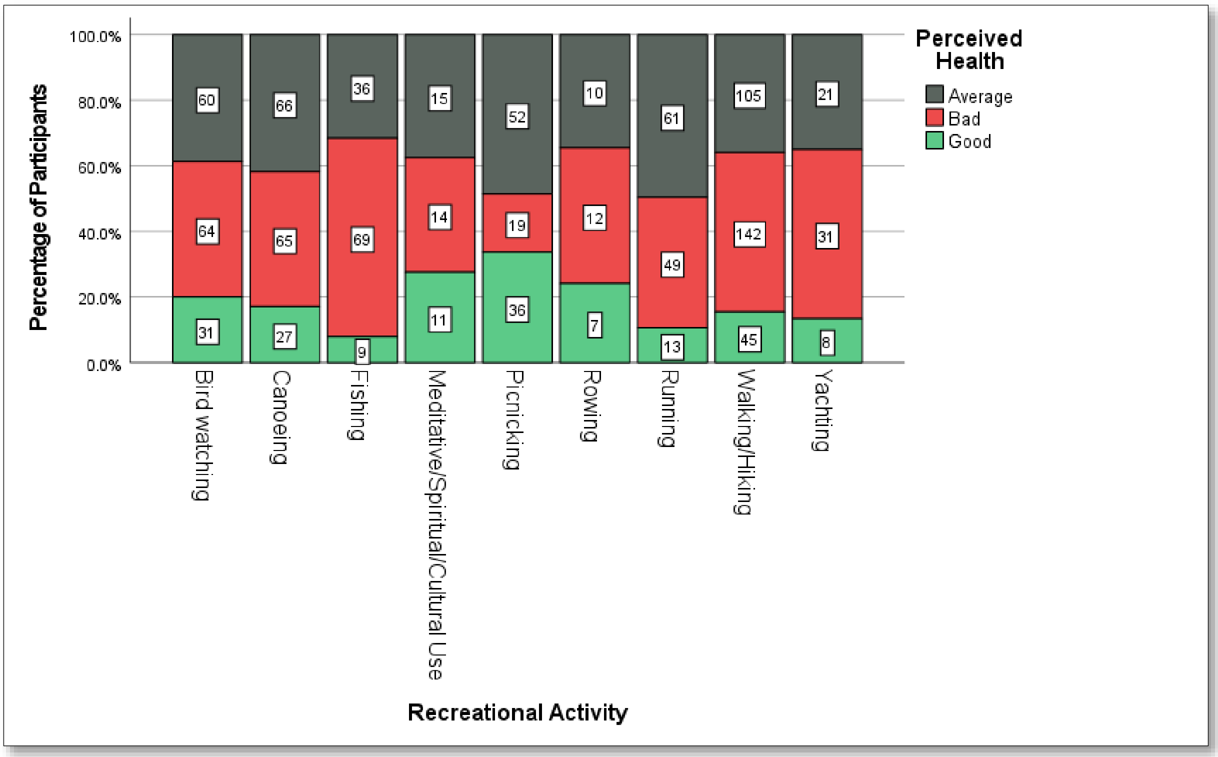

Figure 11 Percentage breakdown of the perceived health of the Zandvlei Estuary indicated by respondents for the duration of the study period (July 2018 – August 2019) with actual count displayed within the bars $X^2 = 67.64$, $p < 0.001$, $n = 1078$.

The Chi-square test revealed an association between the perceived health of the ZENR and recreational activity (Chi-square = 67.64; df = 16; $p < 0.001$; n = 1078). Picnickers and meditators perceived the ZENR to be the healthiest out of the activity groups and yachters and rowers perceived it to be of the poorest health compared to other user groups.

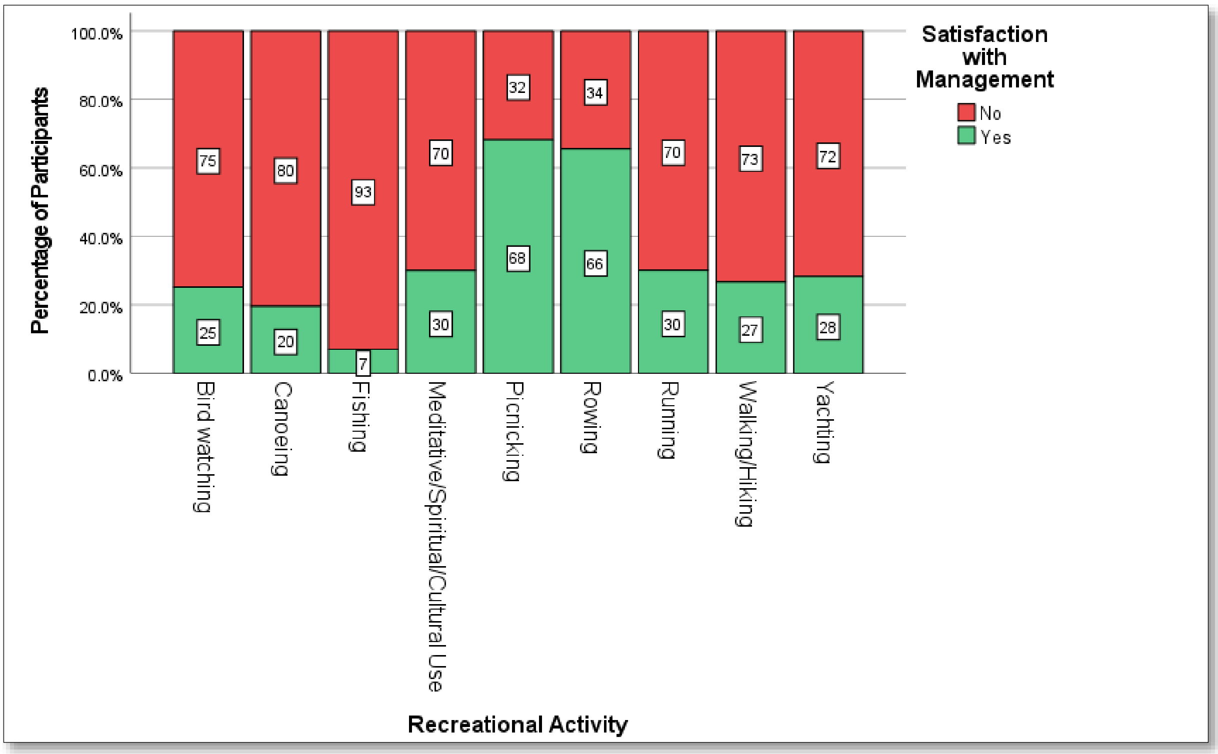

Figure 12 Percentage breakdown of satisfaction with management by recreational user groups of the ZENR for the duration of the study period (July 2018 – August 2019) with the count for each group displayed within the bars. $X^2 = 133.84$, $p < 0.001$, $n = 1078$.

There was a significant association ($p < 00.001$) found using the Chi-square test between respondents' activity of choice and their satisfaction with management at the ZENR during the study (Chi-square = 133.84; df = 8; $p < 0.001$; $n = 1078$). Picnickers and rowers were the most satisfied with management whereas most other user groups were not satisfied.

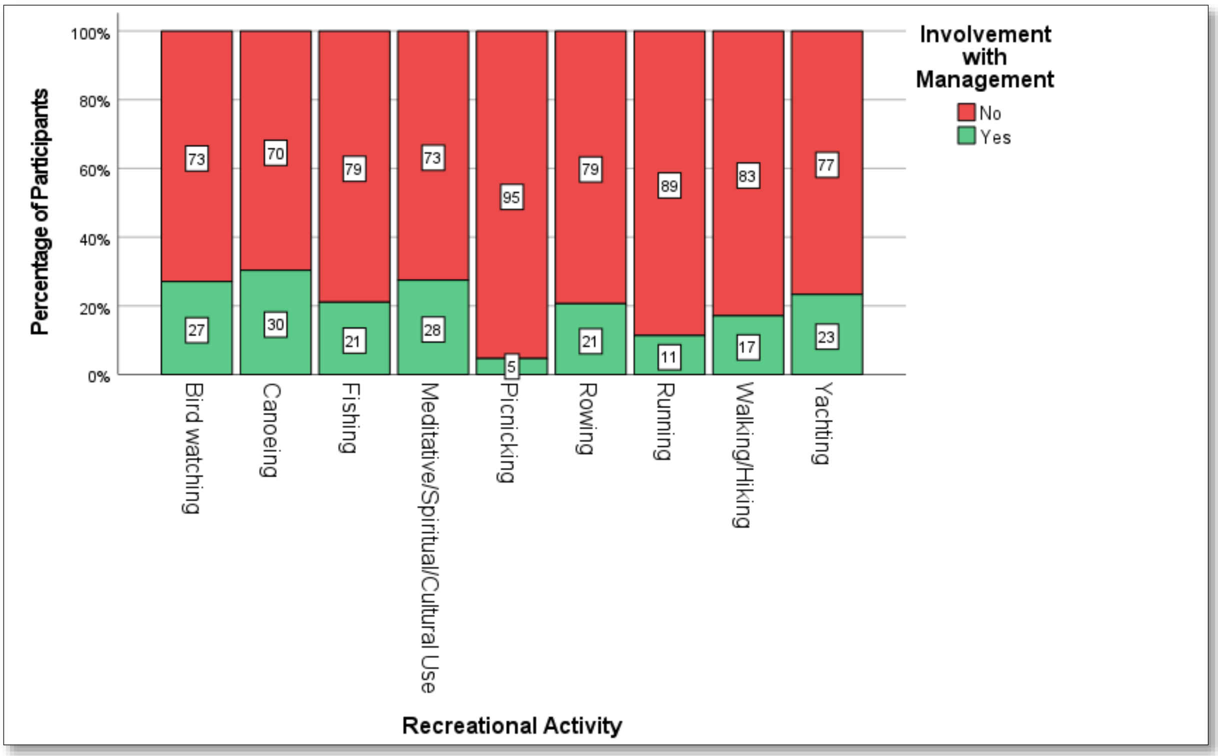

Figure 13 Percentage break-down of respondents' involvement with management across recreational user groups at the ZENR for the duration of the study period (July 2018 – August 2019); $X^2 = 40.57$, $p < 0.001$, $n = 1078$.

There was a significant association (Chi-square = 40.57; df = 8; $p < 0.001$) between respondents' activity of choice and their involvement in the management of the ZENR. Canoeists, bird watchers, and meditators were the most involved user groups, whilst picnickers and runners were the least involved.

A Chi-square test also revealed an association between users' time spent at the ZENR and their involvement with management, $X^2 = 261.76$, $p < 0.001$. Involvement refers to a user's participation in the management of the ZES, such as attending meetings and voting on procedures during the Zandvlei Protected Areas Advisory Committee meetings.

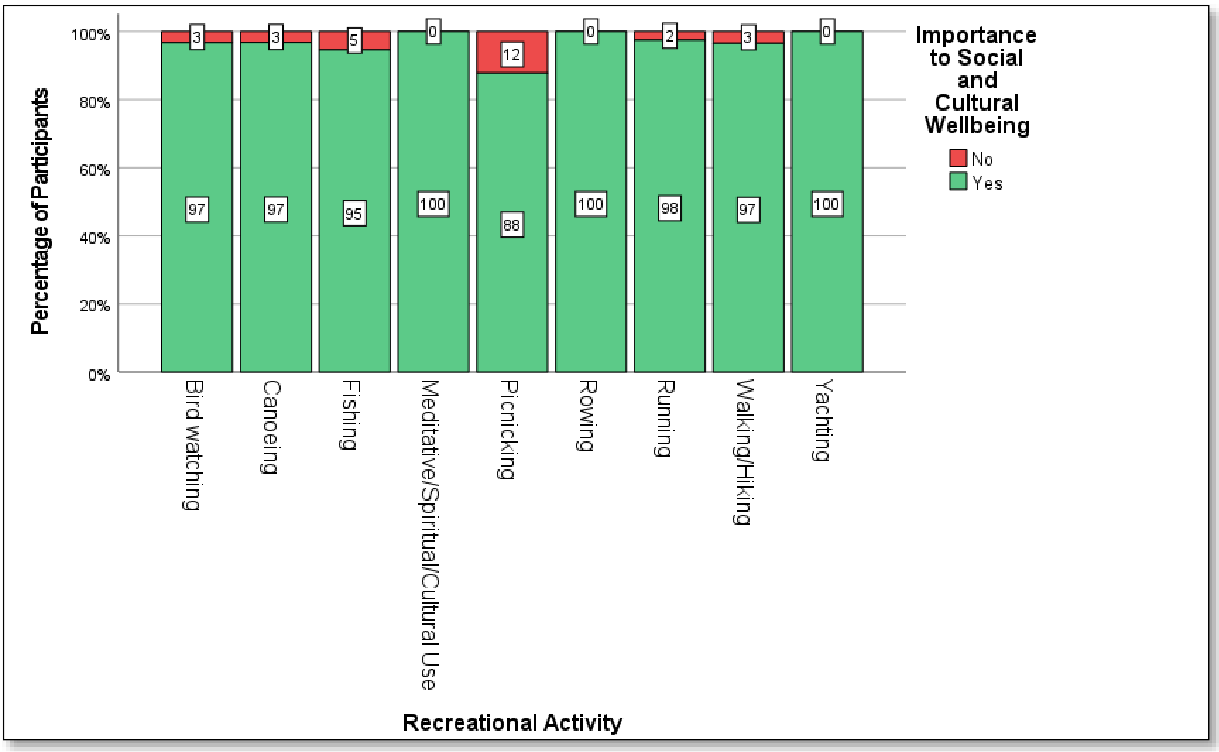

Figure 14 Importance of the ZENR to the culture and social wellbeing as percentages of the various recreational user groups $X^2 = 33.22$, $p = .007$

On average, 95% of the participants stated that Zandvlei was important for their social and cultural wellbeing. A Chi-square test result showed that the importance of the ZENR to a respondent's social and cultural wellbeing was associated to their recreational activity choice (Chi-square = 33.22; df = 8 $p > 0.001$).

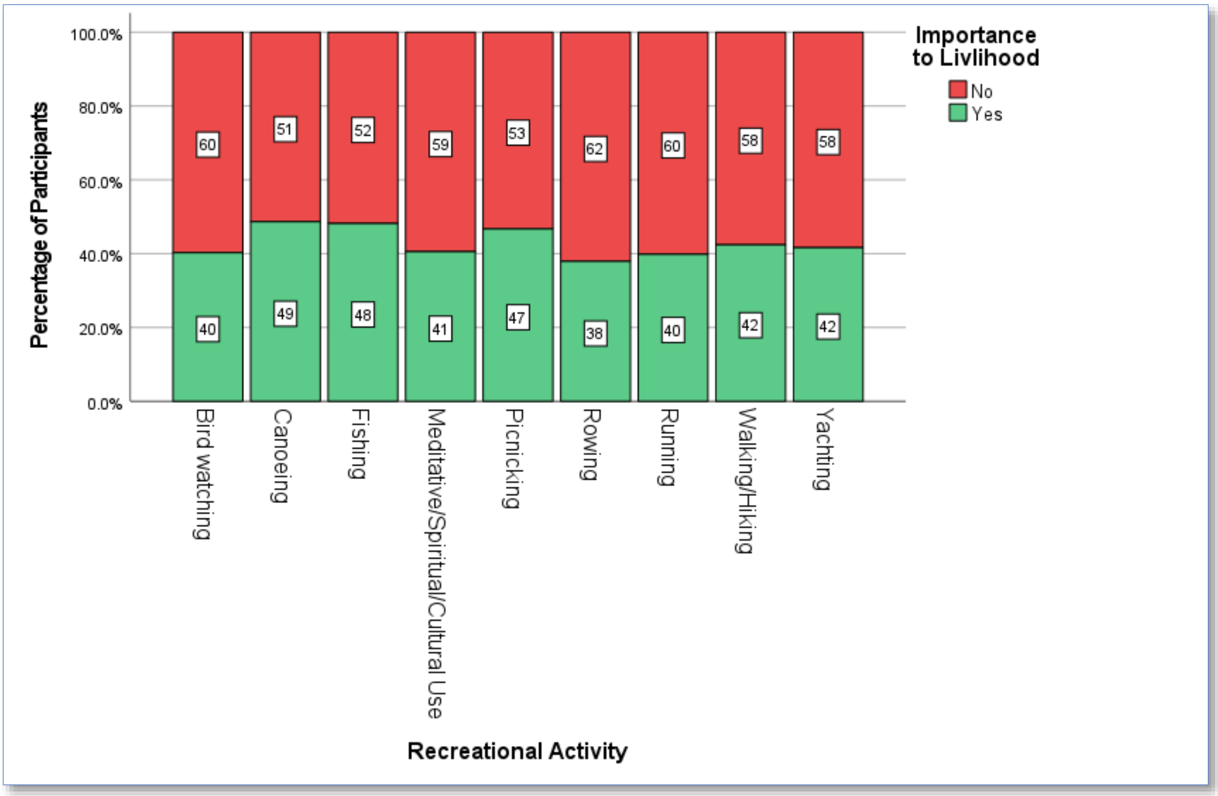

Figure 15 Importance of the ZENR to the livelihood of the various recreational user groups (with actual counts within each bar). $X^2 = 30.98$, $p = .014$

The importance of the ZENR to a user's livelihood was not associated with the user's recreational activity (Chi-square = 30.98; df = 8; p > 0.001) as identified by a Chi-square test. The importance of the reserve to visitor livelihood was evenly spread, with 56% of recreational users stating that it was not important for their livelihood and 44% stating that it was.

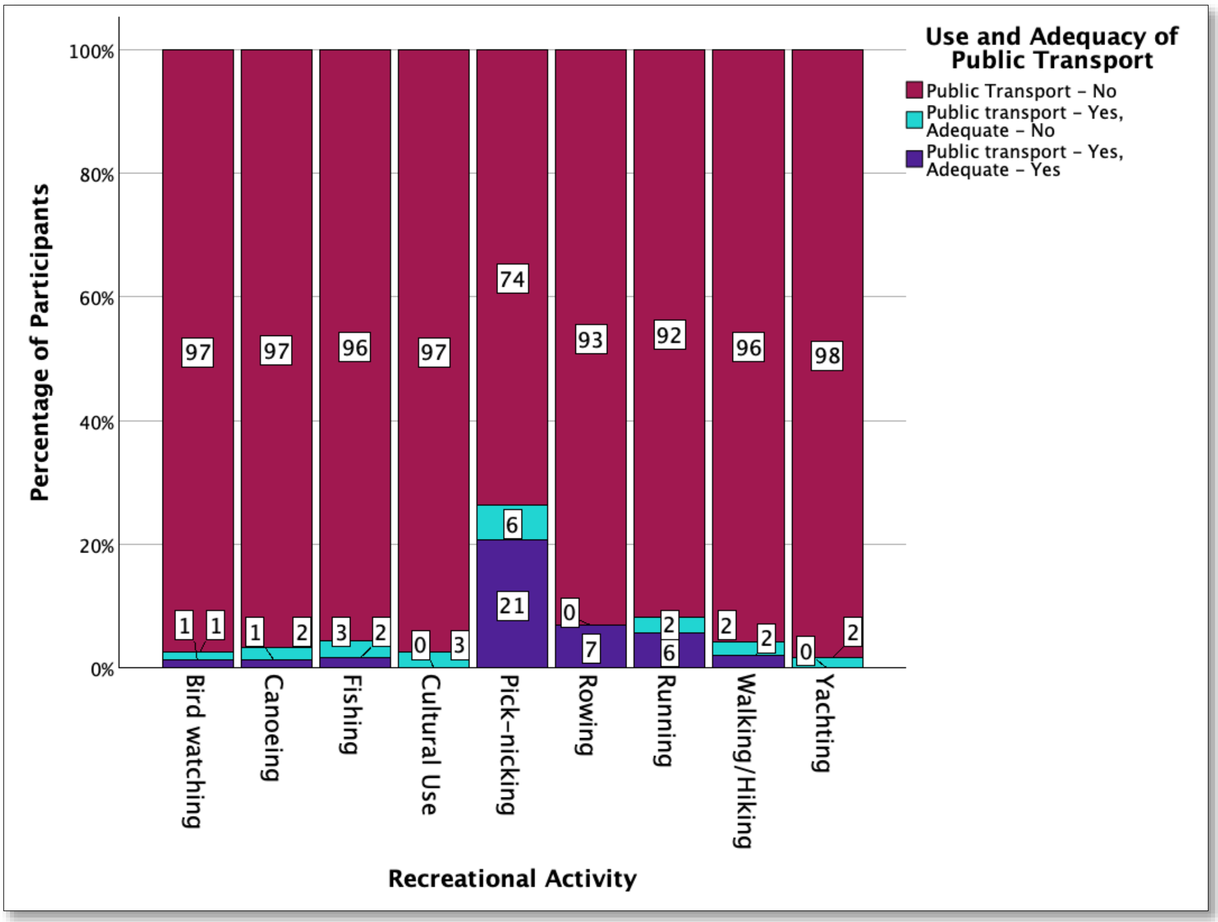

Figure 16 Use and perceived adequacy of public transport by user groups of the ZENR. $X^2 = 111.85$, $p < 0.001$.

Although only 14% of participants stated that they made use of the public transport systems, more than a third (35%) indicated that public transport was inadequate. A Chi-square test showed that the use of public transport was associated with the user's recreational activity of choice (Chi-square = 111.85; df = 16; p < 0.001, n = 1078).

2.4 Discussion

2.4.1 Activities and Visitor Profile at the ZENR

Community-based conservation management of natural areas is becoming increasingly important and implemented around the globe. Some challenges are not easily solved through science alone (see Harrison and Burgess 2000) and support from local communities is imperative for the efficient implementation of management practices (Winter and Lockwood, 2005; Bajracharya et al., 2005). Including local community members in management decisions of natural areas may also contribute to improved health and well-being of local communities (Moore et al., 2006). Understanding the user-profiles for the various recreational activities within a managed natural area is therefore beneficial for improving effective communication to promote community involvement and the subsequent benefits.

Age:

The study demonstrated an association between users' age and their choice of recreational activities. Older respondents tended to select activities that were physically less demanding and more time-consuming, such as bird watching, walking, and picnicking. In contrast, younger respondents preferred more physically demanding sports, such as rowing and yachting. This difference may be influenced by time availability; younger users often face work commitments that limit their recreational options, whereas older individuals, likely being retired, have more leisure time to engage in activities that require a greater time investment, allowing for extended engagement in the natural environment. This information could be beneficial for environmental awareness campaigns, particularly if management aims to promote younger user groups by supporting physically demanding activities like rowing and yachting, which align with their primary concerns regarding litter and water quality.

Gender: Studies have shown the gender differences in activity choices by men and women are related to factors such as fitness, weight, strength, competitiveness, and interdependencies (as in the case of team sports) (Eccles and Harold, 2014; Tsai et al., 2015;

Coakley and White, 2016). This study showed that men preferred activities that were more physically demanding and competitive such as rowing, and yachting whilst women preferred more relaxed, social activities such as picnicking, walking, and meditation. Hence, picnicking and walking were the only two female-dominated activities in the study. A large proportion of female users may have chosen these activities for increased safety benefits due to the large group size of these activities, and that safety and law enforcement was the second-largest management concern among both user groups. Improving visitor safety and increasing law enforcement may prove beneficial to increasing female user numbers.

Income: Users with limited financial resources often face restrictions in their choice of recreational activities due to potential costs associated with travel, equipment, and membership fees. In contrast, more affluent users generally have greater flexibility in their activity choices. The study indicated that users with lower incomes tended to participate in less expensive activities, such as picnicking. Interestingly, while rowers were among the least-earning user groups, they also tended to be younger, which may correlate with their current earning potential.

Despite some users having higher incomes, this does not always translate into engagement in the costliest activities. For instance, runners were identified as the highest-earning user group; however, their chosen activity may not necessarily be the most expensive due to the various costs associated with running gear and events.

The above-average gross monthly income among all respondents compared to the national average suggests that there is a significant luxury benefit associated with open space recreation. This financial capability may encourage respondents to travel from more distant suburbs, as the Zandvlei Estuary Nature Reserve (ZENR) serves as the closest inland freshwater recreational facility. This illustrates the importance of obtaining unbiased data through questionnaire surveys.

The disparity in access to coastal environments should be addressed through educational initiatives and targeted marketing efforts in surrounding low-income suburbs. Lower-income groups primarily utilize the ZENR for more affordable activities, such as picnicking. This user group tends to prioritize the maintenance of public areas and safety, indicating that addressing these concerns could enhance management strategies at ZENR to better accommodate all user groups. Additionally, residents or club facility users are not confined to public amenities, which may influence their recreational choices.

Moreover, potential property buyers near urban green spaces are often influenced by the available recreational opportunities (Lin et al., 2013). Individuals purchasing homes in the vicinity of the ZENR are likely to utilize the nature reserve for their recreational activities. Most questionnaire respondents resided in adjacent neighbourhoods, which aligns with the expectation that property owners will participate in activities offered close to their residences. This trend reflects a broader pattern of individuals relocating to areas that meet their recreational preferences and needs. Notably, picnickers represented a wide distribution of residential areas, showcasing the accessibility of the ZENR to individuals from diverse socio-economic backgrounds.

2.4.2 Visitor's Time and Expenditure for Recreation

Fishing was identified as the most significant activity regarding both individual users' time commitment and financial expenditure. This designation stems from several factors. Firstly, fishing often requires substantial investment in specialized equipment, including rods, reels, bait, and additional gear, which can be costly. Furthermore, users typically incur transportation expenses to reach optimal fishing locations, adding to the overall financial commitment.

Additionally, fishing is inherently time-consuming, as successful angling often necessitates extended periods spent at water bodies. Users may invest considerable time preparing for fishing trips, traveling to the location, and waiting for catches, which can lead to a higher perceived value in terms of time dedicated to this activity.

The combination of significant monetary and time investments reflects a deeper engagement with the recreational experience, suggesting that fishing provides not only tangible returns in terms of catches but also intangible benefits such as relaxation, connection with nature, and social interaction. This multifaceted value can enhance users' overall satisfaction and enjoyment, making fishing a prominent activity among visitors at the ZENR.

Prioritising the ZENR management practices based on this user group's primary management concerns for mouth management/water level and law enforcement management (See Table 2), may result in increased member numbers for this valuable group and therefore further benefits through their expenditure and time at the Estuary.

Whilst user groups that have the largest number of members are likely to be valuable in either group expenditure or time, too many users in one area may exacerbate environmental impacts through increased pressure. The walking / hiking user group was the largest in terms of members at 25% of the questionnaire respondents. Although this individual user's time and expenditure were small compared to other user groups, the group was one of the largest contributors in time and expenditure due to its many members. Pressures on visitor carrying capacity can be limited through the use of access control points or permit systems such as those implemented by Silvermine Nature Reserve, Rietvlei Nature Reserve and Cape Point Nature Reserve.

Users who spend more of their time in a conservation area are more likely to become involved with its management. This was evident by the association between user groups and their level of involvement with its management. Meditative/spiritual users, bird watchers, and walkers/hikers who spent the most time were also some of the most involved in management activities at the ZENR. People who are more involved with management and the conservation efforts of a natural area are more likely to support changes and decisions made by its management and can act as a useful resource for labour (participate in litter clean-ups, invasive plant removals, etc, knowledge and skills) (Moore et al., 2006; Winter and Lockwood, 2005; Bajracharya et al., 2005).

Picnickers spent the least amount of time at the ZENR, likely due to their fewer visits per year. Picnicking is one of the more easily available activities found elsewhere so these users will be less inclined to return compared to bird watching or canoeing which require specific conditions and environments for a visit. Picnicking is also a leisure activity and not a sport that requires repeated practice and routine training therefore, picnickers were likely to visit the ZENR over the weekends and holidays when they had more spare time.

Walkers/hikers were found to spend the least per annum whereas fishers spent the most. This is likely due to walkers/hikers living near the estuary and having minimal transport costs as well as having little to no equipment or membership fees compared to fishers who are required to pay annual licence fees and equipment costs such as fishing rods, tackle and bait. Many fisher people also come from further afield than the walkers and hikers as fishing areas are not as available as areas where one can walk, therefore their transport costs were much greater. Improving the public transport system could reduce these large transport costs and improve accessibility to valuable recreational users such as fishers who reside further afield or those who have fewer financial means such as picnickers.

2.4.3 Attitudes and Perceptions Towards Management

Litter: The management of recreational ecosystems is dependent on the perceptions and attitudes of those who use them (Daily, 1997). The management of these areas can therefore benefit from investigating users' perceptions (Daily, 2000; Schnurr and Holtz, 1998). The majority of questionnaire respondents expressed some concern about the management of the ZENR with the most expressed concern being litter, followed by mouth/water level management, law enforcement and then water quality. The association between management concerns and respondents' recreational activity of choice is apparent as litter was the largest concern for users who spent the most time at the ZENR and were based on or close to the water such as birdwatching, canoeing, fishing, meditation, and rowing. This may be due to the major rise in studies and therefore increased public knowledge as to the current state and consequences of plastics and pollution to humans and the natural environment. Perhaps these user groups have a greater knowledge due to having higher income and subsequent access to education.

Figure 17 *A* litter trap in the ZENR (Image by Michael Ryder, Local Resident)

Despite this being the largest concern amongst respondents, there is little mention of the management of litter within the current plan for the ZENR. The following actions have been proposed in addition to ongoing treatments (Department of Environmental Affairs, 2018):

• The Solid Waste Department to host a mass action campaign for the reduction of litter.

• The City's Informal Settlement Task Team to improve refuse and sanitation services in areas occupied by backyard dwellers.

Educating the public about litter can play a pivotal role in significantly enhancing litter management at the Zandvlei Estuary, contributing to the creation of a cleaner and more sustainable environment. By raising awareness and understanding among the community, public education sheds light on the detrimental impacts of litter on the delicate ecosystem, wildlife, and human health. This heightened awareness tends to foster a sense of responsibility among individuals, motivating them to take proactive steps towards better litter management practices (Chen, 2015; Löhr et al., 2017; Ojedokun, 2011).

A fundamental outcome of public education is the potential for behaviour change. When individuals are informed about the proper ways to dispose of waste and the broader benefits it brings, they are more likely to alter their behaviour in a positive manner (Ryan and Turpie, 2000; Arafat et al., 2007). Education also has the potential to create a connection between the public and their environment, encouraging a more responsible approach to waste disposal. With this sense of connection, the community becomes more invested in maintaining the cleanliness of their surroundings, including the Zandvlei Estuary.

Additionally, public education initiatives can serve as effective tools for community engagement. These initiatives can involve local residents, schools, businesses, and environmental organizations, forging partnerships that work collectively towards a common goal of reducing litter. By engaging the community in clean-up campaigns, workshops, and awareness programs, a shared sense of ownership and pride in the environment is cultivated.

The impact of educating the public on litter management extends beyond individual actions; educated citizens are more likely to support regulations and enforcement efforts related to litter management. Furthermore, incorporating environmental education into school curricula can equip future generations with the knowledge and values needed for responsible waste disposal, establishing a lasting culture of environmental stewardship.

Effective implementation of public education requires utilizing a variety of communication channels, including social media, workshops, community events, and signage. Tailoring messages to address the specific challenges faced by the Zandvlei Estuary and considering the cultural context of the community is essential. Collaborating with local stakeholders ensures that education efforts are inclusive and relevant. Continuous evaluation of education strategies, based on feedback and observed outcomes, allows for necessary adjustments to be made, contributing to sustained improvements in litter management practices.

It's important to recognize that while public education is a significant component, it should be integrated with other elements such as infrastructure enhancements, proper waste collection systems, and ongoing community engagement to establish a holistic approach to effective litter management at the Zandvlei Estuary.

Mouth/Water level management: Mouth management, also known as water level management, holds significant importance for the well-being of the Zandvlei Estuary and its diverse ecosystem. This practice involves the careful control of the estuary's mouth opening and closing, influencing the exchange of water between the estuary and the ocean. This management approach is pivotal in maintaining the health of the estuarine environment, ensuring the safety of recreational users, and supporting the flourishing of estuarine species.

Ecosystem health is deeply intertwined with effective mouth management. By regulating the salinity gradient within the estuary, this practice enables the survival and growth of various estuarine species. These organisms are adapted to specific salinity ranges, and fluctuations due to inadequate mouth management can have detrimental effects on their life cycles. Additionally, the controlled exchange of water aids in nutrient cycling and sediment transport, crucial processes that underpin the estuary's productivity and biodiversity.

For recreational users, proper mouth management translates into favourable conditions for their activities. By maintaining good water quality through sufficient water circulation, water stagnation and elevated pollutant levels are mitigated. This is particularly important for activities such as kayaking, yachting and boating, where water quality directly impacts the safety and enjoyment of participants. Furthermore, maintaining suitable water levels supports safe navigation for recreational vessels, preventing accidents and ensuring a positive experience for users.

Estuarine species heavily rely on regulated mouth management for their survival and reproduction. The movement of water in and out of the estuary is essential for the life cycles of fish, crustaceans, and other aquatic organisms. Opening the estuary's mouth allows these species to migrate for feeding and reproduction, preserving their natural behaviours and sustaining their populations. Moreover, proper water level management safeguards the availability of critical habitats, including wetlands, mudflats, and submerged vegetation. These habitats provide breeding and foraging grounds that are essential for the well-being of a diverse range of estuarine species. It is no wonder then, that Fishers were one of the most concerned user groups with regards to Mouth Management and many reported on the lack of spawning natural/indigenous species as a result of poor water level management (see Appendix B).

In essence, effective mouth management is essential for the Zandvlei Estuary's equilibrium. By maintaining salinity levels, nutrient cycling, and suitable habitats, this practice ensures the continued vitality of its ecosystem. Simultaneously, it guarantees safe recreational experiences for users and upholds the intricate balance that supports the flourishing of estuarine species.

The Zandvlei Management has now prioritized the mouth to be kept open as much as possible during peak fish recruitment periods (August to November) whilst ensuring sufficient water depths for boating purposes (>1 m) and scheduling the main yachting events around neap tides.

Safety and Law Enforcement (Department of Environmental Affairs, 2018)*:* Compliance monitoring and safety concerns have been an ongoing task for the Management of the ZENR since its proclamation in 2006 (Jackson et al., 2010). The ZENR experiences daily issues regarding compliance, including the lack of control at slipways, poaching, lack of visible policing, visitor compliance and safety. Despite safety and law enforcement being identified as a top concern by users, specifically Picnickers and fishers, it is not identified within the six priority management areas by the Reserve authorities. Fishers commented on the illegal fishing and poaching that has occurred unabated in the area (Appendix B). This concern is likely a result of fishers having to pay an annual fee and abide by very strict rules to fish legally. Should the management of the ZENR wish to prioritise this user group, improving law enforcement, specifically concerning illegal fishing and poaching would be ideal. Prioritisation would ensure that users feel safer and therefore encourage more user activity, as well as enhance the protection of biodiversity by reducing activities such as poaching and illegal fishing.

