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Costs and Consequences at the Population-Environment-Development interface in St Francis Bay: Exploring the linkages of a Complex System

By

Geena Pringle

217442048

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Supervisor: Dr A. H. de Wit

Declaration

I, Geena Pringle, hereby declare that this thesis entitled: **Costs and Consequences at the Population-Environment-Development interface in St Francis Bay: Exploring the linkages of a Complex System**, submitted for a Master of Science in Geography at Nelson Mandela University is of my own work. Work of Authors who were included in the project has been credited. It has not been submitted previously for any other degree at any other University.

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Abstract

Coastal zones the world over are particularly attractive for the development of human settlements. Naturally, this trend frequently results in human induced disturbances of sensitive ecosystems, often resulting in dramatic and unintended consequences. The South African coastline is no stranger to this phenomenon. Dynamics at the population-environment-development interface in the coastal zone often presents affected communities and institutions with complex challenges. An infamous case along the South African coastline is the settlement of St Francis Bay, the focus of this dissertation. St Francis Bay was established as a holiday village around sixty years ago and its economy is today firmly dependent on the fragile bond and reciprocal relationship between the tourist trade and the integrity of sandy beaches. The dissertation, against this background and drawing from complex systems theory, explores the links between human activity and the bio-physical environment and the ominous costs and consequences that are produced at the local population-environment-development interface. Domains that are considered within the nexus of relevant aspects include the wind-driven sediment bypass system across the local headland; climate change; the local economy; social wellbeing, inequality and social justice; as well urban planning and political governance. The desktop study applied to St Francis Bay made use of Geographic Information Systems and statistical information to form the basis of the methodological approach in this dissertation. The Population-Environment-Development nexus was formed as a result. The results illustrate how critical levels of beach erosion are connected amidst an intricate reciprocal nexus to these and other aspects. It demonstrates that the sustainability of the settlement hinges on the understanding of such linkages and underscores the relevance of the methodological approach that is applied. The sustainability of the environment and the resulting impact on the quality of life of the human population remains a challenge for future generations as well as governance systems. By acknowledging and understanding the complexity that exists in coastal zones allows for future research on the topic to be explored and enable key role players to proactively intervene to benefit the population and the environment.

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List of Acronyms

CBA	Critical Biodiversity Areas
DPSIR	Driver-Pressure-State-Impact-Response
ECBCP	Eastern Cape Biodiversity Conservation Plan
EIA	Environmental Impact Assessment
ESA	Ecological Support Areas
GDP	Gross Domestic Profit
GIS	Geographic Information Systems
HDI	Human Development Index
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
MA	Millennium Ecosystem Assessment
NBA	National Biodiversity Assessment
NEMA	National Environmental Management Act
NSIP	Nuclear Siting Investigation Programme
NVM	National Vegetation Map
PED	Population-environment-development
PES	Present Ecological State
PDP	Provincial Development Plan
RDP	Reconstruction and Development Programme
SDG	Sustainable Development Goals
SRA	Special Rating Area
UOG	Unconventional Oil and Gas
WEF	Water-energy-food
WGS	World Geodetic System

CHAPTER 1: INTRODUCTION

1.1. Background

Coastal zones are dynamic, responding to natural processes and human activities where natural processes include sediment transport, climate (fires and floods), erosion and human activities, namely, tourism, fishing and trade. Coastal zones offer a variety of ecosystem goods and services such as food, water, wood, nutrient cycling and aesthetic services. This contributes to the appeal of human settlements (Palmer *et al*., 2010) as does much of the human activity in the world inclusive of people residing in the coastal zones. These zones are naturally multi-faceted environments with different components which are interlinked (Esterhuyse *et al*., 2016). The complexity of these systems requires a framework in order to be analysed. One approach that has emerged in understanding complex systems is through a Population-environment-development (PED) nexus. This conceptualizes complex systems that exist among population, environment and development domains where the domains are in constant and dynamic interaction (Pelser & Redelinghuys, 2008).

Coastal zones are undergoing high levels of development due to their popularity. This would include job creation from the fishing industry and the aesthetic value of living close to the coastline and having an ocean view. These zones have different components, including cultural (urban development) and biophysical components. Population growth in coastal zones places greater than before pressure on the coastal environment as the land cover is altered to provide accommodation for residential development, tourist attractions, ports and marinas (Palmer *et al*., 2011). According to La Cock & Burkinshaw (1996), a large proportion of human settlements and their socioeconomic activities occur on land close to the shorelines, and it is estimated that 60% of the world's population lives within 60km of the coastline. In South Africa, 40% of the population lives within 100km of the coastline (Figure 1.1) (Wigley, 2011). This results in enormous pressure on the coastal zones. As coastal zones offer ecosystem goods and services, it contributes towards the attraction of human settlements and activities relevant to these zones (Palmer *et al*., 2010). This forms a relationship between the population, environment, and development domains.

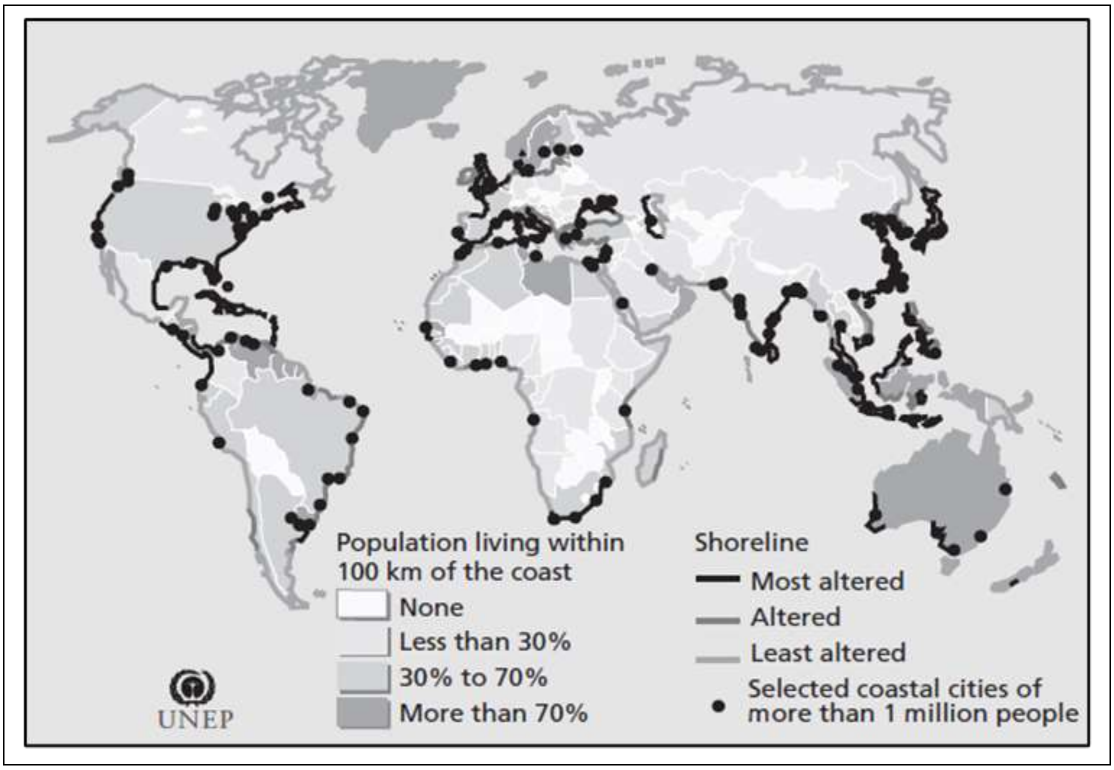


Figure 1.1: Coastal populations and shoreline degradation in the world

Source: Creel. 2003

A major climate change threat to South African coastal zones is sea-level rise, and coastal zones are considered most at risk from these impacts (Fitchett *et al.*, 2016). The impacts of climate change are affecting ecosystems and communities on both a global and local scale (Parmesan, 2006). As many coastal towns are dependent on the environment for their livelihood through the creation of jobs, there is a social concern with regards to employment, income and poverty. GhulamRabbany *et al*. (2013) identify climate change as a major threat to tourism. Climate change influences the economic value of the tourism sector and therefore this sector can therefore be considered as climate-sensitive (Law *et al.*, 2012).

Coastal towns attract many tourists and this may have resulting threats which can have extensive economic effects and may compromise the feasibility of the tourism sector (Fitchett *et al.*, 2016). Coastal environments may suffer from the increase in the tourism sector, and this has led to the environment and the community having greater vulnerability to incoming sensitivities (Mustelin *et al.*, 2010). The vulnerability of the environment arises as more tourist resorts, roads and recreational spaces are built to accommodate the growing population. Due to the socio-ecological feedbacks, a community can become environmentally and economically fragile (Elliott, 1998). As pressure on coastal zones increases due to human and environmental factors, there is a need for frameworks that can be used to conceptualise complex systems (Lewison *et al.*, 2016). The application of the framework allows for an improved understanding of interacting ecological and societal processes and the arising management solutions of these coastal systems.

The various components interact as a system and this will result in various outcomes. An example would include climate change and the rise in sea-level causing an increase in erosion. It is important to understand these outcomes, as unintended consequences may arise, such as beach erosion. In Florida, the United States, extensive erosion is evident as the designation of critical erosion constitutes for over 50% of the sandy beaches of the coastline (Marshall *et al.*, 2011). Increasing development has acknowledged the ecological impacts which arise from this. The extent of the ecological impact of the coastal development on beach ecosystems is considered to be significant.

The nexus concept builds on the foundation of many approaches by highlighting the importance of understanding the connections, synergies and trade-offs of the model (Liu *et al.*, 2018). The multiple interactions among population, environment and development are best described as a "nexus of interrelationships" (Groenewald, 2011). Understanding the complex and dynamic relationships between people and their surrounding environment is crucial for environmental management and sustainability (Blaikie *et al.*, 2014). Complex systems consider systems, such as the terrestrial environment which consist of various components, and the interactions that occur within these systems. The theory focuses on a theoretical understanding of systems that cannot be understood by examining individual components only but needs to be understood by examining the components holistically (Theise & D'Inverno, 2004; Coetzee, 2021). These systems are represented by a network where nodes represent the components and links represent the interactions among the components, such as with a nexus. Systems differ from each other due to how the components depend on and affect one another (Siegenfeld & Bar-Yam, 2019). For any complex system, there is a tradeoff and feedback among the components.

The Driver-Pressure-State-Impact-Response (DPSIR) framework provides an overview of the large-scale drivers that affect and influence the environment and as Palmer *et al*. (2011) states this emphasises the need to "address the impacts that result from change" in order to manage the resulting changes from the impacts (Christian *et al.*, 2005). This links relationships among components and assesses societal and ecological change in coastal zones which have been exposed to anthropogenic influence (Gari *et al*., 2015). The link between social and ecological systems has been acknowledged but less attention has been given over the years to understanding the importance of the interactions involved among all the components that exist within systems (Bowen & Riley, 2003). It is important to have a well-defined understanding of the components which form part of the system. The significance of the study is to understand the relationship and linkages among development, population and the environment in the form of a nexus. This contributes to how the population and the different inequalities that exist within the population are affected by the alterations which occur with changes in the environment and associated development.

