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Evaluation of hourly physico-chemical data between 2012 and 2015 from two permanent probes on the Berg River Estuary, Western Cape, South Africa

by

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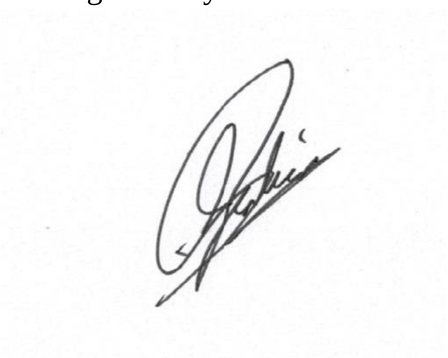
PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Water Resource Management, Department of Biochemistry, Genetics and Microbiology, Faculty of Natural & Agricultural Sciences, University of Pretoria, South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.



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Signed: **Dr Gerhard Cilliers**

Date: 28/10/2021

DECLARATION 1: PLAGIARISM

I, **Isiaka A Lawal** declare that the thesis/dissertation, which I hereby submit for the degree MSc in Water Resource Management at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution

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Signed: **Isiaka Ayobamidele Lawal**

Date: 28th October 2021

List of abbreviation and meaning

Abbreviations	Full name
LF	Low flow
HF	High flow
LF1	Low flow 2012/13 hydrological year (Spring 2012 / Summer 2013, October 2012 - March 2013)
HF1	High flow 2013 (Autumn 2013 / Winter 2013, April 2013 – September 2013)
LF2	Low flow 2013/14 (Spring 2013 / Summer 2014, October 2013 – March 2014)
HF2	High flow 2014 (Autumn 2014 / Winter 2014, April 2014 – September 2014)
LF3	Low flow 2014/15 (Spring 2014 / Summer 2015, October 2014 – March 2015)
B2	Site 2 on Berg River (Berg 2)
B4	Site 4 on Berg River (Berg 4)

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ABSTRACT

Climate change is affecting ecosystems all around the world, and estuaries are no exception. Because estuaries are rich in nature, it will be one of the most impacted elements by these climatic alterations, both in terms of structure and dynamics, with clear consequences for the estuary ecological health. This mini thesis aimed to study the effects of climate change on the Berg River estuary. The Berg River Estuary is a coastal outlet located on the West Coast of South Africa. Over three hydrological years (2012 to 2015), a multidisciplinary case study of the estuary was undertaken, monitoring the dynamic reactions of temperature, salinity, mean flow and sea level behaviour to long-term climatic variability patterns, at two sites (Berg 2 and Berg 4). Trends, patterns, and periodicity in natural cycles were identified using Microsoft Excel and SPSS. The data was categorised into two categories, High flow (HF) and low flow (LF). Data from temperature, salinity, mean flow, and estuarine water level were cross correlated as a probable driving mechanism for climatic changes. The data revealed that there was a significant change (increase) in temperature in the months of LF for the three hydrological years studied. Also, there was an increase in the temperature of estuary in the months of HF across the years. However, after statistical analysis, the increase in temperature was not deemed significant. Correlation analysis of mean flow and salinity data shows significant (95%) correlations. Also, there exist a significant (>95%) correlation (negative) between salinity and mean flow. This study identifies potential driving mechanisms of estuary perturbation and whilst causal mechanisms can only be proposed, these observations can form a baseline for future targeted modelling, monitoring and management. Lastly, some recommendations are made for the future monitoring and management of this estuary.

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CHAPTER 1

1 Introduction

According to Meire *et al.* (2005) "estuaries are dynamic ecosystems with the tidal influence generating many gradients and a large variety of habitats". Humans settlements have always been drawn towards estuaries, with big cities and even small villages around the world settling close to estuaries (Davis and Kidd, 2012), due to the benefits derived from them. These benefits range from many ecosystem services and various sub-habitats such as river and intertidal that provides fish and water, to water purification, opportunities for recreation, water for transportation, cultural services and flood and storm protection (Russi *et al.*, 2013; Boerema and Meire, 2017).

There are about 300 estuaries across the South African coastline and the effects of humans on these estuaries are known and well documented (Cilliers, 2017). Estuaries in South Africa are very important to our biodiversity resources and are some of the most productive ecosystems which has substantial socio-economic benefits such as commercial fisheries, tourism and industrial (Cooper *et al.*, 2003; Adams, 2012; Van Niekerk and Turpie, 2012b; Cilliers, 2017).

These benefits and that attract humans to estuaries have led to global anthropogenic degradation such systems, therefore, impacting negatively on their value and various ecosystem goods and services. This loss has affected the ecosystem operation associated with ecological structure, geomorphology and hydrodynamics. This can create problems like eutrophication, marsh reclamation and alteration in hydrologic regimes (Barbier *et al.*, 2011). It is important to note that estuaries are also affected by sea level rise and climate change.

Wolanski *et al.* (2019) reported that estuarine ecosystems globally have been badly disturbed because of climate change and also through activities from humans. The pattern of precipitation, sea temperature and atmospheric-oceanic conditions have been altered due to climate warming. Combined with the impacts of human activities on the river-basin, particularly construction of dam, overuse of fertilizers, discharge of sewage effluents, deforestation, water diversion, industrialization and urbanization have considerably worsened the estuarine environment and irreversibly degraded the healthy ecological condition of the estuary (Diaz and Rosenberg, 2008).

The health of estuaries is impacted if certain parameters change due to climate change. For example, change in river flow, turbidity, salinity, temperature, habitat availability and estuarine mouth condition can all affect the health of estuaries. The stress level of many organisms increases towards their range boundaries and alteration in the species distributions would occur if there were any significant changes in the environmental conditions. Increase in extreme weather, alongside with rise in level of sea could also lead to estuarine habitat loss (James *et al.*, 2013).

Temperature changes due to change in climate have been a major factor distorting the ecosystem of estuaries. An increase in sea temperature, due to global warming, could have effects on organisms living in the estuaries (Hare, 2011). Salinity regimes is another parameter that affects organisms in estuaries. Harrison and Whitfield (2006) found that salinity and temperature plays a notable role in the biogeography of fishes in South African estuaries. Elliott (2002) reported that changes in salinity and temperature affects the physiology of fish. This ultimately affects fish ability to occupy estuarine habitats and therefore distort species distribution on a larger scale. Rise in sea level is another factor that has been reported to affect estuaries health. Increase in sea level, may modify estuary's hydrogeomorphology, and may lead to the loss of essential estuarine habitat e.g., mangroves and salt marshes. This could affect fishes in the estuaries and will have implications for fisheries targeting estuary-associated species (Elliott, 2002; Clark, 2006).

In South Africa, the Department of Water and Sanitation (DWS) is the overseer of all water resources, as enshrined in the National Water Act (Act no 36 of 1998) (NWA)(NWA, 1998), therefore, it is in charge of managing this very limited resource. To effectively monitor and manage the estuaries in South Africa, DWS set up a National Estuarine Monitoring Programme in 2012 to monitor the health of all the estuaries in the country. Components of estuarine health sampled includes water quality and biological parameters. This involved the use of probes to take the temperature, salinity and water level of the estuaries on hourly or two hourly bases. The data from these monitoring programmes have been used for this study.

The Berg River Estuary on the West Coast of South Africa (*Figure 1*) is one of the most important estuaries in the country, because of its habitat's diversity and associated biodiversity (Clark and Ractliffe, 2007a). The main driver of this diversity of habitat includes temperature, salinity, and the level of inundation. The Berg River Estuary is located 130 km from west of Cape Town in South Africa and is considered to be one of the largest estuaries in the country, with a surface area of 61 km^2. It is also one of only three estuaries on the Atlantic seaboard that is permanently open. It has a rich habitat diversity making it an important estuary for conservation purpose. Several researchers have identified this estuary as an important bird area that is protected (Clark and Ractliffe, 2007a; Cilliers, 2017). A key national fishing harbour is also located at the mouth of the estuary.

Figure 1 Position of the Berg River estuary in the Western Cape.

Tidal oscillation is propagated upstream for a distance of 69 km, although the saline intrusion only extends to a distance of approximately 45 km from the mouth (DWA, 2011). The mouth is 200 m wide, but the channel becomes smaller and shallower further inland from the mouth. The average depth is between 3 and 5 m although deeper areas of up to 9 m do exist (James *et al.*, 2013). The total volume of this estuary is approximately 12 Mm^3. The catchment receives most of its precipitation in the winter.

The Berg River originates in the Jonkershoek Mountains and is 294 km long with a catchment area of 7715 km^2. The catchment is characterised by small to medium urban areas (Paarl, Wellington, Piketberg, Hopefield and Veldrif) and agricultural activities. There are four major dams namely Wemmershoek (storage capacity = 60 Mm^3), Voëlvlei (storage capacity = 170 Mm^3), Misverstand (storage capacity = 7.9 Mm^3) and Berg River Dam (storage capacity = 130 Mm^3). Various smaller dams are also present. Supplement Schemes divert water from the Dwars River to the Berg River Dam. The present day mean annual runoff (MAR) of the Berg River has been estimated to be around 520 Mm^3a^{-1}. This is approximately 46 % lower than under natural conditions (DWA, 2011).

In the current project, data collected from two sites on the Berg Estuary (*Figure 2*) was used to predict the effect of climate change of the estuary. One of the sites is situated at the mouth of the estuary, where the marine environment dominates, and the second site is situated approximately 40 km upstream where there is a stronger freshwater signal from the catchment.

1.1 Problem statement

Estuaries are particularly affected by the climate change impacts. Variations in hydrologic and climatic variables affect freshwater and marine systems, and this in turn impacting the health of estuaries. The DWS has been monitoring some variables including temperature, salinity and water level on various estuaries in South Africa since 2012. Up to now, there has not been a critical analysis of this data to predict the trend or effect of climate change on these estuaries. The Berg Estuary is one of most important estuaries in South Africa due to its diversity of habitats and associated biodiversity. There is a large amount of data available for three hydrological years (2012/13, 13/14; 14/15) for this estuary on an hourly or two hourly-basis. Therefore, this project analysed and investigate this data so as to understand the effects of climate change on Berg estuary for the past 3 years. The work also provides recommendations based on findings to the appropriate authorities.

1.2 Aim and objectives

The aim of the project was to analyse data from Berg River Estuary on the West Coast of South Africa for 3 hydrological years: 2012/13, 2013/14 and 14/15.

The objectives of the study were:

1. To determine if there were differences in temperature and salinity between the low flow and the high flow levels, and temperature and salinity between different hydrological years between 2012 and 2015 at each site.
2. To determine if there were difference between the low flow and the high flow in levels, temperature, and salinity for different hydrological years (2012 to 2015) between the two sites.
3. To determine if the available data set is enough to start evaluating the impact of climate change on the Berg River Estuary.
4. Make recommendations for further climate change monitoring using permanently deployed probes.

Chapter 2 of this thesis gives a review of South Africa estuaries and the effect of climate indicator (rainfall, temperature, salinity, see level and so on) on it. This will include of definition, types, distribution, and economic values of estuaries in South Africa. It will describe in detail the environments within an estuary which includes natural climate of estuaries, estuarine processes, and mixing processes within estuaries. This chapter thus contextualises the effect of climate change on estuaries globally and in South Africa.

Chapter 3 (Material and methodology) gives a detailed description of the sampling site (Berg River), sample plans, description of instrument used in collecting the data, the agencies that collected the data and statistical analysis tools used in the interpretation of the data.

Chapter 4 (Result) will include an analysis of data obtained from the sites. Data were analysed using Microsoft Excel 2018 and Statistical Package for the Social Sciences (SPSS) (Levesque, 2007)

Chapter 5 (Discussion) will give a detailed interpretation of the result, conclusion, and recommendation.

Finally, lists references (detailed) were provided.

CHAPTER 2

2 Literature Review

According to (Glamore *et al.*, 2016) estuaries are active systems that constantly adjust to changes. Estuaries are partially closed or permanently open coastal waters in which fresh water from upland catchments mixes with waters from the ocean. They can be linked to the ocean permanently or temporarily. They are affected by tides and are shielded from the oceanic storms, winds and waves by surrounding landforms (coastal floodplains, beach sand dunes and headlands). However, future climate changes can change the systems away from their present adaptability. Process understanding and scientific analysis is the only way to understand the possible future consequences for estuaries.

2.1 The Importance of South African Estuaries

Estuaries are home to unique communities of plants and animals that are specially adapted to life at the edge of the ocean. Therefore, estuaries are some of the most diverse and dynamic ecosystems in world containing a diversity of habitats. Examples are seagrass beds, tidal pools, river deltas, mangrove forests, oyster reefs, rocky shores, salt marshes and sandy areas, shallow open water, sandy beaches, swamps, fresh and salt water. The vegetation and flora that live on the edges and within estuaries serve as a habitat that are home to important terrestrial and aquatic species.