Water Quality: Water quality concerns were largely felt among yachters and canoers which is to be expected considering these activities are performed in close contact with the water, these users are at a higher risk for contamination with polluted water. Sewage spills can also cause disruptions for these sports as they can lead to water closures where users are forced to find alternative areas to practice or compete. Furthermore, as there are very few inland areas that provide water recreation in the Cape (Zeekoevlei and Rietvlei), these users are often forced to suspend their activities altogether.

Thornton and McMillan's (1989) research emphasized the significant apprehensions related to water quality, particularly issues such as excessive plant growth and visual factors impacting water quality, thereby shedding light on environmental quality concerns in recreational water bodies. In contrast, this study offers a comprehensive perspective, not only considering environmental issues but also exploring the socio-economic and cultural dimensions of the estuary's importance to its users. Exploring the tangible benefits and challenges faced by visitors, including their monetary and time expenditures, the estuary's role in their livelihood and overall well-being, as well as their perceptions of system management and health.

Environmental Education: Community participation and understanding of the importance of ecosystems and their associated ecosystem services are vital for the management of conservation areas. This is especially true for Zandvlei as an urban Estuary, surrounded by multi-cultural communities (Department of Environmental Affairs, 2018). Public engagement and environmental education were of the least concern among questionnaire respondents. This may not reflect the importance of such management areas but rather that they are managed sufficiently enough to not be of concern to the respondents. Currently, Zandvlei has a well-run and reputable education programme in connection with the Zandvlei Trust. Current environmental awareness programmes primarily target the surrounding schools. The focus of these programmes involves identifying the ongoing issues that the Reserve is faced with and finding relevant solutions to these problems. Interactive campaigns to implement these solutions include litter clean-ups, safety walks with neighbourhood watch, alien vegetation clearing, and recycling campaigns. These programs are vital for enhancing support from the surrounding community for the protection of the ZENR.

Pondweed: Pondweed occurs naturally in the ZENR and plays a vital role in the ecosystem as it provides habitat for many species, oxygenates the water and reduces nutrient loading within the aquatic system (Jackson et al., 2010). However, pondweed can become a problem under certain nutrient conditions as it can form thick mats which inhibit boating activities, increase the risk of flooding, reduce light, and water flow and thus increase stagnation. Its decomposition creates an unfavourable smell and further increases nutrient levels. Furthermore, a lack of pondweed will increase nutrient loading and the potential for blue-green toxic algae. Considering its ecological importance, management strives to find appropriate levels of pondweed such that enough is needed to provide the ecological benefits yet not too much that it may hamper recreation or property values (Department of Environmental Affairs, 2018). To do this, the current management plan includes various objectives for pondweed management such as ensuring a third of the area is set aside for the species, recreation areas are cleared completely and increasing the understanding of the species dynamics with users and surrounding residents.

Pondweed was one of the major management concerns among respondents, the majority of which were on-water users such as rowers which is to be expected considering their activity would be the most affected by excessive growths of pondweed. This could illustrate an inadequacy in management's ability to control the growth of pondweed within the recreational areas or in raising awareness about its importance to the ecosystem.

Public Maintenance: Considering that picnickers spent the most time in the picnic sites at the ZENR where most of the public facilities are located, it's no surprise that their primary concern was with the maintenance of these public areas than any other management practices.

Prioritising this concern would serve to enhance their enjoyment at the ZENR and therefore their support for the conservation thereof. Furthermore, maintenance could include the provision and clearing/cleaning of dustbins which would assist with the major concern of litter above. However, the maintenance of these areas is not the responsibility of the ZENR Management but that of City Parks (Department of Environmental Affairs, 2018).

Perceived Health of the ZENR: Almost all user groups perceived the health of the ZENR as poor. Activity groups in close contact with water such as fishers or canoeists rated the ZENR with a much lower health score than respondents who utilised areas further away from the water such as meditators, picnickers and runners. This justifies the trend that water users were mainly concerned with water-related management concerns. This may not necessarily indicate poor management but is more likely the continued anthropogenic pressures identified above that compromise the use of the system.

Picnickers rated the ZENR in the best health, perhaps as they spent the least time at the ZENR and particularly its water body (as full contact recreation is prohibited) and therefore may have been less knowledgeable or concerned for its conservation. They may have been unaware of any environmental concerns due to having little interaction with the water, where such issues may be more prevalent such as litter accumulation along the water's edge, poor water quality/visibility, poor species diversity and alien species etc. Picnickers were the least concerned for the health of the ZENR, and were the most satisfied with its management, except for their concern for the maintenance of the public areas. Considering the requirements of picnickers are fairly simple, they are generally met by management.

Importance of the ZENR for the Social and Cultural well-being of Users: Cheesbrough *et al.* (2019) explored the perceived health and well-being effects of access to Natural Area Parks in Edmonton, Canada through photovoice interviews with 33 participants. They found the wild aspects of the parks of particular importance. Critically, the therapeutic value of the park emerged from the totality of the experience rather than from its individual components and access to wilderness increased opportunities for relaxation, deep connection, and reflection.

Much like the findings of Cheesbrough et al. (2019), many survey respondents in this study identified that the ZENR was important to their well-being as it provided a place to relax, spend time with their friends and family or exercise, which illustrates its importance within the welfare sector. A large percentage of users across all activity groups felt that the ZENR was important for their social and cultural wellbeing. So, the importance of the ZENR to a user's social and cultural wellbeing was not dependent on the user's recreational activity.

During the school holidays, several women from the surrounding lower-income areas identified in questionnaire responses that they used the ZENR to teach their community children about nature, away from the social issues associated with their lower-income neighbourhoods. Many of these women used their income/funds to do so, illustrating the opportunities of the ZENR for social upliftment (see Appendix B).

Importance of the ZENR for the livelihood of users: It has been well noted that estuaries supply a variety of harvestable products and services which contribute to the livelihood of the surrounding communities and local economy. The importance of the ZENR to visitors' livelihood was not dependant on their recreational activity of choice and is evident within the equal distribution of importance to visitor livelihood throughout all user groups. Almost half of the respondents stated that the ZENR was important to their livelihood, and fishers had the greatest proportion of benefit to their livelihood as they can use the caught fish for food or income. Respondents may not have fully understood the question, illustrating the importance of having clear and understandable questions within questionnaire surveys.

Use and Adequacy of Public Transport by Users: The association between the use of public transport and respondents' recreational activity of choice is evident as the majority of recreational users did not make use of public transport, likely because they either lived close enough to walk or they had the means to use alternative travel such as a car or that they felt the public transport was inadequate. The two user groups that did make use of public transport were picnickers, likely as they had the lowest gross monthly income and public transport would be an affordable way to get to the ZENR. Access to Zandvlei is well served by the Lakeside and False Bay stations on the Southern Line in Cape Town. However, the service has fallen into disrepair and for example, no longer runs on a Sunday when many groups such as picnickers would require it. Considering that 10% of all users travel from low-income areas, it would be beneficial for these users to have an improved public transport system to Zandvlei. This would not only increase the number of users to Zandvlei but the resultant economic activity for the area and its surrounds.

In conclusion, the significance of community-based conservation management within the context of the Zandvlei Estuary Nature Reserve (ZENR) is paramount to its longevity. This approach recognizes that involving local communities in management decisions fosters not only effective conservation practices but also contributes to the well-being of residents. The user-profile analysis above highlights the correlation between age and activity preference, revealing that older individuals tend to engage in leisurely activities while younger respondents gravitate toward more physically demanding sports. Gender differences further emphasize that men and women often opt for activities aligning with their physical attributes and social preferences. Moreover, the income factor underscores how financial resources influence activity choices, potentially impacting user diversity.

The findings also accentuate the connections between user behaviours, environmental conditions, and management concerns. Water level management emerges as a cornerstone for the estuary's health, recreational quality, and species vitality. Effective management in this aspect facilitates ecosystem well-being, ensures safe recreational conditions, and supports estuarine species' life cycles. Equally important is the insight into visitors' engagement with management efforts, where increased time spent correlates with greater involvement. The potential for education to engender a sense of responsibility and behaviour change stands out as an essential tool for promoting litter management, reflecting its potential to cultivate long-term stewardship.

Safety and law enforcement, water quality, and other management concerns underscore the complex interdependence between human activities and ecological integrity. Environmental education and community engagement is also important in shaping perceptions and fostering support for conservation efforts. Public education is shown to play a pivotal role in nurturing informed and responsible behaviour, encouraging connections between the public and their environment, and creating a culture of stewardship.

Furthermore, the relevance of management practices like mouth/water level management, the role of pondweed in the ecosystem, and addressing concerns like litter management demonstrate the intricate balance needed for sustaining both human recreation and environmental health. Finally, the ZENR's contribution to social, cultural, and livelihood well-being underscores its multifaceted role within the community, suggesting the importance of addressing management concerns to ensure continued benefits for both users and the estuarine ecosystem.

This study showcases the intricate web of interactions between recreational activities, management practices, environmental conditions, and user perceptions, illuminating the challenges and opportunities in achieving a harmonious balance between human recreation and the preservation of the Zandvlei Estuary Nature Reserve.

Limitations and Further Research

While this study provides valuable insights into the recreational use value of the Zandvlei Estuary Nature Reserve (ZENR), several limitations warrant consideration. Firstly, the ZENR is not a closed reserve, making it challenging to obtain accurate daily visitor numbers. This openness may result in fluctuations in user access and demographics that are difficult to quantify, potentially leading to underestimations or overestimations of visitor frequency and activity participation. A more robust visitor tracking system could be beneficial for future studies to better understand daily and seasonal variations in recreational use.

The use of both face-to-face and electronic survey methods may have also introduced sampling biases. Although the combined total of 1,078 respondents offers a comprehensive overview, the reliance on electronic surveys may have limited participation from users without internet access, potentially skewing the demographic representation of respondents.

Additionally, the survey was conducted over a year-long period from July 2018 to August 2019, which may not capture seasonal variations in recreational use and expenditure patterns. Factors such as weather conditions, school holidays, and local events could significantly influence visitor numbers and activity preferences, necessitating a more detailed temporal analysis to fully understand these dynamics.

Moreover, while the survey addressed various aspects of users' experiences, certain qualitative factors—such as the intrinsic motivations behind recreational choices or the subjective enjoyment derived from activities—were not deeply explored. Future research could incorporate in-depth interviews or focus group discussions to provide richer qualitative data on user motivations and experiences at ZENR.

Another limitation lies in the representation of activity categories. Some recreational activities may not have been adequately represented in the survey, leading to an incomplete understanding of their impact on the overall use value of the ZENR. Future studies should aim to include a broader range of activities to provide a more comprehensive assessment of recreational use and associated expenditures.

Furthermore, the statistical analyses employed in this study, such as Chi-square and Kruskal-Wallis tests, are based on categorical and numeric variables, respectively. Future research should consider incorporating multivariate analyses to account for potential interactions between different factors affecting recreational use, such as socio-economic status, environmental awareness, and perceived management effectiveness.

Additionally, comparisons with similar reserves such as Zeekoevlei, Rietvlei, and others could provide valuable context and highlight potential differences or similarities in recreational use patterns. Understanding how these reserves attract different user demographics and what activities are popular in each location could inform management practices not only at ZENR but across similar ecosystems.

2.5 Appendices

Appendix A Questionnaire Survey used to sample users of the ZENR between July 2018 and August 2019

Demographic (Quantitative)
What is your gender?
What is your age?
What suburb do you reside in?
What is your gross income per month?
Use of the Vlei (Quantitative)
How do you utilize the ZENR? (If you partake in more than one activity, please complete a separate survey for each activity)
How often do you use the ZENR?
How much time do you spend at the ZENR on each use for this activity?
How much time do you spend travelling to the ZENR when utilizing it on each use for this activity?
Costs involved partaking in activity (Quantitative)
How much do you spend a month on transport to and from ZENR to undertake this activity?
Do you have other expenses to take part in your activity? (Please specify)
How much do you spend on equipment for your activity at ZENR per year?
How much do you spend on membership and other fees (e.g. permits) for your activity at ZENR per year?

Importance of Estuary and Management (Quantitative)
Is the ZENR important to your livelihood?
Is the Zandvlei Estuary valuable to your social and cultural wellbeing?
Have you experienced any conflict with the ZENR management? if so, please explain.
What management methods, if any, would you like the ZENR Management to implement and why?
How healthy do you think the ZENR Ecosystem is based on your experiences? (1 = Terrible health; 5 = Excellent health)
Are you satisfied with the current management of the system in terms of your use of the system?
Are you involved in estuary management? If so, in what way?
Other
Are there other natural systems (including beaches or mountains) in the Cape Town region that you utilize?
What do you use other natural systems for?
Do you utilize public transport to access the Zandvlei Nature Reserve and if so, is this transport adequate?
Do you have any comments or advice for the City of Cape Town and the management of their protected areas for increasing the value of the ZENR?

Appendix B Examples of feedback from users regarding management area concerns

Litter	"*Address the water litter problem both at its sources (upstream and the picnic area) and after the fact (municipal cleaners only collect litter on land, not in or on the edge of the water)". ~ Muizenberg Walker*
	"Free braai area to be a pay area. Money to be used for cleaners and will help in litter prevention and prevent alcohol abuse as is the case now." ~ Marina da Gama Runner
	"Waste catchment - land (more dustbins) and water-based (rubbish catchment traps at inlets and the Atlantic / Beach Road bridge)" ~ Muizenberg Walker/Hiker
	"Regular cleaning of the water's edge. Too much plastic for volunteers to manage Microplastic needs rakes and bags. Fewer fishermen because they leave plastic bags, fishing line and hooks and even fish." ~ Muizenberg Walker
Mouth Management	*"As an ecologist, I don't understand why they keep on closing the mouth. It is a polluted system with sewage leaks every few months. Why is the system not kept open so that it flushes regularly?" ~ Rower*
	"STOP closing the mouth. It affects the ecosystem. The mouth was always open till the residents of Marina da Gama moved in. The fishing in False Bay is disastrous. Why? Because our fish have no safe place to spawn. Why does the Breede River hold such healthy breeding stock Kob and Zandvlei doesn't?" ~ Canoeist
	"Open the estuary mouth permanently! It was open for the entire rainfall period and I have still not found any argument to convince me that it should be closed!" ~ walker/hiker
	"Re-engineer the mouth and dredge the lower reaches." ~ Bird watcher
Water Quality	"*Keep it clean and safe and protect biodiversity. Control weed, manage river mouth, sort out sewage system so raw sewage spills are no longer an occurrence. Arrange clean-ups with public participation, we would take part." ~* Picnicker
	"*Dredge the vlei, sort the sewage pipe out under the bridge at the mouth, it's the main cause of the silt that's choking the vlei, control the weed, open mouth on spring high and close on low, just..." ~* Fisherman
Safety and Law enforcement:	*"Picnic areas need monitoring and the public need to be educated regarding littering and plastic contamination of water. Darters get beaks caught in plastic and die of starvation- seen this at least 6 times."*
	"I would also like some form of ranger patrolling taking place as I witness a lot of illegal use in terms of fishermen throw netting or

	leaving behind fishing nylon waste which is detrimental for wildlife (I pick it up whenever I see it).”
	“I have caught individuals poaching. When you call, officials do not have the power to arrest/fine culprits. Bring back the old system of honorary nature conservation officers. Check for licenses. I have not been asked to produce a fishing license once in seven years! I fish most mornings.”
Education	*“Better educational signs about the impact of rubbish.” ~ Bird Watcher*
	“Cleaning, more publicity for awareness that it exists, children and adult programme (walks, birds, tour, canoe around tours) map, operating times.” ~ Picnicker
	“It would be nice to some action and engagement with the community to bring awareness to the importance of Cape Town's largest Vlei area. It's imperative that we as a community learn to take care of our natural surroundings. As far as I understand, the whole estuary area is an integral part of the water catchment system in Cape Town. It's so sad to all the mess, especially the rubbish in and around Keyser's River at Steenberg Station and the old peeling and neglected sign about the Keyser's River Restoration Project. Some public talks or clean-up events organised by management could be a fun way to engage and educate the community.” ~ Walker/Hiker
Pondweed	*“A fully serviced "weed eater" needs to be stationed here permanently during summer when weed proliferates*” ~ Canoeist
	“Drastically improve the reliability of the weed harvesting, better systems for containing sewage spills, better litter and pollution control from inflowing stormwater and rivers, regular dredging of the channel leading to the sea to allow better high tide flushing” ~ Meditative/Spiritual/Cultural User
	“Need weed harvester and open to the sea more” ~ Fisherman
Public Areas Maintenance	*“More dustbins (that are built to be windproof) provide bags for dog poo at key points, collect donations using snap scan so that users can contribute. Provide bike stands so that people can lock their bikes up.”*
	Children's play areas are terrible and there are lots of children. The structures get removed but never replaced. The estuary is a big recreational area for locals, not only users but children are ignored and left with dangerous playground equipment.”
	“I would also like the public toilets being open for public use and being watched over by an employed service attendant.”
	“More rubbish bins, more frequently emptied, repairing the road that runs along the outside of the Zandvlei caravan park - currently falling into the vlei.”

	Provide accessible and clean toilets. enforce and provide litter bags for dogs to reduce dog poop.”
Importance to social and cultural wellbeing	*Zandvlei is important both for the social and cultural life of Cape Town - not only for local residents. It is also an important wildlife habitat. It needs to be kept pristine in order for it to survive. It is therefore important to clean the water and keep the entire environment clear of rubbish and effluent*

CHAPTER 3: ASSESSING THE ECOSYSTEM SERVICE FUNCTION OF WATER FILTRATION AND NUTRIENT ASSIMILATION IN THE ZANDVLEI ESTUARY

3.1 Literature Review

Wetlands serve as natural treatment facilities for the waters flowing into the system (Breaux et al., 1995). Polluted or nutrient-rich water slows and is retained as it enters the reedbeds of estuaries, where nutrients are taken up by vegetation systems (Breaux et al., 1995). This filtration service not only benefits the people that make use of the system as a supporting service or a final ecosystem service (such as increased aesthetics for the surrounding property market, and improved recreation opportunities) but also the surrounding ecosystems, as heavy pollutants could cause dire consequences for many species (Barbier et al., 2011; Barbier et al., 1996).

Boyd and Banzhaf (2006) are known for their contributions to the field of ecosystem valuation, particularly the development of methods for estimating the economic value of ecosystem services. They distinguish between supporting services, provisioning services, regulating services, and cultural services as categories of ecosystem services (Boyd and Banzhaf, 2006).

Consider a wetland ecosystem as an illustrative example within Boyd and Banzhaf's (2006) framework of ecosystem valuations. Wetlands play a crucial role in providing supporting services that form the foundation for various other ecosystem services. One of these supporting services is soil formation and nutrient cycling, where wetlands act as natural filters, trapping sediment and absorbing excess nutrients from runoff. This process not only aids in maintaining soil fertility but also contributes to the overall health of the ecosystem (Farmer, A., 2012). Another supporting service is the provision of biodiversity habitat. Wetlands offer a diverse range of habitats for numerous species, from plants and insects to birds and fish. This diversity fosters ecosystem resilience and stability.

These supporting services offered by wetlands give rise to final ecosystem services that directly benefit human well-being. One such final service is water quality improvement. The wetland's capacity to absorb nutrients and trap sediments enhances downstream water quality. The cleaner water becomes suitable for various uses, including drinking, recreation, and irrigation, thereby promoting better human health and increased agricultural productivity (Carpenter et al., 2009; Vallecillo et al., 2019; Mahan et al., 2000; Farmer, A., 2012). Additionally, wetlands hold recreational and aesthetic value. People can engage in activities like bird watching, fishing, and boating in these areas. Moreover, the natural beauty and aesthetic appeal of wetlands contribute to cultural and spiritual values, enriching the overall quality of life for nearby communities.

In summary, the wetland ecosystem demonstrates Boyd and Banzhaf's (2006) distinction between supporting services and final services in ecosystem valuations. The supporting services, encompassing soil formation, nutrient cycling, and biodiversity habitat, lay the groundwork for essential final services such as water quality improvement and recreational/aesthetic value. This framework provides a holistic understanding of how various ecosystem services interconnect and collectively contribute to human well-being and the broader economy.

The inclusion of the value of water quality as an ecosystem service within urban planning enables authorities to better understand and manage the risks associated with poor water quality (Cullis et al., 2018). With a rise in urban development, peri-urban wetlands have been used as natural water treatment facilities since the 1970s (Bolund and Hunhammar, 1999), For example, in Uganda, the Nakivubo urban wetland is used for the treatment of wastewater from the nearby city of Kampala (Kansiime and Nalubega, 1999b). However, more than half of this ecosystem has been cleared for urban development threatening the entire wetland (Schuyt, 2005). A valuation study of the wetland which included the water treatment and purification service that it provided estimated that the cost of a wastewater treatment plant with the same efficacy would cost up to $2 million per annum. This replacement valuation approach highlights the need for investing in the maintenance and conservation of wetlands as a cost-effective method to ensure the treatment of the City's future wastewater (TEEB 2011; Cilliers et al., 2013).

Breaux *et al.*, (1995) estimated the cost savings of using wetlands for the treatment of wastewater in Louisiana, U.S.A as up to $34 700 per acre of wetland. Additional benefits suggested by these authors included the improvement of wetland health due to the nutrient inputs from untreated wastewater (Breaux *et al.*, 1995). In July 2005 Hewlitts Creek Estuary in North Carolina, USA was subjected to a raw sewage spill of 11 355 000 litres when a bulk sewer main burst. This resulted in the depletion of oxygen, hypoxia, algal blooms, large fish kills and of course, large concentrations of *E. coli* within the estuary. However, monitoring showed the strong filtration mechanism of the estuary was able to significantly reduce these levels over the first few days (Mallin et al., 2007).

Several studies have been conducted in South Africa as to the value and significance of water filtration by wetlands and estuaries. Cullis et al., (2018) investigated the risks of declining water quality for the Breede River catchment in the Western Cape and found that social and economic risks related to declining water quality standards included:

- Declining crop yields due to increased salinity could cost up to R132 million per year.
- Export/international trade risks due to poor water quality concerns could cost up to R570 million as well as impact employment security of 14 291 permanent and 16 680 seasonal labourers.
- Increased human health risks could cost up to R140 million per year for the government.
- Impacts on tourism, recreation and property market for the area could cost up to R90 million per year.

Turpie *et al.* (2001) also investigated the value of Zandvlei as a water treatment facility. They estimated the replacement cost of the estuary to be R180 million. Its value for flood alleviation was estimated at R24 million, illustrating the importance of these regulating services to the surrounding communities and the local economy.

Biological Parameters Influencing Water Quality

Escherichia coli is a rod-shaped bacterium, commonly found in the intestines of warm-blooded animals and grows quickly when inside the intestine, replicating every 20 minutes (Jang et al., 2017). A study by Ishii and Sadowsky (2008) revealed that *E. coli* can survive for long periods outside of a body, although it is unable to replicate outside of its natural host (Ishii and Sadowsky, 2008). Levels of *E. coli* are measured in Colony Forming Units (cfu). High *E. coli* levels can severely impact the environment, human health, and the economy (Ishii and Sadowsky, 2008). Environmentally, it can reduce light penetration, result in unpleasant odours, and decrease levels of dissolved oxygen (DEA, 2012).

Escherichia coli infections can become costly for the economy as many people become sick and therefore rely on government health programs (Jang et al., 2017; Western Cape Government, 2013). In the 1980s, studies revealed a strong correlation between *E. coli* and intestinal illnesses in humans during sewage spills (Šolić and Krstulović, 1992). This led to the use of *E. coli* as an indicator of the presence of faecal matter in recreational waters. Maintaining optimal target levels for full-contact recreation is crucial for ensuring visitor safety (Wade et al., 2003).

In the United States, full contact with contaminated water is prohibited when *E. coli* levels are over 235 cfu per 100 ml (Jang et al., 2017). The target range in South Africa for full contact recreation is recommended between 0 – 130 cfu/100ml (Republic of South Africa; Department of Environmental Affairs: Oceans and Coast Branch, 2012).The ZENR Management Plan aims to maintain levels for intermediate contact recreation (such as canoeing or yachting) at 1000 cfu/100ml and 130 cfu/100ml for full contact recreation (such as swimming) (Republic of South Africa; Department of Environmental Affairs: Oceans and Coast Branch, 2012). Currently, the management goals for water quality at Zandvlei include minimising the number of raw sewage spills, wastewater discharges and litter into the system.

The current protocol for a major sewage spill at the ZENR includes notifying City reticulation officials, informing stakeholders (recreational users, and surrounding communities), treating the raw sewage with bio enzymes, conducting emergency water sampling, and monitoring waterways for pollutants (Department of Environmental Affairs, 2018).

Escherichia coli can be released into natural systems via faeces from damaged wastewater treatment plants, septic systems, storm-water runoff, and runoff from agricultural farmlands. Identified possible sources of *E. coli* within the ZE catchment include:

i. Stormwater outflows, septic tanks and sewage pumps and lines.

Fourteen sewer pump stations surround the ZENR. These are monitored by a telemetry system that warns management should any fault and subsequent overflow occur. Ten pump stations can be found in Marina da Gama, three along Military Road, and one on Henley Road (North of the waterbody). Overflows from the Marina stations result in sewage running directly into the main water body and those near the Northern section flow into the inlet rivers. Overflows are usually a result of blockages from the disposal of solid objects into stormwater drains (Department of Environmental Affairs, 2018). Sewage spills into Zandvlei have also occurred because of vandalism and theft of cables, pumps or parts thereof. The ageing sewer lines are also in need of regular maintenance. Substantial rainfall can also contribute to overflows of stormwater drains as their pipes reach maximum capacity (Haskins, 2016).

ii. Run-off from agriculture and residential lands

To the North of the ZENR, along the upper reaches of its Keyser’s inlet river lie multiple vineyards in the Constantia Valley. These uses can contribute to organic waste (such as compost and manure) (Department of Environmental Affairs, 2018). Local *E. coli* input directly into the main water body of the vlei results from the run-off of organic fertilisers, and pet and bird faeces, however inputs from the resident bird population, should be regarded as a natural part of the system (Haskins, 2016).

Haskins (2016) investigated the water quality of the ZES including *E. coli* concentrations. She found that the northern area of the Zandvlei waterbody (near the inflowing rivers) exhibited poorer water quality than the central and southern areas, illustrating the effect of the in-flowing rivers on the vlei. While the monthly water sampling has reflected results below the stipulated threshold guideline for intermediate recreation (1000 cfu/100ml), the general trend over time does show an increase in this area, with peaks during and after the first winter rains due to the flushing effect of accumulated debris along the river edges.

Haskins reports that the improved quality of water in the central part of the water body was likely due to the dilution of these influent rivers as the main vlei has a much greater volume. There was also an improvement in the water quality for this area over a long-term period with a notable improvement during 2014 and 2015 compared to previous years (Haskins 2016). *E. coli* results within the outlet were regarded as acceptable and improved over the long-term period barring results in 2014 and 2015 when sewage spills occurred as a result of broken pump stations due to theft and vandalism.

Salinity is thought to be a mortality factor for bacteria such as *E. coli* ((Harding, 1994). Whilst laboratory studies suggest that *E. coli* can survive several days in seawater, recent in-situ studies reveal that other variables play a bigger role in *E. coli's* survival including solar radiation, temperature, pH, predation and competition, rather than salinity alone (Šolić and Krstulović, 1992).

<u>Physico-Chemical parameters influencing water quality</u>

The Nitrogen Cycle

The nitrogen cycle, a vital biogeochemical process, encompasses the transformation and cycling of nitrogen through various forms within the environment. This intricate cycle, involving both biological and non-biological mechanisms, holds significant sway over the water quality of freshwater ecosystems like estuaries and rivers. Beginning with nitrogen fixation, where atmospheric nitrogen is converted into Ammonia by nitrogen-fixing bacteria, the cycle progresses through ammonification, nitrification, assimilation by plants and algae, and denitrification, culminating in the release of nitrogen gas back into the atmosphere. In the context of water quality, the nitrogen cycle plays a crucial role. However, excessive nitrogen runoff from human activities, such as agriculture and industry, can disrupt this cycle and lead to adverse effects. The accumulation of nitrogen can cause nutrient enrichment, triggering eutrophication, algal blooms, and oxygen depletion in water bodies. The resultant oxygen-depleted zones and altered pH levels can harm aquatic life and impact biodiversity, ultimately affecting the delicate balance of these ecosystems. Thus, maintaining a harmonious nitrogen cycle is essential for safeguarding the water quality and ecological integrity of freshwater environments.

Concentrations of organic nitrogen deposits in natural environments have increased dramatically with the rise in urbanisation (Brush, 2009). There is a high correlation between unnatural nutrient inputs into catchments and increasing urban and agricultural development. The largest contributors to these inputs come from wastewater discharge and run-off from fertilizers and pesticides. (DEA, 2012).

As early as 1982, Zandvlei was classified as a eutrophic system due to high levels of Nitrogen and Phosphorus (Morant and Grindley, 1982; Harding, 1994). Furness (1979) recorded Nitrogen concentrations in the estuary of between 1 and 2 mg/l (Morant and Grindley, 1982), although influent rivers had Nitrogen concentrations far higher, ranging from 6 to 7 mg/l (Morant and Grindley, 1982). Harding (1994) found the northern section of the main water body and inlet rivers had the greatest concentrations of Nitrogen and recorded an average concentration of 1.79 mg/l per year over four years. Quick and Harding (1994) found no seasonal changes in the concentrations of Nitrogen at ZENR.

<u>Ammonia</u>

Ammonia occurs naturally in the environment as a result of the breakdown of organic matter and the weathering of nitrogen-rich sedimentary rocks (DEA, 2012). Many aquatic species also excrete Ammonia. Anthropogenic sources of Ammonia include discharges from industrial processes and agricultural run-off. Undisturbed systems will present low levels of Ammonia, usually <0.02mg/l as N (or mg/l N) (EPA, 2009).

Ammonia can be highly toxic to fish and other marine life at low concentrations (< 0.2 g/l N). A system is considered toxic when levels exceed 0.6g/l N (DEA, 2012). For vertebrates, Ammonia can cause seizures, coma and death. When levels exceed 0.1 mg/l N, effluent may be present in the system and the consequent possibility of pathogens such as *E. coli* (DEA, 2012). The South African Water Quality Guidelines for Coastal Marine Waters (2012), stipulate that in the absence of human influences, Ammonia levels in estuaries are usually less than 0.05g/l. Limits for slightly disturbed ecosystems are (0.04-0.05g/l).

Using data from 1973 to 1978, Morant and Grindley (1982) found that Ammonia concentrations exceeded the guidelines at several sites within the Zandvlei Estuary, particularly in the northern areas. Harding (1994) found the average concentration of Ammonia s within the inlets to be 150mg/l. Using data from 2000 to 2009, Haskins (2016) found the centre of the main waterbody at Zandvlei also exceeded the guidelines regularly.

<u>Nitrate + Nitrite as Nitrogen</u>

Nitrate is the most organic (oxidized) form of Nitrogen as a nutrient for aquatic plants. Nitrite is formed during the oxidation of Ammonia to nitrate. Increased sewage spills, rich in Ammonia can result in increased nitrites within water systems and therefore increased levels may indicate levels of such contaminants. Nitrite is also a source of nutrients for plant growth. Large amounts of nitrogen can lead to excessive growth in plants, contributing to eutrophication which in turn reduces species diversity. At high levels, Nitrogen is toxic to infants. At small concentrations, Nitrite can be toxic to aquatic species. Current guidelines recommend levels in pristine waters to be less than 0.01 mg/l for Nitrite and less than 0.1 mg/l for Nitrate. Nitrate within very disturbed waters can be more than 1 mg/l. Harding (1994) found the average concentration of Nitrate and Nitrite as Nitrogen within the inlets at the ZES was 1.48mg/l.

<u>Total Oxidized Nitrogen</u>

Total persulphate oxidized Nitrogen is the sum of all organic (oxidized) Nitrogen. i.e. all forms of Nitrogen that can be readily absorbed by plants and algae (e.g. Ammonia and nitrite/nitrate) and therefore, occurs in higher concentrations than just Ammonia and nitrate/nitrite (Environmental Protection Agency EPA, 2001; DEA, 2012).

Morant and Grindley (1982) found levels of Total Oxidised Nitrogen between 1 and 2 mg/l in the main water body of Zandvlei, which indicated slight eutrophication. Similar values were found by Jackson et al., (2010) where Nitrogen levels were only slightly below the 2.5mg/l level which indicated eutrophic conditions (Morant and Grindley, 1982; Jackson et al., 2010). Harding (1994) found Total Oxidized Nitrogen levels within the inlets to range between 0.8-1.9 mg/l.

<u>Phosphorus</u>

Phosphorus is generally found in lower concentrations than Nitrogen and is the limiting nutrient for aquatic plant growth in aquatic environments. It is found naturally in rocks and is slowly released as water-soluble Phosphate ions through the weathering process. (DEA, 2012). The main types of Phosphorus found in water systems include Orthophosphate, condensed Phosphates and Organophosphates. Human sources of Phosphate include waste from fertilizer production, phosphatisation of metals in metal processing industries, sewage and stormwater discharges and agricultural run-off (DEA, 2012).

Although not harmful at natural levels in aquatic systems, an abundance of orthophosphates ($H^2PO4^-$and HPO_4^{2-}), can have detrimental effects on ecosystems. Nutrient loading as a result of increased Nitrogen and Phosphorus from the run-off of fertilizers can result in eutrophication, acidification, large and toxic algal blooms, reduced oxygen in freshwater systems (and hypoxia), and reduced ecosystem services such as freshwater and fish species abundance/variation (Millennium Ecosystem Assessment, 2005).

Increased Phosphorus in soils can increase the vulnerability of freshwater systems to conditions that quickly reduce oxygen and cause algae blooms, and fish kills (Millennium

Ecosystem Assessment, 2005). High levels of Phosphorus can also restrict the coral calcification processes such as the (alien) tube/coral worm (*Ficopomatus enigmatica*) found at Zandvlei (UNEP/Nairobi Convention Secretariat and CSIR, 2009). Phosphorus concentrations are found between 0.001 and 0.050 mg/l in "pristine" waters (oligotrophic), although they can reach 0.2 mg/l in some estuaries. A system is considered hypertrophic when levels exceed 0.25 mg/l (Jackson et al., 2010).