The South African coastline has various examples of coastal developments, with an infamous example being that of St Francis Bay. Development in St Francis Bay as escalated over the past 60 years in a sensitive ecosystem zone and this has produced unintended consequences. A complex systems approach applies to the study of St Francis Bay as the town is characterised by a variety of components across the human and physical environment. Developing the nexus conceptual framework is crucial to identify complex relationships across various domains and the reciprocal dynamics that may arise and the resulting consequences. This provides a foundation for further analysis in research (Liu *et al.*, 2018). These linkages will aid with future management plans and improve the quality of life of the residents and tourists. The complex nexus approach is considered beneficial from an environmental management and socio-economic development planning perspective to explore and understand the PED linkages in coastal such as with St Francis Bay. The sustainability of St Francis Bay therefore hinges on the understanding of the linkages which exist within the nexus.

This is the implication of the title as it considers the costs and the consequences resulting from these costs which assume that there is systematic behaviour involved among the components of a complex system. Through exploring a complex system, it will identify the components and analyse the linkages in a system, where the framework of a complex system will have an influence on the methodology throughout the study. The study research questions and objectives will conceptualise this concept.

1.2. Research Questions

The study will attempt to answer the following questions:

1. What are the major attributes of St Francis Bay's physical and human geography? For instance, the ecological characteristics, as well as the social and economic attributes and the functioning thereof.
2. What linkages exist at the population-environment-development interface in St Francis Bay? For example: the linkages between physical and human activities (beach erosion and the socio-economic status in the township)
3. What is the nature of the linkages with regards to feedback loops and reciprocal dynamics between the components?
4. What are the severity and the significance of the consequences of the linkages?

1.3. Research Aim and Objectives

The aim of the study is to conceptualise and analyse the PED nexus as a complex system as it manifests in St Francis Bay.

In order to achieve the aim, the following objectives are pursued:

- Providing a theoretical overview for the study by examining existing research with regards to complex systems in coastal zones and the reciprocal relationships which may arise from this.
- Identify the PED components and analyse their position and functionality within a complex system.
- Identify and analyse the nature and dynamics of the complex system.
- Identify costs and consequences of this dynamic.
- Predict the costs and consequences of future change in the complex system.
- Describe the implications of the identified reciprocal relationships of the components within the nexus as it applies to St Francis Bay.

1.4. Study Area

The study area of St Francis Bay is located along the southern coastal margin of the Eastern Cape Province, South Africa (Figure 1.2). The area is part of the Kouga Municipality in the Sarah Baartman District. St Francis Bay covers an area of 10.04km^2 with a population which consists of approximately 4933 people (Stats SA, 2011). Within this area, 396 people live in the Sea Vista zone, 4512 people in the main St Francis Bay zone and 25 people in the St Francis Links zone (Figure 1.3).

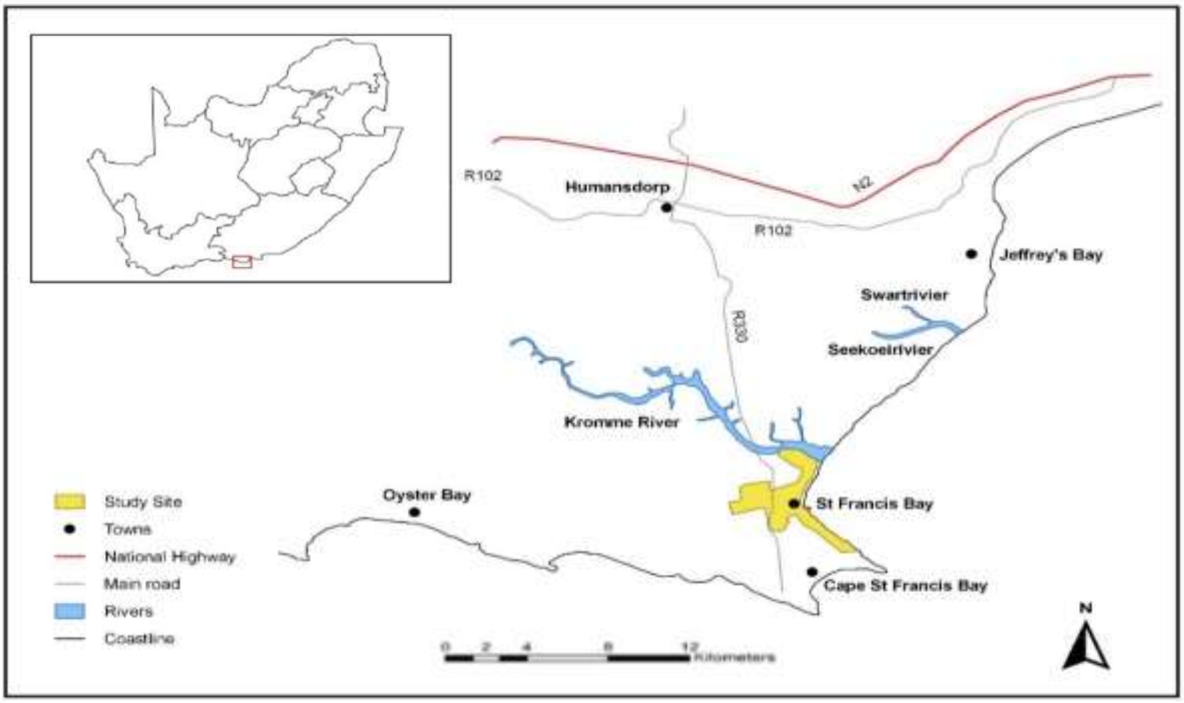


Figure 1.2: Location of the study site of St Francis Bay, Eastern Cape.

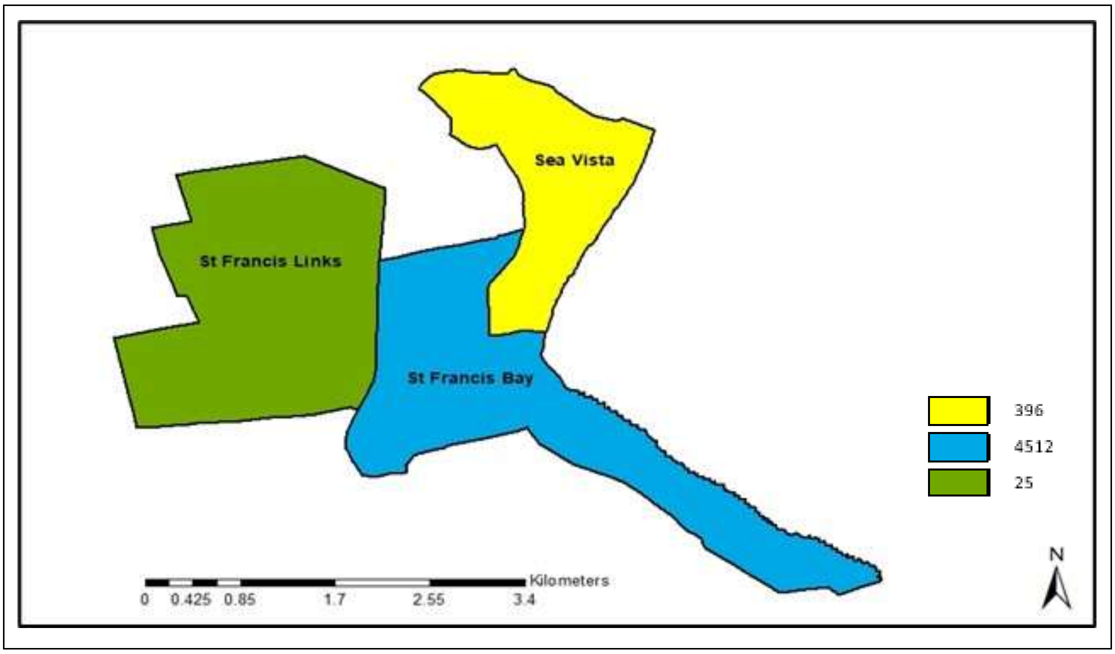


Figure 1.3: The number of people who live in each zone of St Francis Bay.

St Francis Bay is described by LeBlond (2006) as a "logarithmic-spiral bay", as the rocky points at Seal Point and Cape St Francis have resulted in the formation of a headland-bypass system. This formed from the waves being diffracted by the nearby headland which is sheltered. These spiral bays have its origin in the Cape Fold Belt as folding and faulting produced capes consisting of resistant Table Mountain quartzite (Rust, 1991). The capes anchored a spiral bay with less resistant Bokkeveld shale.

As stated by Schroeder (2015), sand spits are dynamic in the coastal zone and are "easily disturbed by human interference." The stabilisation of the headland bypass dunefields (further explained in Section 2.3.4 of Chapter 2) for the expanded development of St Francis Bay, led to the reduction in sediment supply (van der Weide *et al*., 2001) to the St Francis Bay beach and therefore resulted in shoreline retreat. Due to this and the increase in sea-level and storms, an artificial spit was constructed from the beach into the Kromme estuary with the dredged sand from canal construction in order to limit the natural movement of the Kromme estuary, wave action and erosion and thus reduce the impact on the houses in the Marina. This spit has implications for St Francis Bay further described in the study.

1.5. Study Justification

The nexus concept emphasizes the importance of understanding the connections and feedbacks which take place within a system (Liu, *et al*., 2018). The nexus concept is rapidly expanding in literature, mostly in the form of the Water-Energy-Food (WEF) nexus (Albrecht *et al.*, 2018) with research by Dargin *et al*. (2019), Markantonis *et al.* (2019), Simpson *et al.* (2019), Torres *et al.* (2019), Laspidou, *et al.* (2018) and many more. There is a shortage of research using the PED nexus as a framework. One recent publication was by Esterhuyse *et al.* (2016) on unconventional oil and gas extraction in South Africa. More research is required to have an improved understanding of the dynamics of a PED nexus within a complex system. The study aims to start bridging the gap in the limited research on the PED nexus in South Africa. As mentioned by Esterhuyse *et al.* (2016), it is important to understand the linkages that they examined in their study to "aid in the development of integrated policy for the protection of environmental resources and the human population".

There is increasing awareness of the importance to include population, environmental and development issues in decision-making surrounding environmental issues, especially in coastal zones. With the aid of future research this will allow for integrated policies to be developed and implemented that will be beneficial to both the human population and the surrounding environment. It is critical to understand the PED nexus to identify potential consequences arising from the linkages and demonstrate how sustainability relies on the understanding of these linkages in the nexus. A nexus approach will contribute to a better understanding of the complex and dynamic interrelationships (Food and Agriculture Organization of the United Nations, 2014) that exist among the population, environment, and development in order for sustainable human development to occur.

The South African coastline is no exception to the increase in development and the resultant coastal vulnerability. For example climate change impacts and coastal erosion may lead to collapse of aquatic and terrestrial ecosystems. Land cover change may also result in an alteration of the coastline and surrounding ecosystems. The increase in human activities and the resulting pressures in coastal zones are of global concern. Popular semi-gration areas in South Africa are along the coastline due to the multiple functions these coastal zones offer such recreational, commercial and light industrial activities resulting in rapid urbanisation. As a large proportion of human settlements are in coastal zones, it is of concern how further development along the coast will have an impact on the bio-physical environment (Neumann *et al.,* 2017). As stated by Goble & van der Elst (2012), "development in coastal areas is inevitable", and although the development can contribute to the economy and well-being of the towns, it must be effectively regulated and managed. In 2022, Durban experienced devastating floods. The most vulnerable and hardest-hit areas were the informal settlements built close to rivers, in low-lying areas (ABC News, 2022). The socio-economic losses associated with the floods were significant as lives were lost and many casualties as well as damage to infrastructure. This demonstrates that human activities in fragile ecosystems, such as the coastal zone, should be understood especially in terms of costs and consequences. Therefore there is a necessity for information on the PED nexus along coastlines. This is to promote sustainability as well as enhance the viability of coastal zones. The growing pressures on the coastal zones highlight the importance of coastal development management and that sustainable development along the coastal zones is critical (Goble & van der Elst, 2012).