Furthermore, estuaries are a major ground for spawning, nursery, and feeding different animals. More than 83 % of South African coastal fish species complete their life cycle in estuaries (Lamberth and Turpie, 2003). Also, some biota like crabs depend on estuarine water throughout their life cycle, while migratory birds visit estuaries to feed and sleep. According to Borja and Dauer (2008), about half of the global population lives in coastal areas. In South Africa, the coastal areas are an important point of convergence for people due to the availability of economic activities which results in high population density. It is estimated that the nation’s coastal zone contributes 35% of the annual GDP (about R 57 billion) (DEA, 2014). Coastal zones experience environmental pressures due to urban development, activities that are catchment related such as water abstraction, water pollution as well as agricultural activities further affects the estuaries. In essence, estuaries are the final receiver for all perturbations that is catchment related, before it is discharged into the marine environment. In the last forty years, there has been a significant amount of pressure on these ecosystems due the anthropogenic activities mentioned above (DEA, 2014).

According to National Water Act (NWA) (Act no 36 of 1998), an estuary is defined as a "fully enclosed or partially enclosed body of water that is (a) open permanently or periodically to the sea (b) or that within which the seawater can be diluted to an extent that is measurable, with freshwater drained from land". There are estuaries that closes periodically - the effect of this is that back flooding will occur within the estuary, eventually causing wider extension of the estuary during an open phase and causing complication in their management. To mitigate this, Van Niekerk and Turpie (2012a) suggested the 5 metre contour line as the estuaries boundary (estuary functional zone, EFZ).

2.2 Types and Distribution of Estuaries in South Africa

Estuaries in South Africa have different ranges of size, and shape, from drowned rivers to large open embayments, small coastal lagoon systems and tidal deltas. Estuaries characteristics are affected by a variety of factors such as human activity, biota, geology, wave motion, tidal currents, sediment supply, tectonic environment, topography, climate, and sea level history. The physical properties of estuaries are the predominant reasons for large-scale patterns in their ecology, resulting from variation between estuaries as a result of the long-term effects of various dynamic processes.

According to the National Biodiversity Assessment (NBA), South Africa's 291 estuaries are classified into 46 types (Nel *et al.*, 2011). The 46 estuarine ecosystems is a modification of Whitfield (1992) classification system, which include only 5 types and are based on important physical features of estuaries. However, in 2018, NBA has further modified it (Van Niekerk *et al.*, 2019). This modification came has a result of some flaws in the 2011 NBA classification. The typology of estuaries developed by Whitfield (1992) has been mostly utilized to classify estuaries in the South Africa.

Unfortunately, Whitfield (1992) approach left out a huge number of minor estuaries and micro-outlets in its original classification. In addition, the strategy focused on functional types of estuaries and left out regional biogeography. Untraditional types of estuaries, like coastal lagoons with no stream or river, where just a modest freshwater signal from groundwater, were similarly underrepresented. Also, the approach largely ignored the small high-salt systems along the west coast, which is low in fish but important for birds and plants but focus more on fish-rich estuaries. The scheme classified a majority of (75%) of the estuaries as "temporarily open/closed systems", failing to differentiate between larger systems with more diverse and species-rich habitats and comparatively poorer small habitats. Finally, estuary types include a variety of river-dominated estuary types, from large sediment-rich catchments to clear, small catchments with very limited floating sand and black water systems were included.

All these limitations gave rise to the development of new estuaries classification in South African with an extended ecosystem-level scheme, which allows easy historical studies and evaluations.

Three steps were laid out for developing more inclusive classification scheme at the ecosystem level. The steps are:

- A formal biogeographical organization of South African estuaries that include regional biological reactions.
- Improvements of estuary types to include the wide variety of estuary types found in South Africa.
- Addition and organization of previously ignored "micro-system types".

In 2012 (Van Niekerk and Turpie) reported that EFZ cover 173 930 ha in South Africa, while Veldkornet *et al.* (2015) reported 186 887 ha that covered 304 estuaries/outlets. This implies that EFZ were underreported in the earlier work (Cilliers and Adams, 2016). Traditional South Africa's estuaries are divided into 3 biogeographical regions, which are: warm temperate, cool temperate and subtropical (Day, 1981; Whitfield, 1992, 1998; Whitfield and Baliwe, 2013). However, due to the tropical distribution record of species in the northern estuaries (uMgobezeleni and Kosi), the tropical transition zone was carved out of subtropical region in South Africa north-eastern area. Both systems differ in size, function and type, but are unique clear estuaries in a small coastal area of the South African where the high latitudes of coral reefs in the western Indian Ocean are located (Schleyer, 1981).

Therefore, the newly classified tropical region runs from Kosi to uMgobezeleni, the subtropical region is located on the of South Africa eastern coast and covers from St Lucia in KwaZulu-Natal to Eastern Cape Mbashe Estuary. The warm-temparate stretch from Eastern Cape (Mandwana Estuary) to Ratel Estuary close to Cape Agulhas, while the cool-temperate runs from Uilkraals Estuary to the coast of Northern Cape (Orange Esturay) (Emanuel *et al.*, 1992; Van Niekerk *et al.*, 2019).

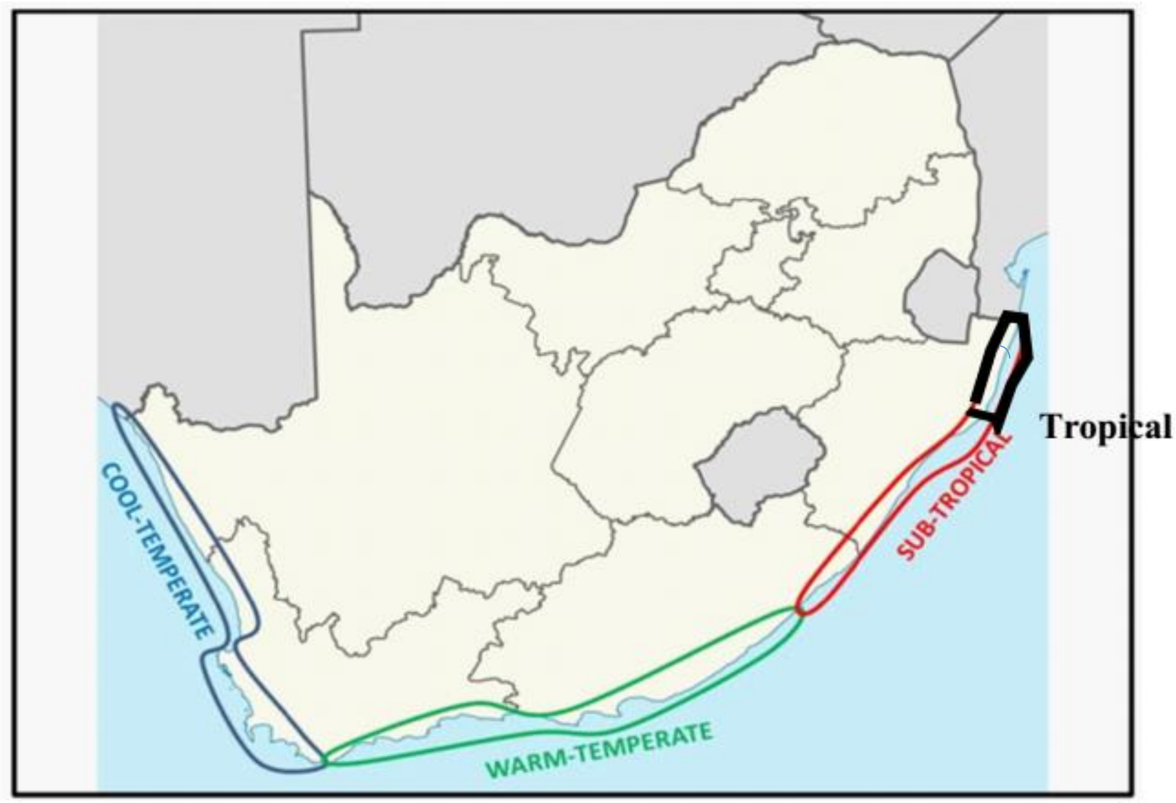

Figure 2: The 4 South African biogeographical regions (Van Niekerk *et al.*, 2019)

Meanwhile, warm temperate region extends from the Mbashe Estuary, over the southern coast of South Africa to the Ratels Estuary *(Figure 2*). There are a lot of estuaries in this area, which includes the Knysna system, Swartkops, and Breede Estuary which is one of the largest estuaries in South Africa. These estuaries are known for their activities such as tourism (Wilderness lakes, Breede and Knysna), industrial activities in Buffalo and Swartkops estuaries, agricultural activities in Kromme, Gamtoos and Gourits estuaries. Also, harbour activities can be found on the Coega and Buffalo estuaries) (Cilliers, 2017). These activities further lead to sprawl of urban in this area. The NFEPA has identified 52 estuaries in this region. According to Nel et al. (2011), 52 estuaries have status in this region (Nel *et al.*, 2011).

Furthermore, cold temperate region starts from the Ratels Estuary straight down to the mouth of Orange River but has only 15 estuaries according to according to Nel et al. (2011). The fewer estuaries at this region can be associated with the arid nature of the South Africa's western part. Also, because of the nature of this area, the estuary in this area plays vital economic and ecological roles. The estuaries in this region include the Olifants, Verlorenvlei and Berg estuaries (the subject of this study). The Berg estuary is known for its tourism and harbour development activities, Olifants estuaries are known for fishing and agricultural activities, while Verlorenvlei is known for tourism. Whitfield (1992) distributed South Africa's estuaries into types and is presented in *Table 1* and Berg River falls under an open estuary.

Table 1: Distribution of South African estuary into 4 biogeographical regions and their classification into 22 types of estuary ecosystem (Van Niekerk *et al.*, 2019).

Estuary type	Biogeographical Regions				# Estuaries in type	# Estuaries in ecosystem types
	Cool Temperate	Warm Temperate	Subtropical	Tropical		
Estuarine Lake	4	3	3	2	12	4
Estuarine Bay		1	1		2	2
Estuarine Lagoon	1				1	1
Predominantly Open	3	25	16		44	3
Large Temporarily Closed	9	40	45		94	3
Small Temporarily Closed	8	48	60		116	3
Large Fluvially Dominated	1	1	5		7	3
Small Fluvially Dominated	1	6			7	2
Arid Predominantly Closed	6				6	1
Total	33	124	130 (131)*	2	289 (290)*	22

Tidal (tide-dominated) estuaries – often consist of a narrowing inland funnel-shaped valley with different tidal sediment environments (e.g., salt lakes, salt marshes, mangroves and tidal flats). Tidal estuaries are larger with deep inlets and tidal areas that looks like those of the open ocean. The tidal energy at the entrance of tidal estuaries is usually high. Tidal estuaries are created by filling river valleys with terrestrial and sediments from marine and are usually by a displacement of sedimentary and geomorphic environments towards the sea. Vegetation that are closely related with mangroves, marshes, and salt flats plays an important role in determining the shape of the estuary during the early stages of evolution, as it can trap fine sediments. These habitats are often home to temporary and permanent marine species.

Wave-dominated estuaries – are estuaries with narrowed inlets, caused usually by beach sand accumulated by wave which forms tidal deltas and barriers at the inlets. The inlets formed are generally smaller when comparing with the ones in tide-dominated estuaries. Tidal regions within estuarine basins are much smaller, on the order of 5-10% of those in the ocean, and the currents of the tidal are insignificant. The major mechanisms of sediment transportation is the wind-induced water movements and local wind waves. Also, runoff from rivers largely affect estuaries (Glamore *et al.*, 2016). There are several types of wave-dominated river estuaries, such as inter-barrier, barrier lagoons and barrier estuaries. Intermittently closed and open lakes and lagoons (ICOLLs) are a subset of wave-dominated river estuaries that formed when there is high wave energy and have small catchment area. The inlets of these estuaries are usually clogged with beach sand for long time because of the low volumes of run-off or upstream runoff. These estuaries may be non-tidal for long time, but they can open naturally to the ocean after heavy rains, or they can be mechanically opened to lower the water level upstream.

2.3 Different environments within an estuary

Estuaries in South Africa are as diverse as the climate, from tropical north with unregulated large rivers that flows into extensive tidal deltas to small lagoon at the country's southeast coastal area. The diverse range of estuarine systems within a variety of geological and climatic conditions help create diverse environments that are home to habitats and species that make up the unique biodiversity of the coastline regions. Due to the different movements of tides, waves, and freshwater currents, different estuarine environments occur that support different ecosystems. Listed are typical estuarine environments: continental shelves, fluvial deltas, barriers, intertidal flats, central basins, mangroves, flood and ebb tidal deltas, saltmarshes channels - salt flats (salt pans), rocky reefs - tidal sand banks.