As previously stated, the ZENR has been classified as a eutrophic system since the 1980s (Morant and Grindley, 1982; Harding 1994; C.A.P.E., 2013). Furness (1979) found that phosphorus levels ranged between 0.01 and 0.3 mg/l. The highest Phosphorus levels were found within the inlets and ranged from 1 to 2 mg/l (Morant and Grindley, 1982; Harding, 1994). Harding (1994) found the average phosphorus levels to be 0.18 mg/l per year over four years, whilst Quick and Harding (1994) found no seasonal changes in the concentrations of phosphorus at the ZENR.

C.A.P.E. (2013), reported a steady increase in total phosphorus and orthophosphate at the ZENR between 1978 and 2012. The total phosphorus concentrations classified the ZENR into Category D (a large deviation from natural conditions) of the Water Quality Index estuary threshold levels (C.A.P.E., 2013). Harding (1994) found the average concentration of Total Phosphorus within the inlets ranged between 0.106-0.160 mg/l.

<u>Orthophosphate</u>

Orthophosphate is the most readily available (reactive) form of Phosphorus for plants to absorb during photosynthesis. Orthophosphate is therefore commonly analysed for monitoring Phosphorus in natural waters and high amounts of Orthophosphates usually occur during or just before algal blooms (EPA, 2009). Orthophosphate levels are known to be higher in land-based water systems such as rivers and estuaries than those in coastal marine waters due to inputs from surrounding urban-based sources. Estuaries with heavy inputs of nutrient-rich pollutants can reach levels of more than 0.01 mg/l. In pristine aquatic environments, these levels are usually less than 0.05 mg/l (DEA, 2012). Harding (1994) found the average

Orthophosphate concentrations within the inlets of Zandvlei to range between 0.037 – 0.057 mg/l.

Suspended Solids

Suspended solids are a measure of particles suspended in the water that is carried out by filtration as mg/l (Environmental Protection Agency EPA, 2001). Suspended Solids comprise sand, clay, fine particles of organic and inorganic material, plankton and other microscopic organisms derived from natural processes as well as further inputs derived from unnatural processes such as farming, canalization, deforestation, urbanisation, dredging, mining, and wastewater. These inputs are known to unnaturally increase the sediments in our freshwater and marine environments (DEA, 2012).

High concentrations of suspended solids can lead to increased turbidity which can limit light penetration and therefore affect photosynthetic activity. It can also clog fish gills which will likely increase stress levels and susceptibility to disease (Jordan et al., 2003). Settling particles can suffocate the fish eggs of spawning species (Jordan et al., 2003). Suspended solids also affect certain water treatment procedures (DEA, 2012).

One benefit of suspended matter is its ability to absorb certain pollutants such as pesticides, thus removing it from the water column (and sequestrating it into the sediment) (United States Environmental Protection Agency (USEPA), 1986).

There are no set guidelines for suspended solids for the coastal waters of South Africa due to the large natural variation of this parameter (DEA, 2012). Harding (1994) found the average mean Suspended Solids concentration within the inlets was 145 mg/l.

Water clarity as measured by Secchi depth

Secchi depth is a measure of the water clarity by taking into account the water colour, turbidity and suspended solids. It is measured visually using a Secchi disc that is lowered into the water until it is no longer visible at a certain depth (DEA, 2012). Secchi depths are more commonly used to gauge the presence of algae which can respond very rapidly to nutrient changes and can dramatically reduce water clarity within a matter of days (Environmental Protection Agency EPA, 2001). Morant and Grindley (1982) found the Secchi depth at ZENR to range between 0.2 – 1.8 m and had an average of 0.7 m for the whole system (Morant and Grindley, 1982). Harding (1994) found Secchi depth within the ZENR increased with distance from the inlets and was lowest during winter rains and highest during summer. Secchi depth was found to range between 0.09 and 1.2 m with an average of 0.54 m for the whole system (Harding, 1994).

<u>Salinity</u>

Salinity refers to the dissolved salt content within the water. In estuaries, salinity varies more than in the marine environment due to the fresh water entering the system from the catchment which mixes with seawater which flows in tidally from the estuary mouth. Salinity largely determines the distributions of living organisms found within an estuary (Ohrel and Register, 2006). Freshwater species [such as the Cape Galaxias (*Galaxias zebratus*), Cape Sandfish (*Ammotragus angolensis*), Cape Platanna (*Xenopus gilli)* and Redfin Minnow (*Pseudobarbus asper*)] will be restricted to the upper reaches while marine species [such as the Cape Rock Crab (*Plagusia chabrus),* Southern Sand Octopus (*Octopus vulgaris*), Striped Mullet (*Mugil cephalus)* and Garrick (*Elops machnata*)] will occur nearer the outlet. For the stenohaline species such as the Flathead Mullet (*Mugil cephalus*), Southern African Glasswort (*Sarcocornia perennis*), Marine Lugworm (*Arenicola marina*), Estuarine Roundherring (*Gilchristella aestuaria*), Estuarine Mud Crab (*Rithropanopeus harrisii)* and Cape Stickleback (*Aulorhynchus flavidus),* large changes in the salinity will directly affect their distribution, life cycles and health (Ohrel and Register, 2006).

The 2013 Cape Estuaries Programme suggests salinity ranges within estuaries of between 6 ppt and 18 ppt during Summer and between 11 ppt and 13 ppt for Winter (C.A.P.E., 2013). The salinity regime for the ZENR should allow for the maintenance of the marine fish populations such as White Steenbras, Leervis and Haarders (*Chelon richardsonii*), invertebrates such as the Sandprawn (*Callichirus kraussi*) as well as the halotolerant grass species such as *Enteromorpha intestinalis* that previously occurred there (Town et al., 2014). The estuary mainly comprises fresh-water species such as Pondweed, Common Carp (*Cyprinus carpio*) and Catfish (*Silurus glanis)* (Department of Environmental Affairs, 2018).

Changing the height of the weir greatly affects the salinity range of the ZENR. Hutchings (2016) noted several instances where the average salinity for the system changed by either lowering or raising the weir. Mean annual salinity declined from 10 ppt to 5 ppt from the 1980s to the 1990s when the weir was increased. Salinity then increased to between 9 and 11 ppt between 2002 and 2010 after the weir was lowered slightly (Hutchings *et al*. 2016).

In terms of seasonal variations, the highest salinity concentrations are usually recorded during summer due to lower freshwater inflows and high evaporation rates (Muhl *et al*. 2003). Spatial variations have shown salinity to increase towards the mouth as ranges were found between 5 and 15 ppt near the head of the estuary, 5 and 20 ppt in the middle reaches and 5 and 32 ppt near the mouth (Hutchings *et al*. 2016). Haskins (2016) found the salinity concentrations indicated the mouth management regime was ensuring regular inputs of salt water during open-mouth periods.

Conductivity

Conductivity is a key parameter used for assessing water quality within coastal aquatic environments, functioning as a surrogate measure for the water's capacity to conduct electrical currents. Measured in millisiemens per meter (msm), conductivity provides an indirect quantification of the concentration of dissolved ionic particles present in the water. As ionic substances, such as salts, contribute to the electrical conductivity of water, an elevation in the conductivity reading correlates with an augmented presence of dissolved ions. This measurement is particularly insightful for discerning variations in dissolved solids content.

In the context of the Zandvlei Estuary and Nature Reserve (ZENR), the intricate relationship between conductivity and salinity warrants special attention. A study conducted by Harding (1994) intricately examined this interplay within the ZENR. Notably, the investigation revealed a mean conductivity range of 269-274 msm within the estuarine inlets. This empirical insight underscores the profound correlation between conductivity and salinity dynamics that orchestrate the hydro-chemical composition of the ZENR. Consequently, conductivity emerges as a metric for revealing the intricate mosaic of coastal water quality, particularly within ecosystems as intricate and diverse as the Zandvlei Estuary.

3.2 Methods and Materials

Nutrient and chemical loading is an increasing concern for the estuary management at Zandvlei as these can cause detrimental effects such as eutrophication. Management protocol for resolving such concern involves locating the sources of nutrient deposits via monthly water quality tests at various locations throughout the system (Department of Environmental Affairs, 2018).

Water quality and nutrient loads were analysed using the measurements obtained from the monthly water quality testing performed by the City of Cape Town's Scientific Services. Results from eight sampling sites over 10 years (2009 to 2018) were analysed to investigate seasonal and spatial trends. The sites included the three influent river systems (Keyser, Sand and Westlake), three points within the main waterbody (North, centre and South) and the mouth outlet to the sea (Figure 18).

Figure 18 The ZENR and surrounding area (Source QGIS 3.22; City of Cape Town 2019) (repeated for ease of reference).

Data were imported into Microsoft excel 2016 spreadsheets and organised so that analyses could be carried out. To investigate spatial variations between the main water body, influent rivers and the outlet channel, stations within the three influent rivers (Keyser's, Sand and Westlake) were grouped as "Site one", the waterbody North section is referred to site two, the waterbody centre section as "site three", the waterbody South section as "site four" and the two sampling stations near the estuary mouth were grouped as "site five" in the tables below. To quantify temporal variations, sampling events falling within September, October and November months were combined as Spring, months December, January and February as Summer, months March, April and May as Autumn and months June, July and August as Winter. Data were entered and organised and then imported into IBM SPSS Statistics 28.

Tables and graphs were created to illustrate spatial and temporal variations for each sampled parameter. Data were investigated for normality using the Kolmogorov-Smirnov test and Shapiro-Wilk test for each parameter sampled (physico-chemical, nutrient, sediment and biological) across sampling sites and sampling seasons. The data were found to be not normally distributed and non-parametric analyses were performed. Descriptive statistics were calculated for physico-chemical, nutrient, sediment and biological parameters.

A non–parametric Kruskal–Wallis One-Way ANOVA on Ranks test was performed for each parameter to test for significant differences between sites and between sampling seasons. Seasons were compared consecutively to one another i.e., Winter was compared to Spring, Spring was compared to Summer, Summer was compared to Autumn and Autumn was compared to Winter to determine if there were significant trends in the seasonal changes. If significant differences were detected amongst data sets, pairwise comparisons were performed post–hoc to specify differences.

3.3 Results

3.3.1 *E. coli*

Descriptive statistics for the *E. coli* concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 3 below.
A total of 742 samples were taken to be analysed for *E. coli* concentrations which were found to be highest in site 1 (Figure 18) and lowest in site 4 and highest in the autumn and lowest in the Spring.

Table 3 Descriptive statistics for *E. coli* concentrations at the ZES during the study period (10 years)

E. coli (cfu)		N	Minimum	Median	Maximum	Mean	Std. Deviation
		742	1.00		10,000,000.00	25,470.72	381,211.80
Sample Site	**Site 1**	268	8.00	1,750.00	10,000,000.00	68,601.97	632,743.50
	Site 2	113	1.00	88.00	40,000.00	1,535.29	5,026.38
	Site 3	133	3.00	76.00	30,000.00	931.08	3,111.16
	Site 4	28	10.00	85.00	3,000.00	485.89	848.29
	Site 5	200	2.00	84.50	21,000.00	1,015.11	3,218.49
Sample Season	**Autumn**	196	4.00	300.00	10,000,000.00	60,654.40	716,090.08
	Spring	179	4.00	110.00	105,000.00	4,623.94	14,648.13
	Summer	184	1.00	44.00	1,000,000.00	15,843.36	105,351.04
	Winter	183	10.00	450.00	2,300,000.00	17,858.74	170,221.57

Spatial trends of *E. coli* concentrations

Significant differences were found in the mean *E. coli* concentrations between sample sites. A Kruskal–Wallis One-Way ANOVA on Ranks test indicated that the mean *E. coli* concentrations decreased significantly between the influent rivers (site one) and the main water body (site 2) [$H(2) = 200.76$, $p < 0.05$)].

Site one (influent rivers) had the highest *E. coli* readings of all the sampling sites throughout the study, with a mean *E. coli* concentration of 68 601.97 cfu/100ml (SD= 632 743.5). The northern section of the main waterbody (site two) also presented poor results with a mean *E. coli* concentration of 1535.29 cfu/100ml (SD= 5026.38) over the 10 years. The central and southern sections of the main waterbody were compliant with the ZENR management's target for intermediate recreation (1000 cfu/100ml). *E. coli* concentrations were lowest in the Southern section of the main water body (site four). The Outlet Canal (site five) showed *E. coli* levels that were one and a half times greater than the recommended guideline for intermediate contact recreation throughout the study, likely due to the faulty sewer line that runs underneath the outlet channel or perhaps an inflow of poor-quality seawater.

Seasonal trends of *E. coli* concentrations

The mean *E. coli* concentration was highest during autumn (60 654.40 cfu/100ml, SD= 716 090.08), and lowest during spring (4 623.94 cfu/100ml, SD= 14 648.13) (Figure 18). Significant differences ($p < 0.05$) were recorded in *E. coli* concentrations between seasons [H (2) = 68.12, $p < 0.001$]. Post-hoc tests revealed that the mean *E. coli* concentration increased significantly from summer to autumn [H(2) = 126.16, $p < .05$)] and decreased significantly from winter to spring [H(2) = -113.6, $p < 0.001$)].

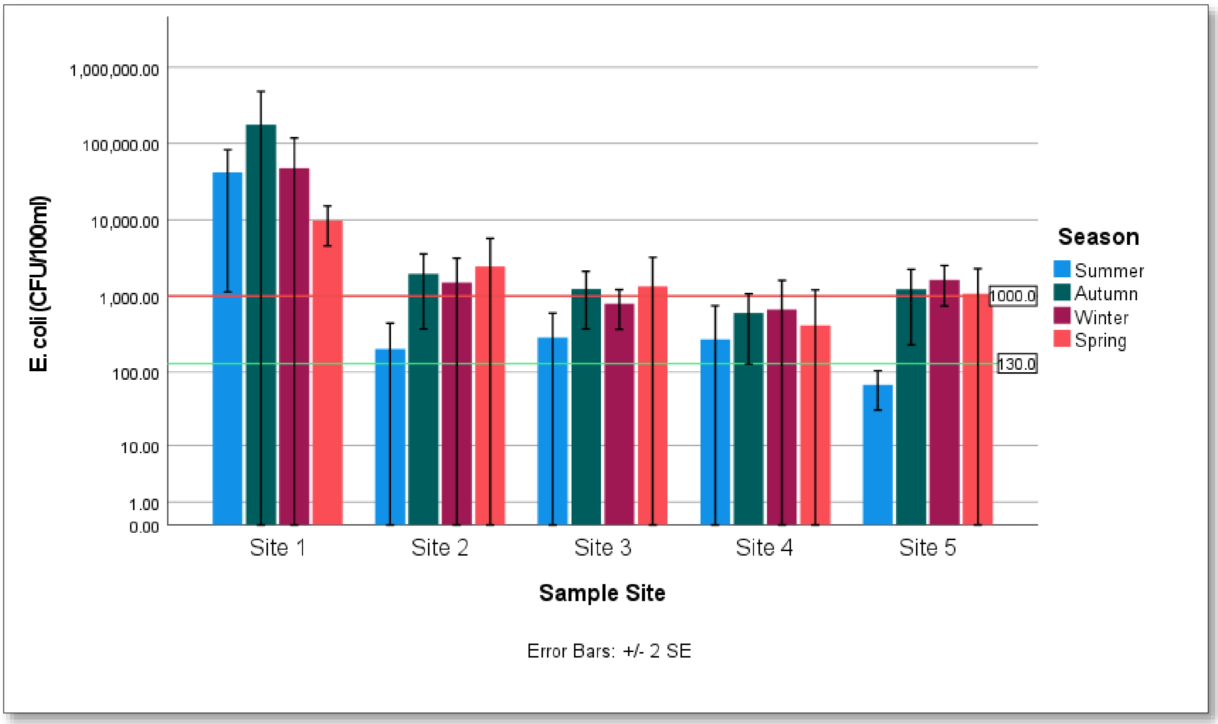

Figure 19 The mean (±SE) concentrations (cfu/100ml) of *E. coli* measured within the ambient water at five sample sites at the Zandvlei Estuary System (ZES) for the sample period of 10 years (2009 to 2018; n = 268) with intervals for each season and recommended concentrations for full-contact (green line) and intermediate-contact water recreation (red line).

Long-term trends of *E. coli* concentrations

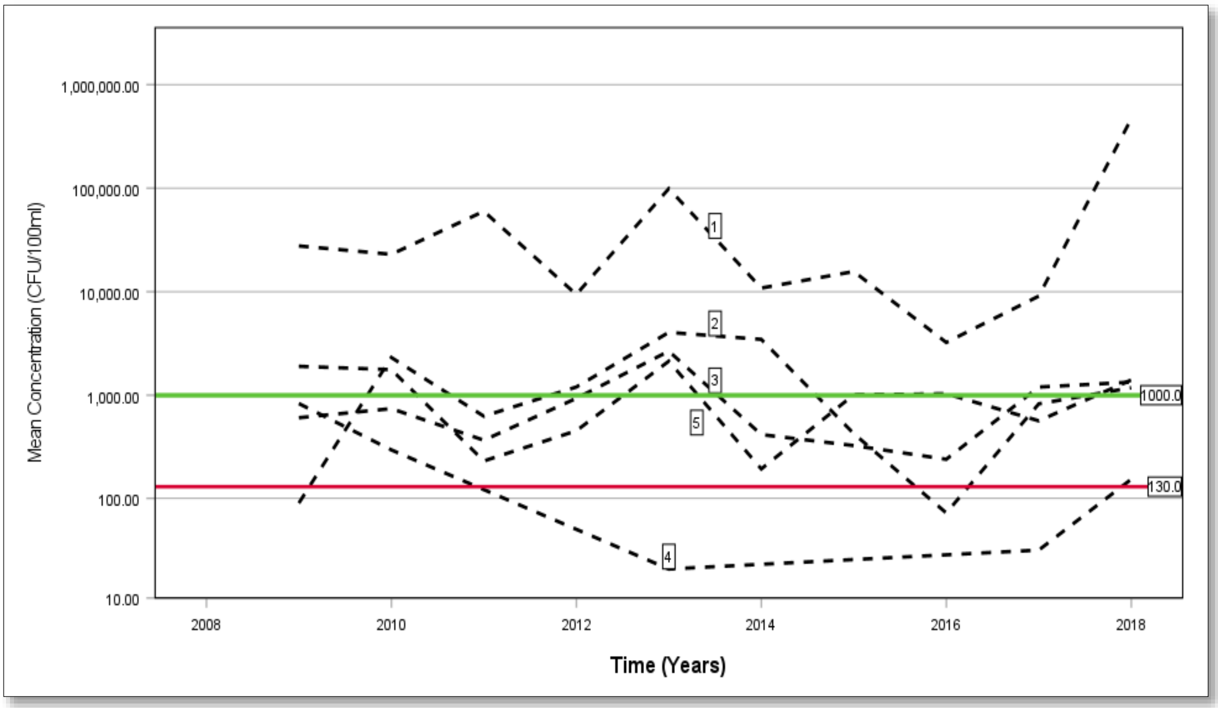

Figure 20 The mean *E. coli* concentration (cfu/100ml) for each of the five sample sites over 10 years (2009-2018) (±Standard Error of the Mean) with recommended guidelines for intermediate (green) and full-contact (red) water recreation.

There was a large increase in the mean *E. coli* concentration in 2018, when a bulk sewer line collapsed, allowing raw effluent to contaminate the ZES. On average the outlet measured twice the recommended guideline for intermediate recreation for the 10 years (2807 cfu/100ml) however, there was an improvement since 2009 as it had decreased from 11 443 cfu/100ml to 1 437 cfu/100ml. This was similar to Haskins (2016) who found acceptable *E. coli* results within the outlet and an improvement over the long-term period barring one result in 2014 and 2015.

Over the 10 years, the mean *E. coli* concentration increased within the influent rivers (site one) and the main water body (sites two and three) and decreased within the lower reaches (sites four and five). The mean *E. coli* concentration over the study period was 931 cfu/100ml which is within the recommended guideline for intermediate recreation of 1000cfu/100ml. Severe sewage spills occurred between 2013 and 2018 which resulted in a large increase in *E. coli* concentrations during those years. The main body of the vlei was generally suitable for intermediate contact recreation such as yachting, canoeing and rowing.

3.3.2 Ammonia

Descriptive statistics for the ammonia concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 4 below.
A total of 776 samples were taken to be analysed for ammonia concentrations which were found to be highest in site 1 and lowest in site 4 and highest in the autumn and lowest in the Summer (Table 4).

Table 4 Descriptive statistics for the ammonia concentrations (mg/l) measured within the ambient water of five sample sites at the ZES for the duration of the study period (2009 and 2018) for each season.

Ammonia (mg/L)		N	Min.	Median	Max.	Mean	Std. Deviation
		776	0.01		9.45	0.15	0.54
Sample Site	**Site 1**	355	0.01	0.06	9.45	0.25	0.77
	Site 2	97	0.01	0.02	0.60	0.06	0.11
	Site 3	125	0.01	0.02	0.75	0.07	0.12
	Site 4	2	0.01	0.03	0.05	0.03	0.03
	Site 5	197	0.01	0.03	1.43	0.08	0.17
Sample Season	**Spring**	196	0.01	0.05	6.12	0.15	0.53
	Summer	185	0.01	0.03	2.72	0.11	0.32
	Autumn	206	0.01	0.03	9.45	0.19	0.79
	Winter	189	0.01	0.05	2.50	0.17	0.33

The mean seasonal ammonia concentrations measured in the ambient water of five sampling sites in the waterbody for the duration of the study period (2009 to 2018) are displayed in Figure 21 below.

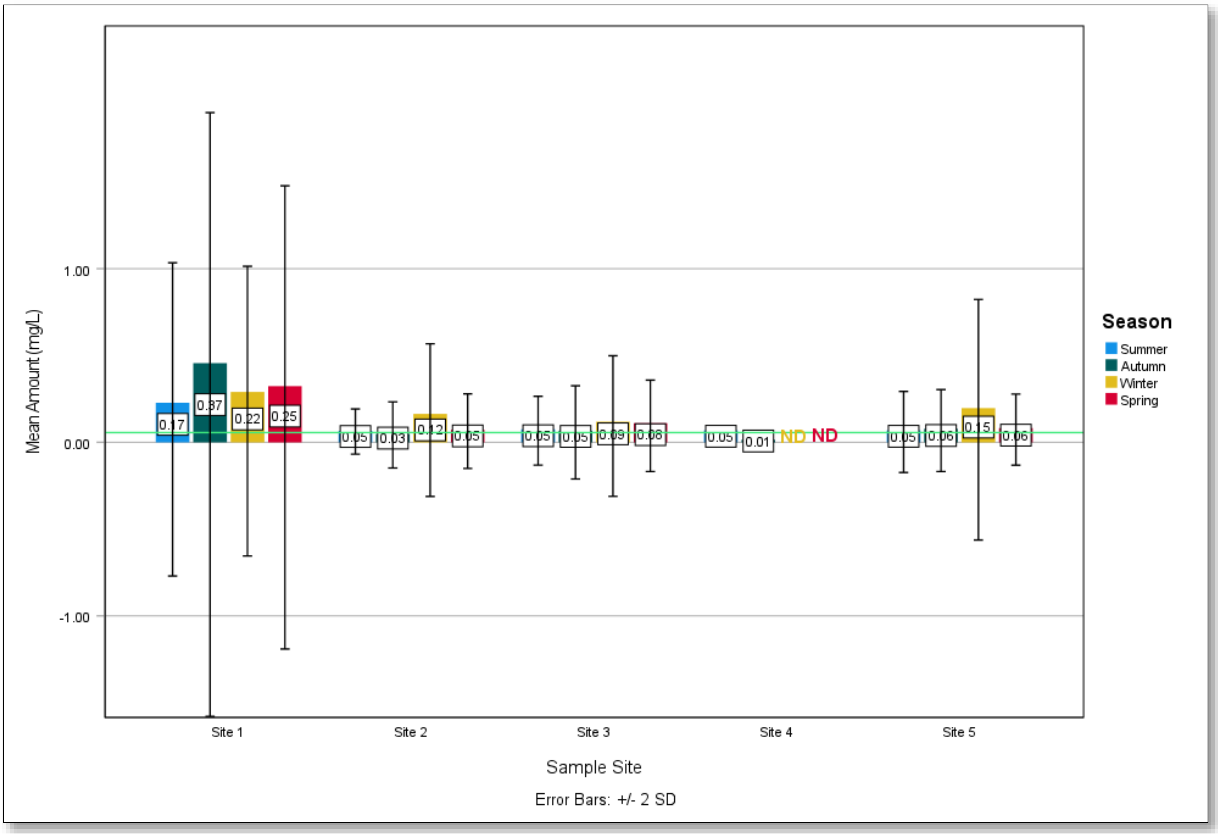

Figure 21 The average (±SE) concentrations (mg/l) of seasonal ammonia within five sampling sites at the ZENR between 2009 and 2018 and the recommended guideline for slightly disturbed estuarine environments (< 0.05 mg/l) are displayed in green.

<u>Spatial Trends (Between sample Sites) of ammonia Concentrations:</u>

Significant differences were found in the mean ammonia concentrations between sample sites [$H(2) = 77.803$, $p < 0.001$]. Pairwise multiple comparisons indicated that the mean ammonia concentration decreased significantly [$H(2) = 156.65$, $p < 0.001$] from 0.25 mg/l (SD = 0.77) in the influent rivers (site one) to 0.06 mg/l (SD = 0.11) in the Northern section of the main water body (site two). Site one (influent rivers) had the highest mean concentration of Ammonia (M = 0.25 mg/l, SD = 0.77) throughout the study period. The Southern section of the main water body presented the lowest mean ammonia concentration (M = 0.03 mg/l, SD = 0.03), which is in line with the estuary management guidelines for ammonia (< 0.05 mg/l). The estuary overall had a mean ammonia concentration of 0.16 mg/l which is 4 times greater than the estuary management guidelines (< 0.05 mg/l) (Department of Environmental Affairs, 2018).

Seasonal Trends (between seasons) of Ammonia Concentrations:

The mean ammonia concentration was highest during the Autumn (0.19 mg/l, SD = 0.79) and lowest during Summer (0.11 mg/l, SD = 0.32). A significant difference ($p < 0.05$) was recorded in ammonia concentrations between seasons [($H(2) = 24.07$, $p < 0.01$]. Post-hoc tests revealed that the mean ammonia concentration increased significantly from Autumn (0.19 mg/L, SD= 0.79) to Winter (0.17 mg/l, SD= 0.33) [$H(2) = -88.49$, p = <001].

Long-term Trends of Ammonia Concentrations:

The mean ammonia concentrations for all five sampling sites over the 10-year study period are displayed in Figure 22 below.

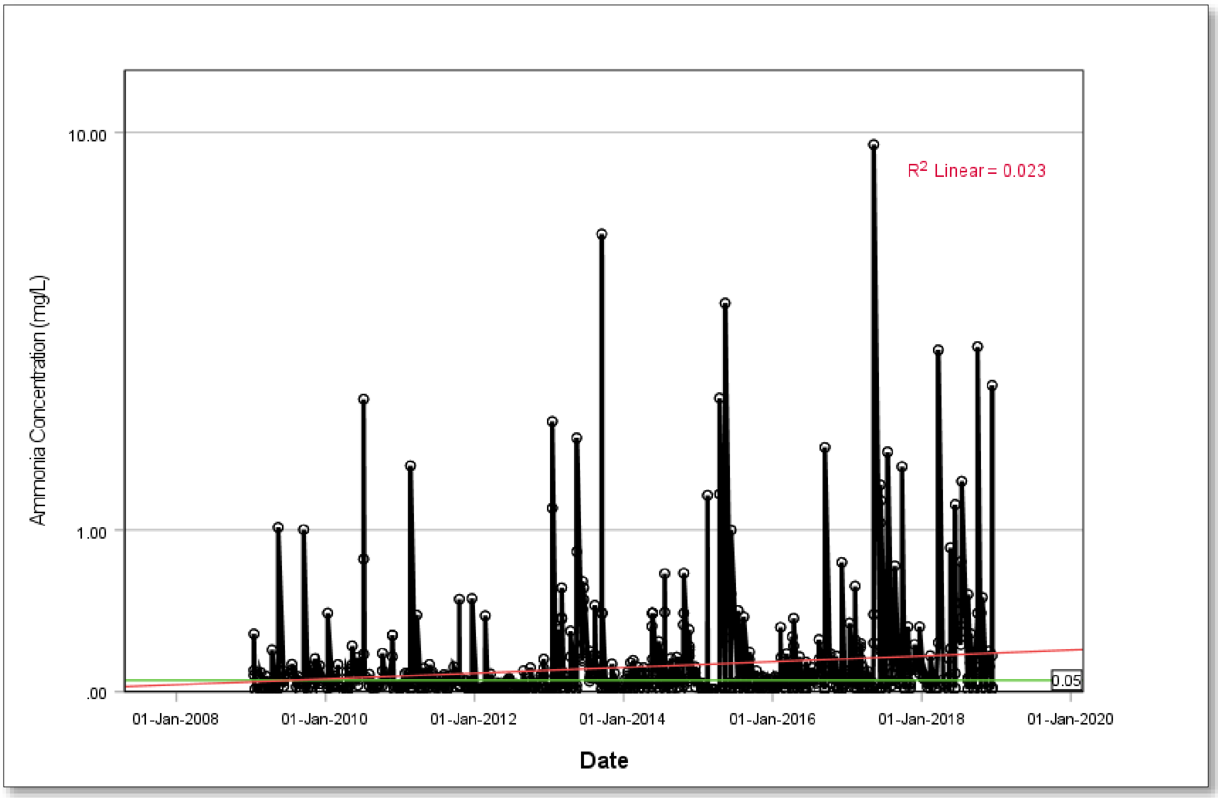

Figure 22 Ammonia concentration (mg/l) at the ZES between 2009 and 2018 with the recommended guideline for slightly disturbed estuarine environments (0.05mg/l) displayed in green and the general trend line displayed in red.

Ammonia concentrations were well above the recommended guidelines for slightly disturbed estuarine environments (> 0.05 mg/l), throughout the 10-year sampling period, except for a short period during 2012 (Figure 22 and Table 4). There was a slight increase over the 10 years ($R^2 = 0.023$) with severe amounts occurring in 2013, 2015 and 2017/2018. The mean ammonia concentration increased by 0.2 mg/l (5 times the recommended guidelines). Within the 10 years (2009-2018).

3.3.3 Nitrate and Nitrite as Nitrogen

Descriptive statistics for the Nitrate and Nitrite as Nitrogen concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 5 below.

A total of 347 samples were taken to be analysed for Nitrate and Nitrite as Nitrogen concentrations which were found to be highest in site 1 and lowest in site 4 and highest in Winter and lowest in Summer (Table 5).

Table 5 Descriptive statistics for Nitrate and Nitrite as Nitrogen concentrations at the ZES during the study period (10 years) across seasons as well as sample sites. Nd = Not Detectable.

Nitrite and Nitrate as Nitrogen (mg/L)		N	Min.	Median	Max.	Mean	Std. Deviation
		347	ND	0.55	3.50	0.69	0.59
Sample Site	**Site 1**	347	ND	0.55	3.50	0.69	0.59
	Site 2	96	ND	0.05	1.23	0.16	0.25
	Site 3	123	ND	0.05	0.77	0.12	0.17
	Site 4	2	0.03	0.04	0.05	0.04	0.02
	Site 5	195	ND	0.05	0.92	0.08	0.11
Sample Season	**Spring**	193	ND	0.17	2.25	0.41	0.50
	Summer	184	ND	0.05	1.42	0.19	0.31
	Autumn	197	ND	0.05	3.50	0.30	0.48
	Winter	189	ND	0.43	2.57	0.60	0.60

The mean seasonal Nitrite and Nitrate as Nitrogen concentrations measured in the ambient water of five sampling sites in the waterbody for the duration of the study period (2009 to 2018) are displayed in Figure 23 below.

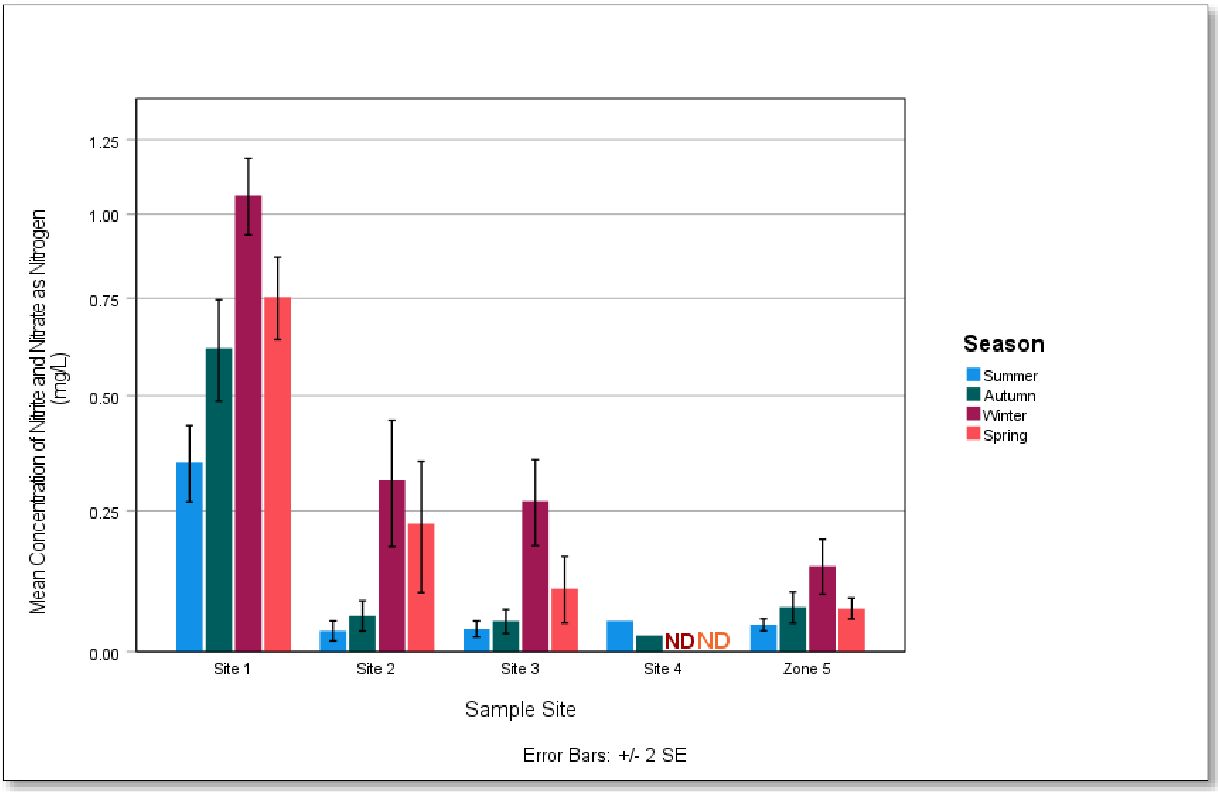

Figure 23 The mean (±SE) seasonal concentration (mg/l) of Nitrate and Nitrite as Nitrogen at 5 sampling sites within the ZES for the duration of the study period (2009 and 2018). ND represents No Data.