1.6. Study Outline

In line with its objectives, this study is divided into the following five chapters:

CHAPTER 1 commences with a general introduction of the research problem, during which the concepts of complex systems, the population-environment-development nexus and DPSIR framework are introduced. The study aim and objectives are outlined.

CHAPTER 2 discusses the theoretical foundation of the study. The concept of complex systems is introduced, and the categories of complex systems are explored. The population-environment-development nexus and the attributes which form part of the nexus in coastal zones are reviewed. The Driver-Pressure-State-Impact-Response framework is discussed in terms of the nexus concept. Government policies are included in the chapter which is applied in the case of the nexus concept.

CHAPTER 3 describes the chosen study site of St Francis Bay and the methodology applied in the study. This chapter provides background of the study area and the major attributes are mentioned. The methodology follows a mixed-methods approach, with a time-sequential series, thematic analysis and desktop analysis. This creates the component which will be applied in the PED model.

CHAPTER 4 presents the findings of the research. A time-sequential series is first examined as to how the coastal landscape of St Francis Bay has changed over a certain time period. This is followed by a desktop analysis of the quantitative method. A cost estimate of rates and levies for properties is presented due to the damage towards the coastal zone. The cost estimates of mitigation plans towards the coastal zone are also presented. The estimated sea-level rise for St Francis Bay has been included. In terms of qualitative research, a desktop analysis presents the social standings of the town of St Francis Bay. Following this, a thematic analysis is applied to determine the attributes which will form the PED model and the DPSIR Framework. Both methods contribute towards the formation of the PED-nexus model.

CHAPTER 5 discusses the findings of the results in the research in terms of complex systems and the population-environment-development nexus. The various linkages and feedback loops which exist amongst the components are interpreted. The findings of the literature are compared with the results obtained in the research. Following this, the DSPIR Framework is presented and examined in terms of St Francis Bay. Management solutions are further explored in the chapter to mitigate the consequences of the nexus.

CHAPTER 6 contains a synthesis of the study, outlining the key findings of the research. The knowledge gaps are addressed and recommendations are made for future research.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Coastal zones are preferred for human activities as these areas are considered to have the greatest biological productivity (Turner *et al*., 1996), abundant amenity and aesthetic value (Luijendijk *et al*., 2018). As a result, these zones have become severely populated and developed. The development and the associated use of coastal zones have greatly increased during the past few decades and therefore coastal zones are experiencing socio-economic and environmental change (Neumann *et al*., 2015). Human activities in ecologically sensitive coastal zones appear to be the catalyst for complex and reciprocal interactions between natural and man-made processes. This chapter reflects on research on the impact of human development and socio-economic activities in the coastal zone and vice versa. Coastal zones reflect patterns of population development, and these are linked to global trends of growth and urbanization (Neumann *et al*., 2015).

The world is becoming complex as the network of interaction has increased. Complex systems can comprise any combination of human, animate and inanimate components (Tyler & Cohen, 2021). Ecosystems and humans are interrelated and interdependent as stated by Peng *et al*. (2016). The factors which may be responsible for a change in the coastal zone, as described by Labuz (2015), may be grouped into "geological and geomorphological, hydrodynamic, biological, climatic and anthropogenic factors". Geological factors would include sediment type and the resistance of sediment structures, thus forming the basis of morphological processes. Geomorphological processes are influenced by climatic factors. Anthropogenic factors refer to human activities that occur within the coastal zones, such as settlements, industrial development and coastal protection (Labuz, 2015). Coastal processes experience change that varies in geographic scale and duration and this creates dynamic coastal systems (Crossland *et al*., 2006). These systems are vulnerable to pressures from human activities. As Creel (2003) states, government and coastal resource managers are challenged as to how to maintain the economic benefits of coastal resources as well as to preserve the resources for future generations.

The chapter starts by introducing the nexus concept and the theoretical frameworks relevant to the concept. The DPSIR and Millennium Ecosystem Assessment provide frameworks that are applied in the methodology. The biophysical and cultural components which occur in coastal zones are introduced and explored. The components include the headland bypass dunefields, coastal erosion, urban development, tourism in coastal zones, economic activities, socio-economic and political dynamics and how these components interact. The concept of complex systems will be explored and the various categories of complex systems which exist. The chapter concludes with a background to

Government policies along coastal zones and the Integrated Development Plan as proposed by the Municipality.

2.2. Theoretical Frameworks

The following section provides an overview of the theoretical frameworks applicable to this dissertation. Frameworks that will be explored include the population-environment-development nexus, the Driver-Pressure-State-Impact-Response (DPSIR) framework, sustainable development in coastal zones and the Millennium Ecosystem Assessment (MA). Some of the theoretical frameworks are a practical assessment tool to understand the linkages in the nexus. These frameworks will be discussed as related as well as complementary frameworks to the PED nexus, formulating the nexus model of St Francis Bay in Chapter 5.

2.2.1. Population-environment-development nexus concept: An explanatory overview

Complex linkages exist between the biophysical and social environments, and these can be shaped and represented into an "analytical systems framework" known as the population-environment-development nexus (Hummel *et al*., 2013). The PED-nexus framework forms the foundation for analyzing "international and national policy frameworks" (Hummel *et al*., 2013) (Figure 2.1). The nexus concept emphasises the importance of understanding the connections, synergies and trade-offs that exist and occur within a certain environment (Liu *et al*., 2018). The nexus approach consists of two dimensions, interdisciplinary and transdisciplinary. The interdisciplinary dimension addresses the complexity of linkages among resources, systems, and sectors by highlighting the trade-offs and synergies between the components (Endo *et al*., 2020), whereas the transdisciplinary dimension enhances the collaboration with diverse groups of stakeholders and improves governance across sectors systems thinking is enhanced into government policy-making processes and balances different interests (Endo *et al*., 2020).

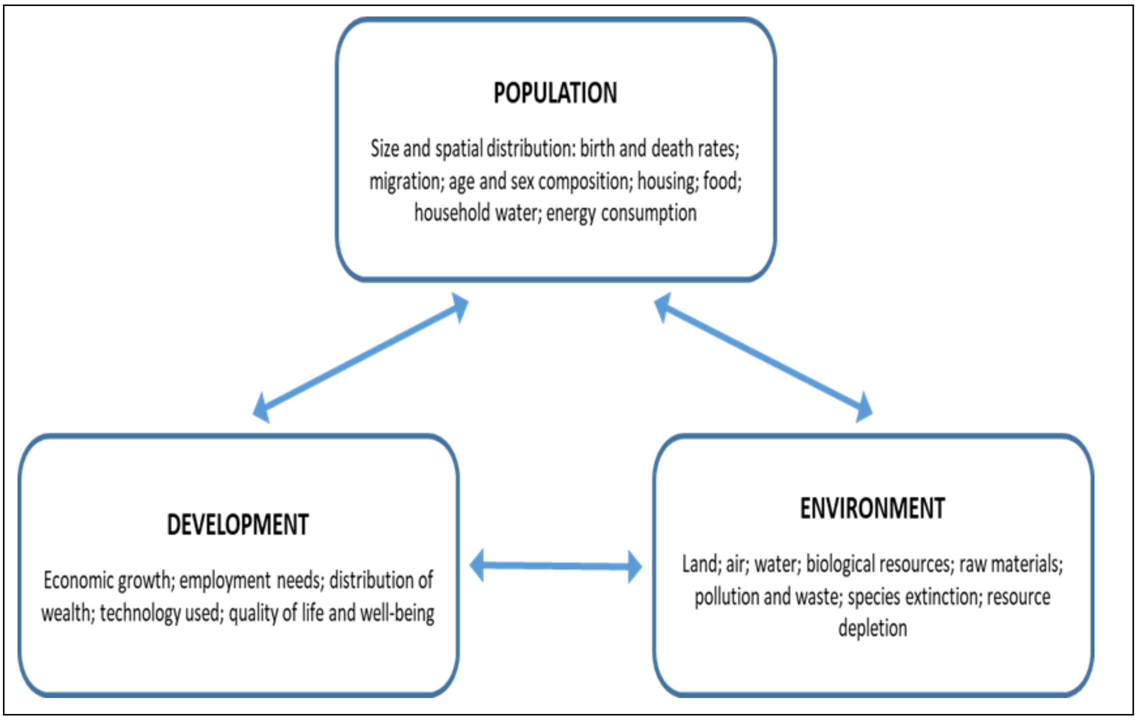


Figure 2.1: The Population-Environment-Development Nexus

Source: Adapted from Pelser & Redelinghuys, 2008

Dargin *et al*., (2019) state the complexity of the nexus model improves the ability to better represent specific nexus interlinkages in an area, but is also unable to capture all of the possible interlinkages among the various nexus components of a system. The nexus concept has expanded to include other resources and disciplines such as land use, climate, economy, ecosystems and health. This allows the nexus model to be more "multi-dimensional and interdisciplinary" in its approach in understanding the relationship between people and their surrounding environment (Laspidou *et al*., 2018).

The application of the nexus concept in policy and decision-making processes are limited due to the complex dynamic nature of a certain system and the shortage of integrated tools that are capable to produce and model these nexus interlinkages in a system (Laspidou *et al*., 2020). As resources are tightly interlinked and the use of one requires the presence of the other, resource use involves complex interactions and potential conflicts among nexus components (Laspidou *et al*., 2018). Different resources have unique characteristics and complexities that are defined by physical resource constraints as well as stakeholder nature and involvement (Dargin *et al*., 2019), as no single model is able to cover an entire range of complexities within a system.

By involving stakeholders in the different sectors, the nexus approach can promote cooperation, coordination and policy coherence (Ross & Connell, 2016). The development of the nexus conceptual framework is essential to clarify the complex relationships across various sectors and provide a foundation that can be applied for further analysis, as stated by Liu *et al*. (2018). The integrated management of these resources by applying this approach should be used to increase resource-use efficiency and to minimise environmental risks and ecological degradation (Brouwer *et al*., 2017). In order to achieve Sustainable Development Goals (SDGs), it requires all relevant stakeholders to manage the trade-offs arising among the different governance sectors (Liu *et al*., 2018). New integrated approaches are needed to address the challenges presented by multiple and conflicting human needs and demands as well as to achieve Sustainable Development Goals successfully (Liu *et al*., 2018).

A study conducted by Esterhuyse, et al. (2016), explored the population-environment-development nexus. The study examined the reciprocal impacts of unconventional oil and gas (UOG) within the nexus, with linkages between energy and water, water and agriculture, and water and human population. By identifying the linkages that exist between the components, it will aid in the development of policies for environmental management as well as promote the sustainability of UOG extraction.

In a study by Simpson *et al*. in 2019, they explore the impact of coal mining on the water-energy-food (WEF) nexus in Mpumalanga. The study evaluates the relationships among agriculture, such as food security, and coal mining (fossil fuel energy) and how these deteriorate the quality of water from the occurring activities. This highlights the "interconnectedness" of energy, food and water and the trade-offs which arise from this nexus. Policies and planning initiatives may therefore be formed to lead towards sustainable development.

Coastal zones, areas that are experiencing a growing proportion of the world's population, are experiencing environmental decline in turn (Creel, 2003). With more of the world's population living and migrating to the coastal zone, there will be an increase in demand for coastal leisure as well as tourism infrastructure. People who live in the coastal zone will be at the forefront of climate change and will suffer disproportionately from the effects of sea-level rise and weather events. Coastal erosion and environmental degradation are accelerating along many coastal zones of the country due to natural and anthropogenic activities occurring (Senevirathna *et al*., 2018). Due to the abundant natural resources, urbanization and population rapidly increase in these zones.