2.4 Natural climate of estuaries

Even under normal known weather patterns, estuaries are dynamic and not in a stable state just like the climate (Glamore *et al.*, 2016). A typical estuary mirrors its' environment, i.e., the physical features of that area will reflect in the estuary. Physical characteristics including the geology of the underwater, subsequent geomorphology and the historical changes in the climate of that region.

Estuarine systems including its geomorphology, distribution and functions are easily influenced by climate. Climate changes over a series time scales (millennial, centenary, decadal, annual, daily, and sub-daily) and spatial (global, continental, regional, catchment and sub-catchment) scales. In addition, estuarine biological and geophysical nature (ecosystems, habitats, and landforms), are affected by freshwater runoff and precipitation patterns, radiation, evaporation, temperature and so on. Disparities between annual heat and precipitation (evaporation and temperature) can lead to extremes in climatic, especially in regions with heavy seasonal precipitation. This can lead to dramatic changes in the estuary's salinity and hydrology of that region because freshwater inflows affect tidal processes.

2.5 Estuarine processes

Estuaries are systems that are dynamic with cycles and processes that operate on a variety of temporal and spatial scales. The physical processes of the estuary are hydrodynamics (water movement) and mixing processes, geomorphological processes, and water quality processes.

The hydrodynamic processes in an estuary influence biological processes considerably. Hydrodynamic processes (*Figure 3*) include water density variations, wave and wind action, tides, and inflow. During this process, gravitational pull from the sun and moon drives the tides and cause the water to move periodically. Estuary water circulation can be affected by gravitational forces cause of the force of gravity acting on estuary's density differences. Also, Coriolis forces, due to rotation of the earth around its axis, can affect large estuaries. Furthermore, rain runoff (without infiltration) can cause freshwater flow into the estuary catchment areas. Due to anthropogenic influences, flows can be increased (for example, through urbanization) or decreased (through retention basins). Also, shallow estuaries, shores or marginal shoals can be affected by waves generated offshore or internally, waves redistribute eroded material onshore/offshore throughout the entire estuary. Wind forces can even significantly change turbulent mixing and circulations in larger environments. Strong winds can cause storm surges in surface waters, which can trigger large amounts of current. Wind also affects the degree of stratification and mixing within the estuary. Large open and shallow estuaries are more affected by wind power than deep and narrow estuaries.

Geomorphological processes are affected by changes within the estuarine river channel, the penetration of marine sediments and catchment run-off. Catchment sediments are obtained through catchment erosion, biological activity, and / or wind transport, while marine sediments are from the continental shelf in front of the estuary. Sediments transported are a result of uneven tidal currents (ebb versus flood tide) to provide sediment on different time scales.

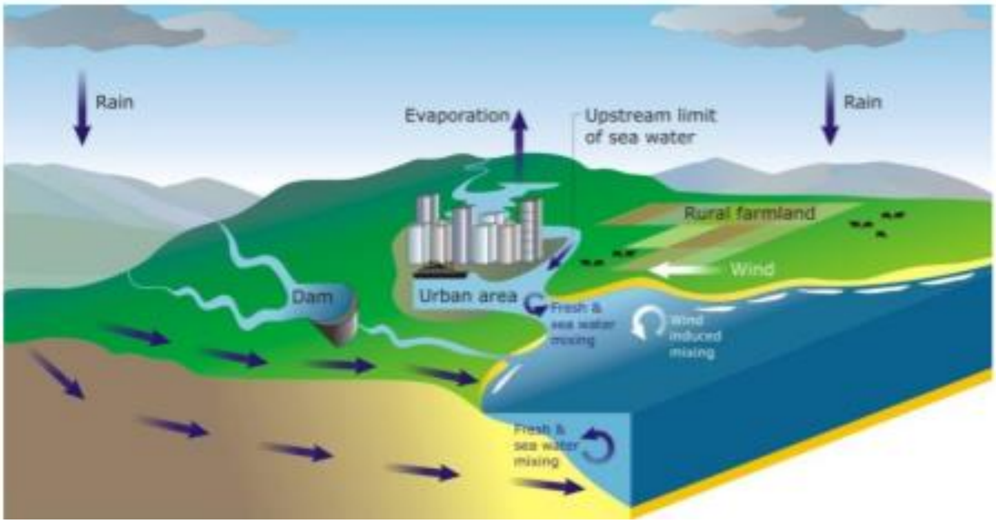

Figure 3 hydrodynamic forces in an estuary (Glamore *et al.*, 2016)

Water quality processes are often affected by drainage processes in the catchment area (for example, changes in water quality due to changes in land use) and in-estuary processes (e.g., biological processes). While individual events such as spring tide, change in inlet conditions and major flood can determine an estuary short-term feature. The long-term composition can be caused by mixture of different forces acting on various spatial scales (catchment - regional and wide climate) and temporal scales (centuries, decades, and years). Water quality parameters include temperature, salinity, turbidity, oxygen nutrients and acidity/alkalinity.

2.6 Mixing processes within estuaries

Mixing processes (mixing dynamics and flow circulation), affect the salinity, nutrients, pollutants, and transportation of sediments within an estuary at different temporal and spatial scales. Mixing can be as a result of different factors such as tides and wind; however, the mix of freshwater tributaries and ocean salinity may be important in defining the functional and structural properties of estuaries (Glamore *et al.*, 2016).

2.7 Estuaries under a changing climate

Climate influences estuarine and coastal systems distribution, functioning and geomorphology. The environments of estuaries are inextricably linked and influenced by changes in climate over a range of temporal and spatial scales. Precipitation patterns and freshwater runoff, temperatures of sea surface, solar radiation, wind and evaporation, as well as many other drivers, determine and shape the biological and geophysical nature of estuarine ecosystems, landscapes and habitats. The following are the important climate processes that may affect estuaries under climate change:

- surface heat budget (solar radiation, evaporation and temperature)
- sea-level rise
- rainfall
- wind
- ocean acidification.

Prediction of climate change differ considerably based on future CO_2 emissions in the next century. The forecast change in South Africa weather is likely to vary in magnitude across the country (Ziervogel *et al.*, 2014). Some areas may experience more rainfall, while other areas may become drier. Also, wind fields can vary based on latitude, the influence of seasonal storms, or global circulation patterns. Ocean acidification is likely to affect some estuaries and not others, as different ecologies are sensitive to acidification. The extent of possible changes to an estuary depends on its geographic location and future CO_2 emissions. Climatic processes affect the physical, chemical and ecological processes of estuaries in different ways. It is important that the future effects of these processes are not evenly distributed, and the relative effects depend on the extent to which these climatic factors vary at the regional and catchment scales and on the adaptability of the various environments and estuarine components.

2.8 Impacts of sea-level rise

Variation to average sea levels play a major role in the environments of many estuaries. Except for event of heavy flood, rainfall and run-off have no significant effect on estuary depth. Estuary depth is majorly controlled by the water levels of ocean, the tidal prism and the geology of the regional. There will not be uniformity in the rise of sea-level in space and time. Climatic and processes in ocean can lead to regional differences in sea level, including variations in geological processes (e.g., isostatic rebound, land subsidence and tectonic displacement), offshore currents, freshwater fluxes, local topography, winds and air pressure.

There are many ways rise in sea-level affects estuaries. The most important threats are rise in floodplains and shorelines vulnerability, which may lead to increased level of water when there is coastal flooding, extreme storms, and permanent submergence. In these situations, infrastructure built very close to the coastal area, adjoining roadways, abutments and drainage pathways may be at high risk. Even coastlines that are not developed may equally be at risk, with possible major ecological consequences.

Rise is sea-level will also leads to the following problems below:

- rise in coastal erosion
- rise in inundation of floodplains, estuaries, coastal wetlands and low-lying areas
- reduction in drainage and lengthy low-lying coastal areas inundation
- there will be displacement of salt marshes, estuaries, shorelines, and wetlands landward
- forcing of salt water upstream into groundwater systems and estuaries
- alter the overall temperature and salinity distribution in the estuary
- alter the aquatic vegetation distribution by changing the inundation levels
- displaced the boundaries of properties in coastal area
- speed up changes to land use and ecosystem habitat distribution
- changes estuarine circulation patterns and tidal range
- changes the transportation of sediment regimes of an estuary
- alters the nutrient dynamics of sediments and neighbouring floodplain

2.9 Impacts of changing rainfall

Climate change is projected to affect patterns of precipitation, that may thereafter have effect on the delivery of freshwater quality, timing, rate and magnitude into estuaries, and will likely worsen human alteration of these flows (Alber, 2002). Estuaries system is larger affected by freshwater runoff timing and magnitude getting to them (Taljaard *et al.*, 2009). Regional climate models from global climate models shows a high probability of increased rainfall in the summer around the eastern region of South Africa and a small reduction in rainfall during the winter in the Western Cape (Hewitson and Crane, 2006; Engelbrecht *et al.*, 2009). The rise in rainfall predicted for east coast can be like more rain days and rise in the events of heavy/extreme precipitation in summer (Hewitson and Crane, 2006).

Rainfall is dependent of temperature and moisture supply from wind and evaporation from the surface. Though future rainfall variations are not influenced directly by increasing greenhouse gases, heavier precipitation may be caused by hotter atmosphere which holds more water. Winds (circulation) may also cause variation in precipitation.

Rainfall catchment run-off can be affected by moisture of the soil, land use and catchment characteristics (e.g., landform, soil characteristics, infiltration, roughness slope). Alteration to run-off may also be from anthropogenic effects, such as water diversion and consumption, water demand, changes in activity of human, land use, and physical obstacles like detention basins and dams. Anthropogenic factors (direct and indirect) factors affect the catchment inputs into estuaries at different rates depending on the change in the climate of a particular region and catchment development (existing and future).

Furthermore, freshwater flows into estuaries are majorly controlled by rainfall through groundwater recharge and surface run-off. Changes in patterns of rainfall may probably have a consequential effect on the systems of estuarine, as freshwater flow is a major contributor of physical changes in estuaries. Run-off of rainfall control the seasonal flows pattern, extreme flow timing, extreme flow frequency, magnitude of low/intermittent flow and events of no-flow.

Variations in rainfall can affect freshwater inflows, rise the frequency of flood, alters salinity regimes (including circulation and stratification patterns), changes the water balances and water quality and alters erosion rates and sedimentation. Furthermore, it changes nutrient loads, which may lead to alteration in water quality, times of flushing and residence may change, especially for occasionally open estuaries. Also change to rain fall can affect the ecology through changes to flows magnitude and frequency of freshwater and changes in water quality (sediments and nutrient delivery).

2.10 Impacts of increasing temperature

Oceanic and atmospheric processes work together on a variation of time scales to control both surface and air ocean temperature. The annual average temperature in South Africa is supposed to increase parallel to the average temperatures globally; but there is probability of substantial variation in some region, especially the coastline. Though the surface heat budget of some regions is majorly determined by patterns of global climate, also, it can be affected by regional local climate, and human activities.

Estuarine processes are influenced by the surface heat budget majorly *via* water quality impacts and *via* hydrodynamics and mixing. Furthermore, processes of hydrodynamic are affected by alteration in soil moisture and catchment evapotranspiration. Like majority of climate change stressors, radiation and temperature interact with other stressors like rainfall to influence run-off, this further make it difficult to predict the total effect of change in climate of an estuary. Though surface heat budget is predictable on a daily timescale, it is difficult to predict for centennial and inter-decadal scale fluctuations.

It is expected that estuaries will be affected by alteration in temperatures of ocean and surface air, because of the greenhouse gases and aerosols (caused by human activities) causing rise in temperature of ocean and air globally in the last 50 years (Solomon *et al.*, 2007). Solomon *et al.* (2007) reported that the analysis of the temperature of ocean from 1961 to 2003 showed that the time series analysis of ocean heat content (0−700 m layer) as increased by 0.1°C. Although, significant decadal changes occurred during this time, some regions still experience cooled ocean temperature.

Cury and Shannon (2004) reported a steady rise in the sea surface temperature (SST) in the Benguela region, and the hottest years falls with 1980s. Also, the SST of the Agulhas Current has significantly raised up to about 0.7°C per decade (Rouault *et al.*, 2009). Which is attributed to a increase of the current related with rise in “wind stress curl in the South Indian Ocean” (Rouault *et al.*, 2009). The coastline of KwaZulu-Natal and Transkei have recorded a warmed up temperature of about 0.55° C per decade (Rouault *et al.*, 2010).

With the highly inconsistences nature of South African coastal regions, there is variability in pattern of many areas along the coastline (west, south, and southeast), with cooled seasonally SSTs resulting from rise in upwelling-favourable winds or/and strengthening of the Agulhas Current. There is a cooling pattern along the inshore of west coast (Hutchings *et al.*, 2009; Rouault *et al.*, 2009), especially during the winter (Rouault *et al.*, 2010). For instance, about 0.35° C and 0.4° C cooling per decade was reported for south coast and Port Elizabeth/Port Alfred upwelling region, respectively, between the month of May and August. With no significant changes reported for temperature during summer for these three areas (Rouault *et al.*, 2010).