<u>Spatial trends (between sample sites) of nitrite and nitrate as nitrogen concentrations:</u>

The mean nitrate and nitrite as nitrogen concentration was highest within the influent rivers (site one; 0.7 mg/l, SD= 0.58) and lowest in the southern section of the main water body (site four), where it had the lowest average reading of 0.04mg/l (SD= 0.02). Post-hoc tests revealed that the nitrogen concentrations decreased significantly from 0.7 mg/l (SD= 0.58) in the influent rivers (site one) to 0.19 mg/l (SD= 0.27) in the northern section of the main water body (site two) [$H(2)$ = 250.63, p < 0.001] (Table 5).

<u>Temporal Trends (between seasons) of nitrite and nitrate as nitrogen concentrations:</u>

The mean nitrite and nitrate as nitrogen concentration was greatest during Winter (0.61 mg/l, SD= 0.6) and lowest during Summer (0.22 mg/l, SD= 0.32). A significant difference was found between seasons [$H(2)$ = 109.6, p < 00.001]. Post-hoc tests revealed that the mean nitrite and nitrate as nitrogen concentration increased significantly from 0.33 mg/l (SD= 0.5) in the Autumn to 0.61 mg/l (SD= 0.6) in the Winter [$H(2)$ = -171.19, p < 0.001] and decreased significantly to 0.43 mg/l (SD= 0.5) in the Spring [$H(2) = -95.34$, $p < 0.001$] and decreased significantly again to 0.22 mg/l (SD= 0.32) in the Summer [$H(2) = 125.87$, $p < 0.001$] (Table 5).

Long-term trends of nitrite and nitrate as nitrogen concentrations:

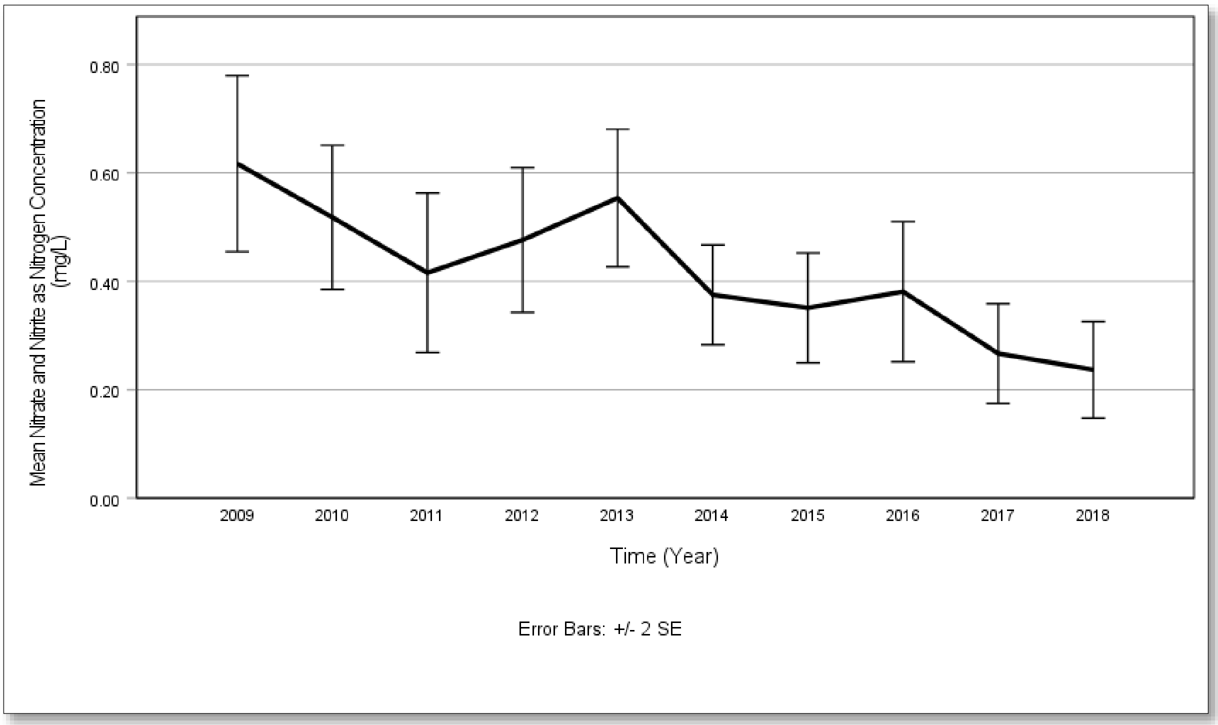

Figure 24 The mean (±SE) concentration (mg/l) of Nitrate and Nitrite as Nitrogen at the ZES for the sampling period between 2009 and 2018 with intervals for each year.

Nitrate and Nitrite as Nitrogen showed a gradual decrease over the 10-year study period with peaks between 2013 and 2016 when acute sewage spills occurred.

3.3.4 Total Oxidised Nitrogen

Descriptive statistics for the Total Oxidised Nitrogen concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 6 below.

Nitrite as Nitrogen concentrations were found to be highest in site 1 and lowest in site 4 and highest in Winter and lowest in Summer (Table 6).

Table 6 Descriptive statistics for Total Oxidised Nitrogen concentrations at the ZES during the study period (10 years).

Total Oxidised Nitrogen (mg/L)		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	337	0.17	1.23	10.74	1.57	1.26
	Site 2	93	0.08	0.85	10.22	1.07	1.16
	Site 3	120	0.10	0.73	7.73	0.95	0.96
	Site 4	2	0.10	0.36	0.63	0.36	0.38
	Site 5	189	0.05	0.58	7.98	0.83	1.06
Sample Season	**Spring**	184	0.08	0.85	7.98	1.12	1.10
	Summer	178	0.05	0.60	6.78	0.90	0.97
	Autumn	194	0.05	0.83	10.74	1.30	1.44
	Winter	185	0.24	1.29	7.73	1.54	1.11

The mean seasonal Total Oxidised Nitrogen concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Figure 25 below.

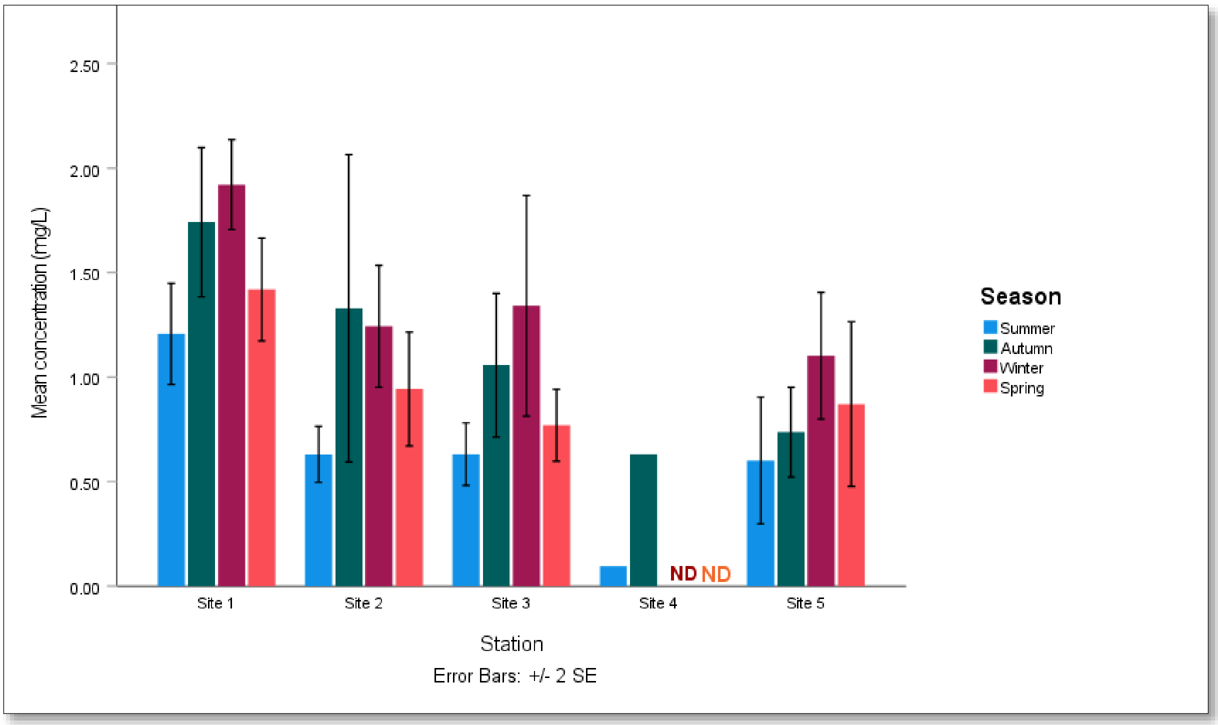

Figure 25 The average (±SE) concentrations (mg/l) of Total Oxidised Nitrogen within the ambient water of five sampling sites at the ZENR for the sampling period of 10 years (2009-2018), with intervals for each season. ND = not detectable.

Seasonal trends of Total Oxidized Nitrogen concentrations

The mean total oxidised nitrogen concentration was highest in Winter (1.54 mg/l, SD= 1.11) and lowest in Summer (0.9 mg/l, SD= 0.97). A significant difference was found between all seasons [$H(2)$ = 70.6, p < 0.001]. Post-hoc tests revealed that the mean concentration of total oxidized nitrogen increased significantly from Summer to Autumn [$H(2)$ = 100.83, p < 0.001], as well as from Autumn to Winter [$H(2)$ = -86.79, p < 0.001], decreased significantly from Winter to Spring [$H(2)$ = -106.76, p < 0.001], and from Spring to Summer [$H(2)$ = 80.86, p < 0.05].

Spatial Trends of Total Oxidized Nitrogen concentrations

Total oxidized nitrogen was highest at the influent rivers (site one; 1,57 mg/l, SD= 1.26) and lowest near the southern section of the waterbody (site four; 0.36 mg/l, SD= 0.38). The outlet sample site (site 5) also had high mean concentrations (0.83 mg/l, SD= 1.06). Post-hoc tests revealed that the total oxidized nitrogen concentrations increased significantly from the influent rivers (site one) to the northern section of the main water body (site two) [$H(2) = 116.5$, $p < 0.001$].

The average concentrations of Total Oxidised Nitrogen within the ambient water of the five sampling sites at the ZENR for the duration of the sampling period of 10 years (2009-2018) are displayed in Figure 26 below.

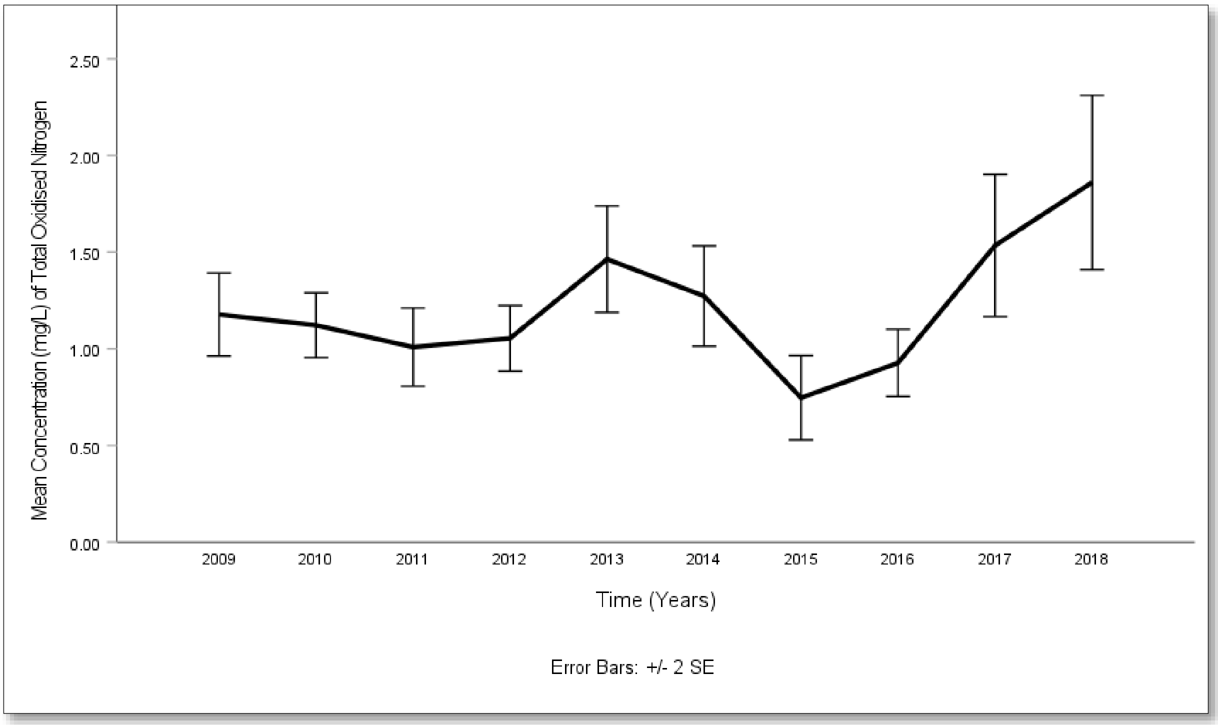

Figure 26 The mean (±SE) concentrations (mg/l) of Total Oxidised Nitrogen within the ambient water at the ZES for the sampling period of 10 years (2009-2018), with intervals for each year.

The mean concentration of Total Oxidised Nitrogen increased by 37% over the 10 years with peaks coinciding with the large sewage spills during 2013 and 2018.

The mean Total Oxidized Nitrogen within the estuary, throughout the 10-year study period, was 1.22 mg/l (SD= 1.2).

3.3.5 Orthophosphate

Descriptive statistics for the Nitrate and Nitrite as Nitrogen concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 7 below.

Orthophosphate concentrations were found to be highest in site 4 and lowest in site 3 and highest in Autumn and lowest in Spring (Table 7).

Table 7 Descriptive statistics for orthophosphate concentrations at the ZES during the study period (10 years).

Orthophosphate		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	342	0.01	0.06	1.71	0.11	0.19
	Site 2	97	0.01	0.07	0.32	0.08	0.06
	Site 3	122	0.01	0.06	0.23	0.07	0.05
	Site 4	2	0.11	0.12	0.13	0.12	0.02
	Site 5	190	0.01	0.10	0.84	0.10	0.09
Sample Season	**Spring**	191	0.01	0.06	0.61	0.07	0.07
	Summer	181	0.01	0.06	0.76	0.08	0.08
	Autumn	194	0.01	0.10	1.71	0.15	0.23
	Winter	187	0.01	0.06	0.84	0.08	0.10

The mean seasonal orthophosphate concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Figure 27 below.

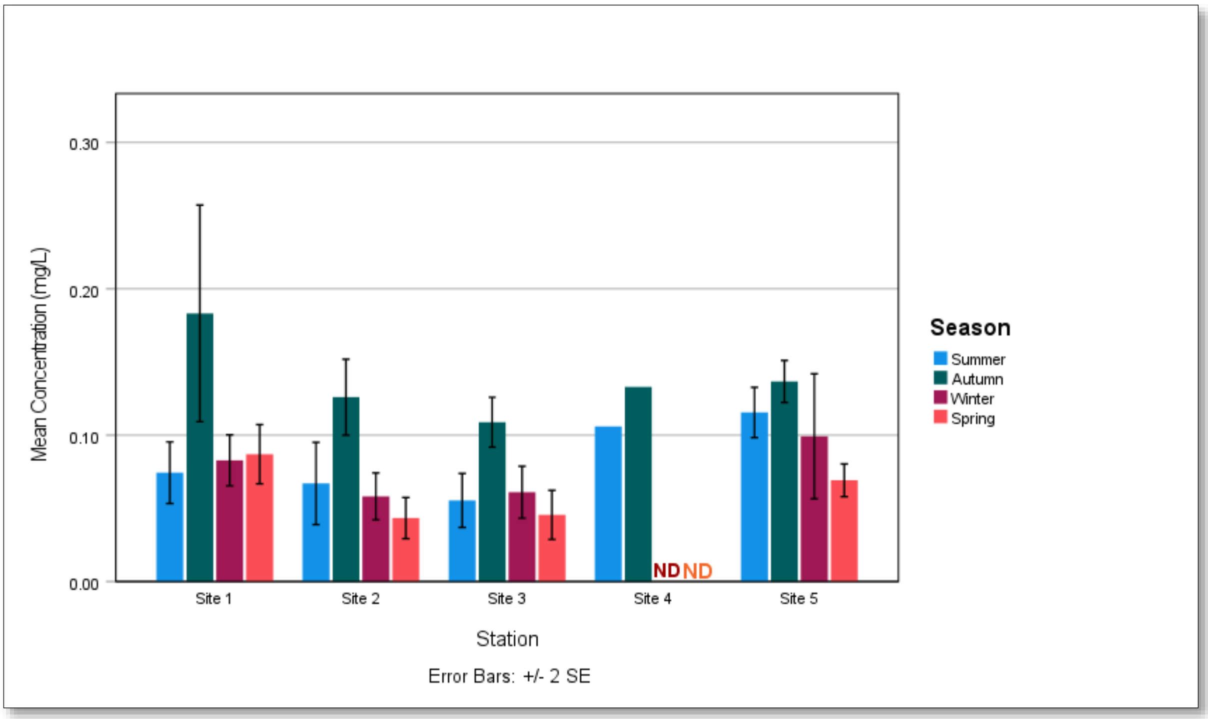

Figure 27 Mean Orthophosphate (mg/l) at the ZES (±Standard Error of the Mean) between 2009 and 2018. ND represents no data.

Seasonal trends of orthophosphate concentrations

The mean orthophosphate concentration was highest in Winter (SD= 0.1) and Summer (0.08 mg/l, SD= 0.08) and lowest in Spring (0.06 mg/l, SD= 0.07). A significant difference was found between all seasons [H (3) = 48.97, p < 0.001]. Post-hoc tests revealed that the mean concentration of orthophosphate increased significantly from Summer to Autumn [H (1) = 115.80, p < 0.001] and decreased significantly from Autumn to Winter [H (1) = 118.22, p < 0.001].

Spatial Trends of orthophosphate concentrations

Orthophosphate was highest in the Southern section of the main water body (site four; 0.12 mg/l, SD= 0.02) and lowest near the northern and central sections of the waterbody (site three and four; 0.07 mg/l, SD= 0.05). The Kruskal-Wallis test revealed that the orthophosphate concentrations differed significantly between sample sites [H (4) = 32.53, p < 0.001] however, post-hoc testing revealed that such differences did not occur between consecutive sample sites.

Long-term Trends of orthophosphate concentrations

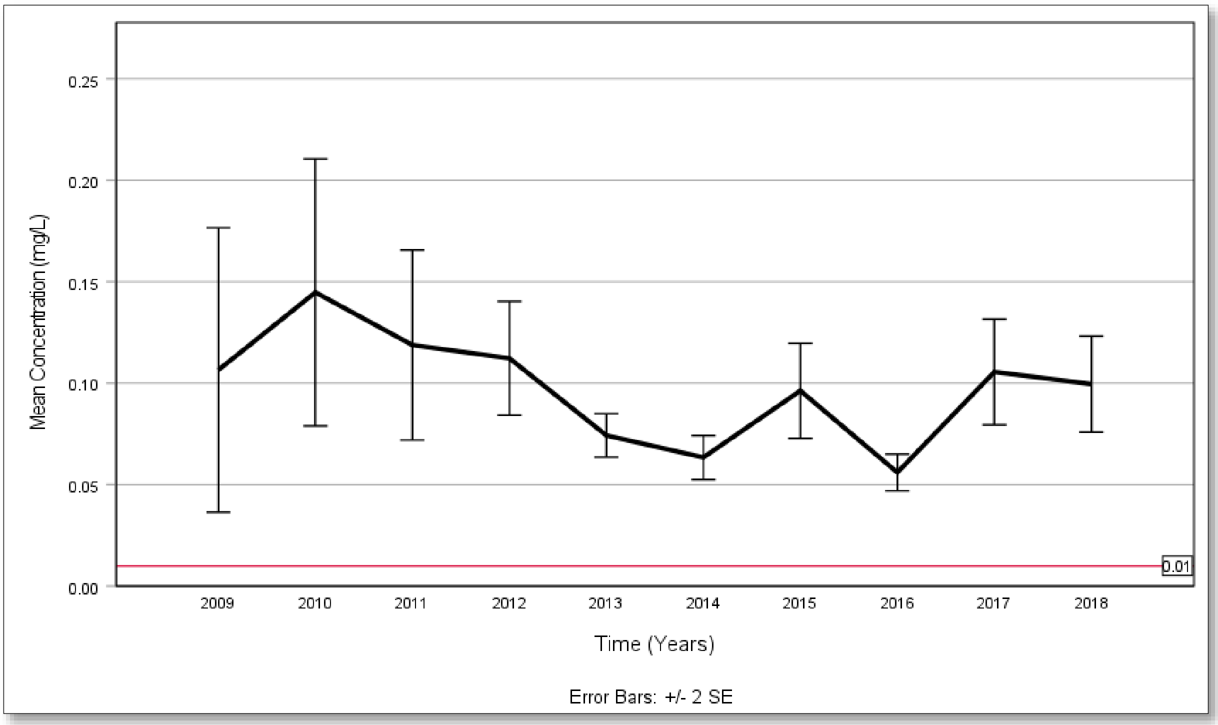

Figure 28 Mean orthophosphate concentrations (mg/l) at the ZES (±Standard Error of the Mean) between 2009 and 2018 with the DEA (2012) guideline for orthophosphate concentration within estuaries indicated by the red line (<0.01mg/l).

Over the 10 years, orthophosphate concentration decreased slightly at the ZES with heavy inputs occurring during 2010, 2015 and 2017. The mean orthophosphate concentration for the ZES for the duration of the study period was seven times greater than that which the Department of Environmental Affairs (DEA, 2012) regards as nutrient-rich for estuaries with heavy inputs (< 0.01mg/l).

3.3.6 Total Phosphorus

Descriptive statistics for the Total Phosphorus concentrations measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 8 below.

Total Phosphorus concentrations were found to be highest in site 1 and lowest in site 3 and highest in Winter and lowest in Summer (Table 8).

Table 8 Descriptive statistics for Total Phosphorus concentrations at the ZES during the study period (10 years).

Total Phosphorus		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	345	0.01	0.14	4.21	0.26	0.38
	Site 2	96	0.01	0.15	0.44	0.16	0.08
	Site 3	120	0.01	0.13	0.33	0.14	0.06
	Site 4	2	0.17	0.19	0.21	0.19	0.02
	Site 5	195	0.02	0.13	0.90	0.15	0.11
Sample Season	**Spring**	184	0.08	0.85	7.98	1.12	1.10
	Summer	178	0.05	0.60	6.78	0.90	0.97
	Autumn	194	0.05	0.83	10.74	1.30	1.44
	Winter	185	0.24	1.29	7.73	1.54	1.11

The mean concentrations for Total phosphorus within the five sampling sites of the ZES for the duration of the study period (2009 and 2018) are displayed in Figure 29 below.

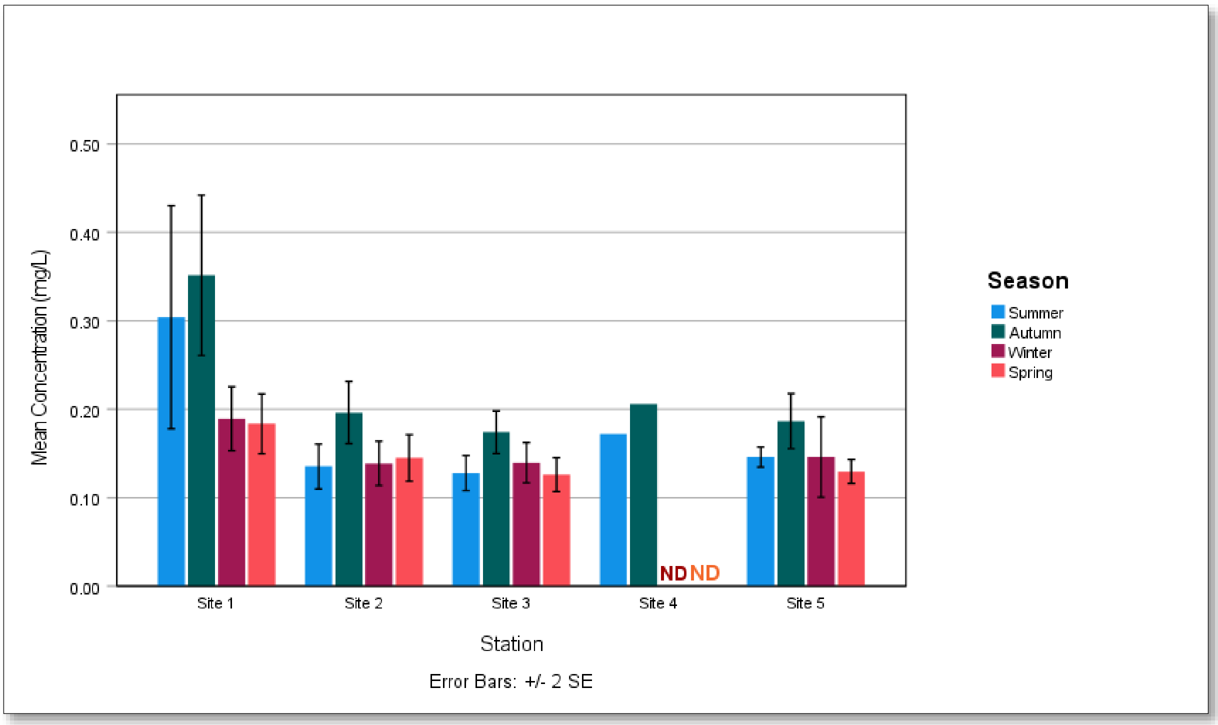

Figure 29 Mean (±SE) Total Phosphorus concentrations (mg/l) within the five sampling sites at the ZENR between 2009 and 2018 with intervals for each season. ND represents no data.

<ins>Seasonal Trends of Total Phosphorus concentrations</ins>

The mean total phosphorus concentration was highest in Autumn (1.3 mg/l, SD= 1.44) and lowest in Spring (0.12 mg/l, SD= 1.1). A significant difference was found between all seasons [$H(2) = 28.75$, $p < 0.001$]. Post-hoc tests revealed that the mean concentration of total phosphorus decreased significantly from Autumn to Winter [$H(2) = 105.41$, $p < 0.001$] and increased significantly from Summer to Autumn [$H(2) = 87.1$, $p < 0.001$].

<ins>Spatial Trends of Total Phosphorus concentrations</ins>

Total phosphorus was highest in the influent rivers (site one; 0.26 mg/l, SD= 0.38) and lowest at the central section of the waterbody (site three; 0.14 mg/l, SD= 0.06). The Kruskal-Wallis test revealed no significant differences in total phosphorus concentrations between sample sites [$H(2) = 3.14$, $p = .535$].

Long-term Trends of Total Phosphorus Concentrations:

The mean concentration for total phosphorus at the ZES was 0.2mg/l (SD= 0.27) over the 10 years. There was a gradual decline in concentrations in previous years (2009-2016), followed by a large increase (2016 – 2018).

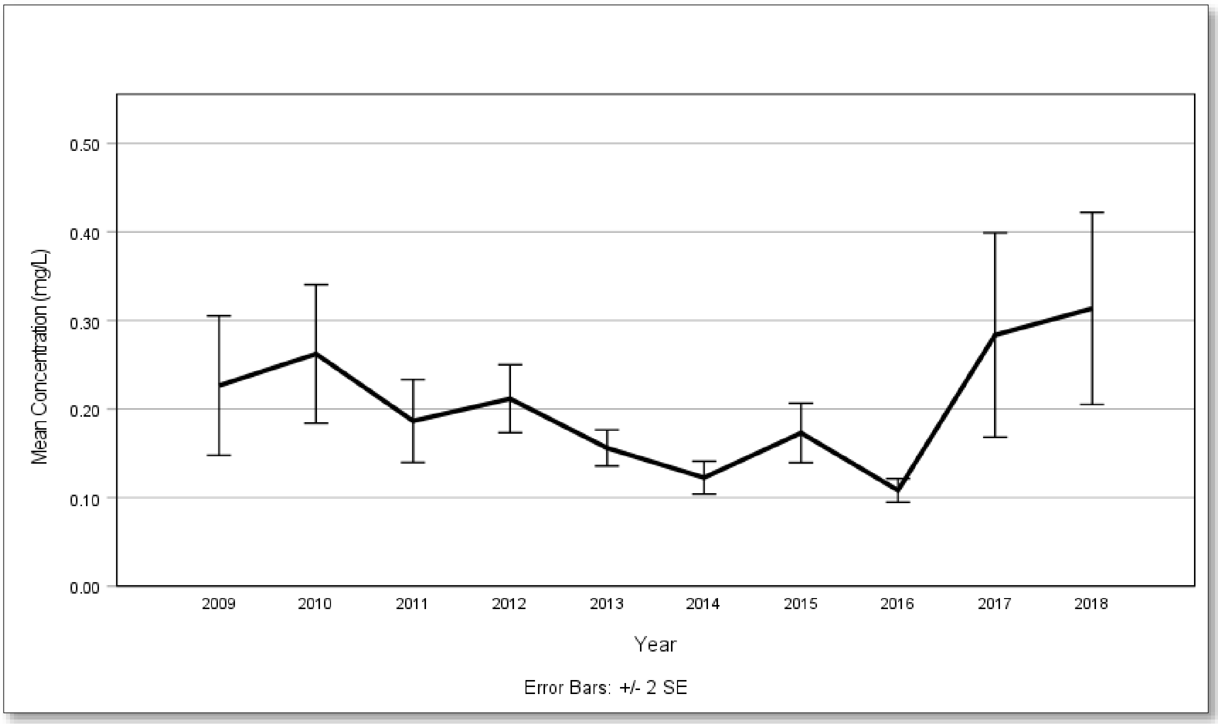

Figure 30 The mean total phosphorus concentrations (mg/l) at the ZES (±Standard Error of the Mean) between 2009 and 2018.

3.3.7 Suspended Solids

Descriptive statistics for the Suspended Solids measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 9 below.
The measurement of Suspended Solids was found to be highest in site 5 and lowest in site 4 and highest in Autumn and lowest in Winter (Table 9).

Table 9 Descriptive statistics for orthophosphate concentrations at the ZES during the study period (10 years).

Suspended Solids		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	347	1.00	9.00	261.00	22.53	37.67
	Site 2	97	2.00	22.00	98.00	27.63	22.71
	Site 3	124	2.00	22.00	318.00	31.39	35.15
	Site 4	2	4.00	5.50	7.00	5.50	2.12
	Site 5	196	1.00	26.00	514.00	41.92	53.08
Sample Season	**Autumn**	203	1.00	26.00	514.00	40.97	53.98
	Spring	191	1.00	16.00	261.00	25.17	30.04
	Summer	183	1.00	11.00	229.00	26.82	37.90
	Winter	189	1.00	13.00	242.00	24.26	35.18

The mean concentrations of suspended solids within the five sampling sites at the ZES for the duration of the study period (2009 to 2018) are displayed in Figure 31 below.

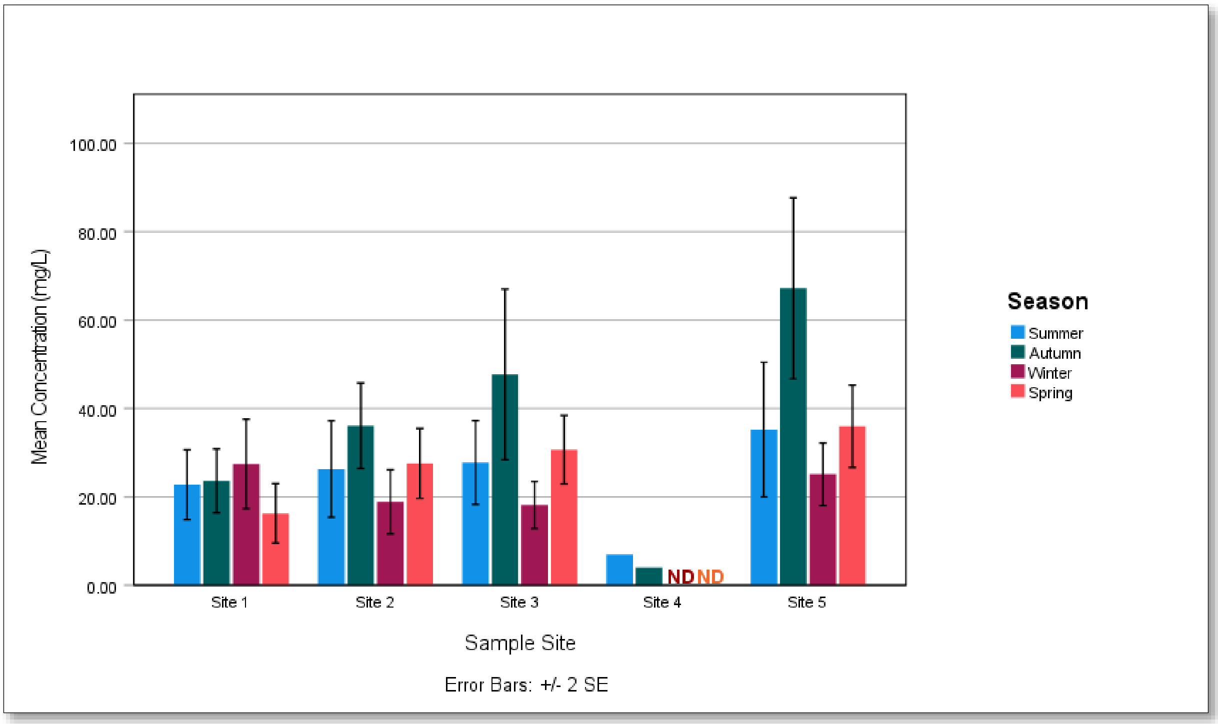

Figure 31 Mean concentrations (mg/l) of suspended solids at the ZES (±Standard Error of the Mean) within five sampling sites between 2009 and 2018 with intervals for each season. ND represents no data.