2.2.2. Driver-Pressure-State-Impact-Response Framework

The DPSIR framework identifies and presents a visual representation of the cause and effects of the relationships which exist among components in society and the environment (Smaling & Dixon, 2006; Tscherning *et al*., 2012). Links are formed within the framework among the categories and create feedback loops among the categories and the components which exist within the five categories (Figure 2.2). The five categories include driving forces, pressure, state, impact and response. The information which has been obtained from the DPSIR framework has contributed to the development of Integrated Coastal Zones Management (ICZM), as stated by Gari *et al*. (2015). This framework is a management tool used to analyze environmental problems by establishing relationships among anthropogenic activities and the environmental and socio-economic consequences (Gari *et al*., 2015). The DPSIR approach can be applied to most ecosystems.

As stated by Kristensen (2004), *Driving Forces* is the first category in the framework. *Drivers* of the framework define the social, demographic and economic development that occurs in a society. These include population, land use, transport and agriculture. *Driving forces* exert *Pressures* in an environment, where human activities apply pressure on the environment due to the excessive use of environmental resources and changes in land use. As a result of the *Pressures*, the *State* of the environment will experience a change. This can include air quality, water quality and soil quality. This forms part of a combination of physical, chemical and biological conditions. From a change of *State*, this may lead to *Impacts* on the environment. The changes in the physical or biological state of the environment will determine the quality of the ecosystems and therefore the welfare of human-beings. Changes in the State category may have resulting environmental or economic impacts on the ecosystem. A societal *Response* will arise from the *Impacts* on the environment and society where the *Response* may create a feedback to *Drivers*, *Pressures*, *State* or *Impacts*. This can affect any part of the chain between driving forces and impacts (Kristensen, 2004).

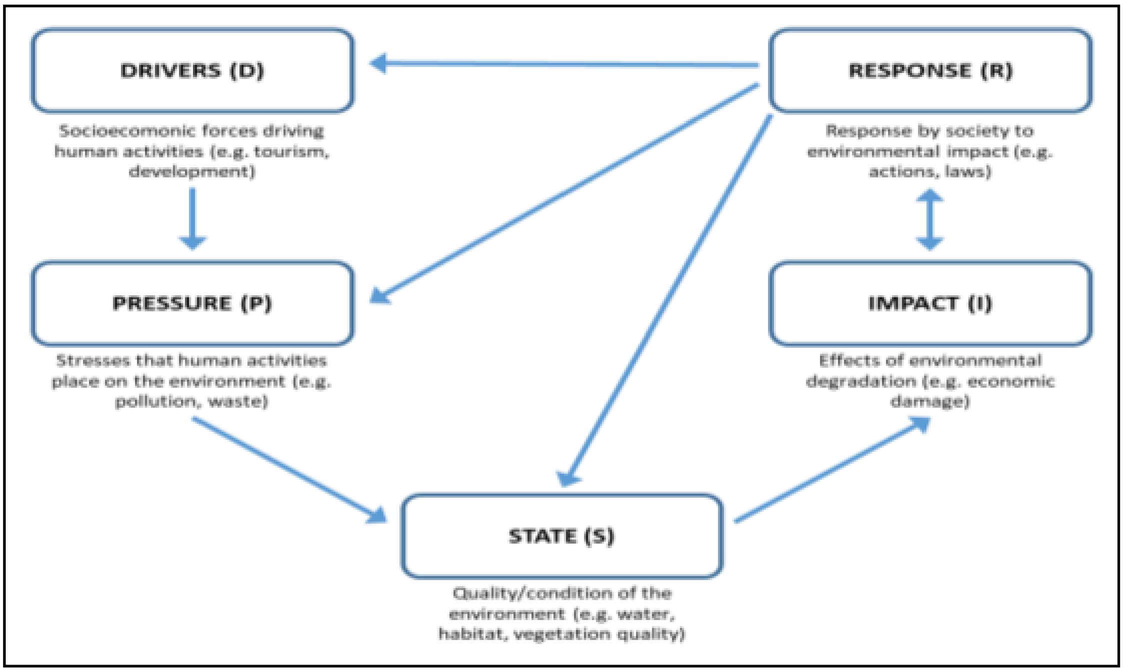


Figure 2.2: The DPSIR Framework Source: Adapted from Bowen & Riley (2003) and Kristensen (2004)

The DPSIR framework was applied to a study by Caiero *et al*. (2004) in the Sado estuary, Portugal. The study conducted was to propose a coastal management system in order to resolve the conflicts between development and conservation goals along the estuary. Having identified the appropriate indicators along the estuary, the environmental quality was assessed through the state and impact indicators of the framework and the results from this were incorporated with the driver and pressure indicators. Combining this framework with other methods allowed the authors to predict the zones in the estuary which are vulnerable to pressure and to implement appropriate management policies (Gari *et al*., 2015).

In another study by Mangi *et al*. (2007), the DPSIR framework was applied in Kenya. The framework was used to analyse socio-economic issues, environmental changes and policy measures in coastal zone fisheries. The authors identified variables belonging to the coastal fishery categories of the framework and the corresponding indicators were developed. The state of the corals caused by the pressure exerted by the socio-economic drivers was presented (Gari *et al*., 2015). This indicates the relations between the socio-economic and ecological conditions of Kenya and how it can be applied to other coral ecosystems. This also allows for management solutions to be identified and implemented.

There is a need to understand how humans benefit and impact coastal environments (Lewison *et al*., 2016). The DPSIR framework has the ability to integrate knowledge across various disciplines and create and present policies. Although the DPSIR framework is useful in the visual representation it presents, it is warned that the world is more complex than can be expressed in certain visual scenarios. A need for clear and specific information is stressed (Gari *et al*., 2015) in the categories for decision-making to occur and for policies to be implemented and applied in the case of St Francis Bay.

2.2.3. Sustainable Development: A concept in coastal zones

A commonly known definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Nair *et al*., 2012). Sustainable development depends on three dimensions: environmental, economic and social. The definition of an SDG for oceans and coasts is, as stated by Visbeck *et al*. (2013), "the formulation of a set of specific targets and the development of an underlying indicator set to measure these objectives are essential elements of a prudent ocean management strategy."

Coastal zones are vital to achieving Sustainable Development Goals, due to their importance for human habitation, employment, resource provisioning as well as cultural practice, according to Singh *et al*. (2021). It is also stated by Singh *et al*. (2021) that the "land-sea interface", where these areas are in need of frameworks to meet SDGs, are "inherently interconnected" and therefore incorporates the complex interdependencies among human livelihoods, the environment and energy. Coastal zones are highly impacted by human activities and the associated land-based pressures, including increased erosion and sedimentation, nutrient loading and pollution due to urbanization. As coastal zones are ecologically complex, sustainable coastal development is important to achieving SDGs. Coastal zones have the potential for complex dynamics across the social, economic and biophysical dimensions of the SDGs (Singh *et al*., 2021).

Various social, economic, and political activities intersect with natural processes in the coastal zone (Alencar *et al*., 2020). Sustainable development along the coast requires a holistic perspective that instills social, economic, and governance dimensions as well as environmental (Visbeck *et al*., 2014). The management of complex systems, as stated by Rumson *et al*. (2017), including coastal zones, requires data that can lead to an understanding that can be applied across multiple disciplines in order to link the environment with societal activities. It is important to note that the data presented should not be seen as individual inputs but rather seen as holistically that integrates components of human and natural systems in order to understand the socio-economic and environmental interconnections that exist and therefore create sustainable development.

Environmental goals with regards to water (SDG 8), climate (SDG 3), ocean and coasts (SDG 14), and terrestrial ecosystems (SDG 15) have been integrated to ensure that the SDGs are more comprehensive than before (United Nations, 2016). The sustainability challenges of coastal zones are interconnected across time, space and organizational levels. It is therefore important to link this disconnected information. Understanding the changes presented across the disciplines is crucial for holistic and integrated policy and management decisions (Liu *et al*., 2015; Rockström *et al*., 2009).

2.2.4. The significance of the Millennium Ecosystem Assessment in a research context

Human demands on ecosystem services are rising. The Millennium Ecosystem Assessment (MA) is the assessment of the human impact on the surrounding environment and how changes in ecosystem services have affected human well-being. The MA focuses on how ecosystems changes may affect people in the future, influencing the sustainability of the area and what type of mitigation options can be adopted in order to improve ecosystem management, and human well-being and therefore relieve poverty.

The Millennium Ecosystem Assessment was established in 2001 by international institutions to examine how ecosystem services and human well-being are interlinked. This assesses the resulting consequences of ecosystem change for well-being and the complex links that exist between ecosystems and human well-being, thus creating a conceptual framework. The MA framework places well-being as the center focus for assessment and ecosystems has essential value.

The MA framework assumes that a dynamic interaction exists between people and their surrounding ecosystems. This includes the change in human activities affecting change in ecosystems and the reciprocal changes resulting in the ecosystem. This causes changes in human well-being. Quality of life and the environment are interrelated as one's lives are affected by the quality of the environment (King *et al.,* 2018). Human well-being is described as a state where human needs are met, one can act to pursue one's goals and have a satisfactory quality of life (King *et al.,* 2018). Well-being also includes social and psychological needs. The quality of life experienced can impact a sense of well-being.

The model (Figure 2.3) flows from ecosystem services on the left to constituents of well-being on the right. The width of the arrows indicates the importance of the links between the components, with a wide width suggesting a strong link. MA stresses the components of the ecosystem concept and human well-being (Braat & de Groot, 2012), exploring the nexus concept and the complex links which arise between these two components. The arrow with the highest potential for mediation by socioeconomic factors and the strongest intensity of the link is that between provisioning (food, fresh water and fuel) and that of basic material for a good life (shelter, adequate livelihoods and access to nutritious food).