Furthermore, rise in air temperatures will have significant consequences on estuaries and especially on temporarily open/closed estuaries. Because permanently closed estuaries are isolated for a long time from the influence of temperatures form sea, making it to respond to a larger extent to usual temperatures of land, air and river water (James *et al.*, 2008). Report of time series analysis (26 climate stations) from 1960 to 2003 showed that South African surface air temperatures for spatial and temporal are warmest in autumn of 1980s and lowest in spring (Kruger and Shongwe, 2004).

Also, temperature and salinity are major factors affecting the biogeography of fishes in South African in estuaries, especially tropical species (Harrison and Whitfield, 2006). Climate change influence on fishes usually implies temperature change in water bodies (Elliott, 2011). Changes in climate can have significant effect on the physiology of fish (temperature and salinity tolerances), which affect their capacity to stay estuarine habitats and finally the larger-scale distribution of species (Elliott, 2002).

When the average temperature of an estuary is high, this can lead to rise in the rate of water evaporation., decrease in soil moisture, that may influence estuary's water balances, catchment run-off and sediment loads. Also, higher temperature will affect the key productivity and biological processes of estuary, alters toxic chemicals degradation and biogeochemical processes. Higher temperature may also result in alteration of salinity and stratification, encourage hypoxic conditions, reduction in soil moisture which may lead to changes in dissolved organic carbon. Furthermore, higher temperature may change the process at which submerged plants photosynthesized, it also increases the risk of parasitism and disease that may result in changes in mortality rates, reproduction, and species distribution of estuarine organisms.

2.11 Ecosystem Services

Naturally the environment provides the society with variety of ecosystems services. The environment provides services, cultural services, regulating services and life-support services such as food, water purification, water, air, aesthetic, educational and cultural benefits, spiritual, recreational, soil formation and nutrient cycling (Breen and McKenzie, 2001; Reid, 2005; Van Niekerk and Turpie, 2012a). Furthermore, estuaries play vital role for some businesses and associated community in the coastal area of South African. Reports have shown that estuaries play significant role in the national and local economy in South Africa (Cooper *et al.*, 2003; Lamberth and Turpie, 2003; Turpie, 2006; Turpie and Clark, 2007). Communities on the coastal area depend largely on estuaries for revenue (Van Niekerk and Turpie, 2012a). Estuaries are normally not considered as a local government asset. Their presence in a particular area significantly increases the taxes and rates of the area. Especially when the properties values are linked to waterfront. Also, estuaries bring opportunities like tourism, development of harbour and industrial activities.

Estuaries serve as a major area to nurse marine fish and juvenile species (Day, 1981), some of the fish species enter estuarine nursery as larvae and some as juveniles (Beckley, 1985; Whitfield, 1998). The nursery plays vital function of make sure the marine environment and estuaries are restocked. About 50 % of 160 of the fish species present in estuaries are used for recreational, commercial or subsistence fisheries, about 2480 tons comprising of difference species of fishes are harvested from estuaries directly (Lamberth and Turpie, 2003). Where about 60 % are partially or entirely depends on estuaries. Though it is considerably less than what was harvested from inshore (28 000 tons), but, up to 83 % of the fish may depend or associated with estuarine region (Lamberth and Turpie, 2003).

Estuarine plants are another useful gift from the estuaries, they are used as building material and ecotourism basketry (Van Niekerk and Turpie, 2012a). Furthermore, salt marsh is a source for food or alternative energy because of its high protein and oil. It can also be possible sources of eco-friendly biofuel. Also, marine, and coastal wetlands ecosystems are servers as carbon storage because of the presence of biomass and sediment in this area. Marshes, mangroves and submerged macrophytes capture and store carbon from the atmosphere in the soil (Van Niekerk and Turpie, 2012a). The carbon builds up in the estuarine sediment, but when there is degradation through conversion to agriculture or mariculture or drainage, the CO_2 is emitted to the atmosphere.

Another benefit from South Africa estuaries is that it serves as buffer against floods. With about 61000 ha open water area and about 171000 ha floodplain area, which amount to 60 % of the subtropical biogeographical area (Van Niekerk and Turpie, 2012a).

Indiscriminate development along the estuarine zone reduces the capacity of estuarine ecosystems to provide the desire services. For example, the risk of flooding in high if there is flow reduction as a result of decrease in mouth breaching. Also, if there is inappropriate mechanical opening of estuaries, it may result in reduction in sediment flushing from the system. This can cause long-term sediment accumulation which increases flood risk when there is high rainfall. Stopping improper development within the estuarine area and sustaining the required baseflows will guarantee a sustainable ecosystem service. Sand bar accumulation at the mouth of closed systems or temporarily open systems, especially during the summer rainfall periods, serves as a shield for the properties against wave action caused by severe sea-storms for during the winter months (Van Niekerk and Turpie, 2012a).

In addition, estuaries serve as safe areas to swim because there is no high wave action and near shore current (Van Niekerk and Turpie, 2012a). Therefore, it increases the tourism and recreational activities in this area. Estuaries are valuable national assets that provides important ecosystem services which supports ecosystem resilience and help climate change to adapt.

Activities and services that estuaries provide should be checked so as to sustain the integrity of the estuaries. To achieve this, it is necessary to have a pointer/indicator for estuaries real-time health status. Therefore, informed decision-making is vital to ensure estuaries survival. This information can be obtained from consistent and systematic monitoring estuaries key health indicators. Monitoring the changes in estuaries ecosystem services by tracking their health indicators helps in the management to be proactive in making good decisions that can help in maintaining the ecosystem services.

2.12 Conclusion

Since it is said that estuaries are dynamic region between the sea and rivers, which are affected by alteration in marine conditions, terrestrial and freshwater, climate change could have a major influence on its ecosystems. Taking all the above factors into consideration, climate change effects on estuaries in South Africa will probably be from a rise in the occurrence of coastal storms, alteration in precipitation, and temperature. A decrease in the amount of rainfall in South Africa's west coast area will lead to a reduction in the flow of freshwater and can lead to the frequent closure of estuaries. It may also constrict estuaries that are currently permanently open or even lead to their eventual closure later.

Fish species in estuaries are known to be sensitive to reductions in the volume of freshwater runoff and this may reduce the abundance of these species, which will also have fisheries implications. Reduction in freshwater flow may also reduce the quantity of nutrients entering estuaries, with a resultant impoverishment of the biota. Increases in extreme precipitation events projected for the east coast may result in increased freshwater flow and elevated delivery of sediment to estuaries as a result of runoff from land and river and stream channel erosion, which may significantly alter estuarine fish communities through the clogging of their gills and smothering of the benthos, and create indirect impacts through elevated turbidity (e.g. prey detection and predator avoidance) (Elliott, 2002).

As in most of the world, South Africa have seen a general increasing trend in air temperature which has a direct impact on the water temperature of rivers and estuaries, especially in small temporarily closed systems. It is expected that globally, as well as in South Africa, coastal SST changes will be more heterogeneous. For instance, James *et al.* (2013) reported that there is no uniformity in South Africa SST mean, which increases by 0.25°C very decade. The author also found there are signs of cooling in some regions, which is as a result of strengthened upwelling (for example, the coasts of southern and western Cape). Rising estuarine temperatures along with episodes of ENSO in the future are expected to cause changes in species distribution, while tropical species migrating south to estuarine areas will be predominated by many temperate taxa. However, the cooling of the coasts in some regions may restrict the capability of these species to redistribute toward the pole.

Furthermore, increase in the level of sea waters may also have a consequential effect on estuaries and the species in it in a long-term. Displacement of coastal wetlands upstream as a result of increase in level of sea water can restricted by development of coastline and inland topography. This may lead to habitat loss and therefore, may have an effect on the quantity of fish in estuarine. Also, the infiltration of marine water into estuaries can lead to alteration in estuary depth and salinity. Increase in the sea level will also affect the status of the estuaries' mouth (closed or open).

To mitigate this uncertainty about the effect of climate change on estuaries in South African, present long-term programmes of estuaries monitoring need to continue. This will enable the authorities to have long term data sets available in order to do modelling and make predictions for the future.

In summary, rainfall, change in sea surface temperature, increasing frequency of extreme coastal storms (resulting in runoff and turbidity), and arise in sea level will probably affect estuaries in the subtropical areas. It is important to monitor these in order to manage these valuable systems and to preserve all the benefits it provides.

CHAPTER 3

3 Material and method.

3.1 Study Area

According to Cooper (2001) the Berg Estuary is one of the three large rivers estuaries within the cool temperate region. The Berg River catchment is located in the Western Cape Province stretches over about 9000 km^2, which is segmented into twelve quaternary catchments. The size of the catchments ranges from 125 km^2 close to the headwaters to 2000 km^2 in the western area which is the drier part of the catchment. The Berg River originates from the Drakenstein Mountains near the town of Franschoek, and flows 285 km northward into St. Helena Bay located on 34°46'S, 18°09'E (west coast of South Africa), where it joins the Benguela upwelling system (Shillington, 1998). The larger part of the catchment is flat, but there is a catchment divide by mountains (a north-trending ridge), making the Berg River flow through a poort between De Hoek and Koringberg (Clark and Ractliffe, 2007b). The Berg River is flanked in the northern reaches by mountains with an elevation of above 1000 m.

Another important feature of the catchment is that it has a low density of drainage channels with unconsolidated sandy deposits on the western parts of the catchment. Also, at the central part of the catchment, significant higher drainage densities are present, while weathered and fractured rocks lie underneath the eastern parts. The geology of the Berg River Basin encompasses upland areas mountains and Table Mountain Sandstone (TMS) (Ractliffe, 2007). In 1966, entrainment of Berg Estuary mouth occurred, because of the problems faced by fishing vessels trying to access the sheltered harbour at Laaiplek (Shillington, 1998). Therefore, 1 km of sand dunes to the north was cut to pave way for a new mouth (Eagle and Bartlett, 1984). The new expanded mouth was reinforced with concrete walls making it accessible for fishing vessels. Also, to allow the ease of passage of the boat navigation, the lower 4 km of Berg was dredged to about 4 m depth. The mouth is about *ca* 100–200 m wide and shallowed upstream. The average depth and width of the Berg estuary is about 3 m and 150 m, respectively. In the upper part of the estuary (15 km from the mouth), riparian woodland grows on its steep banks, while the lower part (downstream) is flanked by a floodplain, which ranges from 1.5 to 4 km in the middle reaches to <1.5 km in the lower 15 km. This area is a floodplain and seasonally swamped and inhabited by a lot of wading birds (Wooldridge and Deyzel, 2009). It is one of the protected areas in South Africa because it hosts important birds and other biota (Turpie *et al.*, 2002). It is also one of the recognised South Africa fishing harbours. The river has tidal oscillation propagation up to about 69 km upstream, though only about 45 km of the river from the inlet has saline intrusion (DWA, 2012). The estuary has 12 Mm^3 in total water volume, with the catchment getting most of its rainfall during the winter. There are agricultural activities along the river and also small, urban settlements (namely Veldrif, Hopefield, Piketberg, Wellington and Paarl).

The Berg River houses Wemmershoek and Voelvlei Dam, with the capacity to store 58.5 x $l0^6$ m^3 and 164.1 x 10^6 m^3, respectively, with mean runoff (annual) of 693 x 10^6 m^3 (Berg, 1993). The 294 km long Berg River is seasonal, which means it experiences high flows (HF) during the winter months (May to August) and low flows (LF) during the summer months (November to February) (Slinger and Taljaard, 1994). When the inflow is relatively low during the summer, the Berg estuary is usually dominated by marine water (Slinger and Taljaard, 1994). But during the winter rains, the estuary in dominated by fluvial processes downstream, and is predominately fresh during the rainy season (Slinger and Taljaard, 1994). There is strong seasonal variation in flow. During the summer, the flow is 0.2–2.0 m^3 s^{-1} (that is between November to February), and in winter the flow is between 15–60 m^3 s^{-1} (between May and August) (Wooldridge and Deyzel, 2009).