Spatial trends (between sample sites) of suspended solids concentrations:

The mean concentration of suspended solids was highest within the outlet canal (site five; 41.92 mg/l, SD= 53.08) and lowest in the southern section of the main water body (site four; 5.50 mg/l, SD= 2.12) which suggests that this does not arise from within the catchment.

Non-parametric testing revealed that the mean concentration of suspended solids differed significantly between sample sites [$H(2) = 92.28$, $p < 0.001$]. Post-hoc tests showed that the mean concentration of suspended solids increased significantly from the influent rivers (site one) to the northern section of the main water body (site 2).

Temporal Trends (between seasons) of suspended solids concentrations:

The mean concentration of suspended solids was highest in the Autumn (40.97 mg/l, SD= 53.98) and lowest in the Winter (22.42 mg/l, SD= 35.18). Non-parametric tests revealed that the mean concentration of suspended solids differed significantly between seasons [$H(2) = 33.23$, $p < 0.001$]. Post-hoc tests revealed that suspended solids increased significantly from summer to autumn [$H(2) = 113.48$, $p < 0.001$] and then decreased significantly from Autumn to Winter [$H(2) = 108.58$, $p < 0.001$].

Long-term Trends of Suspended Solids Concentrations:

The mean concentrations for Suspended Solids within five sampling sites for the duration of the study period (2009 – 2018) are displayed in Figure 32 below.

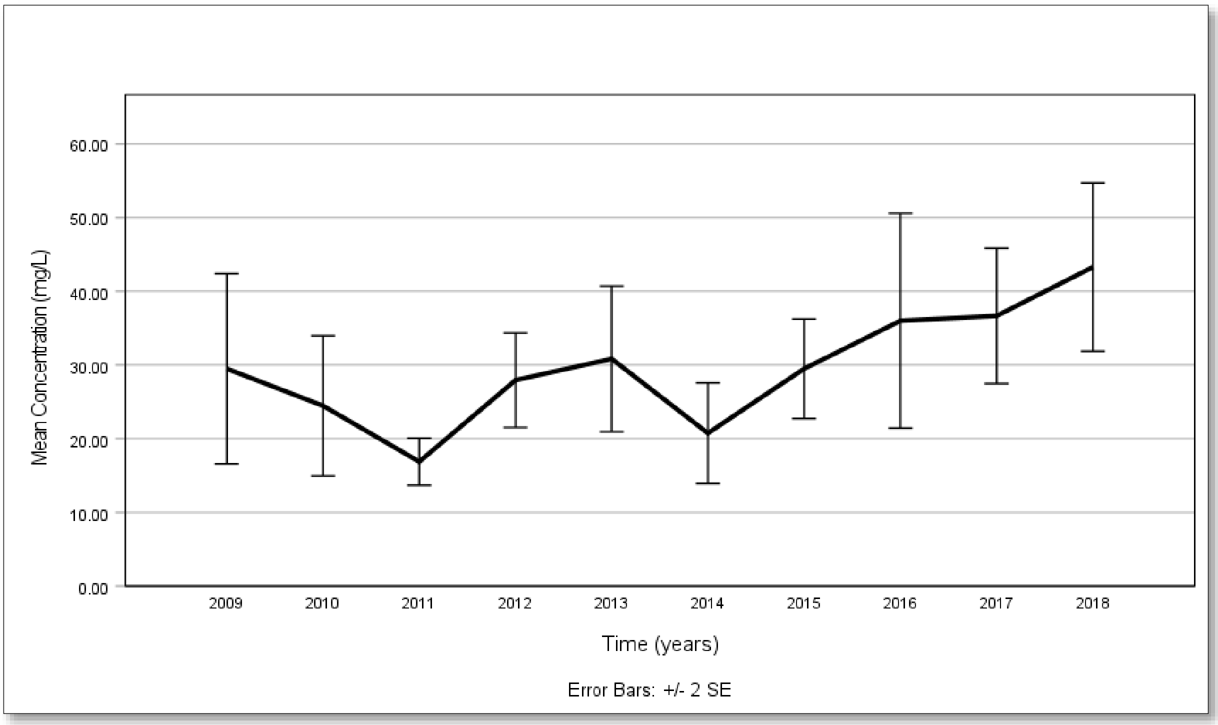

Figure 32 Mean concentrations for suspended solids (mg/l) within five sampling sites at the ZES (±Standard Error of the Mean) for the duration of the study period (2009 - 2018).

Suspended solids showed a gradual increase over the 10 years. There was a sharp decline in concentrations between 2011 and 2014. Dredging activity occurred in July 2015 to remove the build-up of sand in the outlet canal and increase the rate of flow through the system. This activity may have caused the sharp increase in suspended solids seen from 2014 – 2018 as the increase in the rate of flow would allow for higher turbidity in the lower reaches.

3.3.8 Secchi Depth

Descriptive statistics for Secchi Depth measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 10 below.

Secchi Depth was found to be deepest in site five and shallowest in site one and deepest in Summer and shallowest in Winter (Table 10).

Table 10 Descriptive statistics for Secchi depth (cm) at the ZES during the study period (10 years).

Secchi Depth		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	3	5.00	5.00	5.00	5.00	0.00
	Site 2	80	0.95	40.00	160.00	52.82	29.46
	Site 3	90	0.78	45.00	160.00	56.88	31.16
	Site 4	ND	ND	ND	ND	ND	ND
	Site 5	133	1.00	60.00	100.00	65.23	22.53
Sample Season	**Spring**	77	18.94	50.00	100.00	55.51	22.84
	Summer	71	0.78	60.00	160.00	67.05	30.96
	Autumn	84	0.95	55.00	150.00	58.64	31.58
	Winter	74	25.00	50.00	130.00	55.07	24.31

The mean seasonal measurements of Secchi depth (cm) within the five sampling sites at the ZES (±Standard Error of the Mean) for the duration of the study period (2009 – 2018) are displayed in Figure 33 below.

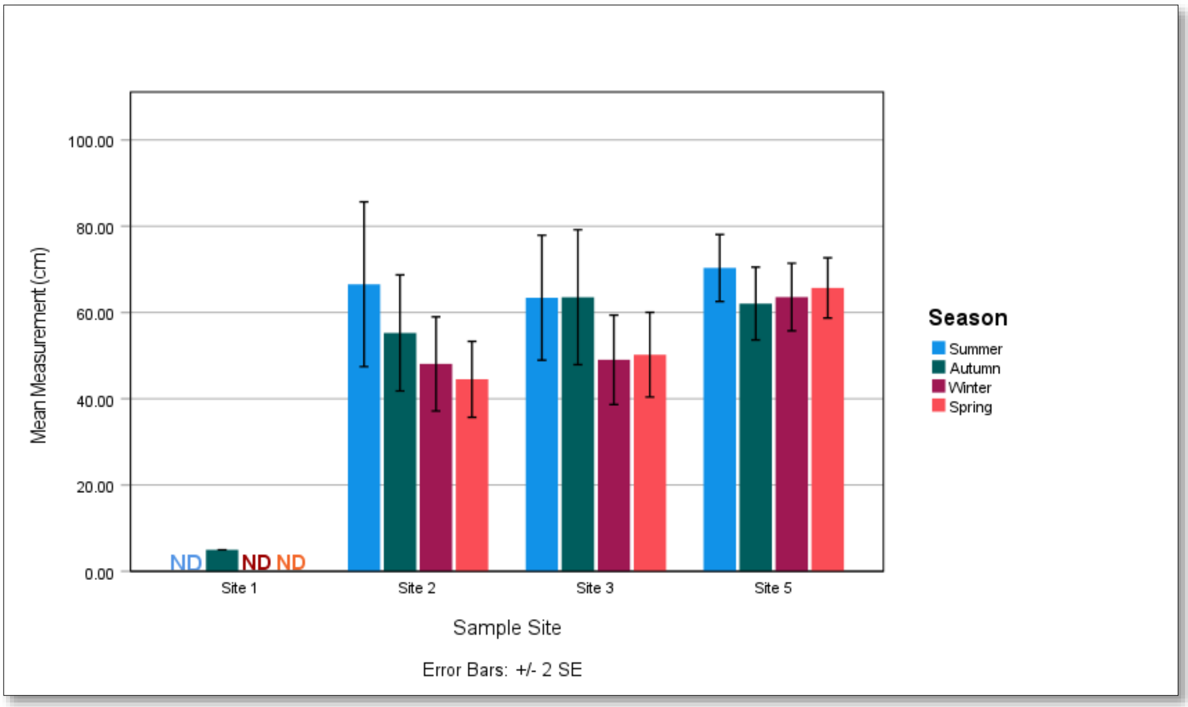

Figure 33 The mean Secchi depth (cm) at the ZES (±Standard Error of the Mean) between 2009 and 2018 with intervals for each season. No data was available for Site four (The southern section of the main water body). ND represents no data.

The Secchi depth was highest at the outlet sampling site and lowest at the inlets. It was highest during Summer and Spring and lowest during Autumn and Winter.

Spatial trends (between sample sites) of Secchi depth:

The mean Secchi depth measurement was deepest within the outlet canal (site five; 65,23 cm, SD= 22.53) and shallowest in the influent rivers (site one; 5 cm, SD= 0).

Non-parametric testing revealed that the mean Secchi depth measurement differed significantly between sample sites [$H(2) = 32.20$, $p < 0.001$]. However, post-hoc testing showed that there were no significant differences within the Secchi depth measurement between consecutive sites and only between the northern section of the main water body (site two) and the outlet canal (site five).

Temporal Trends (between seasons) of Secchi depth:

The mean Secchi depth measurement was highest in the Summer (67.05 cm, SD= 30.96) and lowest in the Autumn (58.64 cm, SD= 31.58). Non-parametric testing revealed that the mean Secchi depth measurement did not differ significantly between seasons [$H(2) = 7.73$, $p = .052$].

Long-term Trends for Secchi Depth:

The mean measurement for Secchi depth within five sampling sites at the ZES for the duration of the study period (2009 – 2018) is displayed in Figure 34 below.

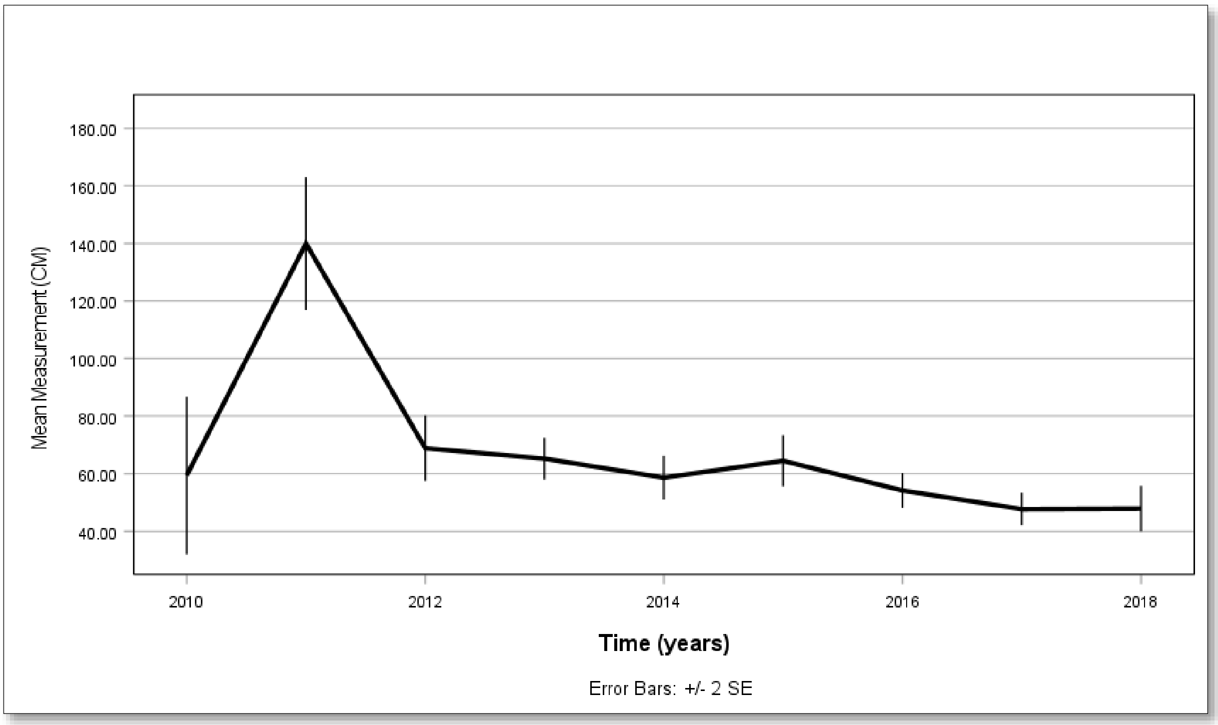

Figure 34 The mean (±SE) Secchi depth measurement (cm) within the five sampling sites at the ZES for the duration of the study period (2009 and 2018).

Secchi depth data indicated a large peak during 2011 and a gradual decline thereafter over the long term.

3.3.9 Salinity

Descriptive statistics for the Salinity measured at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 11 below.

Salinity was found to be highest in site 5 and lowest in site 2 and highest in Autumn and lowest in Spring (Table 11).

Table 11 Descriptive statistics for salinity concentrations at the ZES during the study period (10 years).

Salinity		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Site 1**	ND	ND	ND	ND	ND	ND
	Site 2	77	0.20	9.70	32.79	10.26	7.07
	Site 3	83	0.20	11.66	33.29	11.23	6.98
	Site 4	1	ND	ND	ND	ND	ND
	Site 5	156	0.10	17.05	31.40	15.51	8.85
Sample Season	**Spring**	79	0.10	12.80	31.10	13.54	9.57
	Summer	68	1.00	14.30	31.40	15.55	7.13
	Autumn	83	0.20	16.50	33.29	16.44	7.68
	Winter	87	0.10	6.20	23.30	7.65	5.31

The average (±SD) salinity concentrations within the five sampling sites at the ZENR for the duration of the study period (2009 – 2018) are displayed in Figure 35 below.

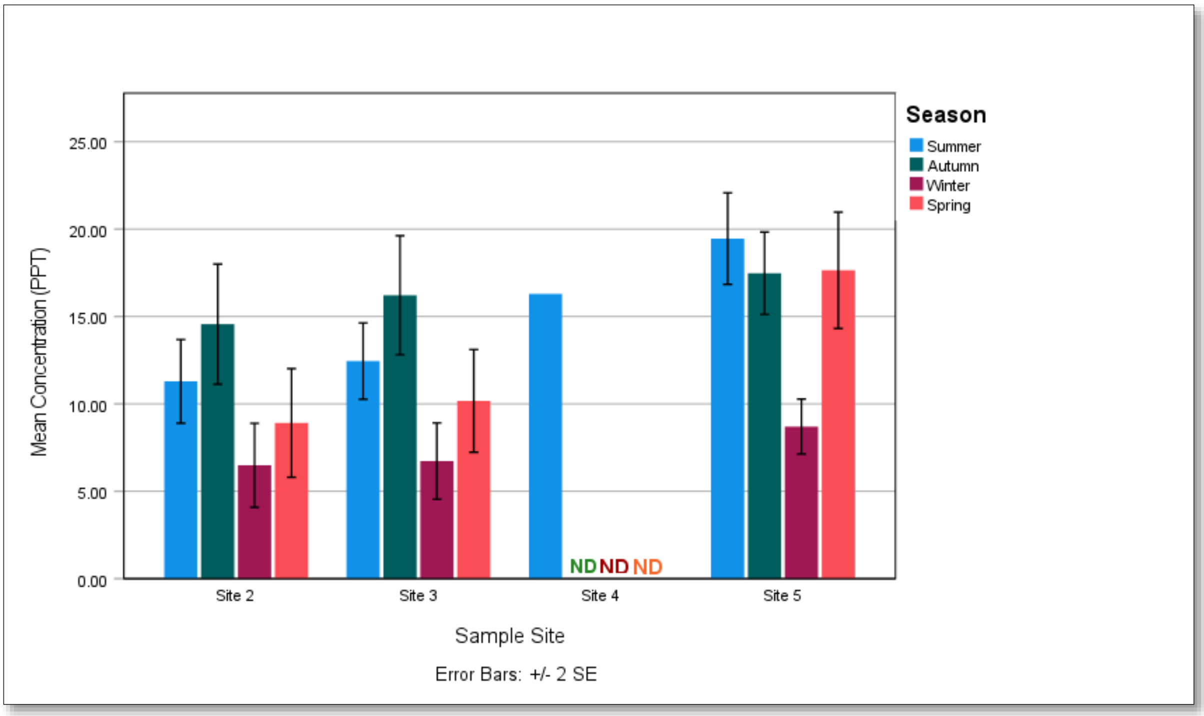

Figure 35 Mean (±SD) salinity concentrations (PPT) at the five sampling sites of the ZES for the duration of the study period (2009 – 2018) with intervals for each season. ND represents no data were available for the influent rivers (site one).

Spatial trends (between sample sites) of salinity:

The mean salinity concentration was largest within the outlet canal (site five; 15.51 PPT, SD= 8.85) and lowest in the northern section of the main water body (site two; 10.26 PPT, SD= 7.07). Non-parametric testing revealed that the mean salinity concentration differed significantly between sample sites [$H(2) = 24.69$, $p < 0.001$]. However, post-hoc testing showed that there were no significant differences in the mean salinity concentration between consecutive sites but only between the northern section of the main water body (site two) and the outlet canal (site five).

Temporal Trends (between seasons) for mean salinity concentration:

The mean salinity concentration was highest in the Autumn (16.44 PPT, SD= 7.68) and lowest in the Winter (7.65 PPT, SD= 5.31). Non-parametric testing revealed that the mean salinity concentration differed significantly between seasons [$H(2) = 61.91$, $p < 0.001$]. Post-hoc testing revealed that the mean salinity concentration decreased significantly from Autumn to Winter [$H(2) = 100.42$, $p < 0.001$] and increased significantly from Winter to Spring [$H(2) = 66.66$, $p < 0.001$].

Long-term trends in salinity concentrations:

The mean measurement for salinity concentration within five sampling sites at the ZES for the duration of the study period (2009 – 2018) is displayed in Figure 36 below.

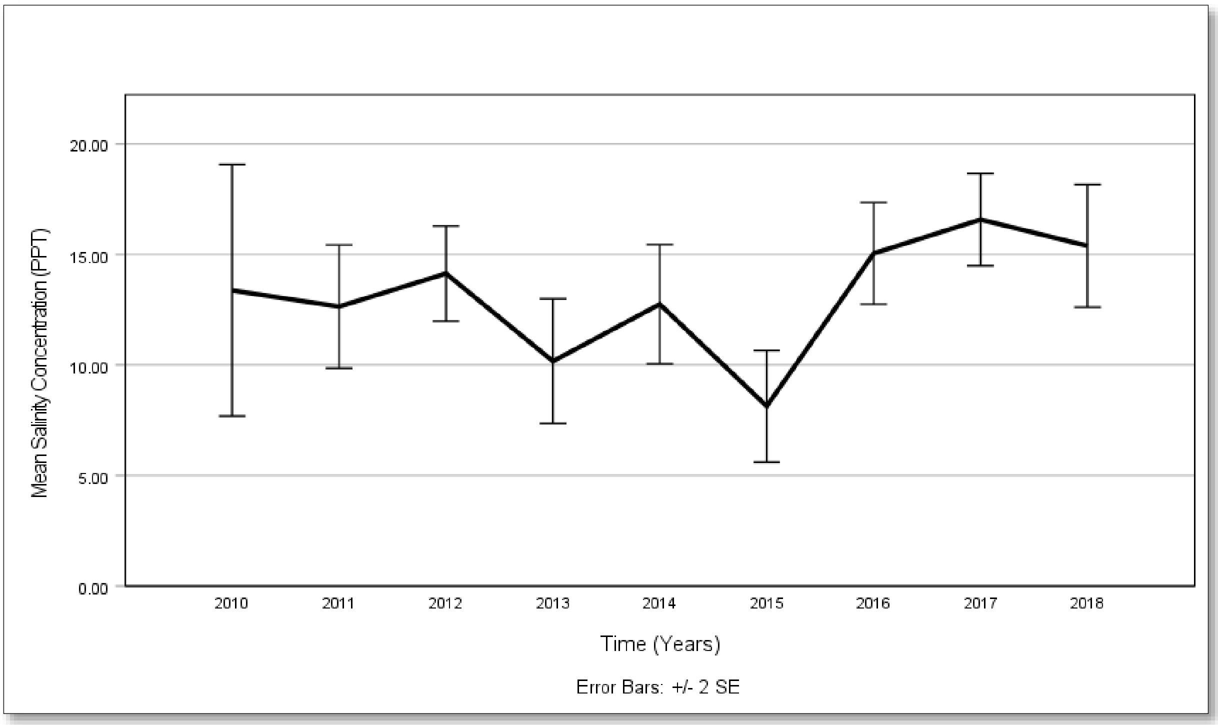

Figure 36 Mean salinity concentrations (PPT) at the ZES (±Standard Error of the Mean) for the duration of the study period (2009 – 2018).

There were large declines in concentrations for salinity during 2013 and 2015 with a gradual increase over the long term.

3.3.10 Conductivity

Descriptive statistics for the Conductivity measurements at the five sample sites at the ZES for the duration of the study period (2009 and 2018) are displayed in Table 12 below. Conductivity measurements were found to be highest in site 5 and lowest in site 1 and highest in Autumn and lowest in Winter (Table 12).

Table 12 Descriptive statistics for conductivity concentrations at the ZES during the study period (10 years).

Conductivity		N	Min.	Median	Max.	Mean	Std. Deviation
Sample Site	**Zone 1**	352	23.00	68.00	122.00	68.46	16.62
	Zone 2	97	61.00	1,435.00	3,385.00	1,496.00	845.34
	Zone 3	125	23.00	1,430.00	3,410.00	1,503.74	862.97
	Zone 4	2	789.00	1,784.50	2,780.00	1,784.50	1,407.85
	Zone 5	196	45.00	2,440.00	15,510.00	2,548.31	1,518.09
Sample Season	**Spring**	195	23.00	284.00	4,496.00	1,063.08	1,246.08
	Summer	185	23.00	620.00	15,510.00	1,283.31	1,751.11
	Autumn	203	28.00	1,199.00	4,982.00	1,409.40	1,386.17
	Winter	189	25.00	177.00	3,060.00	684.62	807.29

The average conductivity within the five sampling sites at the ZENR for the duration of the study period (2009 – 2018) with intervals for each season is displayed in Figure 37 below.

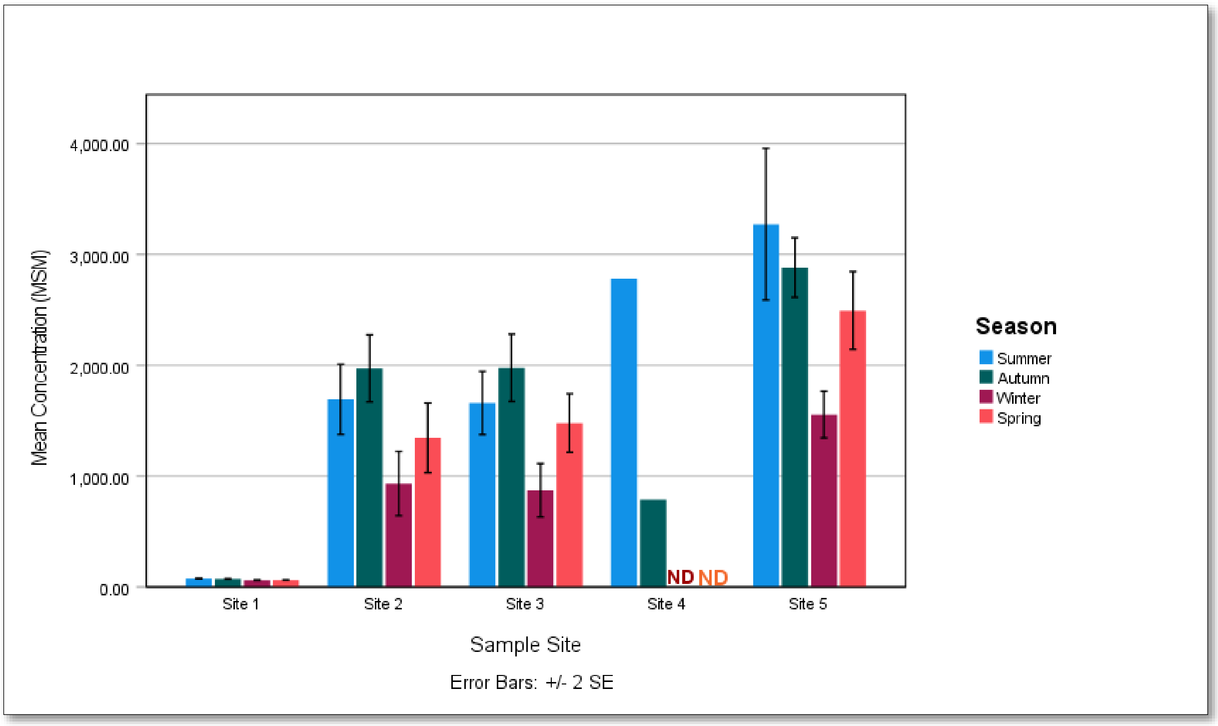

Figure 37 The mean (±SE) Conductivity (msm) within the five sampling sites at the ZES for the duration of the study period (2009 – 2018) with intervals for each season. ND represents no data.

Spatial trends (between sample sites) in the mean conductivity measurement:

The mean conductivity measurements were largest within the southern section of the outlet canal (site five; 2548.31 SMS, SD= 1518.09) and lowest in the influent rivers (site one; 68.46 MSM, SD= 16.62) due to the influx of sea water from the ocean at the outlet canal and fresh water from the inlet rivers. Non-parametric testing revealed that the mean conductivity measurements differed significantly between sample sites [$H(2)$ = 578.55, p < 0.001]. Post-hoc testing revealed that the mean conductivity measurement increased significantly between the Influent rivers (site one) to the more estuarine northern section of the main water body (site two) [$H(2)$ = -333.29, p < 0.001].

Temporal Trends (between seasons) in the mean conductivity measurements:

The mean conductivity measurement was highest in the Summer (1283.31 MSM, SD= 1751.11) and lowest in the Winter (684.62 MSM, SD= 807.29). Non-parametric testing revealed that the mean conductivity concentration differed significantly between seasons [$H(2)$= 39.92, p < 0.001]. Post-hoc testing revealed that the mean salinity concentration decreased significantly from Autumn to Winter [$H(2)$ = 122.61, p < 0.001].

Long-term Trends of conductivity measurements:

The mean measurement for salinity concentration within five sampling sites at the ZES for the duration of the study period (2009 – 2018) is displayed in Figure 38 below.

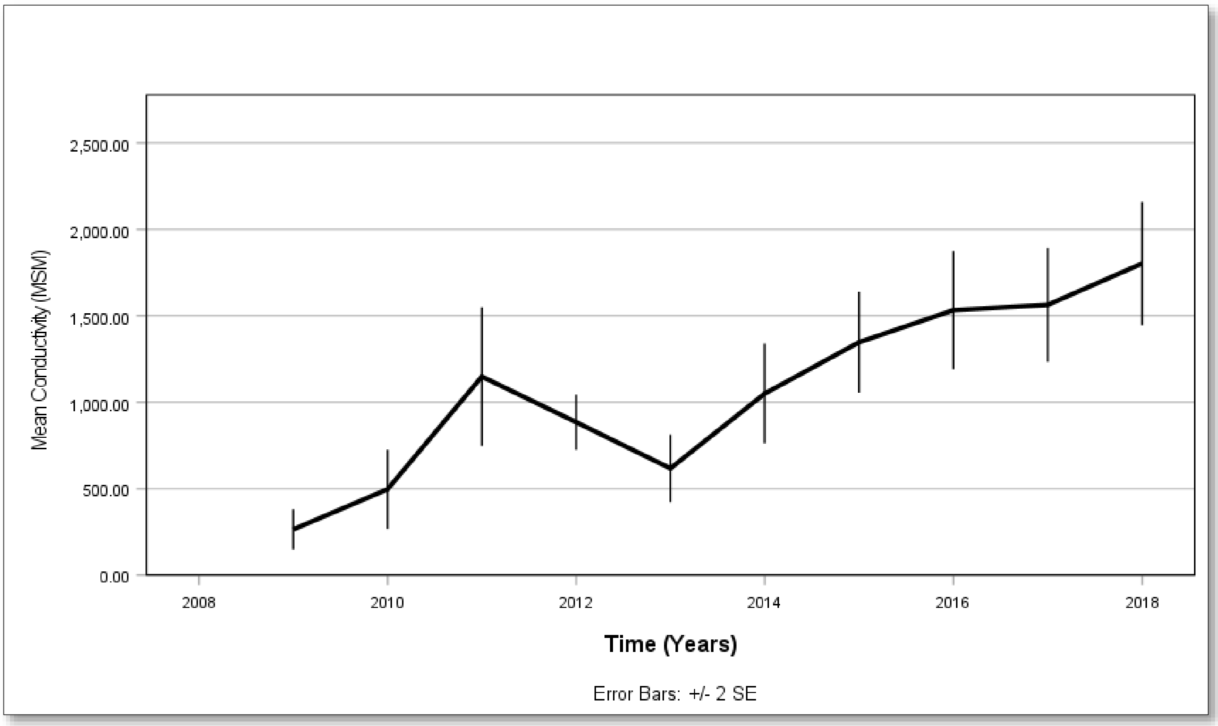

Figure 38 The mean (±SE) conductivity (MSM) within the five sampling sites at the ZES for the duration of the study period (2009 – 2018) with line intervals for each year.

Conductivity was lowest during 2013 and gradually increased over the 10-year study period, likely due to the amendment of the mouth management plan to allow for increased flows of salt water into the system.

<u>3.4 Discussion</u>

3.4.1 Sewerage and Microbiological Inputs – *E. coli*

<u>Seasonal Trends of *E.coli* Concentrations:</u>

Seasonal *E. coli* concentrations were in keeping with Haskins (2016) who found *E. coli* concentrations increased with the first Winter rains which flushed accumulated faecal matter from the aged sewer system.

Another explanation for the seasonal trend in *E. coli* concentrations could be due to the severe sewage spills that occurred during the first quarter during the data period under review. In April 2018, a sewage leak caused by a collapsed bulk sewer main near the Northern shoreline resulted in *E. coli* concentrations of up to 10 million cfu/100ml. The estuary was consequently closed to the public due to the risk to human health. Not only did this have immense environmental impacts on the system but lost revenue through recreational use of the system as well.

The increase in concentrations during Spring within the main water body was likely due to two large incident spills that occurred close to this section during the Spring of 2013 and 2018 which had readings of up to 40 000 and 10 000 cfu respectively. Had these spills not occurred, *E. coli* concentrations would have been highest in Autumn, due to the influence of the inlet rivers and the initial winter rains. In general, the main waterbody was compliant (give ranges) with the Zandvlei management's target for intermediate recreation (1000 cfu/100mL).

27 APRIL 2018

CITY OF CAPE TOWN MEDIA RELEASE

Zandvlei water area closed to public until further notice

The City of Cape Town is temporarily closing the Zandvlei water area from today, Friday 27 April 2018, as a precautionary measure following water quality concerns. The closure only applies to recreational activities in the Zandvlei water area, including fishing. Access to the Zandvlei Estuary Nature Reserve and other visitor facilities in the area remain open to the public. Read more below:

Figure 39 Media release by Media Office, City of Cape Town regarding the closure of the estuary due to dangerously high levels of *E. coli* in the water. Picture (below) by Helen Bamford/ African News Agency (ANA).

<u>Spatial Trends in *E. coli* Concentrations:</u>

The high *E. coli* concentrations within the inlets as well as the general increase over the 10 years were in keeping with the Haskins (2016) findings. This was likely due to the direct deposits and sewage spills that occur along the Sand River Canal in particular. The average *E. coli* level for all three inlets over the 10-year study was almost 52 times greater than the recommended guidelines for intermediate recreation (<1000 cfu/100ml) and therefore not suitable for intermediate or full-contact recreation. Furthermore, the high *E. coli* concentrations found within the Northern Section of the main waterbody demonstrate the influence of the inlet rivers on the system. The average *E. coli* concentration in the Northern Section over the 10 years was 50% greater than the recommended guidelines and therefore not suitable for intermediate or full-contact recreation.

The large *E. coli* concentrations during Autumn and Winter in the outlet channel were likely due to the two large sewage spills that occurred in 2009 and 2010 at the old and poorly maintained sewer line that runs underneath the rubble weir in the outlet channel.

Long-term Trends in *E.coli* Concentrations

Apart from the severe sewage spill that occurred in April 2018, *E. coli* concentrations showed an improvement in recent years (up to 2020). This was a similar finding for Haskins (2016) who found an improvement in the quality of water in the central part of the main water body and a long-term improvement in the water quality for this area (Haskins 2016). The lower concentrations of *E. coli* in the main water body and outlet channel compared to the inlets throughout the study period were likely due to the dilution when *E. coli* entered the larger body of water as well as the exposure to seawater and increased exposure to UV rays due to the shallower water nearer the mouth. The southern section of the waterbody had the lowest concentration of *E. coli* for the duration of the study at 486 cfu/100ml which was less than half the recommended guideline for intermediate recreation in South Africa.

Summary:

The ability of the ZES to filter harmful pathogens such as *E. coli* is evident by the sharp temporal declines in concentrations of *E. coli* after a major sewage spill occurred as seen in 2013 and 2018. However, due to the overall high levels of *E. coli* and the increasing long-term trend within the inlets, the water is not suitable for full-contact recreation such as swimming. Some parts, such as the central and southern sections of the main waterbody, were compliant with intermediate recreation contact guidelines. Parts of the estuary have shown improvement over the 10 years, such as the outlets and the main water body, however, the inlets have deteriorated significantly. The severe sewage spills over the years as a result of the poorly maintained pump stations' sewer lines are the causes at hand. These issues will only become more frequent and more severe as the demands of the increasing urban development which surrounds the estuary continues to meet with a lack of infrastructure and/or maintenance. The consequences of this increasing trend will not only result in loss of revenue (through the lack of recreational use of the ZENR, as well as impacting the surrounding property market which relies on the ZENR to provide aesthetic values, resources and access to recreational use) as well as environmental impacts such as algal blooms and fish die-offs resulting in the reduction in species abundance and richness.