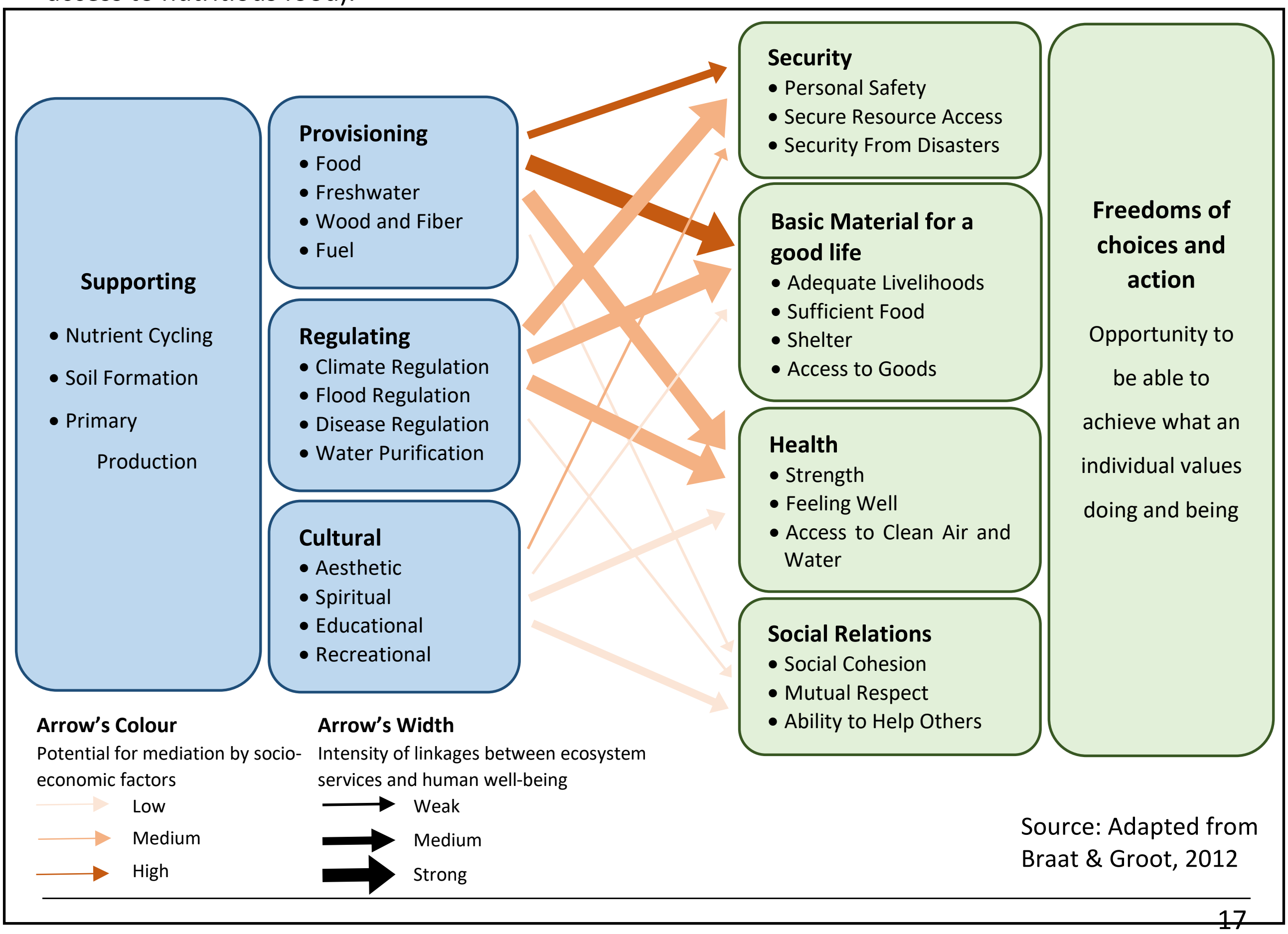


Figure 2.3: Overview diagram of the Millennium Ecosystem Assessment

The MA contains a methodological approach and presentation style which can be applied to the case of St Francis Bay. The management of the relationship between humans and ecosystems is needed in order to enhance the contribution of ecosystems to human well-being without affecting the long-term capacity of ecosystems to provide services. The aim of the MA is to contribute to improved decision-making with regards to ecosystem management and human well-being. The PED nexus in coastal zones are complex systems areas (Hopkins *et al*., 2011) as a number of the components interact, producing a variety of outcomes.

2.2.5. Synthesis

Various theoretical frameworks applicable to the coastal zone were examined and will be further explored in the dissertation. The PED nexus concept and the complementary theoretical frameworks mentioned above forms the basis in understanding the complexity that occurs in coastal zones and the interactions between the human population and the surrounding environment. These frameworks provide a foundation for further analysis with regards to the PED nexus as the concept is vital for governance of coastal zones.

The PED nexus concept highlights the importance of understanding the connections and trade-offs that occur within an environment. The DPSIR framework integrates knowledge across various disciplines and represents linkages that occur between domains. This frameworks indicates that a reciprocal relationships exists among the domains in a system. The sustainable development concept incorporates the complex interdependencies among human livelihoods, the environment and energy in order to meet SDGs. The Millennium Ecosystem Assessment identifies how the human population impacts the environment and the reciprocal relationship in how the environment affects the human population. This will therefore influence the sustainability and the governance of these areas. These frameworks will be discussed as related as well as complementary frameworks to the PED nexus, formulating the nexus model of St Francis Bay in Chapter 5.

2.3. Biophysical and cultural components of coastal zones

Following the above explanatory overview of a PED nexus and the complementary theoretical frameworks, the next sections look at how some components are specifically linked in a coastal zone context. In order to explore the PED nexus further in a coastal context, the interlinkages among certain components are explored. As stated previously, the nexus concept has been expanding to include resources such as land use, soil, climate, economy, ecosystems and health.

2.3.1. Urban development in coastal zones

Coastal zones are experiencing rapid development due to the desirability for residence, leisure, recreation and tourism (Martinez *et al*., 2006; Palmer *et al*., 2010). This is of global concern.

Developing countries have experienced high levels of migration of people from inland areas to coastal cities or towns (Tibetts, 2002) due to the variation of ecosystem goods and services. In 2002, South Africa (Figure 2.4) was experiencing medium to high human development along the coastline. In 2050, it is predicted that the entire coastline of South Africa, and the majority of the coastline across the globe, will have very high levels of human development. With these changes occurring along the coastal zones, the land cover becomes highly altered.

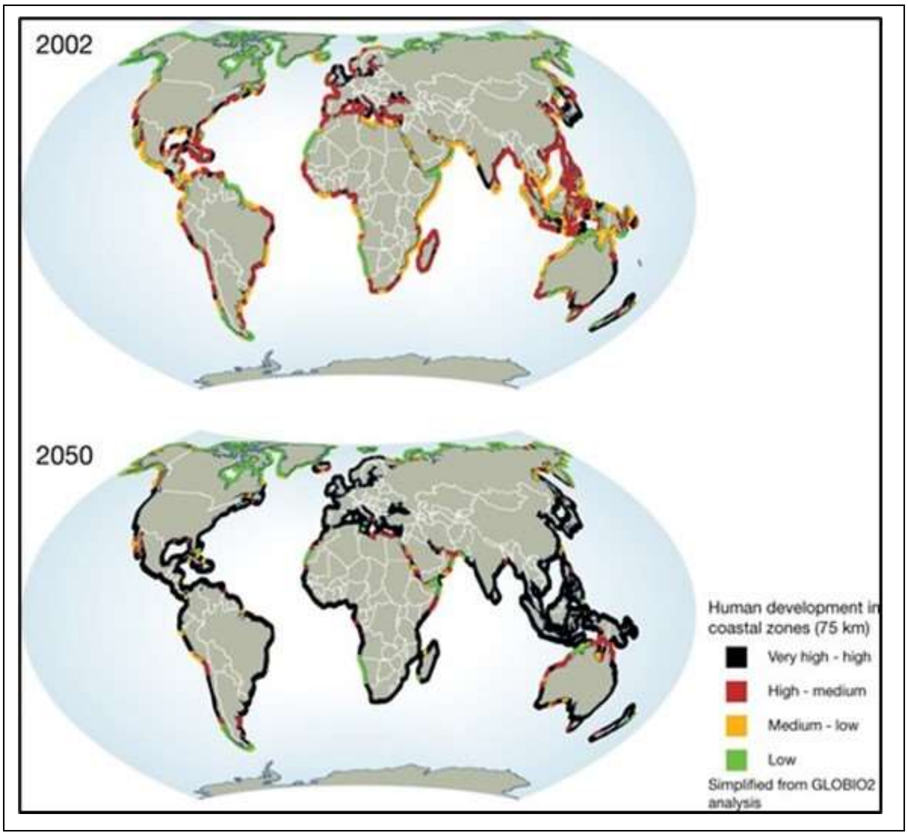


Figure 2.4: Human development in coastal zones in 2002 and predicted development in 2050. Source: Ahlenius, 2008

Population and development pressures in coastal zones alter hydrological regimes, increase impervious surfaces, disrupt natural ecosystems, alter the aesthetic landscape and compromise sense of place which is associated with coastal environments (Crawford, 2007). Changes in land cover, especially those in the form of urban development, can be regarded as one of the most important variables that affect ecosystems (Goble & van der Elst, 2012). As stated by Eastern Cape Biodiversity Conservation Plan (ECBCP) (2019), approximately 69% of the land in the Eastern Cape is in a natural, un-degraded state. This includes bare ground and vegetation categories (such as grassland, indigenous forest and shrublands). In contrast, degraded land makes up 12% of the land cover of the Province.

In Cooktown, Queensland, Australia, as stated by Pressey *et al*. (2015), most of the Reef's coastal zone has been transformed to land-uses such as housing and urban infrastructure, including roads, commercial and light-industry areas, highways, refineries and ports. Human development has altered the Reef's coastal zone dramatically and therefore has contributed to the decline of the Reef's ecosystem. The water which flows from the town into the lagoon is polluted with sediments and pesticides. Coastal waterways have also been blocked by roads and dams, and recreational and commercial fishing has damaged coral habitats (Pressey *et al*., 2015).

Successive constructions carried out on the coast zone, such as those of harbours and breakwaters, have led to imbalances arising in the surrounding environment, thus producing erosion and a resulting decline in the quality of coastal waters (Lopez *et al*., 2017). In order to prevent flooding in the lower areas of the rivers, the construction of dams has been carried out in rivers where the main consequence has been the decline sediments carried by the rivers to the coast (Aragones *et al*., 2016), reducing coastal beach width and lessens the resilience the beach towards erosion. Anthropogenic and natural factors have caused significant changes in coastal zones.

Development in coastal zones is unavoidable as it is considered economical and good for the well-being of coastal communities but this has to be effectively managed (Goble & van der Elst, 2012). Where population increases in an area, the infrastructural facilities and related resources increase in order to fulfil the demands of the people and tourists (Senevirathna *et al*., 2018). This leads to damage to the environment and related resources. It is essential that natural coastal functioning be maintained effectively, not only to ensure that ecosystem goods and services are delivered but also maintained and to prevent damage to coastal developments as a result of coastal storms and weather events (Goble & van der Elst, 2012), where this will have a ripple effect on the surrounding population.

2.3.2. Climate change in coastal zones

Coastal zones are at risk due to natural and human-induced hazards. These hazards include the rise in sea-level, storms and the construction of buildings, thus removing the natural protective barriers the coastline offers. Climate change threatens coastal zones which are already stressed due to human activity, pollution, invasive species, as well as storms. Coastal lands with increasing populations, high levels of investment in infrastructure, and ecological resources are in danger of climate change (Sandifer & Scott, 2021). The effects of climate change can result in the devastation of the structure and function of marine and terrestrial ecosystems.

The rise in atmospheric concentrations of carbon dioxide due to urbanisation, are causing the oceans to absorb more gas resulting in more acidity in the water. The rising acidity can have significant impacts on coastal ecosystems. As global temperatures continue to increase, sea-levels will keep rising as there is considerable lag in reaching equilibrium. The UN's Intergovernmental Panel on Climate Change (IPCC) has adjusted sea-level predictions which global sea-level rise is expected to approach 2m by 2100 and 5m by 2150 under greenhouse gas emissions (Ngcuka, 2021). The impacts of global sea-level rise that affect low-lying coastal zones include intensified flooding, increased erosion of shorelines, and an intrusion of saline waters into estuaries (Paskoff, 2004).

In the western Pacific increased rates of sea-level rise up to 1cm per year, affecting coastal infrastructure, freshwater resources, and terrestrial and marine ecosystems on the United States islands (USGS, 2022). These islands include the Marshall Islands and the Northern Marianas Islands. Along the coastline of Alaska, shoreline erosion and habitat loss are "accelerating due to increasing permafrost thaw and sea ice forming much later in the year" (USGS, 2022). This leads to the coast becoming more susceptible to storm surges.