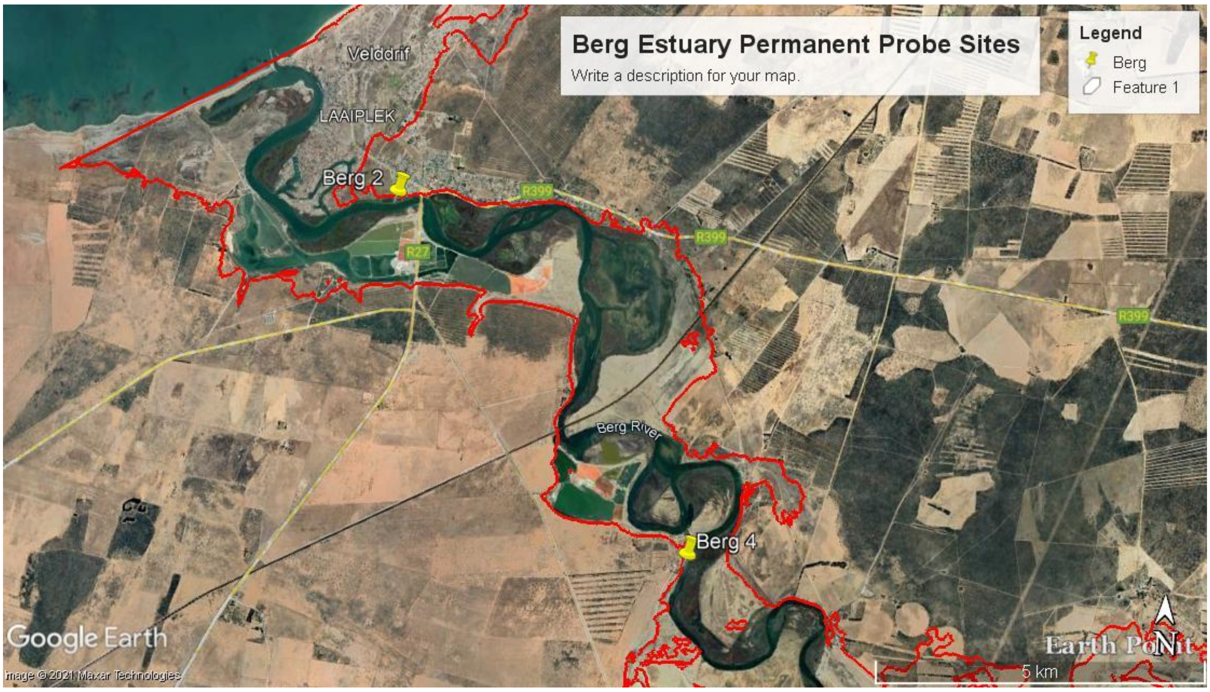

Figure 4: Position of the permanent probes in the Berg Estuary the site names are Berg 2 and Berg 4.

Furthermore, the Berg River experiences flooding regularly in the winter season, which may sometimes be above 700 m^3 s^{-1} (Beck *et al.*, 2006). An average annual runoff of about *ca* 931

$\times 10^6$ m^3 is reported on this river (Turpie and Clark, 2005), and 45% of this runoff is generated by 7% of the catchment. Cyclonic precipitation is very prominent as frontal weather systems pass across the region in winter. An oreographic effect may cause rainfall that is as high as 3200 mm per annum at the catchment's upper parts, which may be reduced to as low as <500 mm per annum at the lower parts (Beck *et al.*, 2006). According to Slinger and Taljaard (1994), the effect of tidal flow in the Berg Estuary can be felt up to 70 km from the mouth and the tidal flow reduced about 1n in the last part (50 km) (Day, 1981).

Furthermore, there is a major water diversion into Berg River dam from the Dwars River. As reported by DWA (2012), the current Berg River daily mean annual runoff (MAR) was reported to be about 520 Mm^{3}a^{-1}, which is 46 % lesser than it was under natural conditions (DWA, 2012).

Data for this project has been collected by DWS. The data is collected hourly from two sites on the Berg Estuary *(Figure 4*). The first site is situated at the mouth of the estuary, where the marine environment dominates, and the second site is situated approximately 40 km upstream where there is a stronger freshwater signal from the catchment.

3.2 Methods

3.2.1 Flow Data

The DWS mounted a flow gauge (G1H031) at about 120 km from the inlet (Misverstand) of Berg Estuary, and hourly data was collected from this gauge between the month of August 2012 and February 2015.

Table 2: Detail summary of date analyses and interpretation per flow seasons

Season	Season description	Data to be used	Months
LF 1	Low flow 2012/13	Spring 2012 / Summer 2013	October 2012 - March 2013
HF 1	High flow 2013	Autumn 2013 / Winter 2013	April 2013 – September 2013
LF 2	Low flow 2013/14	Spring 2013 / Summer 2014	October 2013 – March 2014
HF 2	High flow 2014	Autumn 2014 / Winter 2014	April 2014 – September 2014
LF 3	Low flow 2014/15	Spring 2014 / Summer 2015	October 2014 – March 2015

3.2.2 Monthly Sampling

This study is limited to only some water quality and quantity parameters namely temperature, salinity, estuarine water level and flow rate. The data was stored in Excel format (spreadsheets) after downloading into a computer. To ensure quality data, the data were inspected, and outliers were removed.

All data were evaluated based on flow conditions and divided into low flow (LF) and high flow (HF) conditions. *Table 2* shows the detailed dates for this classification.

3.2.3 Permanent Loggers

The measurement (data) of variation in water level, temperature and salinity were collected using two permanently loggers (In Situ Aquatrolls) on the Berg Estuary. One logger is located at 6 km from the inlet, Berg 2 (Site 2), while the other is located at about Berg 4 (Site 4), 20 km from the inlet *(Figure 4).* The loggers were stationed at permanent depths without being surveyed in (that is, no the accurate water level is not known), therefore, the change in water level recorded is not absolute but is measured as relative changes of mean sea level. Calibration was done monthly on the loggers as per the user manual during the monthly collection and storage of the data (Excel spreadsheets).

3.3 Statistical Analysis

Objective 1 and 2: Descriptive statistics was used to summarize the data. Data was processed and analyzed using a Microsoft Excel 2018 (Jacobson, 2007) and SPSS (Levesque, 2007). Data was check for possible errors and missing values before analysis. Frequencies and 95% confidence intervals (CI) were used to estimate for all the two groups using the t-test. When there was statistical significance between the data, analysis of variance (ANOVA) from SPSS was be used to indicate where the significance lies. The relationships between the variables were estimated using the Pearson pairwise correlation coefficient and correlations were reported as significant at $p \leq 0.05$. All analysis was performed using the SPSS statistical software package version 27.

Objective 3: The interpretation of the result from objectives 1 and 2 was used to determine if the data set is enough to start evaluating the impact of climate change on the Berg Estuary, after which recommendations for future estuarine management were made (Objective 4).

CHAPTER 4

4 Result and Discussion

4.1 Temperature.

The average temperature across the 3 hydrological years at Berg 2 for LF was 19.73 ºC (*Table 3*) while the average temperature for Berg 4 was 22.85 ºC (*Table 4*). The lowest temperature recorded during the LF1 period for Berg 2 and Berg 4 were 12.81 ºC and 16.29 ºC (*Table 3* and *Table 4*), respectively, while the highest temperature were 26.46 ºC and 27.55 ºC, respectively. The lowest temperature recorded for LF1 for Berg 2 and Berg 4 was 13.00 °C and 16.73 °C respectively, while the highest temperature was 25.40 °C and 27.90 °C, respectively, with an average of 19.77 °C and 22.89 °C (*Figure 5*). Also, the lowest temperature for LF2 for Berg 2 and Berg 4 was 13.82 °C and 16.98 °C, respectively, while the highest temperature was 25.69 °C and 26.80 °C, respectively. The highest temperature recorded for HF 2013 was 20.57 °C and 21.28 °C for Berg 2 and Berg 4, respectively, 12.14 °C and 12.20 °C was the lowest for Berg 2 and Berg 4 respectively, with an average temperature of 14.96 °C and 15.44 °C (*Figure 6*).

Furthermore, *Figure 5* shows that the average temperature of Berg River estuary increased steadily over the 3 hydrological years, and that the temperature at Berg 4 is higher than the temperature at Berg 2.

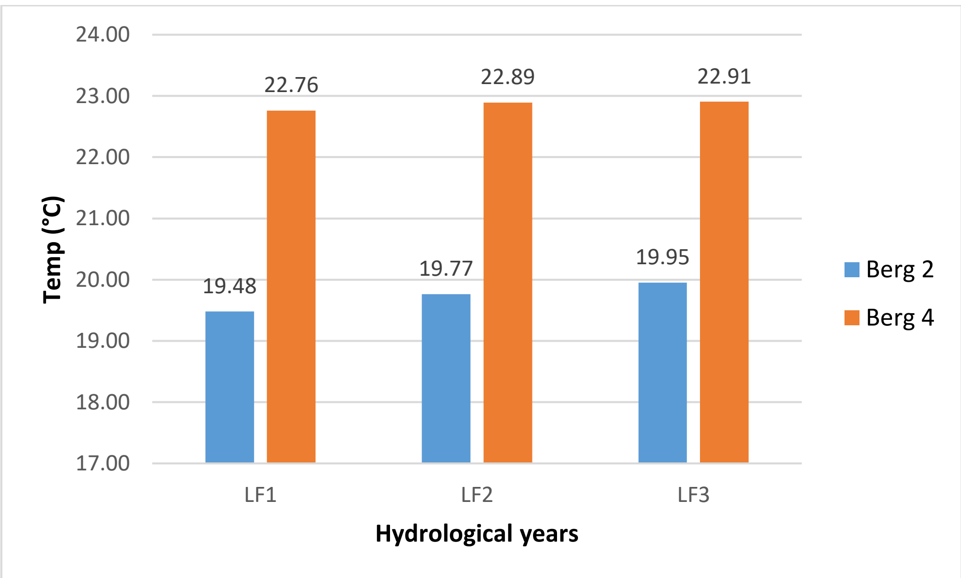

Figure 5: Bar graph showing low flow average Temp (°C) of Berg 2 and Berg 4 for 3 hydrological years.

Table 3: the average, maximum and minimum data of level, temperature, salinity, and mean flow for Berg 2 across the hydrological year

	Level (m)			Temperature (C)			Salinity (PSU)			Mean flow (m^3/s)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
LF3	12.13	12.87	11.51	19.95	25.69	13.82	25.85	33.09	1.59	0.63	12.02	0.15
LF2	11.87	12.60	11.28	19.77	25.40	13.00	20.23	33.55	0.31	9.58	218.95	0.20
LF1	11.75	12.51	11.07	19.48	26.46	12.81	26.63	34.26	0.43	3.91	137.73	0.00
Ave	11.92			19.73			24.23			4.71		
HF2	12.10	12.96	11.35	15.21	22.93	10.91	12.15	33.10	0.32	44.67	368.77	0.28
HF1	11.99	12.88	11.35	14.96	20.57	12.14	11.43	32.46	0.03	78.76	797.99	0.00
	12.04			15.08			11.79			61.71		

Table 4 the average, maximum and minimum data of level, temperature, salinity, and mean flow for Berg 4 across the hydrological year

	Level (m)			Temperature (C)			Salinity (PSU)			Mean flow (m^3/s)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
LF3	11.99	12.54	11.45	22.91	26.80	16.98	7.09	23.71	0.49	0.62	12.62	0.15
LF2	11.84	12.38	11.26	22.89	27.99	16.74	4.83	24.22	0.12	9.58	218.95	0.20
LF1	11.46	12.1	10.83	22.76	27.55	16.29	11.88	28.96	0.23	3.90	137.73	0.00
Ave	11.76			22.85			7.94			4.70		
HF2	12.07	12.70	11.51	15.87	22.93	11.13	2.18	19.87	0.12	44.68	368.77	0.28
HF1	11.92	13.35	11.27	15.44	21.28	12.21	4.75	27.93	0.05	78.87	797.99	0.00
Ave	12.04			15.66			3.47			61.78		

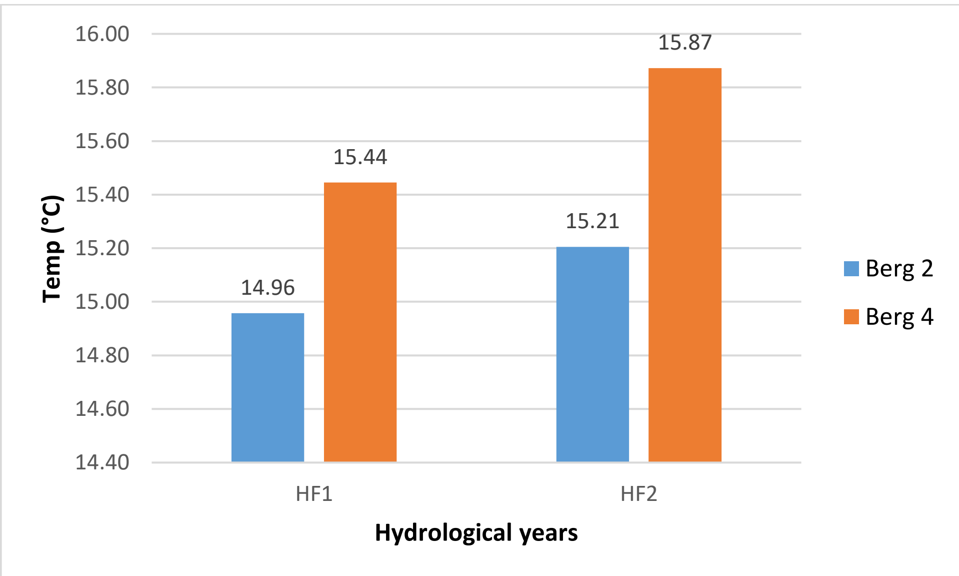

Figure 6: Bar graph showing average high flow Temp (°C) of Berg 2 and Berg 4

On the other hand, the average temperature for HF across the studied hydrological years at Berg 4 was 15.66 °C, while the average temperature for Berg 2 was 15.08 °C. The lowest temperature recorded during the HF1 Berg 2 and Berg 4 were 12.14 °C and 12.21 °C, respectively, while the highest temperature was 20.57 °C and 21.28 °C. The average estuary temperature was 14.96 °C and 15.44 °C for HF1 Berg 2 and Berg 4, respectively. The lowest temperature recorded for HF2 for Berg 2 and Berg 4 was 10.91 °C and 11.13 °C, respectively, while the highest temperature was 22.93 °C and 22.93 °C (*Table 3* and *Table 4*).