3.4.2 Nutrients

Ammonia

The high concentrations of ammonia throughout the system as well as the lower concentrations found in the southern sections of the ZES echoed the findings of Morant and Grindley (1982) who found that ammonia concentrations exceeded the guidelines at several sites within the estuary, particularly in the northern parts of the main waterbody and inlets. Ammonia concentrations were highest within the inlets, where organic matter and effluent concentrations are usually highest. The estuary had a mean ammonia concentration slightly higher than the findings of Harding (1994) who found the average concentration of ammonia to be 150µg/l, three times larger than the recommended guidelines. Ammonia concentrations were well above the recommended guidelines for slightly disturbed estuarine environments throughout the four seasons over the 10 years, except for a short time during 2012 when it dropped significantly. This drop is likely due to the uptake of ammonia by algae which saw a bloom during that same year. There was a steep increase in ammonia over the 10 years with large increases occurring in 2013, 2015 and 2017/2018. These are synonymous with the large sewage spills that occurred during those years, highlighting that the management and control of such contaminants are of critical importance to reducing the levels of ammonia within the system.

Although ammonia occurs naturally in the environment as a result of the breakdown of organic matter, excretion from aquatic species and the weathering of nitrogen-rich sedimentary rocks (DEA, 2012), excessive amounts from anthropogenic sources such as industrial and agricultural run-off can be highly toxic to fish and other marine life. A system is considered toxic when levels exceed 600 µg/l (0.6g/l N) (DEA, 2012). The South African Water Quality Guidelines for Coastal Marine Waters (2012), stipulate the limits for slightly disturbed ecosystems to be 40-50 µg/l (0.04-0.05mg/l).

Over the long term, the average amount of ammonia has increased by 0.2g/l. If that same rate of increase were to continue, the system would reach toxic levels (0.6g/l) by around 2032.

<u>Nitrogen (Total Oxidised Nitrogen, Nitrite and Nitrate)</u>

Levels of nitrate in estuaries are often higher than in coastal waters due to natural and anthropogenic contributions from the catchment and can reach very high levels (>1 mg/l) (DEA, 2012). Sewage spills can result in increased nitrites within water systems and increased levels may therefore indicate such contaminants. It is also a source of nutrients for plant growth so large amounts of nitrogen can lead to excessive growth in plants, contributing to eutrophication which in turn reduces species diversity. At small concentrations, Nitrite can be toxic to aquatic species. Current guidelines recommend levels in pristine waters to be less than 0.01 mg/l for nitrite and less than 0.1 mg/l for Nitrate. Nitrate within very disturbed waters can be more than 1 mg/l.

The high nitrate and nitrite concentrations within the inlet sampling sites indicate the influence of these inflowing rivers. The concentrations were well above the recommended guideline for pristine waters (<0.1mg/l) indicating a possible presence of sewage and therefore posing a threat to the aquatic species within the estuary due to eutrophication. However, it was still below the average level found in very disturbed waters (>1mg/l). Nitrate and nitrite showed a general decrease over the 10 years with peaks between 2013 and 2018 which were synonymous with the large sewage spills in those years. Nitrate and nitrite concentrations mirrored the concentrations found between 1978 and 1991 by Harding (1994), indicating a slight improvement over the long term. It was highest in Winter and lowest in Summer indicating that run-off with the winter rains from surrounding urban-based sources is at hand.

Total persulphate oxidized Nitrogen is the sum of all organic (oxidized) Nitrogen. i.e. all forms of Nitrogen that can be readily absorbed by plants and algae (e.g. Ammonia and nitrite/nitrate) and therefore, occurs in higher concentrations than just Ammonia and nitrate/nitrite (Environmental Protection Agency EPA, 2001; DEA, 2012).

Total Oxidized Nitrogen (TON) was highest at the inlet sampling stations and was lowest within the lower reaches of the system, illustrating the dilution and filtration effect of the estuary. The higher concentrations of TON during the Winter were likely due to increased rainfall during this period which brought increased run-off of such nutrients from the surrounding urban and agricultural settlements into the system. The average Total Oxidized Nitrogen for the Estuary throughout the 10-year study was much like the findings of Morant and Grindley (1982) who found levels of Total Oxidised Nitrogen between 1 and 2 mg/l, which indicated slight eutrophication. Similar values were found by Jackson et al., (2010) where Nitrogen levels were only slightly below the 2.5mg/l level which indicated eutrophic conditions(Morant and Grindley, 1982; Jackson et al., 2010). Harding (1994) also found Total Oxidized Nitrogen levels within the inlets to range between 0.8-1.9 mg/l. TON increased dramatically over the 10 years with highly severe concentrations during 2013 and 2018 which aligned with the large sewage spills that occurred during those years. Such an excess of TON can contribute to excessive algal growth and subsequent fish kills.

Total Phosphorus and Orthophosphate

Whilst Total Phosphorus levels decreased slightly with distance from the inflowing rivers, Orthophosphate showed a slight increase at the outlet channel. Both parameters decreased in the main water body, likely due to dilution within this area or perhaps Phosphorus may have sunk to the (deeper) bottom floor where less mixing occurs. This trend was also noted by Morant and Grindley, (1982) who found Total Phosphorus concentrations in the influent rivers to be considerably higher. Harding (1994) also mentioned that the highest phosphorus concentrations were found in the northern section of the system.

The higher concentrations of Total Phosphorus in the inlet rivers compared to the lower reaches of the system, indicate the influence of the in-flowing rivers carrying large loads of urban-based pollutants. The Total Phosphorus concentrations throughout the system over the 10 years indicate eutrophic conditions according to the guidelines for Phosphorus concentrations in “pristine” waters (oligotrophic) which is in keeping with Morant and Gridley

(1982), Harding (1994), C.A.P.E. (2013) and Furness (1979) who considered the ZES as a eutrophic system. Harding (1994) found Total Phosphorus levels were over 0.025 mg/l. This was also the case in later years for Haskins (2007) who found the average Total Phosphorus concentration to be 0.129 mg/l as well as for Jackson et al., (2010) who found it to be over 0.025 mg/l.

Total Phosphorus and Orthophosphate showed similar seasonal trends; rising with the flushing of the first winter rains in the second quarter and dropping in the third quarter once water levels were at their highest. This is different to the finding of Quick and Harding (1994) who saw no apparent seasonal changes in the concentrations of phosphorus at ZENR.

Over the 10-year study period, Total Phosphorus showed a slight increase in concentrations whilst orthophosphates decreased slightly. The increase in Total Phosphorus is likely a result of increased urban inputs from surrounding communities (sewage and surface run-off). The peak in 2018 is synonymous with the large sewage spill that occurred in that year which did not seem to affect the orthophosphate levels. The decrease in orthophosphates may have occurred due to weed harvesting and the subsequent removal of decomposing plant material from the system. This is a similar finding to that of C.A.P.E. (2013), who noted a gradual increase in total phosphorus and orthophosphate in the middle to the upper region of ZENR over the long term. They, therefore, classified the ZENR into Category D (a large deviation from natural conditions) of the Water Quality Index estuary threshold levels (C.A.P.E., 2013).

Interestingly, Orthophosphate concentrations were highest at the outlet which may have been caused by decomposed marine plant matter such as kelp and seaweed brought in from the tidal action. Orthophosphate concentrations throughout the system were found to be seven times greater than levels the Department of Environmental Affairs regards as nutrient-rich for estuaries with heavy inputs (DEA, 2012), indicating the poor health of the system and the risk to biodiversity.

3.4.3 Physical Parameters:

Suspended Solids (SS)

Suspended solids are a measure of particles suspended in the water and are comprised of sand, clay, fine particles of organic and inorganic material, plankton and other microscopic organisms (DEA, 2012). High concentrations of suspended solids can lead to increased turbidity which can limit light penetration and therefore affect photosynthetic activity. It can also clog fish gills which will likely increase stress levels and susceptibility to disease (Jordan et al., 2003). Settling particles can suffocate the fish eggs of spawning species (Jordan et al., 2003). Suspended solids also affect certain water treatment procedures (DEA, 2012).

One benefit of suspended matter is that it can absorb certain pollutants such as pesticides, thus removing it from the water column (but into the sediment) (United States Environmental Protection Agency (USEPA), 1986). In addition to natural processes such as erosion, human activities such as farming, canalization, deforestation, urbanisation, dredging, mining, and wastewater inputs are known to unnaturally increase the sediments in our freshwater and marine environments (DEA, 2012).

There are no set guidelines for suspended solids for the coastal waters of South Africa due to the large natural variation of this parameter (DEA, 2012). Harding (1994) found the average mean Suspended Solids concentration within the inlets at the ZES was 145 mg/l. This was far greater than the mean concentration found in this study of 22.3 mg/l. Perhaps the ZENR management at the time of Harding’s study was performing regular dredging activities, which would have increased the suspended matter within the water column. The lower concentration within the central waterbody is expected as this is the deepest area of the estuary, with the least turbidity. Large levels of suspended solids were recorded towards the narrow, shallow and turbid waters of the outlet as well which may have been affected by the increase in salinity and turbidity from in-flowing seawater.

The high concentrations of Suspended Solids during Autumn showed a dramatic peak in the northern section of the water body, most likely due to the first winter rains flushing sediment down from the inlet rivers. The lower concentrations within Winter were possibly due to the increase in freshwater which increased the dilution factor. The gradual increase of suspended solids over the 10 years with large decreases between 2011 and 2014 is most likely a result of the amended mouth management plan and subsequent lowering of the weir by 10cm and 20cm during both those years respectively and a similar trend was noted during 2001/2 when the weir was also lowered by 20cm. This was also suggested by Haskins (2016).

Secchi Depth

Secchi depth is a measure of the water clarity by taking into account the water colour, turbidity and suspended solids (DEA, 2012). Secchi depths are often used to gauge the presence of algae which can respond very rapidly to nutrient changes and can dramatically reduce water clarity within a matter of days (Environmental Protection Agency EPA, 2001). Secchi depth ranged from 0.08 m to 1.6 m with an average of 0.6 m for the whole system, which was in keeping with that of Morant and Grindley (1982) who found the Secchi depth at ZENR to range between 0.2 – 1.8 m and had an average of 0.7 m for the whole system (Morant and Grindley, 1982). It was also in keeping with Harding (1994) who found the Secchi depth ranged between 0.09 m and 1.2 m with an average of 0.54 m for the whole system (Harding, 1994).

The increase in Secchi depth towards the outlet channel illustrates the influx of clearer water and the reduction of nutrients and turbidity within this area compared to the high levels noted in the Northern parts of the system. Secchi depth showed a general decrease during Winter across sampling sites as can be expected with the increased flow and debris that is brought with the winter rainfall as well as the extended opening of the estuary mouth during this period. This was also found by Harding (1994) who stated that Secchi depth increased with distance from the inlets and was lowest during winter rains and highest during summer.

It is uncertain why there was a large increase in Secchi Depth in 2011 as there were no unusual events that took place that year that could have affected the water's clarity except for the lowering of the weir by 10cm. However, a similar spike was noted in 2006 when such a lowering did not occur. Rainfall and temperatures were consistent with other years, dredging did not occur, and the mouth management regime was consistent for both 2006 and 2011.

The large increase in clarity may have been a precursor to the algal bloom that occurred in March 2012 which resulted in a large fish kill. Haskins (2016) found a similar spike with regards to Chlorophyll-a, which indicates that algae in the system may have meant the sudden uptake of nutrients by such algae which could have caused the increase in clarity which would have allowed for more light penetration and therefore more absorption of solar energy for Chlorophyll-a production. However, Chlorophyll-a was still high for 2012, which was not the case for Secchi depth as it dropped significantly thereafter.

Figure 40 Dead fish in the waterways around Marina da Gama as a result of the algal bloom in 2012. (Picture: Henk Kruger, Cape Argus, 04.17.2012)

<u>Salinity and Conductivity</u>

Conductivity will increase with an increase in the levels of dissolved ionic salts in the water and is used to indicate dissolved solids. Freshwater species will be restricted to the upper reaches while marine species will occur nearer the outlet while stenohaline species in the main waterbody can tolerate very limited ranges in salinity, whilst euryhaline species can adapt between freshwater and marine. For the saline-limited species, large changes in the salinity will directly affect their distribution, life cycles and health (Ohrel and Register, 2006).

Changing the height of the weir largely affects the salinity range of the ZENR. Hutchings (2016) noted several instances where the average salinity for the system changed by either lowering or raising the weir. Salinity declined from 10 ppt to 5 ppt from the 1980s to the 1990s when the weir was increased. Salinity then increased to between 9 and 11 ppt between 2002 and 2010 after the weir was lowered slightly (Hutchings *et al.* 2016). The same was found in this study where salinity decreased in 2013 and 2015 after light dredging which occurred in both those years.

In terms of seasonal variations, the highest salinity concentrations were recorded during summer due to lower freshwater inflows and high evaporation rates. Spatial variations have shown salinity to increase towards the mouth as was the same for Hutchings *et al*. (2016). Salinity concentrations indicated the mouth management regime was ensuring regular inputs of salt water during open-mouth periods.

The high levels of salinity and conductivity in the Summer were likely due to the drier conditions during this time as well as the opening of the estuary mouth for a few days each month into the dry summer season, allowing increased saline flow into the system. The low levels of salinity and conductivity in the Winter resulted from the increase in rainfall and therefore freshwater inputs during this period. The long-term trend of an increase since 2015, supports the theory by Haskins (2016) that amending the mouth management plan in 2014 in conjunction with some light dredging has been beneficial for ensuring regular inputs of saltwater into the estuary (Department of Environmental Affairs, 2018). This also supports the proposal within the 2018 management plan that the mouth should be kept open as much as possible, especially during peak fish recruitment times (August – November) to maintain the natural functioning of the estuary.

The overall value of ZES for the supply of clean water

The value of the ZES in terms of adequate water supply through its dilution, filtration and nutrient assimilation abilities was evident within the large decline in *E.coli* concentrations following several large sewage spills.

The ZES offers recreational opportunities for the nearby community, such as swimming, boating, and fishing. However, its ability to provide safe and clean water for these activities is compromised by several challenges, notably high *E. coli* levels. While certain areas within the estuary, particularly the central and southern sections of the main water body, meet intermediate recreation guidelines, the presence of *E. coli* in the inlets and variations in water quality parameters raise concerns about full-contact recreational activities like swimming. The estuary's recreational value is, therefore, limited by water quality issues.

The ZES plays an essential role in natural wastewater treatment. As highlighted in the literature, estuarine wetlands serve as effective natural filtration systems by trapping sediments and absorbing excess nutrients (Barbier et al., 2011). This is demonstrated by the estuary's ability to mitigate the effects of pollution, such as reducing *E. coli* levels after spills. If these natural filtration mechanisms were to be degraded, the costs of replacing them with man-made infrastructure could be substantial. Similar studies, such as those on the Nakivubo Wetland in Uganda and the Louisiana wetlands (Breaux et al., 1995), show how valuable these services are, with potential replacement costs running into millions annually. In fact, Turpie et al. (2001) estimated that replacing the water treatment functions of the Zandvlei Estuary could cost around R180 million, or approximately R617 million in 2024 when adjusted for inflation.

The ZES's recreational potential has economic implications for the surrounding region. The closure of the estuary due to dangerously high *E. coli* levels, as observed in the case of a sewage spill in 2018, results in revenue loss from recreational activities. The estuary contributes to the local economy through tourism and property values, as it serves as an aesthetic attraction and provides access to recreational use. However, the ongoing deterioration of water quality, including high nutrient levels and suspended solids, can negatively affect property values and the appeal of the area to potential residents and tourists. As such, the estuary's economic value is closely tied to its water quality and ecological health.

The ZES is ecologically significant, as it supports various aquatic species and biodiversity. However, the estuary's ecological health is at risk due to nutrient pollution, notably high levels of Ammonia, nitrate, nitrite, total phosphorus, and orthophosphate. These pollutants can lead to eutrophication, algal blooms, and fish die-offs, impacting species abundance and richness. Additionally, the presence of suspended solids, variations in water clarity, and changes in salinity can affect the habitat and life cycles of aquatic species. Maintaining a healthy estuarine ecosystem is vital not only for biodiversity but also for the long-term sustainability of the estuary as a recreational resource.

In conclusion, the ZES holds value for the surrounding community, economy, and ecology by providing recreational opportunities, contributing to the local economy, and supporting aquatic biodiversity. However, water quality challenges, particularly related to *E. coli* contamination and nutrient pollution, need to be addressed to fully realize its potential and ensure the long-term well-being of the estuarine ecosystem, the local economy, and the community's recreational experiences. Sustainable management practices and pollution control measures are essential to preserve and enhance the estuary's multifaceted value. Several management interventions such as opening the mouth for extended periods and dredging the lower reaches have proven to be beneficial for the quality of water within the Estuary. Therefore, it is suggested that the mouth be kept open as much as possible, especially during peak fish recruitment times (August – November) to maintain the natural functioning of the estuary. Dredging should be limited during the spawning season (November – February) as the increased siltation that results can have adverse effects on fish by covering spawning sites, destroying benthic food sources, and reducing water clarity to visually feeding animals and extensive education initiatives should be implemented with regards to pollution/litter and recycling in the surrounding communities.

Limitations and Further Research

The analysis revealed considerable variance in water quality parameters, which may be attributed to various factors, including the impact of sewage spills in the Zandvlei Estuary. These spills likely contributed to fluctuations in E. coli concentrations and other nutrient levels, reflecting the complex and dynamic nature of the estuarine system. The high variance observed raises concerns about the reliability of the conclusions drawn from this study, as it complicates the identification of consistent patterns in water quality over time and across different sites. Recognizing this variability highlights the need for further research that examines the underlying factors contributing to these fluctuations, including the frequency and intensity of sewage spills. Future studies could incorporate additional environmental variables, assess the long-term effects of pollution events, and conduct more extensive sampling to improve the understanding of water quality dynamics in the Zandvlei Estuary.

The observed spatial differences in water quality parameters may be largely influenced by increasing distances from point sources of pollution, such as sewage outfalls and urban runoff. As water flows through the Zandvlei Estuary, the degree of pollution typically decreases with distance from these inputs, which could explain the variability in water quality observed at different sampling sites. To gain a deeper understanding of the filtration services provided by the estuary, it is essential to conduct in situ measurements of filtration rates. Such measurements would help quantify the estuary's capacity to filter pollutants and nutrients, thereby providing valuable insights into its overall ecological health and functionality. Future research should focus on both assessing the spatial dynamics of water quality in relation to pollution sources and directly measuring the filtration efficiency of the estuarine ecosystem to develop effective management strategies.

While this study effectively assessed water quality variations both spatially (between sites) and temporally (between seasons), it did not explore the interactions between these two factors. Investigating Site x Season interactions could provide deeper insights into how seasonal variations influence water quality across different sites in the Zandvlei Estuary.

Understanding these interactions may reveal critical patterns that affect the estuary's filtration efficiency and ecological health.

In the context of water filtration services provided by the ZENR, the hydrodynamic aspects of the system play a critical role in influencing water quality, particularly when the estuary mouth is open. During these periods, there is a significant tidal exchange between the estuary and the ocean, which contributes to the dilution of nutrient concentrations and E. coli levels. This exchange facilitates the flushing out of pollutants and reduces the impact of localized sources of contamination. However, the extent and frequency of tidal exchange can vary seasonally or be affected by management interventions (e.g., artificially opening or closing the mouth). This variability introduces a limitation in accurately assessing the estuary’s filtration capacity, as the water quality data collected during periods of mouth closure may reflect significantly different conditions than when tidal exchange is active. Further research could focus on the hydrodynamic modelling of the estuary under various tidal regimes to better understand how these processes influence filtration services over time and across different areas of the system. Incorporating these dynamics would enhance the accuracy of evaluating the estuary’s capacity to mitigate nutrient and bacterial pollution under varying conditions.

The valuation of Zandvlei as a wastewater treatment facility was initially estimated by Turpie et al. (2001) at R180 million. However, given the significant changes in economic conditions and inflation, an updated assessment of the replacement cost would provide a more accurate reflection of its current economic value. Future research could focus on conducting a comprehensive valuation study that takes into account recent data and methodologies to estimate the economic worth of the Zandvlei Estuary's natural services in today's context.

CHAPTER 4: AESTHETIC VALUE OF THE ZANDVLEI ESTUARY SYSTEM

4.1 Literature Review

The aesthetic values of natural landscapes aligned with cultural ecosystem service contribute to the quality of life, health or vitality of human wellbeing by providing inspiration, harmony and peace (Bolund and Hunhammar, 1999). However, few tangible studies account for this service and little understanding of the link between the aesthetic and ecological values of landscapes. Cultural services including aesthetic perception are important for understanding the connections that people have with natural landscapes, as they may strongly influence people's enthusiasm for biodiversity conservation (Saunders, 2013). Assessing the aesthetic value is thus an important area that should be incorporated into the management programmes of natural landscapes.

The limited research regarding the economic value of ecosystems within urban environments uses stated and revealed preference valuation methods (Sylla et al., 2019; Lamberth and Turpie, 2003). Stated preference methods such as contingent valuation techniques estimate a user's expressed rather than an actual willingness to pay for goods that are not reflected within real markets and are gathered using surveys (Bockarjova et al., 2020). Revealed preference methods estimate the monetary value of traded goods and services within markets (Park et al., 2017) using methods such as travel cost or hedonic pricing. Hedonic property pricing assumes that the value of a natural area can be reflected within the surrounding property market (Combrinck et al., 2020; Mazzotta et al., 2014). A buyer's willingness to pay extra for access to a resource (a premium) can be estimated using the surrounding prices on a regression curve or through expert valuations (De Wit et al., 2009). However, such valuation studies of natural landscapes and associated ecosystem services are limited as they can be costly, time-consuming or data-deficient in their assessment (Bockarjova et al., 2020).

The hedonic pricing method was first established by Sherwin Rosen in 1974 and is now widely used to measure the aesthetic value of natural areas around the globe (Mansfield et al., 2005; Walsh et al., 2015; Kovacs, 2012; Maland, 2002). For example, Reynaud and Lanzanova, (2017) presented the first meta-analysis investigating the economic value of ecosystem services supplied by lakes globally. Using 113 studies and 699 datasets they estimated the annual economic value per lake to be between \$106 - \$140 (2010) per person in non-hedonic price studies and between \$169 - \$403 (2010) per property in hedonic price studies.

There has been an increase in such studies conducted on ecosystems in South Africa. Turpie and Clark, (2007) assessed the economic value of 149 temperate South African estuaries and found 77 of the estuaries had a positive influence on the surrounding property markets, with an overall premium (the amount over and above the property price for access to a particular resource) for each estuary ranging from about R1 million to R2 billion per annum. The total premium for all estuaries was estimated at up to R10.6 billion which converted to an annual value of about R320 million.

Cooper et al., (2003) assessed the property values of four South African estuaries (the Berg Estuary, Breede Estuary, Knysna Estuary, and the Keiskamma Estuary) using estate agent interviews. They estimated the premium paid for properties at each estuary as R12 million for the Berg, R50 million for the Breede; R2 billion for the Knysna and R1 million for the Keiskamma estuaries.

Using a similar approach, Turpie *et al.* (2003) obtained similar results to that of Cooper *et al.* (2003) for the Knysna estuary and estimated a premium value of up to R2 billion based on estate agent interviews. Turpie (2006) performed a hedonic analysis on the Kromme and Zeekoei estuaries in the Eastern Cape, using data from residents. For the Kromme estuary, they found that distance to the estuary border was a major influence on the local property market. Based on the premiums paid for properties with waterfrontage, the estuary was valued at R578 million. Property prices at the Zeekoei Estuary were largely related to size and proximity to the beach rather than to the estuary and therefore proximity to the estuary was not a contributing factor in the local property market (Turpie 2006).

Turpie *et al.,(2009)* investigated the economic value of the East Kleinemonde Estuary by using both the hedonic analysis as well as interviewing 137 residents and users of the estuary. Houses located on the water's edge received premiums of up to R460 000 more than others. The total value of the estuary to the local property market was estimated at R133 million (30% of the total value) (Turpie et al., 2009).

Few hedonic pricing studies have been performed on the Zandvlei Estuary Nature Reserve. Van Zyl and Leiman (2001) assessed hedonic theory and the limitations thereof in the valuations of various wetlands within the Cape Town metropole as well as other open spaces including the ZENR. Property price values for access to the ZENR were estimated and hedonic regression analyses showed surprisingly similar results to expert opinions of total premiums of R76.7 million and R87.5 million, respectively (van Zyl and Leiman, 2002). Within the same study, a park in Kuils River generated a premium for the surrounding property market while one in Claremont created a discount where buyers closer to the park paid less apparently due to noise disturbances and safety concerns. They concluded that the hedonic analyses of the values of open spaces, were highly case-specific and therefore expert opinion was advisable (van Zyl and Leiman, 2002). They also found most open spaces generated a premium of 10% or less on surrounding property prices. However, those found near major natural attractions (such as Zandvlei), offered increased services and created higher premiums of up to 20% (van Zyl and Leiman, 2002). A key finding through their interviews with the residents was that the value of the nearby natural space was mainly dependent on the quality of its management. Well-managed areas led to better aesthetic experiences, increased safety and overall services to the surrounding residents which then drove premiums higher (van Zyl and Leiman, 2002).

4.2 Methods and Materials Hedonic Pricing Method

The influence that an ecosystem or environment has on the surrounding property values and market can be estimated using hedonic pricing analyses using the price of a product (dependent variable) that is dependent on the goods and services it provides (independent variable) (Sylla et al., 2019). Hedonic pricing analyses using large datasets however are known to increase the risk of misinterpreting the local realities (Van Zyl, 2007)and therefore stratifying the data into smaller sample sets (i.e. per suburb), can be more useful when analysing local trends (Van Zyl, 2007). This study used a set of independent property price regressions against distance from the estuary's edge for six areas surrounding the ZENR, namely, Muizenberg West, Muizenberg East, Marina da Gama, Marina da Gama (North), Lakeside North, and Lakeside (Figure 41 below).

The main benefit of using property transactions within valuation studies is that it uses known market transactions rather than perceived or expressed value. However, such data can prove to be insufficient and/or unreliable due to inaccurate or varying methods of data collection. The resulting usable / quality-controlled number of property transactions may be relatively low which restricts hedonic analyses to larger areas with higher property sales and movement. In some areas, property movement may not have been active enough to provide sufficient sales data and inadequate property markets can lead to incomplete and lacking transaction data (van Zyl and Leiman, 2002). Some studies suggest the use of expert opinions from local estate agents to be beneficial in conjunction with hedonic pricing studies (Reynaud and Lanzanova, 2017; van Zyl and Leiman, 2002) as such opinions provide greater insight into local property trends. (Twekye, 2018)

Recent data were collated and compiled for the surrounding residential property sales using two datasets. A dataset was provided by the City of Cape Town's Housing Valuation Department as well as one from a private company (Lightstone Property (Pty) Ltd.). The two datasets were combined and consolidated by averaging all duplicate sales and removing any transactions without a sale price or location.

The resulting residential property dataset comprised data for 1864 property sales that ranged between R66 500 and R26 365 620 per property. Property sizes, which ranged from 36 m^2 to 1640 m^2, the prices at which residential properties were most recently sold between 2014-2018 (detrended for inflation using the difference between the average sale price across the years), as well as their erf size were included. Previous studies (Leiman and Van Zyl, 1998; Van Zyl, 2007) have shown that characteristics such as the number of bedrooms and bathrooms and special features often demonstrated significant co-linearity and added little to the analyses, these attributes were therefore excluded from this study. Local influencing variables such as proximity to public transport, shopping centres, noise sources (road or railway), and venues were omitted from the hedonic pricing analysis but discussed as influences.

The locations of properties were plotted using QGIS (Quantum Geographical Information Systems 3.10.1) and stratified into the six suburb areas (Figure 41). The distance (in metres) of each property to the water's edge of the ZES was calculated using the QGIS distance tool and exported into Microsoft Excel 2019. Within each of the five suburb areas, the distance was divided into distance bins from the water's edge (within 50 m; between 50 m and 100 m, between 100 m and 150 m and between 150 m and 200 m from the water's edge). A general regression analysis tool (Microsoft Excel 2019's data analysis package) was used to calculate the coefficients for each of the distance bins. The coefficients represented the premium paid (the amount paid above the property price received if the driver was not present) or the discount received (per m^2) (van Zyl and Leiman, 2002). Proximity to the water's edge and price per m^2 for each property in each of the five areas were displayed graphically and the correlation coefficients specific to different distance bins were obtained. We then applied these coefficients to assess the influence of proximity to the estuary on property values. This granular approach allowed us to account for potential variations in the relationship between distance and property prices across the study area.

These coefficients quantified the change in property prices per unit change in distance within specific distance ranges. The use of relative distance bins provided a customized perspective on how proximity to the estuary affects property values within each area.

Furthermore, we incorporated the number of houses in each area to estimate the localized impact. By multiplying the coefficients by the relative distance bins and the number of houses, we obtained estimates of the influence of the estuary on property prices within each area. These estimates allowed us to quantify the specific impact of proximity to the estuary on property values in a localized manner.

To assess the overall impact of the estuary on the surrounding housing market, we aggregated the results from all five areas, summing up the impacts across the different distance bins and areas. This allowed us to estimate the combined influence of the estuary on property prices across the entire study area.

While this analysis captures the impact of distance to the estuary, it is essential to recognize that other factors, such as property characteristics and neighbourhood amenities, may also influence property prices. For a more comprehensive understanding, future studies may consider integrating these factors into the analysis to provide a more holistic view of the dynamics affecting property values in the vicinity of the ZENR.

4.3 Results

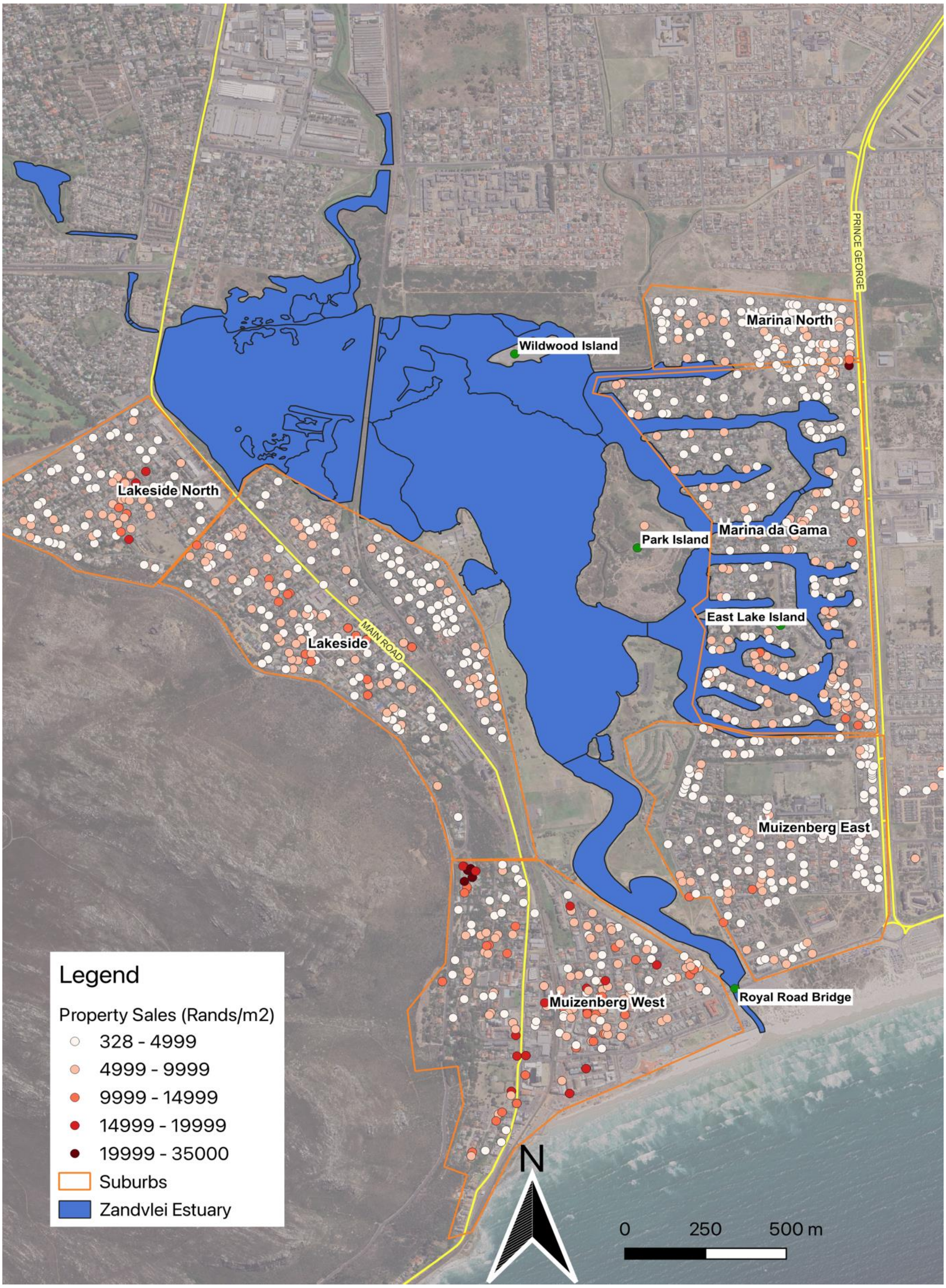

Figure 41 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in each of the six areas surrounding the ZENR used in analyses (Source: QGIS 3.10.1).