According to Fitchett *et al*. (2016), South Africa is predicted to experience changes in precipitation, changes in wind speed and direction and rising sea-levels due to climate change. A major climate change threat to the South Africa coastline is sea-level rise. Sea-levels around South Africa have increased at a "rate of around 3 mm per year" as stated by Allison *et al*. (2022). The eastern coast of South Africa is characterised by sandy beaches with low coastal plains that are vulnerable to flooding and erosion. Locations within urban coastal development are vulnerable, such as Durban (Mather & Stretch, 2012). The rocky shorelines around the Western and Eastern Cape areas are considered to be less vulnerable, however, the estuaries in the areas, some of which may have residential or industrial developments, are at risk (Hughes *et al*., 1993; Mather & Stretch 2012).

Projections of future sea-level rise and the rate of this are needed in order to inform coastal planning and management strategies. The challenge of climate change needs to be addressed through integrated and ecosystem-based approaches such as integrated coastal management. This is crucial in building the foundations for sustainable coastal management and development, as well as support socio-economic development, biodiversity and ecosystem services in the coastal zone.

2.3.3. Coastal erosion and the resulting impacts

Fourie *et al*. (2015) and Unterner *et al*. (2011) state that coastal erosion is a phenomenon that is aggravated by human activities due to the modifications made to the coastal zones from urbanization. Waves, tides and sea-level rise are considered by Theron *et al*. (2010) to be contributing factors to coastal erosion and damage to infrastructure in South Africa. Coastal zones have become more vulnerable to natural and human-made hazards that contribute to coastal erosion. Coastal landforms are considered to be dynamic; however, urbanization and rapid population increase in these areas occur due to the presence of abundant natural resources (Senevirathna *et al*., 2018). Human activities related to this can negatively impact the shoreline.

Sandy coasts are highly developed and densely populated due to the services and aesthetics that they provide. In a study conducted by Luijendijk *et al*. (2018), they found that 24% of the world's sandy beaches are eroding at rates exceeding 0.5 m/yr. Beach erosion, according to (Phillips & Jones, 2006) poses a threat to stakeholders, especially tourism stakeholders, as the World Tourism Organisation considers it the world's largest industry. A study conducted by Housten (2002) identified beach erosion as a major concern of Americans who visit beaches.

Beaches are important for tourism-based economies and these are unfavourably affected by erosion resulting from sea-level rise (Phillips & Jones, 2006). These effects may be further worsened by the reduction of sediment supply associated with a change in wind speed and direction as well as anthropogenic modification of rivers and coastlines (van der Weide *et al*., 2001). This includes the building of dams upstream in the river. Climate change can contribute to beach erosion due to the increase in storm activity. The physical impact of sea-level rise on beach erosion results in the vulnerability of coastal infrastructure to storm waves (Phillips & Jones, 2006).

A study by Senevirathna *et al*., (2018) in Unawatuna found that the primary causes of coastal erosion included both natural processes and human activities that took place along the coastline. To provide the infrasructural facilities to develop the tourism sector is one of the "triggering factors" which damage the natural environment. Low-lying areas are considered to be the most direct by being impacted from sea-level rise. Climate change is one of the significant factors for coastal erosion and environmental degradation in the area (Senevirathna *et al*., 2018).

In Ingleses, Santa Catarina Island, the narrowing of the beach is highly unfavourable for tourism and results in potentially hazardous conditions for houses that are closest to the beach (Boeyinga *et al*., 2010). The town of Ingleses has two headland-bypass dunefields, one of which migration threatens houses and infrastructure and the second forms an important influence on the development of the beach (Boeyinga *et al*., 2010). The management of coastal erosion has important implications for the local tourism economy in the area as well as the quality of coastal resources. This impacts ecological sustainability over the long-term period (Landry & Whitehead, 2015).

2.3.4. Headland bypass dunefields in coastal zones

Active headland-bypass dunefields are likely to be largely unvegetated, consisting of shifting "transverse dune ridges" that migrate across vegetated headlands, parallel to the predominated wind direction of the coastal zone (McLachlan *et al*., 1994). Coastal dunes are undergoing an increase in vegetation cover in order to reduce the mobility levels of sediments in many areas around the world (Delgado-Fernandez *et al*., 2019). Ecology-led approaches to coastal dune management consider this change as “undesirable” as the increase in plant cover leads to a reduction in partially vegetated to bare sand habitats (Delgado-Fernandez *et al*., 2019). Exotic plants, such *Acacia saligna* and *Acacia cyclops* are used for dune stabilization (McLachlan *et al*., 1994).

In South Africa, since the late 1800’s, coastal dunes have been modified by colonial settlers. The reactivation of the dunes is considered unlikely as large sums of money are spent on housing and development that are in the path of the dunefield movement (McLachlan *et al*., 1994). Artificial restoration of the beaches will be necessary to preserve these beaches as well as to protect threatened housing that was built on the foredunes. These foredunes would normally act as sand buffers and are now eroding (McLachlan *et al*., 1994). Beach recreation for residents and tourists is an important activity in South Africa today and large portions of its sandy coast are now prime real estate (McLachlan *et al*., 1994).

The headland-bypass dunefields in St Francis Bay were artificially vegetated in “ignorance of the interdependence of beach and dune systems in coastal sediment transport processes”, resulting in coastal erosion in down-transport areas (McLachlan *et al*., 1994). The environmental implications of dunefield modification were not considered due to a shortage of information in understanding the importance and functioning of the dune systems (McLachlan *et al*., 1994). Since 1960 large-scale developments at the eastern end of the main Oyster Bay–Cape St Francis dunefield have resulted in major environmental problems associated with disruption of the transport function of the dunefield and the Sand River (Figure 2.5) (La Cock & Burkinshaw, 1996). In 1961, the leading nose of the Oyster Bay dunefield reached the shore of the St Francis Bay River (La Cock & Burkinshaw, 1996). The construction of the road across the dunefield as well as the Sand River did not consider the dynamic nature of the dunefield (La Cock & Burkinshaw, 1996).

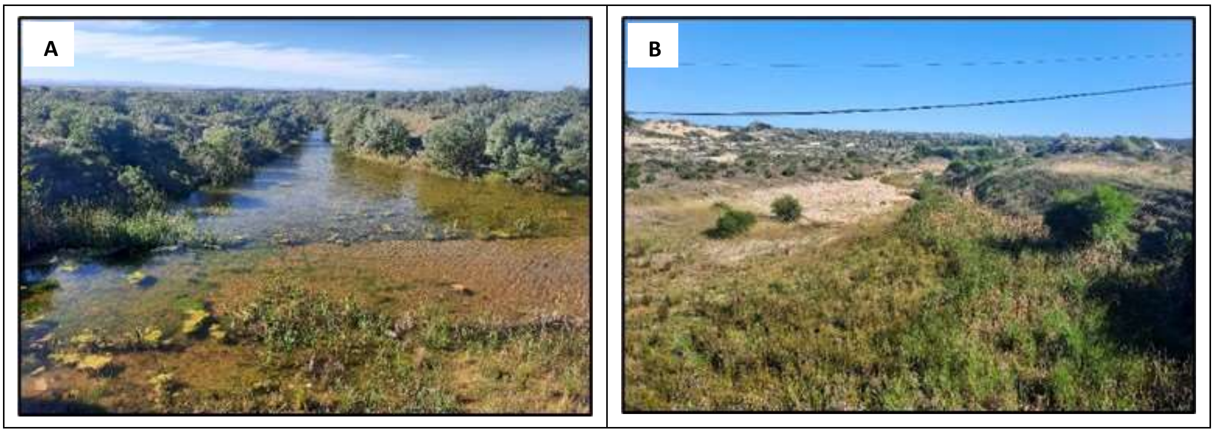


Figure 2.5: The Sand River in May 2021. (A) The river North-east to the road. (B) The river South-west to the road

Source: Author, 2022

The stabilisation of the Oyster Bay and Santareme dunefields plays a significant role in the dynamics of the beaches adjacent to St Francis Bay. The development of Oyster Bay has prevented further input from the sandy beach into the Oyster Bay dunefield, and has resulted in a reduction of sand supply to the St Francis beaches. The foredunes behind the beach, the downwind nose of the Oyster Bay dune system and the smaller northern flank of the Santareme dunefield have been stabilised since 1964 in order to develop the growing St Francis Bay town (McLachlan *et al*., 1994). Stabilisation of the Santareme dunefield for residential development has also contributed to severe erosion of the St Francis Bay beach (McLachlan *et al*., 1994). Any reduction in sand supply to beaches is likely to result in coastal erosion.

2.3.5. Tourism and climate change in coastal zones

Tourism is considered one of the fastest-growing sectors in the economy and has significant environmental, cultural, social and economic effects (GhulamRabbany *et al*., 2013). Tourism is a major activity that occurs in the coastal area, according to Senevirathna *et al*. (2018). Tourism in the coastal environment has increased with the desirability of the destinations. Rapid tourism development in coastal zones has exposed fragile ecosystems to an increased risk of environmental degradation (Zahedi, 2008). Tourism has also contributed towards climate change through excessive energy use, transportation, water consumption and waste generation (Zahedi, 2008). The relationship between tourism and the environment is complex as this relationship involves many activities that can have unfavourable environmental effects. Many of these impacts are linked with the construction of infrastructures such as roads and airports and of tourism facilities which included resorts, hotels and golf courses.

Climate change may influence the tourism industry negatively and this may raise concerns for tourists when selecting their destinations (Fitchett *et al*., 2016; Siddiqui & Imran, 2018). This may cause the local population to migrate to different locations, thus affecting economic growth (Siddiqui & Imran, 2018). The loss of coastal zones and shorelines can destroy the habitats of many ecologically sensitive species, resulting in extinction of the species (Siddiqui & Imran, 2018). Rising sea-level, in combination with large storms and increased wave energy are increasing the rates of erosion of beaches, thus reducing the width of the beach, and resulting in less area available for leisure activities.

The expected increase in storm surges will directly affect built environments within a short distance of the shoreline (Wigley, 2011). Climate change is expected to have intense and long-lasting consequences for coastal systems and the associated ecosystems (Calvao *et al*., 2013). The expected rise in sea-level with the increase in frequency/intensity of storms, will most likely lead to an increase in erosion as well as a loss of habitat (Brown & McLachlan, 2002). According to the Provincial Development Plan (PDP), over 70% of the Eastern Cape's tourism is based in the coastal zone with 52% of international tourism based around the Eastern Cape's beaches. In order to increase the coastal economy, the need for coastal monitoring and protection is recognised and highlights the importance of coastal management (Eastern Cape Vision 2030 Provincial Development Plan, 2014).

2.3.6. Economic activities, socio-economic and political dynamics

Population factors play a significant role in the environmental decline, as stated by Creel (2003). Human interventions on the coastline may interrupt the dynamic equilibrium of a beach and the surrounding systems (Claudino-Sales *et al.*, 2018). In many countries, populations in coastal zones are rising faster than those in noncoastal zones (Creel, 2003). The combined effects of population growth and economic and technological development are threatening the ecosystems that provide these benefits (Creel, 2003). This is of concern as population growth and associated activities can degrade coastal and marine ecosystems.

According to Tuan (1977), sense of place is the attachment to a setting or place by an individual or a group. Sense of place emerges from human interactions and experiences within the environment. The success of a community is linked to the well-being of the residents. Sense of place is about identity and relationships; the identity of a place and the relationship that people have with their surroundings (Feris, 2014). With people forming a connection and experience with a place, it has an influence on the relationships which exist among communities, influencing social sustainability.