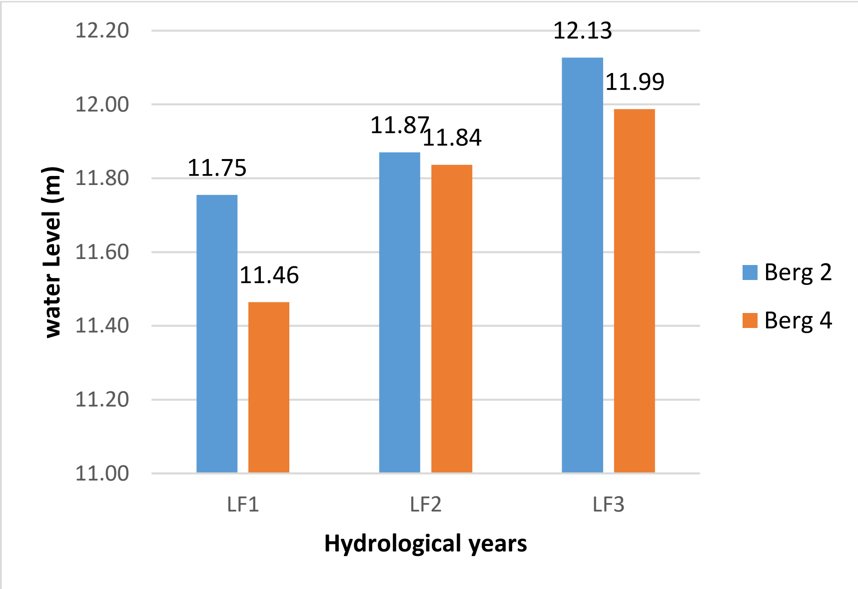

Figure 7: Bar graph showing average water Level (m) of Berg 2 and Berg 4 for 3 hydrological years for LF

Figure 7 shows that there is steady increase in the water level from LF1, LF2 and LF3. The average water level for LF1 was 11.75 m, LF2 was 11.87 m while LF3 recorded a water level of 12.13 m for Berg 2. The same trend was noticed for Berg 4, where the water level for LF2 was 11.46 m, LF1 was 11.83 m, while LF3 was 11.99 m. *Figure 8A* and B shows that the average water level increases as the average temperature increases.

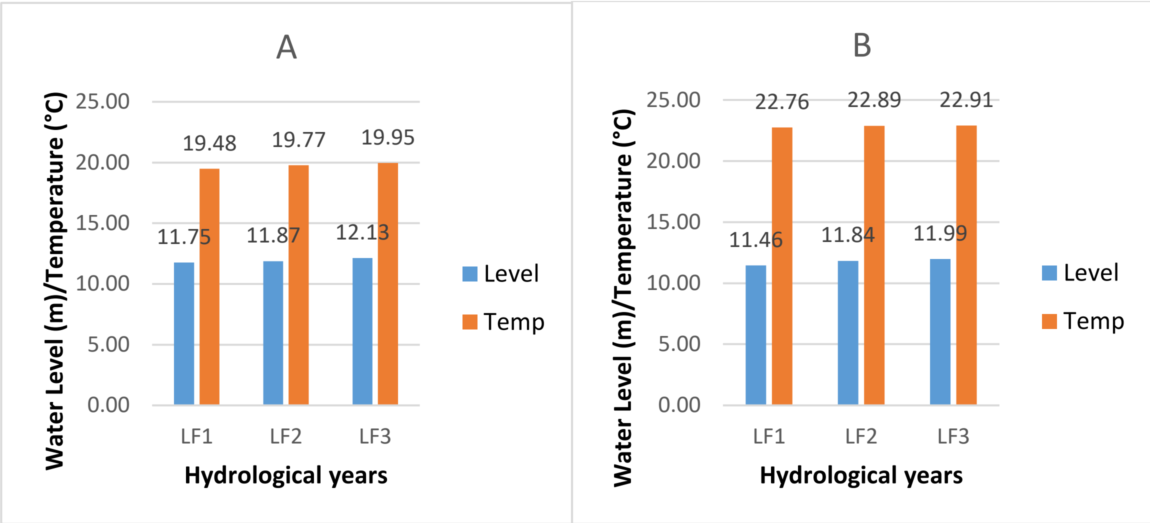

Figure 8 : Bar graph showing relationship between average water Level (m) and Temperature (°C) of (A) Berg 2 and (B) Berg 4 for LF for the 3 hydrological years

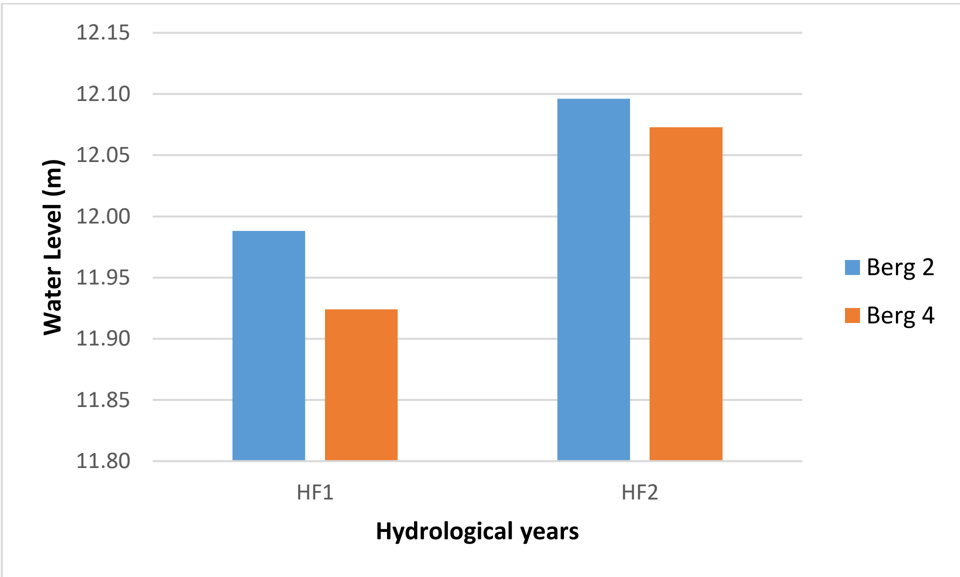

Figure 9: Bar graph showing average water Level (m) of Berg 2 and Berg 4 for 2 hydrological years HF

Figure 9 shows that the average water level for HF 2014 was 12.10 m and 12.07 m for Berg 2 and Berg 4, respectively. while HF 2013 recorded an average water level of 11.99 and 11.92 for Berg 2 and Berg4, respectively.

4.2 Salinity.

The estuary had an average salinity of 24.22 (PSU) for Berg 2 in the span of 3 years, while an average of 7.94 (PSU) was recorded for the Berg 4. The average salinity across 2 hydrological years at Berg 4 was 3.47 (PSU) and at Berg 2 it was 11.79 (PSU). *Figure 10* shows that the average salinity for the LF1 was 26.62 (PSU) and 11.88 (PSU) for Berg 2 and Berg 4, respectively. LF2 has an average salinity of 20.23 (PSU) and 4.83 (PSU) for both Berg 2 and Berg4, respectively, while LF3 has an average salinity of 25.85 (PSU) and 7.09 (PSU) for Berg 2 and Berg 4, respectively. In addition, *Figure 10* B shows that the average salinity of HF1 11.43(PSU) and 4.75 for Berg 2and Berg 4, respectively, and HF2 has an average salinity of 12.15 (PSU) and 2.18 (PSU).

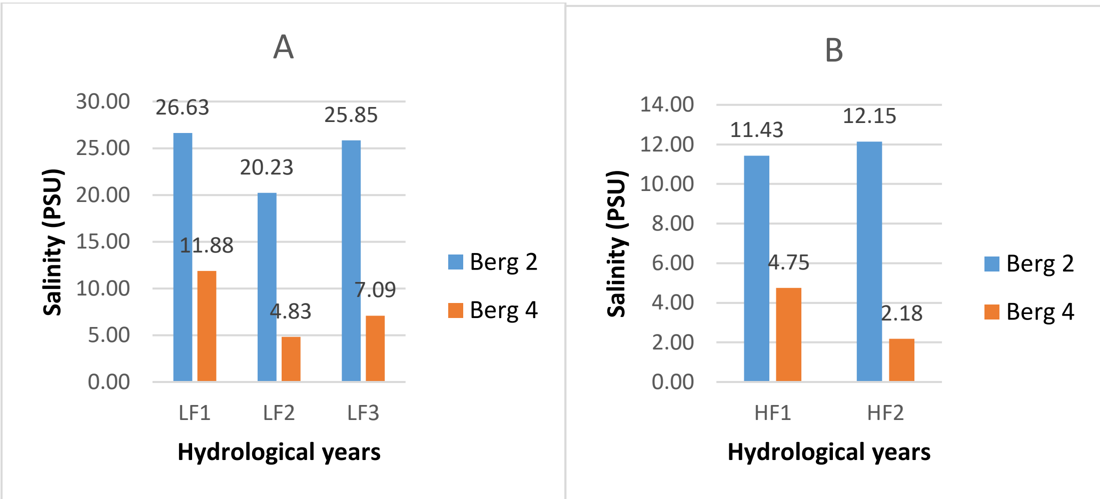

Figure 10: Bar graph showing average salinity (PSU) of Berg 2 and Berg 4 for 3 hydrological years for (A) LF and (B) HF

Chapter 5

5 Discussion

Temperature affects the photosynthesis rate of plants, the metabolic rate of aquatic organisms, and the organisms' sensitivity to toxic wastes, disease, parasites, and other stresses. Salinity is a very important parameter in water quality as it determines the types of species of animal or organism that can live in an estuary. It is defined as the amount of salts dissolve in water, and it can affect the chemical and physical processes (e.g., flocculation and the amount of dissolved oxygen (DO) in the water column.

5.1 Temperature

Effects of climate change are often associated with changes in temperature. It is expected that any changes in surface air and ocean temperatures will have an effect on estuaries. This is because greenhouse gases and aerosols from anthropogenic sources have contributed to the temperature increase of ocean and global air over the last fifty years (Solomon *et al.*, 2007). According to Solomon *et al.* (2007) an 0.1 °C increment of ocean temperature within the period of 1961 to 2003 was reported globally. Analysis of the data from Berg 2 shows that there is 0.14 °C increment in temperature and an 0.47 increment in the temperature for Berg 4 during low flow periods. During high flows, the temperature increased by 0.25 °C and 0.43 °C for Berg 2 and Berg 4, respectively. This is in accordance with the findings of (Cury and Shannon, 2004), which affirm that there has been a gradual rise in temperature in the Benguela current. The Berg River estuary falls within the southern Benguela current. However, this may be as a result of natural variation in temperature, since the dataset is short.