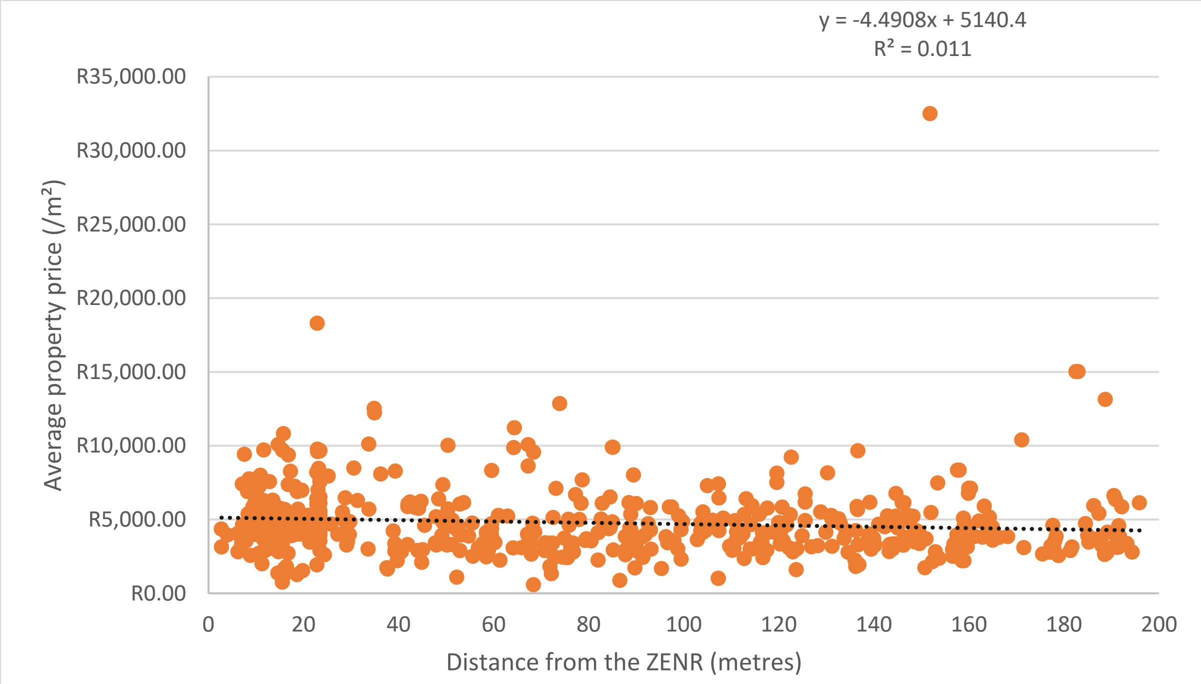

Figure 42 All residential property sales (rands per m²) within 200m of the ZENR between 2014 and 2018 ($y = -4,4908x + 5140.4$, $R^2 = 0.011$).

Summarised residential property sales data for each of the six areas surrounding the ZENR are displayed in Table 13 below.

Table 13 Property sales data for the surrounding areas of the ZENR

Area	Average Property Size (m²)	Average Purchase Price	Average Price/m²	No. of Houses sold between 2014 and 2018.
Muizenberg West	386	R2,132,380.25	R8,161.91	181
Muizenberg East	422	R1,797,396.18	R5,458.54	130
Lakeside	486	R1,943,195.21	R5,298.24	190
Lakeside North	467	R2,070,766.59	R5,638.55	102
Marina da Gama	424	R1,852,347.44	R5,352.07	260
Marina da Gama (North)	395	R1,669,724.38	R5,262.03	116
Average All	430	R1,910,968.34	R5,861.89	163

Average individual property values (per m²) associated with the presence of the ZENR within the surrounding 6 areas with relative percentage contribution to the property's sale price (per m²) are displayed in Table 14 below.

Table 14 Mean premium/discount transacted for properties associated with proximity to the ZENR during the study period (2014 to 2018). Discounts are displayed in red. ND represents no data.

Area	<50m (R/m²)	50m><100m (R/m²)	100m> <150m (R/m²)	150m><200m (R/m²)	Entire Area (R/m²)	Per house	Total
Muizenberg West	R1,943.10	R983.64	R5.51	R3,097.83	R1,507.52	R582,318.36	R105,399,623.58
	24%	12%	0%	37.95%	18.47%		
Muizenberg East	-R4,628.73	-R716.86	-R976.22	-R510.67	-R1,708.12	-R720,446.38	-R93,658,029.95
	-84.80%	-13.13%	-17.88%	-9.36%	-31.29%		
Lakeside	R2,513.61	R1,750.66	R2,170.55	R2,295.07	R2,182.47	R1,060,501.33	R201,495,253.64
	47.44%	33.04%	40.97%	43.32%	41.19%		
Lakeside North	ND	R867.98	R1,690.21	R1,714.08	R1,068.07	R498,652.92	R50,862,598.08
	ND	15.39%	29.98%	30.40%	18.94%		
Marina on the Water	-R582.50	R0.00	-R1,222.97	ND	-R451.37	-R191,464.99	-R49,780,896.39
	-10.88%	0.00%	-22.85%	ND	-8.43%		
Marine Off the Water	ND	-R247.78	-R1,207.89	-R2,030.19	-R871.47	-R344,454.43	-R39,956,713.40
	ND	-4.71%	-22.95%	-38.58%	-16.56%		
Average	-R125.75	R439.61	R76.53	R761.02	R287.85	R147,517.80	**R174,361,835.56**
	-2.15%	7.50%	1.31%	12.98%	4.91%		

The regression analysis resulted in an R-squared value of 0.011, indicating that the model accounts for only a modest portion of the variability in property prices per square meter concerning proximity to the Zandlvei Estuary Nature Reserve. However, the coefficient associated with the distance variable is particularly noteworthy. With a value of -4.4908, it suggests that, on average, property prices per square meter tend to decrease by approximately R4.49 for each additional meter of distance from the Zandlvei Estuary Nature

Reserve. The average property value associated with the presence of the ZENR (premium) per house was R147,517.80. The net-sum value attributable to the presence of the Zandvlei Estuary System reflected in the surrounding housing market for all sold residential properties during the study period (2014 – 2018) was estimated at R174,361,835.56 (Table 14).

Muizenberg West

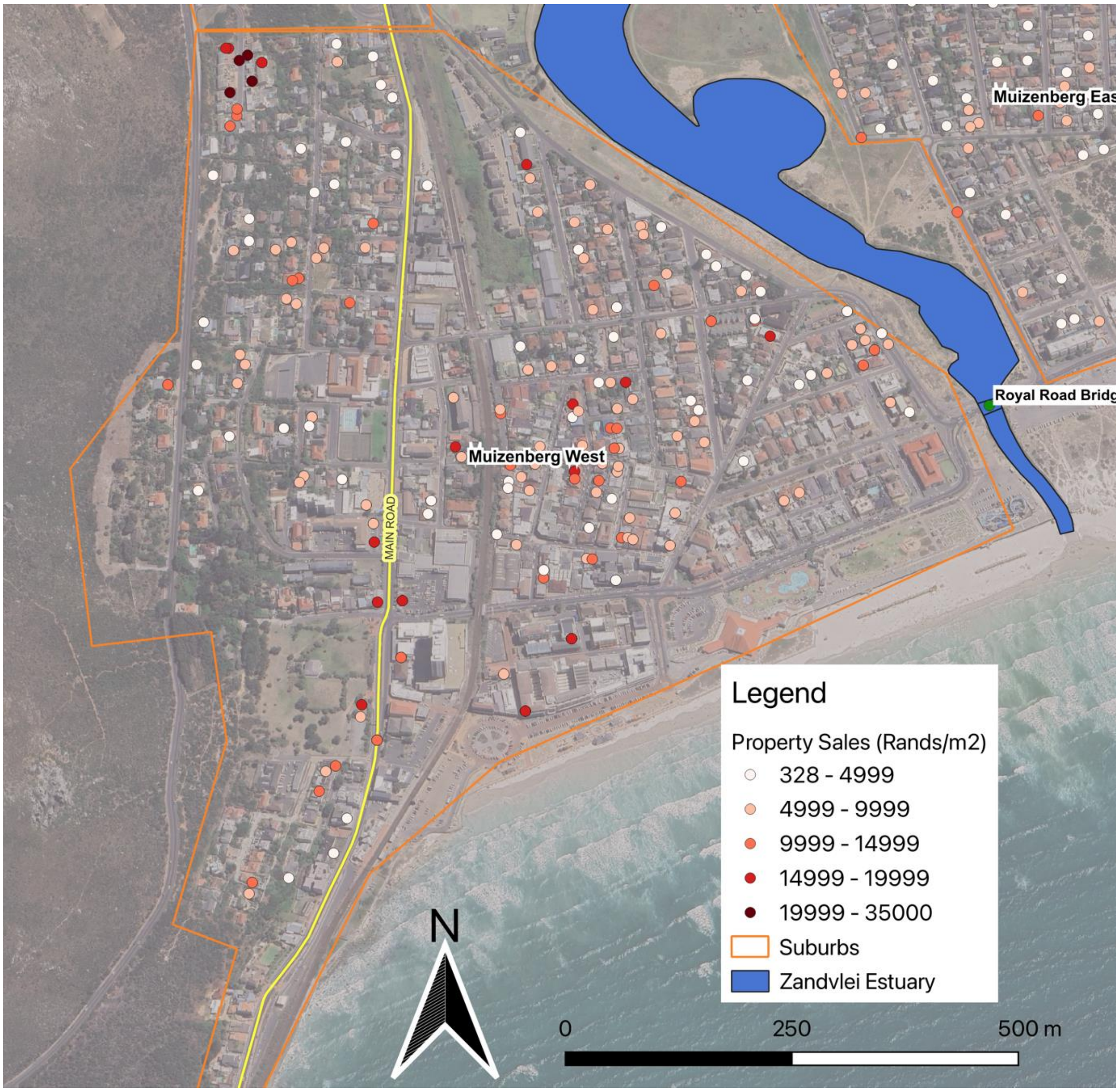

Figure 43 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Muizenberg West area used in analyses (Source: QGIS 3.10.1)

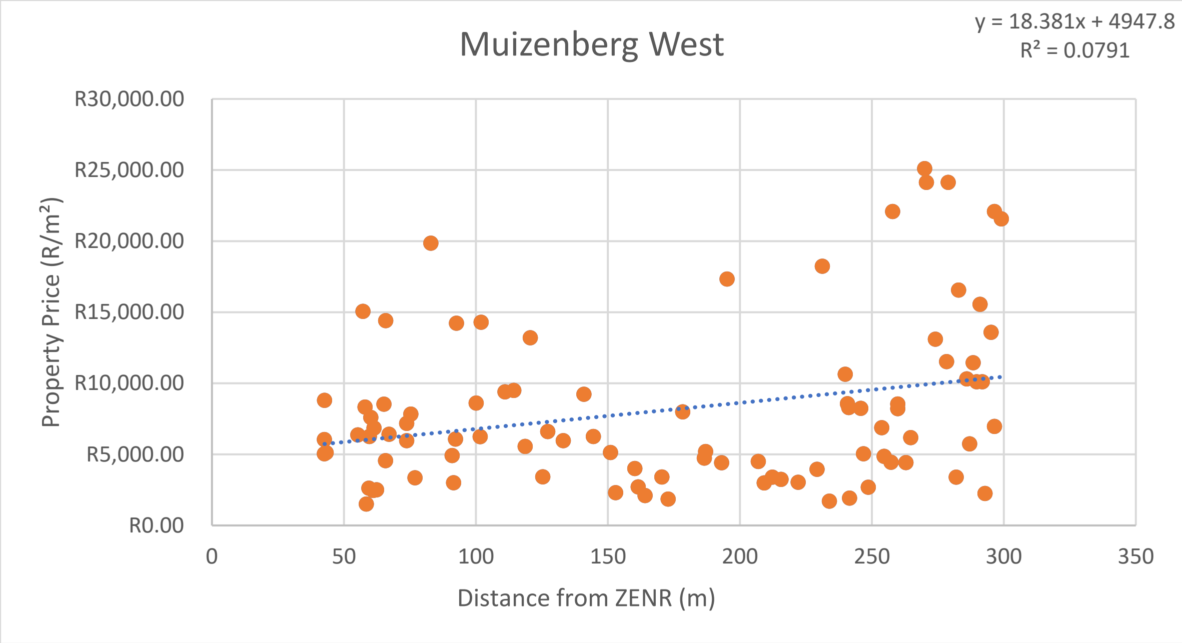

Figure 44 Average residential property sale prices (per m²) for Muizenberg West between 2014 and 2018 (y = 18,381x + 4947,8).

Muizenberg West had the smallest average property size (386m²), the largest average purchase price (R2,132,380.25) and therefore the largest price/m² (R8,161.91). The lowest premium attributable to the presence of the ZES for this area was found within houses located 100-150m from the water's edge (R5.51/m²). The highest premium occurred within 150m - 200m of the Estuary at R3,097.83/m². This area reflected a very large positive coefficient slope for the area (y = 18,381x + 4947,8) indicating either a negative correlation with distance towards the ZENR or a positive association with the beach or other areas/ natural amenities.

Muizenberg East

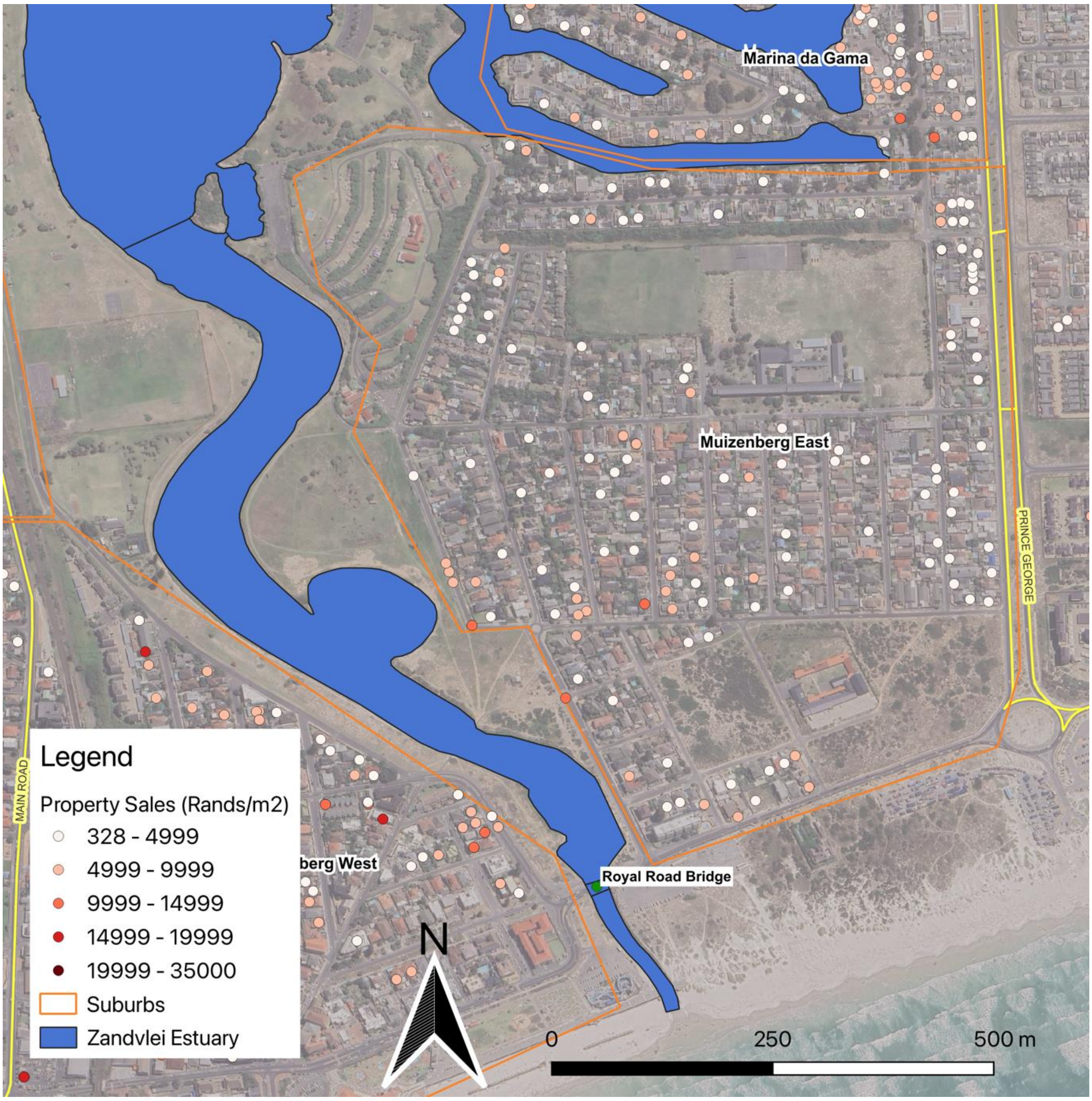

Figure 45 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Muizenberg East area used in analyses (Source: QGIS 3.10.1)

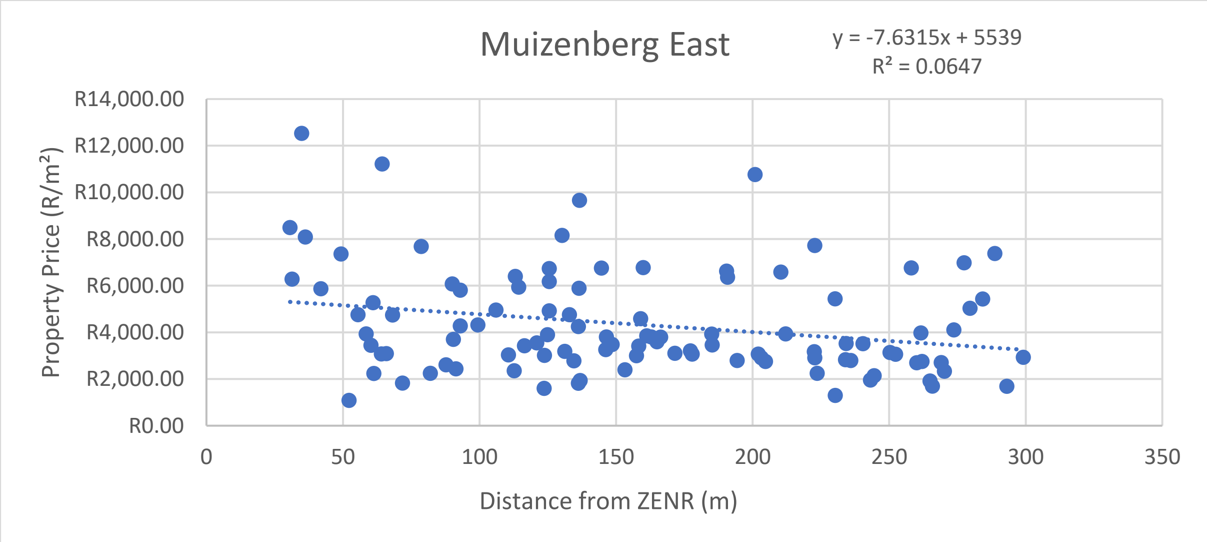

Figure 46 Average residential property sale prices (per m²) for Muizenberg East between 2014 and 2018 (y = -7,6315x + 5539)

Muizenberg East had the second-lowest average purchase price (R/m²) per property of R1,797,396.18 of the 6 areas. Within 50 m from the vlei, it had the lowest average premium (discount) associated with the presence of the Estuary of -R4,628.73/m². This was also the case for properties within 50-100 m of the Estuary reflecting an average discount associated with the presence of Zandvlei at (-R716.86/m²) in all areas. Muizenberg East had the lowest overall premium (discount) per m² (-R1,708.12/m²), per property (-R720,446.38) and for the entire area (-R93,658,029.95). It also had an overall negative slope (y = -7,6315x + 5539) for the area, indicating a positive correlation between property prices with distance toward the vlei.

Lakeside

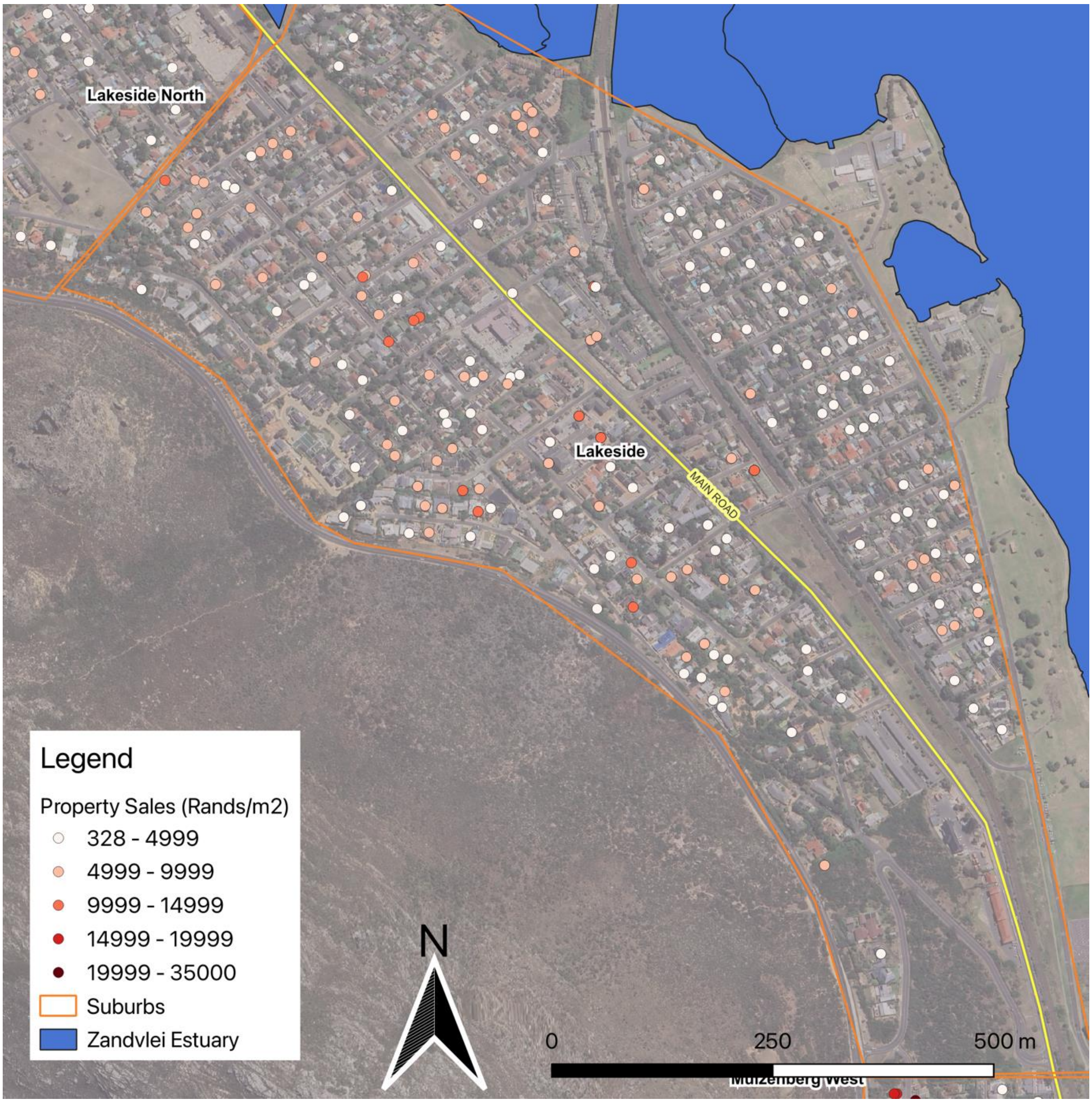

Figure 47 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Lakeside area used in analyses (Source: QGIS 3.10.1)

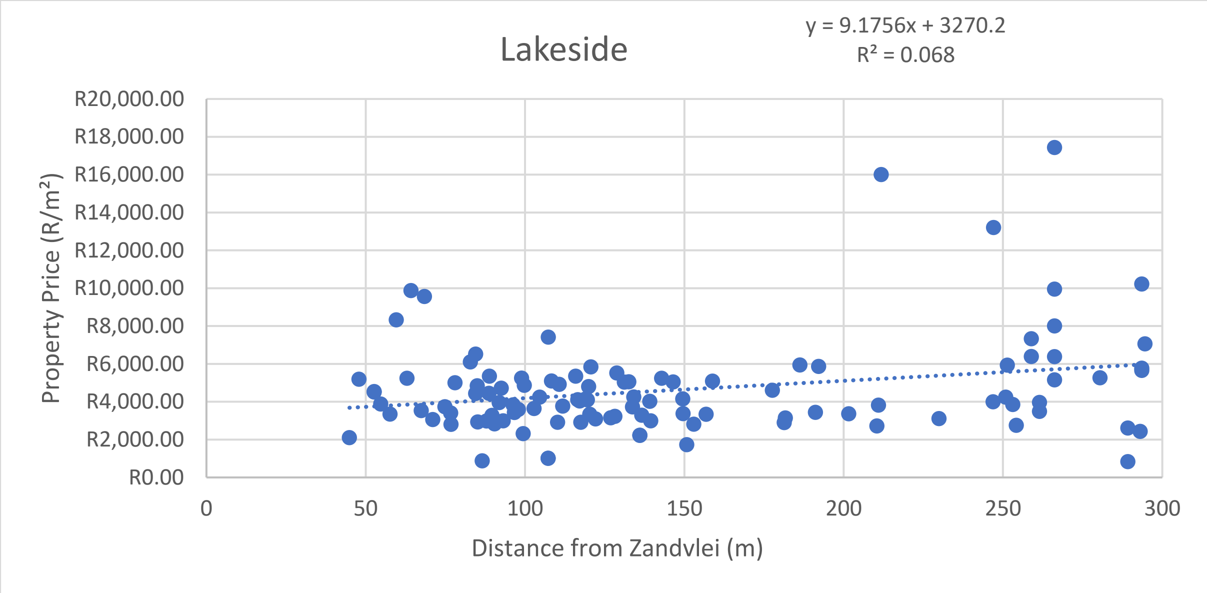

Figure 48 Average residential property sale prices (per m²) for Lakeside between 2014 and 2018 (y = 9,1756x + 3270,2).

Lakeside had the largest average property size of 486m² and the largest property value associated with the presence of Zandvlei for houses within 50m from the Estuary at R2,513.61/m². The lowest premium for this area occurred for houses within the 50 to 100m distance bin from the Estuary at R1,750.66/m². Lakeside had the largest average premium of all the surrounding areas (R2,182.47/m²), per house (R1,060,501.33) and for the entire area (R201,495,253.64). The very large positive slope for the area (y = 9,1756x + 3270,2), indicated that Zandvlei has a negative influence on property prices in the area.

Lakeside North

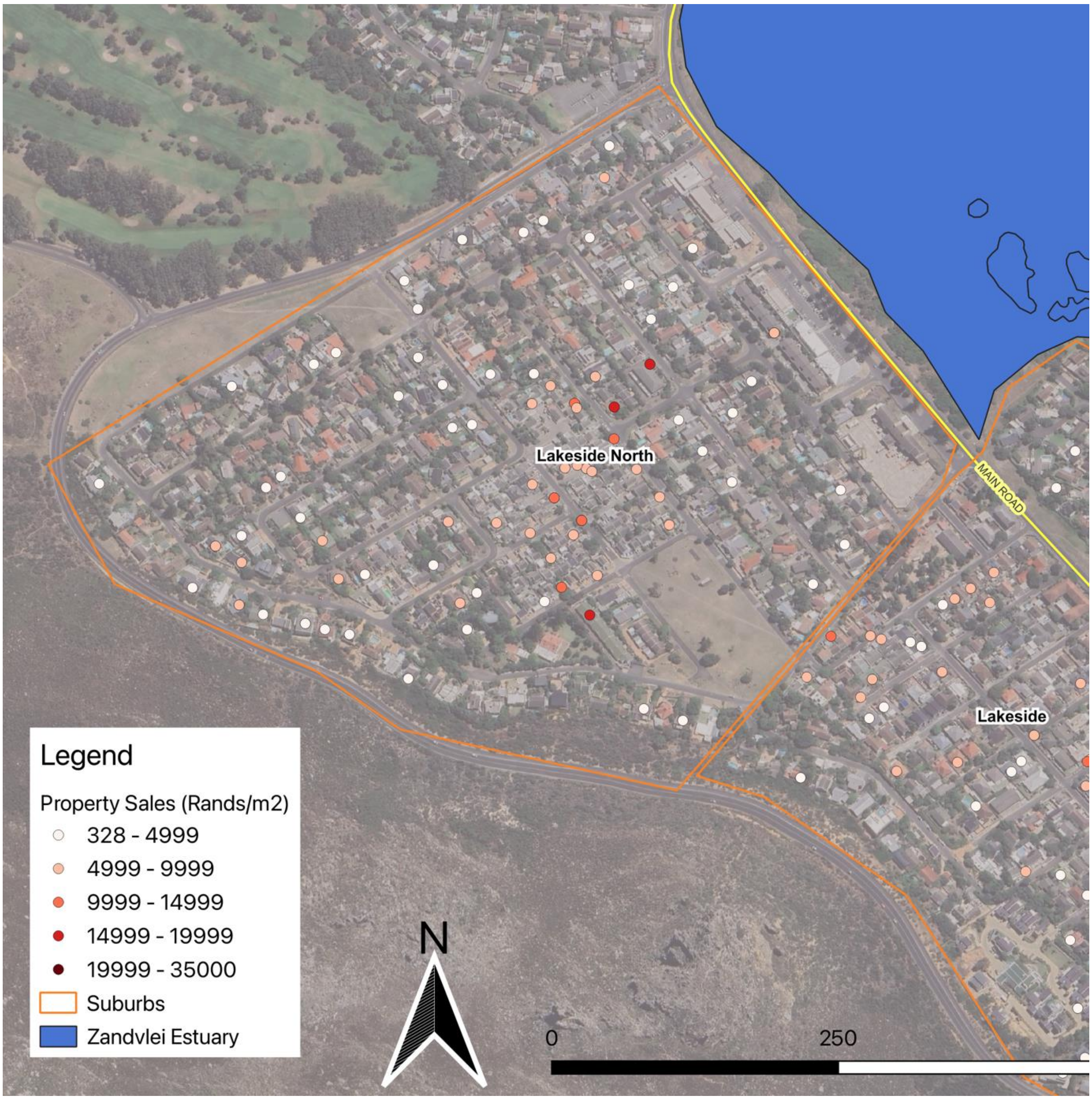

Figure 49 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Lakeside North area used in analyses (Source: QGIS 3.10.1)

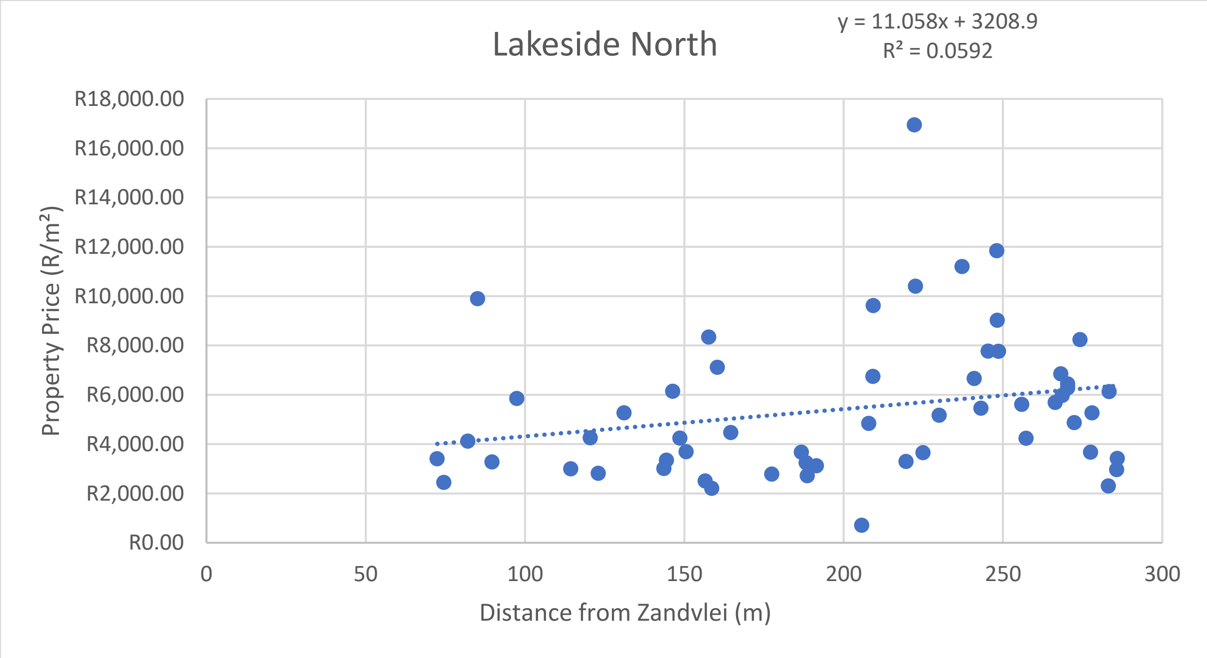

Figure 50 Average residential property sale prices (per m²) for Lakeside North for the duration of the study period (2014 – 2018) (y = 11,058x + 3208,9)

Lakeside North had the second-largest average house price of R2,070,766.59 of the six property areas. No houses were present within 50m of the Estuary. Lakeside North had the largest property values (per m^2) associated with the presence of the ZENR for houses within 150m and 200m at R1,714.08. Lakeside North had a large positive slope which would indicate a negative influence on the ZENR, however, the influence of the mountain slope and subsequent views in increasing property prices is also illustrated as well as that this area is cut off from the ZENR by a large road which removes any benefit from proximity to the ZENR.