Creel (2003) states that people who live in coastal zones may suffer from the increasing "burden" of environmental stress due to rise of activities and overcrowding of the coast as well as from upstream and inland development. This may affect their well-being. Peng *et al*. (2016) argue in their study that the coast may be an important factor in reducing stress. They concluded that the data indicated that visits to the coast are linked with higher levels of reduced stress and positive emotions. Changes in the size and distribution of human populations affect coastal regions by changing the land-use and land cover (Creel, 2003).

The vulnerability of coastal zones has implications for the economic welfare of coastal households, recreation and tourism along the coast, economies adjacent to the coast, and the ecological sustainability of coastal systems (Landry & Whitehead, 2015). Major seaports such as Guangzhou and Shanghai are important industrial and maritime terminals for international trade (Visbeck *et al*., 2013). Damage to port infrastructure due to weather events can affect various supply chains which in turn could threaten the population's food security and health (Hanson *et al*., 2011). It is argued by

Creel (2003) that although the concentration of people in coastal zones is high, it has produced economic benefits. These benefits include improved transportation links, industrial and urban development, revenue from tourism and food production.

The communities in rural areas of the Eastern Cape are complexly linked to their environment (ECBCP, 2019). Economic and social development is a response to the need to resolve social and economic inequalities in the Province, especially in the rural communities. "Inappropriate development", according to the ECBCP (2019), which is not aligned with environmental sustainability criteria, may lead to the collapse of ecological infrastructure and the ecosystem services that support these rural communities, as they are dependent on natural resources for their survival.

The political changes in South Africa will result in increased activity on the coast and will need to make coastal zone management an urgent priority, both to rectify the mistakes of the past and to ensure that altering systems do not recur in the future (McLachlan *et al*., 1994). Management problems originating from coastal erosion, storms, and sea-level rise are worsened by development along the coast (Landry & Whitehead, 2015).

2.4. Complex Systems: A Conceptual Approach

The nexus approach requires a theoretical conceptual framework. A conceptual approach makes use of an abstract concept, such as complex systems, and provides conceptual definitions and key aspects of these systems (Heikkila & Gerlak, 2013). Not all situations or systems are complex. Simple systems, as stated by Holmes *et al*. (2012), are predictable and in contrast, complex systems are not and cannot be understood through reductionism. In contrast, Sayama (2015) describes complex systems science as rapidly rising in scientific research as this concept fills the gap between two traditional views that consider systems are made of either completely independent or completely combined components. Complex systems develop "conceptual, mathematical and computational tools" which describe systems made of interdependent components (Sayama, 2015). These systems may be physical, biological or social. As Byrne (2005) states, complexity is "inherently dynamic."

Complex systems are composed of components of different types and that interact in various ways with one another (Cameron & Larsen-Freeman, 2007; Hassanibesheli *et al*., 2020). The components form part of an organization or system that they contribute to as well as which they are dependent. Complex systems examine the relationships among these components and form a "collective behaviours of a system" as stated by Bar-Yam (2002). The manner in which these systems, with its components, interact with the surrounding environment, forms a relationship among the components. Complex problems in society require intervention at many different levels and engagements across domains (Holmes *et al*., 2012). Complex systems may have a hierarchical structure with smaller components within sub-systems.

Complex systems theory focuses on a theoretical understanding of systems that cannot be understood by examining individual components but needs to be understood by examining the components holistically (Theise & D'Inverno, 2004; Coetzee, 2021), such as with the PED nexus. Complex systems have predominant drivers (which vary in strength over time) and it is the way these interactions which produces complexity and various combinations of outcomes (Pollard *et al*., 2011). These systems are dynamic as the components change over time and the relationships which exist among the components. As stated by Gear *et al*. (2018), complexity theory focuses on the interaction of components in a system at different levels and times, rather than examining the individual components in isolation.

Complex systems, according to Cameron & Larsen-Freeman (2007), are open rather than closed systems as energy and matter can enter and leave the system. These systems move through modes of behaviour. Complexity is concerned with the explanation of change and focuses on the pattern of change in a system (Byrne, 2005). The theory provides concepts that can be applied to theoretical frameworks to view complex phenomena, and enables a transdisciplinary approach (Gear *et al*., 2018). Ecosystems and socio-ecological systems can exhibit complex behaviour (Pollard *et al*., 2011). Ecosystems exhibit changes over time due to internal and external processes, which are regulated by feedback loops.

Complexity theory has been examined by various authors over the decades. Each author has contributed their own view of the definition of complex systems as seen in Table 2.1 These definitions vary but a similar trend is presented by each statement: complex systems consist of multiple components which interact with one another and form reciprocal relationships from these interactions. In Table 2.2, it provides various reasons as to how a system may be considered complex.

Table 2.1: Complex theory defined by various authors

Author(s)	Definition
Yaneer Bar-Yam (1997)	Complex systems are systems which have multiple interacting components whose collective behaviour cannot be inferred from the behaviour of components. Systems may differ from each other not due to differences in their parts but from differences in how these parts depend on and affect one another.
Stuart Kauffman (1993)	Complexity of biological systems and organisms might result from self-organization and equilibrium dynamics as from natural selection.
David Rind (1999)	A complex system is one in which there are multiple interactions among many different components.
Julia Parrish & Leah Edelstein-Keshet (1999)	Complexity theory indicates that large populations of units can self-organize into aggregations that may generate pattern, store information, and engage in decision-making.
William Arthur (1999)	Complexities are systems with multiple elements adapting or reacting to the pattern these elements create.
Friedrich Hayek (1976)	Ecosystems contain complex networks of information, involves an ongoing dynamic process and contains orders within orders.

Table 2.2: Reasons why a system may be considered to be complex

Reasons	Examples
Heterogeneous interacting parts	Cities, companies, climate, ecosystems
Sensitive dependence on initial conditions	Weather systems, forest fires
Networked hierarchical connectivities	Social networks, ecosystems
Multilevel dynamics	Companies, government, transportation
Co-evolving subsystems	Land-use, transportation
Adaptivity to changing environments	Biological systems
Unpredictable emergence	Chemical systems, system breakdown, spontaneous social initiatives

Source: Miguel, et al., 2012

In a simple system, according to Holmes *et al*. (2012), the systems are homogeneous and do not change over time compared to the dynamic nature of complex systems which do change over time as the past has an impact on the future. Simple systems are deterministic as the same results occur for a given set whereas complex systems are stochastic as there is a degree of uncertainty about the outcome of the results. With simple systems, the subsystems are not influenced by other parts of the system as compared to a complex system being interdependent as the subsystems are interconnected. A complex system can be distinguished from a simple system through concepts including non-linearity, self-organisation, emergence, and feedback loops (Pollard *et al*., 2011). The following are concepts associated with complex systems.

2.4.1. Nonlinearity concept of a Complex System

According to Ladyman *et al*., (2013), nonlinearity is considered important for the complexity concept. A system is nonlinear when it may suddenly change behaviour or move to another system (Gear *et al*., 2018). These move from a high degree of stability to unstable behaviour. Complex systems may have nonlinear behavior as they respond in various ways to the same input depending on their setting. Some nonlinear dynamical systems can produce a phenomenon known as chaos theory. Chaos theory in complex systems refers to the sensitive dependence on initial conditions that a complex system can exhibit (Ladyman *et al*., 2013). In this system, if small change to the initial condition occurs it can lead to dramatically different outcome. If a complex system returns to a state similar that it had previously, the system may behave in a different manner in response to the same stimuli.

2.4.2. Emergence concept of a Complex System

Complex systems show emergent behaviour. Complex systems may arise and evolve through self-organisation, indicating that these systems are neither regular nor random, thus allowing the development of emergent behaviour (Sayama, 2015). From the interactions between the individual components in the system, behaviour emerges at the level of the system as a whole. Emergent properties are qualities of a system that are not apparent from its components in isolation but rather result from the interactions they form when placed together in a system.

2.4.3. Self-organisation concept of a Complex System

When emergence describes the appearance of unplanned order, it is described as self-organisation. Complex systems may arise and evolve through self-organization, in that they are neither completely regular nor completely random, as stated in the paragraph above, permitting the development of emergent behavior at macroscopic scales (Sayama, 2015). The concept of self-organisation is the spontaneous emergence of new relationships forming from repeated interactions with components over time (Gear *et al*., 2018). Self-organization is the emergence of order in a system by internal processes instead of external forces (Green *et al*., 2008). An overall order arises from the interactions between components of an initially disordered system (Pan & Shen, 2018). A spontaneous order is initiated by random fluctuations which are amplified by positive feedbacks. The feedback process contributes to self-organization.

2.4.4. Feedback concept of a Complex System

Feedbacks are processes that arise from the interaction of two or more components. With feedbacks, a system receives feedback when the way the components interact at a later time depends on how interactions occur earlier (Ladyman *et al*., 2013). Individual components need to be part of a large group in order for complexity to be present. These components interact over time which either reinforces or undermine one another (Gear *et al*., 2018). Ladyman *et al*., (2013) state that feedbacks are used by a control system. A negative feedback loop is stabilizing and restores balance whereas a positive feedback loop is self-reinforcing and drive non-linear growth, creating disturbances and instability. For a complex system representation of graphs, a chain of arrows indicates no feedback whereas a graph that consists of loops of arrows indicates feedback.

2.4.5. Synthesis

Complex systems are systems composed of many interacting components which give rise to evolving behaviours. The above-mentioned concepts are considered the substance of complex science. These are general characteristics to apply to investigate any type of complex system.

Examples of complex systems are stated by Cameron & Larsen-Freeman (2007). A city is a complex system as it is composed of various components (people, places and activities). These components interact in multiple ways and are always changing. The city, as a system, self-organizes and adapts in response to the ongoing changes occurring in the system. Complex systems also include ecological systems, population systems and economic and financial systems as processes of self-organisation, adaptation and emergence occur in each system.

In a publication by Gear *et al*. (2018), they provide two examples of complex case studies. Booth *et al*. (2013) applied a qualitative approach to a study by collecting interviews, documents, and observation data to explore how chronic illness care changed over a decade. Through using pattern-matching logic, a comparison was made between traditional implementation science discourse and a complexity-informed explanation. It was concluded that complexity theory described how system agents participated in change over time. The second case study was by Browne *et al*. (2015), where they designed a mixed methods case study in order to examine the contextual factors which "shaped the implementation, uptake, and impact of a complexity-informed intervention designed to increase equity-oriented care in primary health-care clinics." The study was expected to show what levels of change and policy and funding contexts are needed to enhance equity-oriented care (Gear *et al*., 2018).

Qualitative research with regards to complex systems has the potential to capture and understand the nature of complex dynamics that may be unexplored (Gear *et al*., 2018). A qualitative complexity approach has been useful in terms of understanding complex emergent phenomena such as sustainability, as stated Ellis & Herbert (2011) and Gear *et al*. (2018). In most systems, only a few variables are observed in terms of measured time series, while the majority of variables remain hidden (Hassanibesheli *et al*., 2020).

Ecological complexity refers to the complex interaction among living systems and their environment and resulting emergent properties that arise from these interactions. Ecological complexity highlights the richness of ecological systems and their capacity for adaptation and self-organisation. The structure and functioning of ecosystems may be understood according to emergence, self-organisation and non-linear dynamics (Parrott, 2010). According to Loehle (2004), complexity in ecology is of six distinct types: spatial, temporal, structural, process, behavioural and geometric. Spatial complexity is visible in forms of vegetation patterns and species distribution. Temporal complexity is population dynamics and effects of changing climate. Structural complexity refers to the relationships within an ecosystem. Process complexities are processes which contain many components (ie. Soil formation).