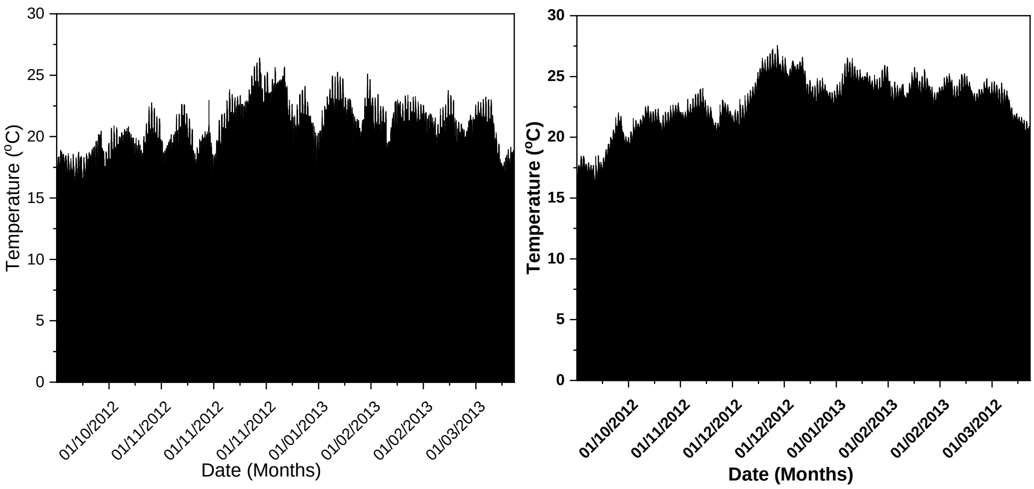

Figure 11: Graphic representation of the daily temperature at LF 1 for Berg 2 and Berg 4

Low flows are experienced in the spring and summer months, during this period between October and March for both Berg 2 and Berg 4, the temperature of the estuary showed the same trend of increasing slightly. The average temperature of the 3 years for Berg 4 (22.85 °C) was almost double that of Berg 2 (11.91). The graphic representation of temperature for LF1 for Berg 2 and Berg 4 are presented in *Figure 11*. The two showed the same trend but the average temperature of Berg 4 (22.76 °C) is higher than Berg 2 (19.48 °C) (*Figure 5*). Further analysis using ANOVA (*Table 5)*, also confirm there is highly significant difference between the temperature patterns of LF Berg 2 and LF Berg 4 with a p value of 0.000. The difference in temperature during this period can be explained in that the bottom of the estuary is cooler as a result of cold marine water entering it (Cilliers, 2017). The hotter upper part is caused by heat from the ambient temperature which is higher. Furthermore, the upper part (Berg 4) is shallow in nature, and this can also contribute to the higher temperature (Cilliers, 2017).

Table 5: showing One-way ANOVA for TempLF1B2 and TempLF1B4 (criteria=cilevel (0.95)).

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	24732.370	3206	7.714	1.759	.000
Within Groups	5075.232	1157	4.387		
Total	29807.602	4363			

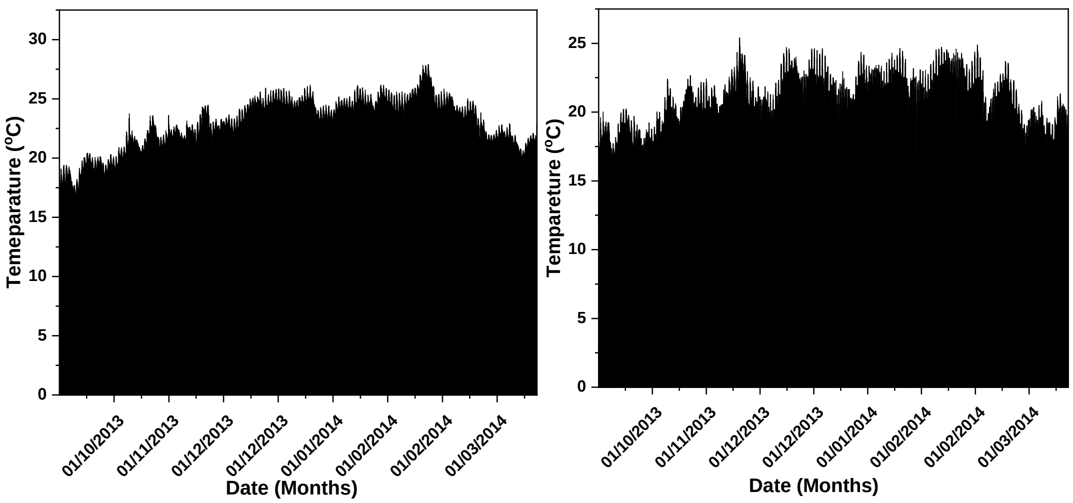

Figure 12: Graphic representation of the daily temperature at LF 2 for Berg 2 and Berg 4

The graphic representation of LF 1 for Berg 2 and Berg 4 are presented in *Figure 12*. The two sites showed the same trend, but the average temperature of Berg 4 (22.89 °C) is higher than

Berg 2 (19.77 °C) (*Figure 5*). Further analysis using ANOVA (*Table 6*), also confirm there is a highly significant difference between LF 2 Berg 2 and LF Berg 4. The trend holds for LF 3 Berg 2 and Berg 4.

Table 6: showing One-way ANOVA for TempLF2B2 and TempLF2B4 (criteria=cilevel(0.95)).

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	21274.986	3240	6.566	1.215	0.000
Within Groups	6050.538	1120	5.402		
Total	27325.525	4360			

The relationship between the temperature of LF 1, LF 2 and LF 3 was studied. The average temperature for LF 1, LF 2 LF 3 at Berg 2 was 19.48, 19.77 and 19.95, respectively, (*Figure 5*). Though there is a slight difference across the years, further analysis using ANOVA shows that there is no significant difference in the temperature across the 3 hydrological years (*Table 7*). This implies there is no significant changes in the temperature of Berg 2 estuary from the 2012/13 hydrological year to 2015. On the other hand, the ANOVA shows (*Table 8*) that there is a significant difference in the temperature across the 3 hydrological years during LF in Berg 4, which also represented in *Figure 5*. The insignificant difference in the estuary water temperature at the mouth is probably as a result of relatively consistent low temperature water coming in from the marine environment, while at the upper part of the estuary, there are more fluctuations in water temperature as a result of more variation in ambient air temperature and the shallow depth of water.

Table 7: showing One-way ANOVA of TempLF1B2 and TempLF2B2 against TempLF3B2 (criteria=Cilevel(0.95)).

		Sum of Squares	Df	Mean Square	F	Sig.
TempLF1B2	Between Groups	2845.983	746	3.815	1.015	.419
	Within Groups	2973.556	791	3.759		
	Total	5819.539	1537			
TempLF2B2	Between Groups	3659.808	746	4.906	.970	.661
	Within Groups	3998.634	791	5.055		
	Total	7658.442	1537			

Table 8: showing One-way ANOVA of TempLF1B4 and TempLF2B4 against TempLF3B4 (criteria=Cilevel(0.95)).

		Sum of Squares	df	Mean Square	F	Sig.
TempLF1B4	Between Groups	4829.254	1456	3.317	3.756	.000
	Within Groups	149.241	169	.883		
	Total	4978.495	1625			
TempLF2B4	Between Groups	4695.672	1456	3.225	4.177	.000
	Within Groups	130.472	169	.772		
	Total	4826.144	1625			

During high flow between April to September (autumn and winter) for 2012 to 2014, the temperature of Berg 2 increased by 0.25 °C and that of Berg 4 increased by 0.43 °C. Looking into the average temperature of HF1 in Berg 2 (15.21 °C) and Berg 4 (15.87°C), there was minor increment, but further analysis with AVONA test (*Table 9*) confirm there is a highly significant difference between the temperature data. Also, comparing HF1 to HF2 in Berg 2 using ANOVA (*Table 10*) show there is significant difference in their data. The same story goes for the HF1 in Berg 2 and Berg 4 (*Table 11*). Furthermore, the comparison of HF1 and HF2 in Berg 4 also shows there was significant difference (*Table 12*) between the data. These results show that there are significant changes in the water temperature between the different sites in the estuary during high flows within the year of study.

Table 9: showing One-way ANOVA of TempHF1B2 against TempHF1B4 (criteria=Cilevel(0.95)).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10045.890	3094	3.247	9.479	.000
Within Groups	440.147	1285	.343		
Total	10486.038	4379			

Table 10: showing One-way ANOVA of TempHF2B2 against TempHF1B2 (criteria=Cilevel(0.95)).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8982.724	666	13.488	5.601	.000
Within Groups	8723.928	3623	2.408		
Total	17706.652	4289			

Table 11: showing One-way ANOVA of TempHF1B4 against TempHF1B2 (criteria=Cilevel(0.95)).

	Sum of Squares	df	Mean Square	F	Sig.

Between Groups	17300.290	670	25.821	26.522	.000
Within Groups	3610.964	3709	.974		
Total	20911.254	4379			

Table 12: showing One-way ANOVA of TempHF2B2 against TempHF2B4 (criteria=Cilevel(0.95)).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19749.205	3407	5.797	5.134	.000
Within Groups	994.630	881	1.129		
Total	20743.835	4288			

5.2 Salinity (PSU)

As seen in *Figure 13,* the salinity of the estuary was always at the lowest point during the winter months (HF) and peaked at the summer months (LF) throughout the studied year. During the LF (spring/summer) for the period investigated, the average salinity was recorded to be 24.24 (PSU) in Berg 2 and 7.94 for Berg 4. This may be attributed to lower flows of fresh water as a result of low rainfall and draught during the summer period, with less dilution of seawater occurring. Looking at the data, there is a substantial difference between in the salinity of Berg 2 and 4. The decrease in average salinity at Berg 4 could also be associated with less rainfall to dilute the salinity in the upper reaches. Cilliers (2017) explained that during the summer the "saline marine water enters further into the estuary, resulting in an extension of the salinity wedge into the upper reaches of the estuary". Furthermore, the difference in the data was further confirmed by AVONA analyses. *Table 13* shows that the salinity data are significantly different from each other, except LF2 in Berg 2.

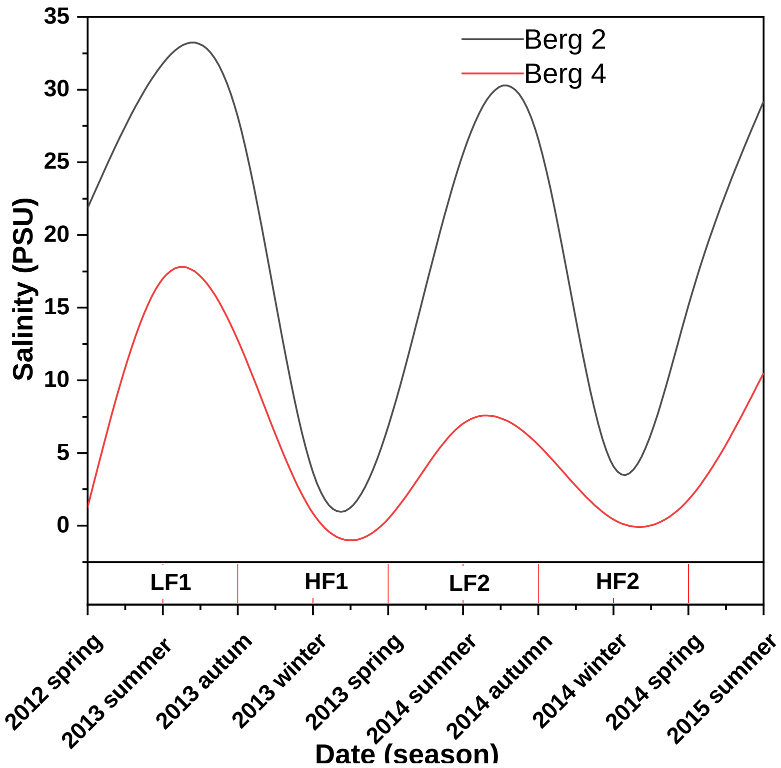

Figure 13: Time series graph of salinity

During the HF period the salinity show a constant pattern between HF1 and HF2 and the salinity was low. “This is indicative of freshwater inflow from the catchment, although the tidal influence is still present during the high flow conditions in the lower reaches of the estuary” (Cilliers, 2017).

Table 13 showing one-way ANOVA of SalinityLF1B2, SalinityLF2B2, SalinityLF2B4, SalinityLF3B2 and SalinityLF3B4 against SalinityLF1B4

		Sum of Squares	Df	Mean Square	F	Sig.
SalinityLF1B2	Between Groups	357826.752	3383	105.772	1.690	.000
	Within Groups	61317.225	980	62.569		
	Total	419143.977	4363			
SalinityLF2B2	Between Groups	392840.073	3383	116.122	1.881	.000
	Within Groups	60444.944	979	61.742		
	Total	453285.017	4362			
SalinityLF2B4	Between Groups	118936.058	3381	35.178	10.887	.000
	Within Groups	3163.257	979	3.231		
	Total	122099.315	4360			
SalinityLF3B2	Between Groups	36664.300	811	45.209	1.125	.052
	Within Groups	29171.740	726	40.181		
	Total	65836.041	1537			
SalinityLF3B4	Between Groups	36137.072	894	40.422	6.252	.000
	Within Groups	4726.250	731	6.465		

Total	40863.322	1625			

5.3 Mean Flow

Figure 14 shows the pattern of Berg 2 mean daily flow between October 2012 and March 2015. Flow gradually increased from the month of June 2013 and peaked at 798 $m^3 s^{-1}$ in the month of August 2013 (HF1). Thereafter, the flow gradually decreases until it gets to zero in the month of December 2013 (LF). The same trend was observed 2013/14 hydrological year, but with lower mean flow during HF as compared with 2012/13 HF. Further analysis using ANOVA also suggest there is significant difference between the two years. A similar phenomenon occurred at Berg 4. This is explained by the fact that the Western Cape is a winter rainfall region, with high flows coinciding with periods of high rainfall. Differences in flow between hydrological years will be a direct result of differences in annual rainfall.