Marina da Gama

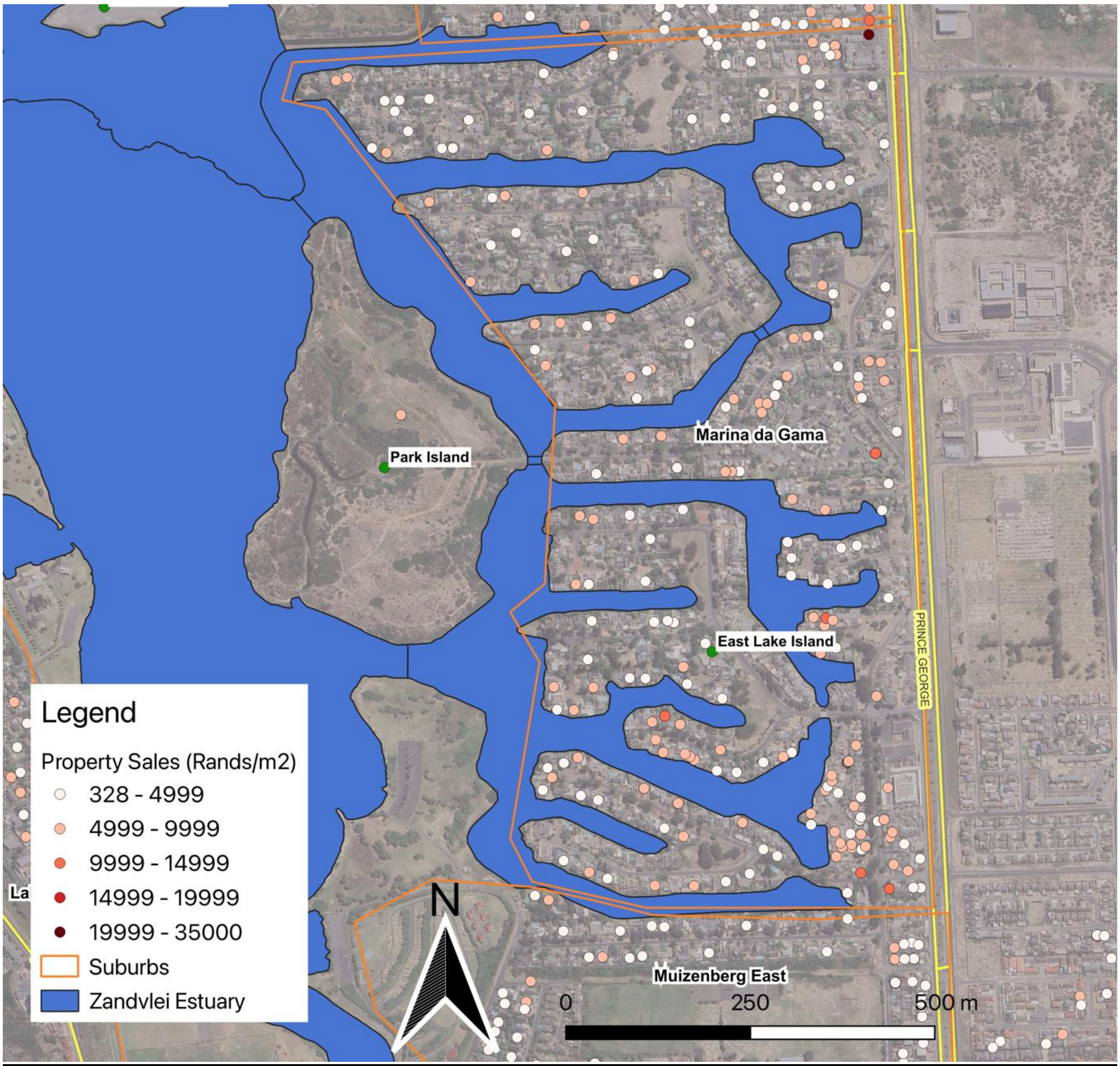

Figure 51 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Marina da Gama area used in analyses (Source: QGIS 3.10.1)

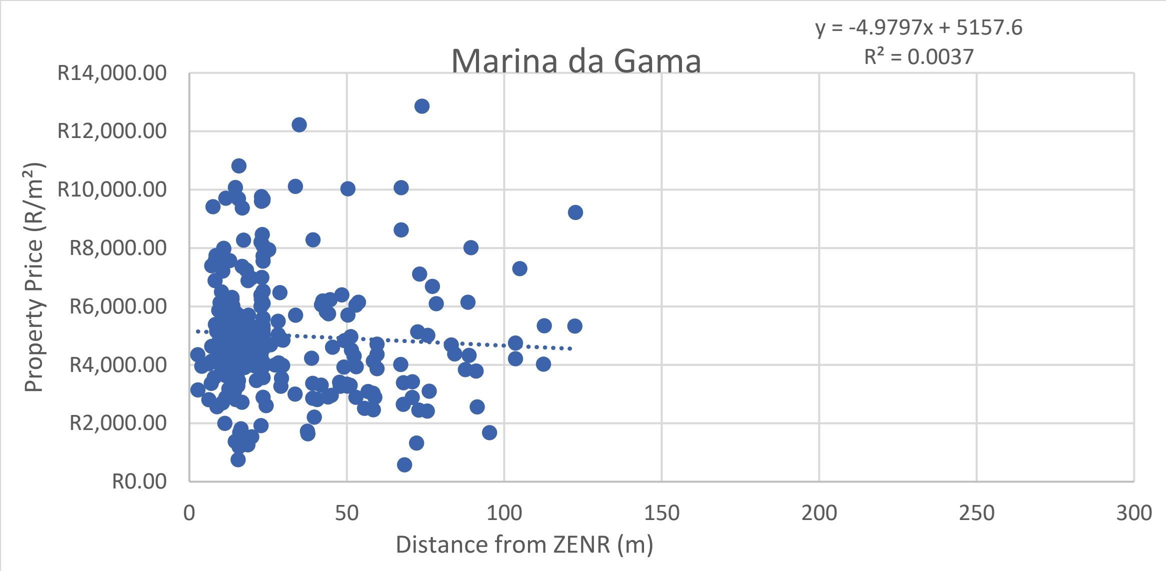

Figure 52 Average residential property sale prices (per m²) for Marina da Gama between 2014 and 2018. (y = -4,9797x + 5157,6).

Marina da Gama had the greatest number of houses sold (260) during the study period. There was no value attributable to the presence of Zandvlei for houses within 50 m – 100 m as well as those within a 200 m and 250 m distance from the Estuary. Marina da Gama had an overall negative premium (discount) associated with the presence of Zandvlei which was -R49,780,896.39. However, there was an overall negative coefficient (y = **-4,9797**x + 5157,6) for the area, indicating a positive correlation between property prices with proximity to the ZENR.

Marina da Gama (North)

Figure 53 Map illustrating the locations of properties sold within the 5-year study period (2014 – 2018) in the Marina da Gama (North) area used in analyses (Source: QGIS 3.10.1)

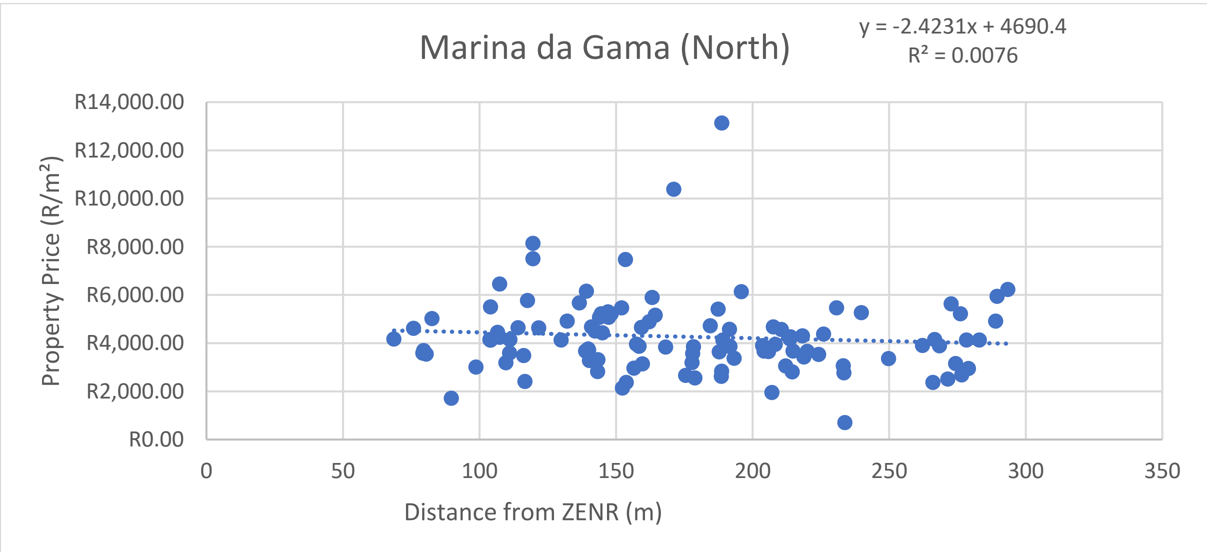

Figure 54 Average residential property sale prices (per m²) for Marina North between 2014 and 2018. (y = -2,4231x + 4690,4)

The area North of Marina da Gama had no houses within 50m of the vlei, therefore there was no value attributable to the presence of the estuary within this suburb. This area had an overall negative premium (discount) of -R39,956. However, the negative slope coefficient indicated a positive correlation between property prices and proximity to the ZENR.

4.4 Discussion

Assessing the aesthetic value of ecosystem services through proxy property prices is a prominent strategy within environmental economics. This method involves examining real estate prices to indirectly gauge the value individuals place on an ecosystem's aesthetic benefits. Since quantifying aesthetic value directly is complex, using proxy property prices offers a means to infer this value from people's willingness to invest in properties with desirable natural attributes. The prevalent approach in this realm is the hedonic pricing method, which scrutinizes the correlation between property prices and features like scenic views, water bodies, green spaces, and biodiversity. By comparing property prices for locations with differing natural characteristics, researchers can deduce the premium individuals are willing to pay for aesthetic amenities(Morancho, 2003; Ma, 2010; Rosen, 1974; Lansford et al., 1995). However, this approach has its constraints, as property prices are influenced by multiple factors aside from aesthetics, necessitating meticulous statistical analysis. Cultural variations also impact aesthetic preferences, and these complexities emphasize the need to integrate proxy property prices with other valuation techniques for a comprehensive understanding of ecosystem service aesthetics. Ultimately, this approach holds significance for policy-making in land use, conservation, and economic valuation of ecosystem services (Brander and Koetse, 2011; Mazzotta et al., 2014; van Zyl and Leiman, 2002).

Previous studies on the housing market have mainly focused on general parameters such as location, size and view and have largely ignored the influence of aesthetics and environmental proximity on house prices. Since the MEA (Millenium Ecosystem Assessment, 2003), the number of studies on the relationship between biodiversity and ecosystem services has increased although most have largely focused on provisioning or regulating services, leaving little understanding of the socio-cultural values that are also essential to human well-being. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework has addressed this gap by defining the concept of “nature’s contribution to people", which includes both material and non-material links between nature and people such as cultural services (Tribot et al., 2018).

The study conducted by Thompson *et al*. (1999), which developed a model to assess the impact of forest conditions on property values in the Lake Tahoe Basin of California, has parallels with the current research on the Zandvlei Estuary System (ZES). Thompson *et al*. examined how tree stand density and health indices, in conjunction with conventional property characteristics like location, house size, and lot size, influenced property values. Their findings suggested that forest density and health factors contributed to property values by 5% and 20%, respectively. While the studies differ in geographical context and the natural asset under consideration (forests vs. estuaries), they both underline the importance of natural elements in determining property values. In the case of the ZES, the results demonstrate that the estuary contributes significantly to property values, though direct percentage comparisons may not apply due to contextual differences. Nonetheless, both studies emphasize the role of environmental factors alongside traditional property features in property valuation.

Cetintahra *et al*. (2014) found that various aesthetic factors, such as pleasantness, coherence, excitement, and complexity, played a significant role in determining property prices. Specifically, they observed that excitement, coherence, and pleasantness influenced estimated sale prices, while complexity, arousal, coherence, and pleasantness were factors impacting estimated rental prices. This research aligns with the current study on the ZES as it emphasizes the importance of aesthetics in the valuation of properties. The ZES, being a natural asset, likely enhances the aesthetic appeal of the surrounding properties due to its pleasant and exciting features. Understanding how aesthetics influence property values, as demonstrated by Cetintahra *et al*. (2014) can provide insights into the premium associated with the ZES and its significance in the local property market.

In this investigation, the relationship between property prices per square meter and their proximity to the nearby Zandlvei Estuary Nature Reserve (ZENR) was examined using a linear regression model. The regression equation derived from the analysis is represented as follows: "Price per Square Meter = -4.4908 * Distance + 5140.4," where "Price per Square Meter" signifies the property sales price per square meter, and "Distance" corresponds to the distance in meters of the property from the Zandlvei Estuary Nature Reserve. The coefficient for "Distance" (-4.4908) was negative, implying that, on average, as properties are situated further away from the Zandlvei Estuary Nature Reserve, the price per square meter tends to decrease by approximately R4.49 for each additional unit (meter) of distance. While this coefficient underscores the trend that homebuyers are willing to pay less per square meter for properties at greater distances from the Zandlvei Estuary Nature Reserve, the overall explanatory power of the regression model is limited, as indicated by the modest R-squared value of 0.011. This suggests that while there is a statistically significant relationship between distance and price per square meter, other unaccounted-for factors likely play a substantial role in influencing property prices in this context.

Overall, the presence of the ZES had a positive correlation with the housing market that surrounds it which could have been influenced by areas nearby that provide enhanced views and access to other amenities. The total premiums associated with the presence of the ZES for the 6 surrounding areas were calculated at R174.3 million, which is more than double that found by van Zyl and Leiman, 2002) of R76.7 million. Considering the studies are more than 20 years apart, a marked increase in value is to be expected with the rise in inflation. This large positive influence of the ZES on the surrounding property market indicated the value that the ZES has in providing aesthetics for the local property owners.

When assessing the premium values associated with estuaries, it's essential to account for the impact of inflation over time. To make a fair comparison, premium values reported by Cooper *et al*. (2003) for the Berg, Breede, Keiskamma, and Knysna Estuaries were adjusted to today's monetary terms, using a conservative assumption of a 5% annual inflation rate over the past two decades. Despite the effects of inflation, the results still indicate a significantly higher total premium for the Zandvlei Estuary System (ZES), amounting to R174.3 million. When compared to the inflation-adjusted values for the Berg (R31.05 million), Breede

(R129.38 million), Keiskamma (R2.61 million), and Knysna (R2.46 billion) Estuaries, it's evident that the ZES continues to have a substantial and enduring positive impact on the local property market. This finding emphasizes the economic value the ZES holds for the surrounding area, even when accounting for inflation, and highlights its significance in the community.

Turpie *et al*.'s (2003) study on the Knysna Estuary reported a similar premium to that of Cooper *et al*. (2003) of up to R2 billion, which, when adjusted for inflation, would translate to a considerably higher amount today and far greater than the finding of this study for the ZES. Furthermore, Turpie *et al*.'s (2006) study on the Kromme Estuary revealed a premium of R578 million, demonstrating its substantial positive impact on the local property market. In contrast, Turpie *et al*.'s (2009) research on the East Kleinemonde Estuary estimated a total value of R133 million, which, when adjusted for inflation, remains significant but lower than that of the ZES. These comparisons emphasize the varying economic importance of different estuaries, with Knysna ranking highest, followed by Kromme, Zandvlei, and East Kleinemonde. This suggests that the Knysna Estuary had a considerably higher premium associated with it in terms of property values. It's important to emphasize that these estuaries are in different locations, and various factors may contribute to the differences in premium values. However, this comparison highlights the distinct economic importance of each estuary in its respective local property market.

Muizenberg West

Muizenberg borders the southern and south-eastern parts of the Estuary. Van Zyl and Leiman, (2002) noted that estate agents identified that property prices were affected by the presence of the ZES similarly to those within Lakeside. Their results suggested that buyers paid 7% – 12% more than the mean market price for the area for properties within the first row of houses bordering the estuary, which decreased to 3% for the second to the fifth rows of the area. They suggested that this was due to the similar views and recreational opportunities from the landscaped park areas at the ZENR in these two suburbs (van Zyl and Leiman, 2002). Within this study, it was found that property buyers paid premiums associated with the presence of ZENR almost double that found by van Zyl and Leiman, (2002) within 50m of the Estuary. As found by van Zyl and Leiman, (2002), this study showed the premium dropped by half, to 12% for properties between 50-100m and 0% for those within 100-150m from the Estuary.

Muizenberg had the smallest average property size (386m²), the largest average property price per m² (R8,161.91) and the largest average house price (R2,132,380.25) out of the six areas. The increase in property prices per m² found with smaller properties was likely due to the larger proportion of building/house on the property (Colwell and Munneke, 1997). The large property prices and associated smaller sizes may also be influenced by the location and proximity to the Muizenberg beachfront. Properties located closest to the beach and nearer the mountain slope (West) were of the highest value, whereas properties closest to Zandvlei in the North and therefore further away from the beachfront were lower in value. This was further illustrated as the average property price (per m²) increased dramatically with distance from the ZENR. Consequently, both positive and negative covariate drivers of values must be considered in a manner that may influence the correlation between value and the vlei.

A study conducted by Colwell and Munneke (1997) offers valuable insights in this regard. They investigated the recognition of nonlinear land prices and their impact on the measurement of land price decline rates with distance from urban centres. Their hypothesis, centred around the concavity of parcel prices and their implications, reflects the assumption above that property characteristics and their influence on price per square meter. By empirically testing the effects of concavity on price decline rates, Colwell and Munneke highlighted the significance of parcel sizes and their association with price trends in that smaller properties exhibit an increase in property prices per square meter due to a larger proportion of building/house on the property (Colwell and Munneke, 1997).

The low premium paid for houses within 100 m – 150 m from the ZENR was likely due to buyers within this range having limited access to either the beachfront or the ZENR. The high premium occurring within houses 150 m – 200 m from the Estuary was likely due to the houses on the North-Western section of this area which were located on the mountain slope and therefore had better views of the vlei and surrounding landscape. The large negative correlation between property prices and distance toward the ZENR could be affected by the presence of the Main Road and associated traffic and noise, Muizenberg train station and the railway line and the associated noise disturbance, and safety issues.

Muizenberg East

Regardless of the low property premiums and overall prices for this area, there was an overall positive correlation between property prices and distance toward the ZENR. The low overall purchase price and premiums paid for houses within 100 m of the ZENR coupled with the lowest overall premiums per m² per house and for the entire area within Muizenberg East was likely due to this area being the furthest away from attractions such as the mountain view slopes, the main beachfront hub and the main water body of the vlei. This area is also bordered by a major highway to the east (Prince George's Drive) which can be associated with noise pollution and traffic. There is extensive research on how housing prices can be affected by the proximity of major highways, which are often associated with noise pollution and increased traffic. This phenomenon is well-studied in the field of real estate economics and urban planning (Boarnet and Chalermpong, 2001; Chandra and Thompson, 2000; Karas, 2015; Cervero et al., 2009).

Lakeside

Lakeside had the largest average property size (486m²) as well as the largest premiums for houses within 50m from the Estuary (R2,513.61/m²) and the entire area (R2,182.47/m²) out of the six areas. Property agents in the study by Van Zyl and Leiman, (2002) were positive about the Estuary's influence on the property prices between the main water body and the railway line. The same positive influence was noted due to the large increase in property prices with distance toward the ZENR. The prices decreased nearer the railway line at 200-250m but then increased dramatically thereafter due to the higher altitude on the mountain slope and the enhanced views of the vlei and surrounding landscape.

As with Muizenberg West, van Zyl and Leiman, (2002) estimated the premium for the first row of houses facing onto the landscaped areas on the Estuary's shores between 7% - 12%. They suggested that this premium was due to the view and sense of open space as well as recreational access. Some estate agents interviewed within their study felt that the houses overlooking the picnic facilities (to the south of the Zandvlei sports club) would experience lower premiums due to the noise levels and increased traffic in this area over weekends. Recreational uses of the vlei, therefore, conflicted with values that could be derived by residents in this area and therefore lowered the premiums (van Zyl and Leiman, 2002). The premium for houses within 50 m of Zandvlei accounted for almost 50% of the house price. Although this may seem like a large proportion, there is an initial decline in house prices with distance from the Estuary as explained above. Also, almost 50% of the residents alongside the Estuary in Lakeside paid no premium due to the disturbances associated with picnicking. To account for this, Van Zyl and Leiman, (2002) halved the total premium for this row which would have been less than 23% in this case. This illustrates the need for extensive interviews with local estate agents as the hedonic regression analysis does not directly account for such influencing factors.

Van Zyl and Leiman, (2002) found that houses from the second row towards the railway line experienced less than 3% premiums due to decreased recreational access to the ZENR. Thereafter (from the railway line and beyond) no premiums were experienced due to the presence of the Estuary. A similar trend was noted within this study as houses within 50 m from the Estuary were more expensive as they experienced superior views and access to recreation than those further away.

Lakeside North

Security is one of the most important considering factors for property buyers in this area. Estate agents have difficulty in selling properties that border the open unmanaged areas along the Northern wetland section of Zandvlei. Buyers believe that criminals could seek refuge and gain access through the vlei. On the other hand, properties bordering the fenced-off Westlake Golf Course were more expensive than those bordering the unmanaged open space (van Zyl and Leiman, 2002).

The influence of the Westlake Golf Course was apparent by the large premiums paid nearest the Golf Course. Properties closer to Westlake Golf Course were overall more expensive than those nearby as well as those bordering Zandvlei. Increasing security on the Zandvlei Nature Reserve border may serve to increase surrounding property prices.

The large purchase price within Lakeside North compared to other areas surrounding Zandvlei is likely due to many houses within this area being located on the Muizenberg mountain slopes and therefore obtaining better scenic views and the surrounding landscape.

Lakeside North had no properties within 50m of the waterbody, due to the presence of the previously unmanaged wetland area in the northern section which has since been proclaimed as part of the Greater Zandvlei Nature Reserve. Considering that Main Road, which runs between this residential area and the reserve, therefore reduces the ease of access to the ZENR for residents, the influence of the ZENR on the property market of Lakeside could be non-existent.

Marina da Gama (on the water)

The Marina da Gama housing development was constructed with access to the ZENR as the unique selling point. As a result of the high demand for housing and the novel concept of a marina in South Africa during the time of its development in the 1970s (Jackson et al., 2010), this area had the greatest number of houses out of the six areas.

The highest premiums were paid for Westward-facing houses which had uninterrupted views of the water and mountain slopes. South-facing houses received far lower premiums due to the lack of direct sunlight. This area also had an overall negative premium (discount) associated with the distance of Zandvlei which may be due to the larger discounts associated with houses located off the water than those on the water's edge, of which there were relatively few. This highlights the benefit of incorporating expert opinion within a hedonic analysis as the analysis does not specify at which point the dependent variable (distance from the vlei) no longer influences the independent (property price) and therefore whether the discounts within the areas further away are from other factors nearby such as the M5 highway or disturbances from picnic sites to the South.

Marina da Gama (North)

There were no houses present within 50m of the Estuary within this area, therefore zero premiums were paid for this variable. The overall negative premium (discount) for this area could have been caused by the location of the M5 highway that borders along the East creating noise pollution and traffic, the informal/low-income suburbs of Steenberg and Capricorn, that border to the North and the potential of associated crime. A small but positive correlation was noted for proximity to the ZENR within the surrounding property market of this area which may be a result of distance from the disturbing areas to the East.

In conclusion, the assessment of the aesthetic value of the Zandvlei Estuary System (ZES) through the lens of property prices has provided valuable insights into the complex relationship between natural assets and the local housing market. The utilization of proxy property prices, particularly through the hedonic pricing method, has proven useful in uncovering the premium that individuals are willing to pay for properties in proximity to the estuary. While this approach is not without its limitations, as it must contend with multiple influencing factors and cultural variations, it offers a unique perspective on the economic value of ecosystem service aesthetics.

Comparative analyses with other estuaries and studies from different geographic locations emphasize the distinctive contributions of each natural asset to local property markets. The ZES stands out for its enduring positive impact, even when adjusted for inflation, underlining its significance in the community. This long-lasting appeal is a testament to the aesthetic and environmental qualities it offers to property owners, which extend beyond provisioning and regulating services.

Moreover, the influence of property characteristics, such as size, location, and views, as well as factors like proximity to main roads and recreational facilities, has become evident in this investigation. The intricate relationship between these variables and property values is a complex one, influenced by considerations of safety, noise pollution, and scenic views. The study also highlights the importance of expert opinions and in-depth interviews with local estate agents to capture nuances that may not be apparent through statistical analyses alone.

In summary, the Zandvlei Estuary System serves as a model of the multifaceted nature of ecosystem services and the varied influences on property values. Its positive correlation with the housing market reflects not only the economic worth of aesthetics but also the importance of safeguarding and managing such natural assets for the well-being of the community. Understanding the intricate interplay between aesthetics, property values, and environmental factors is paramount in shaping informed policies for land use, conservation, and economic valuation of ecosystem services in the region. This research contributes to a deeper understanding of the complex relationship between aesthetics and property values, shedding light on the rich tapestry of factors that shape the local housing market.

Limitations and Further Research

Hedonic regression analysis is a valuable tool for assessing the relationship between property prices and various attributes, yet it is not without its limitations. Firstly, omitted variables can pose a significant challenge, as it is often impossible to account for all factors influencing property prices, potentially resulting in incomplete model specifications. Endogeneity, another limitation, arises when the independent variables are correlated with the error term, potentially leading to biased coefficient estimates. Measurement errors in variables, such as property characteristics and amenity distances, can introduce imprecision into the model. Furthermore, sample selection bias may occur if the dataset is not fully representative, skewing the results. Temporal changes in property prices, spatial autocorrelation among neighbouring properties, heteroscedasticity in variable variability, and issues related to functional form selection all add complexity to hedonic regression analysis. Causality is challenging to establish, as hedonic regression identifies associations rather than causation. Lastly, the generalizability of findings is context-dependent and may not extend easily to different regions, property types, or timeframes. Acknowledging and addressing these limitations is crucial for conducting robust real estate analyses.

As previously mentioned, the hedonic pricing method used here includes all influencing factors within the 200 m distance from the ZES as opposed to determining where the estuary stops having an effect within the surrounding areas like the 100 m mark within the Marina da Gama complex stated by estate agents in van Zyl (2002). This illustrates the need for estate agent/expert opinion within this study although there is bias in that as well as many studies show expert estimates can far outweigh that of the hedonic pricing method (Borchers and Duke, 2012; Liebelt et al., 2019; Ma and Swinton, 2011), hence incorporating both analyses would be ideal for future studies.

CHAPTER 5: CONCLUSION

Values associated with the Zandvlei Estuary can be categorized into two main types: use values and non-use values. Use values refer to the direct benefits that people derive from engaging with the estuary, such as consumptive activities like fishing or boating, and non-consumptive activities like bird watching or simply enjoying the scenery. Non-use values, on the other hand, refer to the importance that people place on the estuary's existence, regardless of direct use, including its ecological health, aesthetic appeal, and cultural significance. Both types of values are influenced by human activities, which can lead to negative impacts like unsustainable resource extraction, pollution, habitat destruction, and the introduction of invasive species. These impacts, in turn, affect the estuary's ability to provide benefits in the future. Therefore, effective management of ecosystems requires balancing these values with their associated impacts. Valuing the goods and services provided by the estuary offers a clearer understanding of its overall worth, both in physical and monetary terms. Such ecosystem service assessments are critical for informing Ecosystem-Based Management (EBM) and guiding policymakers to make decisions that take into account both the needs of the community and the ecological health of the estuary, ensuring its long-term conservation and rehabilitation. Regardless of the abundant goods and services that they supply, estuary systems such as Zandvlei remain undervalued due to a lack of funding, research and understanding by local authorities and government as identified (Turpie and Clark, 2007). Estuaries consequently continue to be degraded due to anthropogenic threats of encroachment by urbanisation, pollution from bacterial, nutrient, and chemical inputs and unsustainable extraction including poaching.

The Zandlvei Estuary Nature Reserve (ZENR) confronts mounting challenges as a result of escalating urban expansion in its vicinity. This expansion brings forth a series of interconnected issues, including heightened nutrient and pollutant loads stemming from aging infrastructure, power disruptions (load shedding), canalization efforts, artificial water level fluctuations, expanded agricultural activities within the catchment area that escalate sediment and nutrient inflows, and a proliferation of infrastructure developments surrounding the vlei, contributing significantly to effluent and litter inputs into the estuary. These cumulative pressures jeopardize the Estuary's capacity to provide crucial ecosystem services, such as maintaining water quality suitable for recreational activities and fostering aesthetic values that benefit the local community and property market.

It's worth noting that the Zandlvei Estuary Nature Reserve has seen limited valuation studies, with none conducted within the past 13 years. Consequently, there exists a pressing need for updated and comprehensive information concerning the environmental, social, and economic value of the Estuary. Such information is indispensable for implementing effective EBM strategies and making well-informed decisions that can address the multifaceted challenges and secure the long-term health and vitality of this vital natural resource.

This study had several objectives:

a) To better understand the use-value of the ZENR as a recreation site.

Estuaries provide many recreational opportunities that are known to generate economic revenue, improve human well-being and encourage public support for conservation practices. It has been well-documented that recreation is one of the most valuable services supplied by these systems. However, previous studies are limited to valuation methods primarily focused on the monetary benefit of recreation and there is a need to understand the importance of social well-being and livelihood as well as visitor perceptions and attitudes towards management for government policy making and budgeting. Therefore, a more holistic EBM approach is needed to broaden the understanding of an ecosystem's value to society.

The ZENR was highly valued among the 1078 recreational user respondents for the opportunities it provides. This was reflected in their expenditure of over 3.1 million rands within the one-year study period (2018-2019). It was also reflected by the unanimous importance of the users' social and cultural well-being across all activity groups. It was also considered highly valuable throughout the year as it provided both summer activities such as running, walking and picnicking, as well as winter activities such as canoeing and yachting (when water levels are highest).

Decisions on the relative value of activities in the management of the ZENR are complex as activities provide different values in both time and monetary expense. Comparisons of fishing, yachting and canoeing expenditure values are important for increasing economic growth through their high expenditure. Users such as meditators and bird watchers that invest more of their time value require consideration in management actions as they can provide valuable input and willingness to assist with management activities where necessary.

It is important to consider the concerns of the relevant stakeholders to encourage and facilitate recreation within urban-green areas such as the ZENR as well as the conservation thereof. Zandvlei's recreational value is at risk if the stakeholder concerns for litter, mouth management, safety, water quality and pollution, education and awareness become mismanaged or poorly communicated. It is recommended that the ZENR management place a higher priority on such concerns by recreational users, especially litter and pollution.

b) To better understand the influence of the ZES on water filtration and nutrient assimilation.

Peri-urban wetlands and estuaries have been used as natural water treatment facilities for decades as they perform valuable filtration functions for the polluted and nutrient-rich waters that flow into them. This results in improving recreation opportunities, and aesthetic values for the surrounding property market as well as the habitats of many species (Barbier et al., 2011; Barbier et al., 1996).

Including water quality assessments within urban planning enables management to better understand and deal with the risks associated with poor water quality. The value of these water filtration and dilution services provided by the ZES was illustrated by the large decline in *E. coli* shortly after several major sewage spills had occurred in 2013 and 2018. Parts of the estuary such as the outlets and the main water body have shown improvement over the 10 years, likely as a result of the changes to the mouth management plan in those years, allowing for a more natural functioning of the system.

However, the significant increase in the long-term concentrations of *E. coli*, Nitrogen (Ammonia, Total Nitrogen) and Total Phosphorus within the inlets indicates that the health of the estuary and therefore its ability to provide clean/safe water for recreation is at risk. The large sewage spills over the years as a result of the poorly maintained pump stations and infrastructure (sewer lines) are the causes at hand. These issues will only become more frequent and more severe as the demands of the increasing urban development which surrounds the estuary continue alongside the lack of improved infrastructure and its maintenance. Such an outcome could lead to a chronic input of nutrients as the estuary's capacity to filter and dilute such nutrients becomes constrained. Considering the potential economic, social and environmental impacts that could arise should these biological and chemical concentrations continue to increase, prioritising the rehabilitation and conservation of the estuary and reducing the harmful inputs into the system is vital for mitigating these risks. The management concerns expressed by recreational users in the first section of this study indicate that users are aware of these risks and the consequences that will impact their activities. Improving the management of litter and nutrient inputs by educating the surrounding communities (residential, agricultural and industrial) and recreational users about the effects of contaminants and litter, protecting the sewer lines and pump stations surrounding the estuary from vandalism and weathering to prevent sewage spills, improving the mouth management plan to allow for more natural inputs (fresh and saltwater), whilst also catering for the recreational activities would not only ease recreational user concerns but also improve the ecological functioning of the system and assist in mitigating a chronic situation from occurring.

c) To better understand the influence of the ZENR on the surrounding property market prices as a proxy for its aesthetic value.

With the increasing demand for development within urban spaces often superseding the value of open green spaces, the need to understand the extent of the value of such green spaces within all sectors (society, economy and the environment) becomes increasingly critical for their longevity. Previous studies on the housing market have mainly focused on general parameters such as location, size and view and have largely ignored the influence of environmental aesthetics on house prices.

Using a hedonic regression analyses, we found that the ZENR had a positive influence on the local property market as reflected by the positive correlation between surrounding property prices with proximity to the ZES within three of the six surrounding areas investigated. It was also reflected by the total property value associated with the presence of the ZES which was estimated at R174,361,835.56 and the average value per house attributable to the presence of the Nature Reserve within 300m of 7.7% (R147 517.80).

Previous studies (van Zyl and Leiman, 2002; Standish and van Zyl, 2007) suggest that this value may not be influenced by the integrity of the open space itself but by the quality of its management and the public's perception of the managements' role for their concerns. Such perceptions of local recreational users investigated in previous sections of this study would suggest that the value of properties surrounding the ZENR can be enhanced by improving the state of litter and pollution, water quality, safety and security within the ZENR.

The hedonic analysis method can be limited in its reflection of the local effects of surrounding green spaces on the housing market as it does not reflect such broader influences and is limited to the data available. This illustrates the need for in-depth knowledge by expert opinions and investigation into the concerns of the local public to maximise the value of the surrounding property market. Considering the hedonic method does not account for the range within which a green open space has an effect, the use of expert analysis would be further beneficial in ascertaining this information and enhancing the analysis.

In conclusion, this study investigated the multifaceted values of the Zandvlei Estuary Nature Reserve (ZENR) and the pivotal role it plays in the broader context of ecosystem management and urban development. The exploration of various values, encompassing resource uses, aesthetic contributions, water filtration, and property market dynamics, has illustrated the complex relationships that highlight the importance of balanced ecosystem stewardship.

Ecosystem service valuations have emerged as a crucial tool in understanding the worth of these natural assets, offering quantifiable measures that bring to light their significance both in physical and monetized terms. By assessing the diverse values of the ZENR, the study has provided insight for more informed decision-making that caters to the needs of the community and stakeholders while safeguarding the ecological integrity of the system. In an era where urbanization encroaches upon green spaces, these valuations provide a compelling case for the preservation and management of vital natural resources.

This research contributes to a deeper appreciation of the multifaceted values of the Zandvlei Estuary Nature Reserve and the urgent need to safeguard and manage these natural assets for the well-being of the community, the vibrancy of the property market, and the ecological health of the region. It serves as a call to recognize and prioritize these critical ecosystems within the landscape of urban development, ensuring a harmonious coexistence between human settlements and the natural world.

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