Table 14 one-way ANOVA of FLOWHF1B2 against FLOWHF2B2 (CRITERIA=CILEVEL(0.95)).

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	73106790.143	3477	21025.824	7.068	.000
Within Groups	2415392.572	812	2974.621		
Total	75522182.715	4289			

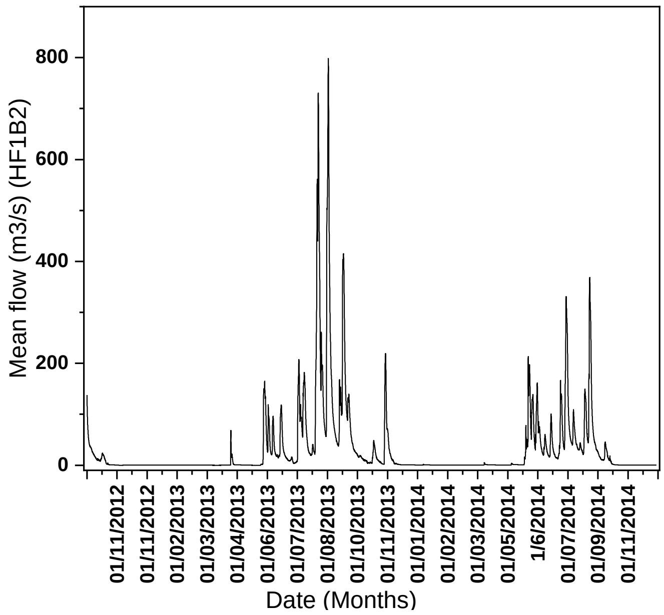

Figure 14: Time series graph of mean flow

5.4 Relationship Between the Parameters

Figure 15 and *Table 15* show there was a positive correlation relationship between temperature and salinity. There were seasonal changes observed during the entire study duration for both Berg 2 and Berg 4. During HF (especially the winter part (Berg 2)), when the temperature of the water decreases, the salinity of the water also decreases. This is because during "rainfall periods and associated freshwater inflow from the catchment, the mouth remained saline for longer periods during summer and winter". Also, when the temperature increases, the salinity also increases during LF. Though there seem to be relationship between temperature and salinity, it is noteworthy to state that the increase and decrease in salinity is actually co-incidental due to changes in flow. Flow is associated with rainfall, which is associated with the seasons (winter rainfall in the Western Cape). Therefore, increased salinity is not a result of increased temperature but is a result of lower flow which happens during summer when it is hotter and when it rains less. However, higher water temperature is directly associated with lower flow, and results in higher, more consistent salinity concentrations as the seawater is able to penetrate deeper into the estuary.

The relationship between the parameters were subjected to further test to see their correlation. Correlation was done using SPSS *(Table 15*), and it shows that the fluctuation of one parameter affects the others. For example, there exist a negative relationship (-0.650^{**}) between FLOWLF1B2 and salinityLF1B2. This mean if the flow is increasing the salinity is decreasing and *vice versa.*

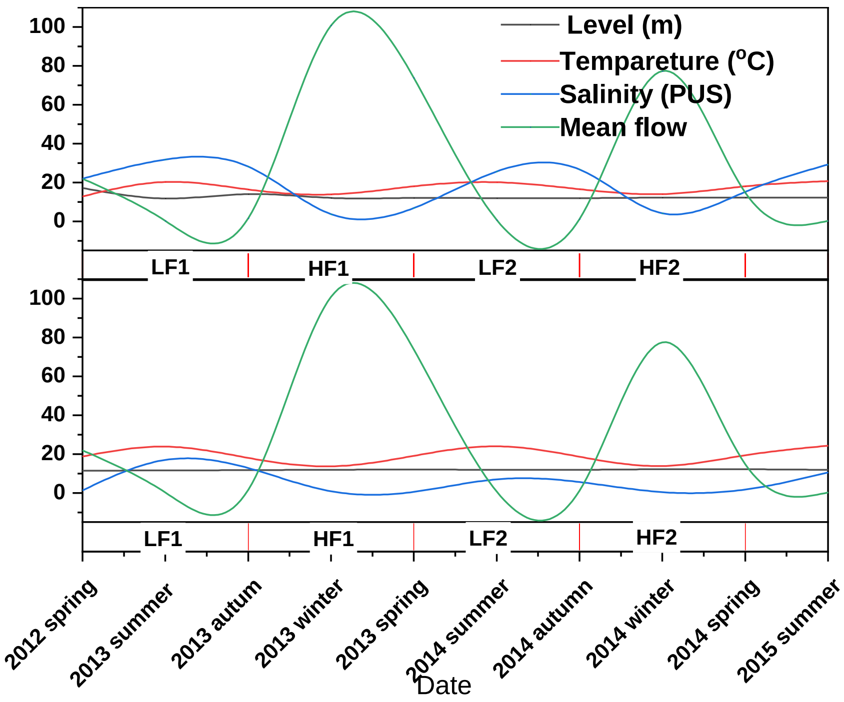

Figure 15: Time series graph of temperature, water level, mean flow and salinity.

Table 15 Correlations table of all the parameters for the 3 hydrological years

		LevelLF1B2	TempLF1B2	SalinityLF1B2	FLOWLF1B2	LevelHF1B2	TempHF1B2	SalinityHF1B2	FLOWHF1B2	LevelHF2B2	TempHF2B2	SalinityHF2B2	FLOWHF2B2
LevelLF1B2	Pearson Correlation	1	-.365**	.269**	-.024	.247**	.050**	-.208**	.087**	.573**	-.026	-.057**	.008
	Sig. (2-tailed)		.000	.000	.108	.000	.001	.000	.000	.000	.089	.000	.622
	N	4365	4365	4365	4365	3863	4365	4365	4365	4290	4290	4290	4290
TempLF1B2	Pearson Correlation	-.365**	1	.178**	-.214**	-.222**	-.347**	-.354**	.105**	-.171**	-.254**	-.540**	.196**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	4365	4365	4365	4365	3863	4365	4365	4365	4290	4290	4290	4290
SalinityLF1B2	Pearson Correlation	.269**	.178**	1	-.650**	.286**	-.621**	-.699**	.316**	.533**	-.628**	-.617**	.366**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	4365	4365	4365	4365	3863	4365	4365	4365	4290	4290	4290	4290
FLOWLF1B2	Pearson Correlation	-.024	-.214**	-.650**	1	-.120**	.416**	.427**	-.179**	-.210**	.463**	.411**	-.214**
	Sig. (2-tailed)	.108	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000
	N	4365	4365	4365	4365	3863	4365	4365	4365	4290	4290	4290	4290
LevelHF1B2	Pearson Correlation	.247**	-.222**	.286**	-.120**	1	-.122**	-.101**	.247**	.447**	-.021	-.023	.027
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000	.000	.191	.159	.098
	N	3863	3863	3863	3863	3885	3885	3885	3885	3788	3788	3788	3788
TempHF1B2	Pearson Correlation	.050**	-.347**	-.621**	.416**	-.122**	1	.519**	-.257**	-.304**	.582**	.648**	-.487**
	Sig. (2-tailed)	.001	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000
	N	4365	4365	4365	4365	3885	4387	4387	4387	4290	4290	4290	4290
SalinityHF1B2	Pearson Correlation	-.208**	-.354**	-.699**	.427**	-.101**	.519**	1	-.443**	-.509**	.409**	.807**	-.495**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000
	N	4365	4365	4365	4365	3885	4387	4387	4387	4290	4290	4290	4290

Continuation of Table 15 Correlations table of all the parameters for the 3 hydrological years

		LevelLF 1B2	TempLF1B2	SalinityLF1B2	FLOWLF1B2	LevelHF1B2	TempHF1B2	SalinityHF1B2	FLOWHF1B2	LevelHF2B2	TempHF2B2	SalinityHF2B2	FLOWHF2B2
FLOW HF1B2	Pearson Correlation	.087**	.105**	.316**	-.179**	.247**	-.257**	-.443**	1	.210**	.046**	-.402**	.403**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000		.000	.003	.000	.000
	N	4365	4365	4365	4365	3885	4387	4387	4387	4290	4290	4290	4290
LevelH F2B2	Pearson Correlation	.573**	-.171**	.533**	-.210**	.447**	-.304**	-.509**	.210**	1	-.299**	-.248**	.229**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000
	N	4290	4290	4290	4290	3788	4290	4290	4290	4290	4290	4290	4290
TempH F2B2	Pearson Correlation	-.026	-.254**	-.628**	.463**	-.021	.582**	.409**	.046**	-.299**	1	.384**	-.350**
	Sig. (2-tailed)	.089	.000	.000	.000	.191	.000	.000	.003	.000		.000	.000
	N	4290	4290	4290	4290	3788	4290	4290	4290	4290	4290	4290	4290
Salinity HF2B2	Pearson Correlation	-.057**	-.540**	-.617**	.411**	-.023	.648**	.807**	-.402**	-.248**	.384**	1	-.540**
	Sig. (2-tailed)	.000	.000	.000	.000	.159	.000	.000	.000	.000	.000		.000
	N	4290	4290	4290	4290	3788	4290	4290	4290	4290	4290	4290	4290
FLOW HF2B2	Pearson Correlation	.008	.196**	.366**	-.214**	.027	-.487**	-.495**	.403**	.229**	-.350**	-.540**	1
	Sig. (2-tailed)	.622	.000	.000	.000	.098	.000	.000	.000	.000	.000	.000	
	N	4290	4290	4290	4290	3788	4290	4290	4290	4290	4290	4290	4290

**. Correlation is significant at the 0.01 level (2-tailed).

Chapter 6

6 Conclusion

Climate change is affecting most global ecosystems. The Berg River estuary is a distinct and vital aquatic ecosystem in South Africa; and limited information exists on the effect of this estuary's response to climate change. Data (from 2012 to 2015) were collected from two Sites (Berg 2 and Berg 4) and analysed using Excel and SPSS packages. For the purpose of this mini thesis the data was limited to only four parameters (estuarine water level, temperature, salinity and mean daily flow). The results were divided into flows (low flows (LF) and high flow (HF). From the results, it was clear that temperature variations occur in the Berg River between seasons and at different sites in the river. The differences between sites and seasons were found to be highly significant, which may imply that climate change may have a negative effect on the Berg River if water temperatures continue to increase. In estuaries, temperature plays a major role in the ecological functioning thereof, and should changes affect these differences, it may have a catastrophic impact on the estuary. However, for the three years observed during this study, there was no significant increase in water temperature due to climate change or other factors. This may be because of the data set being too short to show a significant trend.

The salinity in the tidal river showed the typical pattern of higher salinity concentration at the mouth and lower salinity upstream, due to freshwater flows. As to be expected, statistical analyses also showed a significant difference between salinity concentration upstream and downstream in an estuary. Salinity showed a negative correlation with flow, with the rainfall season having a significant impact on the salinity patterns in the Berg River. A positive correlation was shown between temperature and salinity, but it was found to be coincidental.
It appears as if flow is a major driver in the Berg River estuary – as in most open-mouthed systems.
Based on this, the following recommendations for future management of the system can be made:

6.1 Recommendations (as per Objective 4)

- It is recommended that the hydrological data from these sites be expanded to at least 20 years, to enable the researcher to give a more accurate verdict of effect of climate change and provide information that can inform possible modelling.

- The study of the effect of climate change should be extended to other coastal regions of South Africa. This could include the east coast where there is more rainfall and results can then be compared between different rainfall regions.
- More analytical tools and mathematical models should be used to predict the further trend in key climate change factors. The more data is generated, the better these models can be informed.
- Integration of physical water quality data, with biological indicators of ecosystem health such as birds, fish, invertebrates and plants should be done, to create a holistic picture of the possible impacts of climate change.
- Instead of dividing the data using a seasonal approach based on typical calendar months (i.e., high flow = October to March and low flow = April to September) as done in this study, it is recommended that further work should be done by looking at the flow data. This should entail classification where average flow below a certain level (e.g., 5 m^3/s) is set as low flows and those above this level it is set as high flows. This will give a better understanding of the data as anomalies in flow levels do occur across the different flow seasons. This results in high flows being recorded during typical low flow seasons and vice versa.
- Implement and monitor the success of the estuarine management plan
- Continuation of with the monitoring programme on water quality of estuary
- Continuation of biomonitoring of estuary components as per the estuary management plans monitoring protocol
- Make provision for feedback to estuary management forum on water quality on a quarterly base and culminate in a year report
- Engage stakeholder through estuary management forum to solicit additional funding and support for monitoring effort align estuary management objectives with South Africa climate change strategies.

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