Coastal zones are examples of "stressed complex systems" due to the numerous interactions and overlapping scales which occur in these areas (Hopkins *et al*., 2011). These areas are open systems as it has large mass and energy inputs. Coastal zones are considered to be far from equilibrium and many of the zones are changing in a destabilizing direction. This includes increasing resource consumption while resource assets are decreasing (Hopkins *et al*., 2011). Natural systems are complex and additional complexity is added by the interactions of their components.

2.5. Institutional Context for development in Coastal Zones

Following the research approach described and explored in sections 2.2 to 2.4, various National and Municipality frameworks exist that are applicable to the coastal zone. At a municipal level, the Integrated Development Plan (IDP) is implemented which gives an overall framework for development and aims to improve the quality of life for people in the area. This involves the municipality and residents finding the best solutions to achieve good long-term development, such as the Kouga IDP applicable to St Francis Bay. From a National perspective, certain legislation defines an IDP, and this will be explored in the following sections as well as the Kouga IDP and its relevance to coastal zones, such as St Francis Bay.

At a national level, certain acts of the National Environmental Management Act (NEMA) are applicable to dynamic coastal zones such as with St Francis Bay. These acts form a legal framework that gives affects one's environmental right as well as promotes ecological sustainable development. Some of the NEMA acts are applicable to coastal zones and are explored in the following sections and provides a foundation for the research applied in the methodology.

2.5.1. Integrated Development Plan in a coastal zone context

An Integrated Development Plan is a process whereby a municipality prepares a strategic development plan in order to reduce service delivery backlogs, encourage socio-economic development as well as preserve the natural environment (Kouga IDP Process Plan – 2022/23). The IDP was introduced in 1996, and was proposed to assist the local authorities in fulfilling the objectives of the nationally sponsored Reconstruction and Development Programme (RDP) (Harrison, 2006). The IDP aligns with the National, Provincial and District Planning Frameworks in order to ensure a holistic and integrated approach to development occurs within a municipality.

Stakeholders that are involved in the IDP process include municipalities, councilors, communities and national and provincial sector departments. The IDP is based on community needs and priorities of the area. Government services are delivered by provincial and national government departments at a local level. Departments are encouraged to participate in the IDP process so that they can be guided as to how to use their resources to address local needs of the community (Harrison, 2006). This framework ensures the close co-ordination and integration among projects and programmes (Integrated Development Plan 2006 – 2011 of the Nelson Mandela Bay Metropolitan Municipality). This therefore enhances integrated service delivery and development and therefore promotes integrated communities that are sustainable. IDPs are reviewed annually in line with national planning and budgetary processes and are evaluated every five years (Gueli, et al., 2007).

As local governments operate in ever-changing environments, new challenges and demands are always presented. There are some issues that limit the impact of IDPs, including national departments that have not always managed to participate in municipal integrated development planning processes in a sustainable manner (Gueli, et al., 2007). Therefore, the need for better inter-governmental interaction has become important for South Africa to reach the level of integration needed.

The following legislation defines an IDP according to Integrated Development Plan 2006 – 2011 of the Nelson Mandela Bay Metropolitan Municipality. The following is quoted from the IDP:

"Constitution of the Republic of South Africa Act 108 of 1996

> A municipality must give priority to the basic needs of its communities and promote their social and economic development to achieve a democratic, safe and healthy environment.

Local Government: Municipal Systems Act 32 of 2000

> The need for every municipality to develop and adopt an IDP, which should be reviewed annually. It outlines the IDP process and components.

Municipal Finance Management Act 56 of 2003

> The provision for alignment between the IDP and the municipal budget. The Service Delivery and Budget Implementation Plan is the mechanism that ensures that the IDP and the Budget are aligned.

Local Government: Municipal Planning and Performance Management Regulations (2001)

> Make provision for the inclusion of the following in the IDP: institutional framework for the implementation of the IDP; investment and development initiatives in the Municipality; key performance indicators; a financial plan; and a spatial development framework."

In Figure 2.6, it demonstrates the role of the Kouga Municipality IDP. The IDP is informed by a leadership agenda as well as the needs of local citizens and public and private organizations. The main purpose of an IDP is to improve the delivery of basic services provided by the municipality (Asha & Makalela, 2020). The IDP was developed to ensure compliance with certain quality standards, to ensure that proper coordination among the different spheres of the government is established and that there is community engagement during the preparation of the IDP. This is to reduce the tension that could potentially occur between the government and the community. Key elements for the Kouga Municipality 2017-2022 IDP include: Operational strategies, Disaster Management Plans, Financial Plan with a budget projection, an update of ward profiles reflecting new priority ward projects as well as an assessment of the existing level of development in the municipality. The main aim of an IDP is to co-ordinate the work of the local and government in a plan to improve the quality of life for residents (Tshwane, 2015).

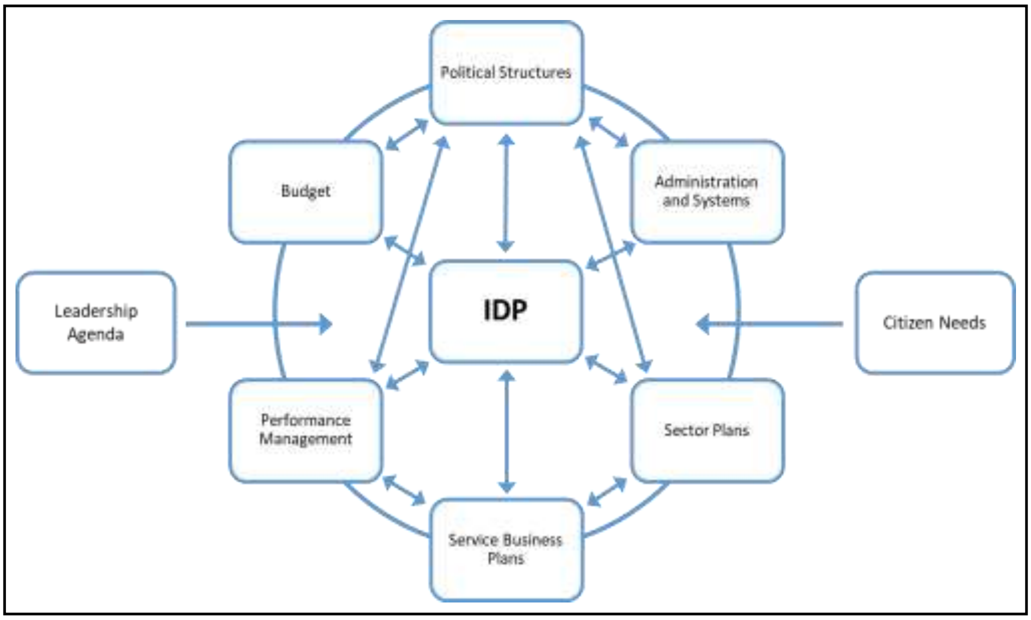


Figure 2.6: Integrated Development Plan as proposed for the Kouga Municipality

Source: Adapted from
Kouga Municipality, 2017

The five-year plan of the IDP captures the development needs of communities. The IDP captures the service-delivery and development requirements for each ward and these requirements determine how the annual budget of the municipality is allocated. The objectives of the Kouga IDP include: decreasing the exposure of the beachfront and infrastructure (roads and parking areas) to dynamic coastal processes, therefore improving the quality of the beachfront; decreasing the shifting sand bars in the Kromme River; increasing the width of the beaches to promote tourism and economic growth and development; and prevent the loss of infrastructure by mitigating the rapid rate of beach erosion. Important projects from the Kouga IDP include masterplans for water and sanitation, drought mitigation projects and the upgrading of nine informal settlements (Kouga Municipality, 2022).

2.5.2. Legislative framework in South Africa: Applicability to a coastal zone

The following section presents the legislative framework that applies to a coastal zone. Some of the Acts are described below with the aims and objectives also stated. Section 24 of the Bill of Rights in the Constitution states that everyone has the right to an environment that is not harmful to their health or well-being, and to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that:

i. Prevent pollution and ecological degradation
ii. Promote conservation

iii. Secure ecologically sustainable development and use natural resources while promoting justifiable economic and social development.

- National Environmental Management Act (Act No. 7 of 1998)

The National Environmental Management Act (NEMA) forms the fundamental legal framework that gives effect to the environmental right in section 24 of the Constitution of South Africa. The main environmental principle of this Act is the promotion of ecologically sustainable development (van der Linde & Feris, 2010). NEMA introduces a framework for environmental impact assessments as part of integrated environmental governance. As stated by van der Linde & Feris (2010), NEMA introduces a duty of care to prevent, control and rehabilitate the effect of pollution and environmental degradation. “NEMA plays a crucial role in providing for co-operative environmental governance by:

i. Establishing principles for decision-making on matters affecting the environment.
ii. Establishing the necessary governmental institutions that will promote the proper implementation of environmental protection.”

- National Environmental Management Act: Integrated Coastal Management Act (Act No. 24 of 2008)

The Integrated Coastal Management (ICM) Act, according to Shaw, et al. (2019), aims to achieve coherence between the “physical processes of estuaries and human activities.” This is to promote the conservation of the coastal environment as well as maintain the natural attributes of coastal landscapes. The Act aims to ensure that development in the coastal zone is “socially and economically justifiable and ecologically sustainable”, as stated by van der Linde & Feris (2010). The Act also prohibits pollution in the coastal zone and inappropriate development of the coastal environment.

Objectives of the NEMA Act as stated by van der Linde & Feris (2010):

a) “To provide, within the framework of the National Environmental Management Act, for the coordinated and integrated management of the coastal zone by all spheres of government;
b) To preserve, protect and enhance the status of the coastal public properly on behalf of all South Africans, and future generations; and
c) To secure fair access to the opportunities and benefits of the coastal public properly”.

- National Environmental Management Act: Biodiversity Act (Act No. 10 of 2004)

The Biodiversity Act aims to conserve biological diversity in an area as well as regulate the sustainable use of biological resources. This includes estuarine and coastal systems and their resources (Shaw *et al*., 2019). The Act provides protection of species and ecosystems and the sustainable use of indigenous biological resources (van der Linde & Feris, 2010).

Objectives of the Biodiversity Act as stated by van der Linde & Feris (2010):

a) "To provide, within the framework of the National Environmental Management Act:
    i. The management and conservation of biological diversity within the Republic and the components of biological diversity;
    ii. The use of indigenous biological resources in a sustainable manner; and
    iii. The fair sharing among stakeholders of benefits arising from bio-prospecting involving indigenous biological resources.
b) To provide for co-operative governance in biodiversity management and conservation."

The Critical Biodiversity Areas (CBA) map indicates areas of land (terrestrial) and aquatic features that must be protected in their natural state for biodiversity processes and ecosystems in order to continue functioning (Holness & Bradshaw, 2009). According to Holness & Bradshaw (2009), CBAs incorporate areas that need to be protected with the purpose to meet national biodiversity thresholds; these areas are required to ensure the continued existence and functioning of species and ecosystems; and important locations for biodiversity features or rare species. Ecological Support Areas (ESA) are supporting zones to the CBAs and are required to prevent the degradation of Critical Biodiversity Areas as well as Protected Areas (Holness & Bradshaw, 2009). These may include areas that are degraded or transformed if the area still plays an important role in supporting surrounding CBAs. In Figure 2.7, it delineates the Critical Biodiversity Areas (CBA) of St Francis Bay, where, as stated by Shaw *et al*. (2019) CBA 1 are areas which are formally protected in terms of the Eastern Cape Biodiversity Conservation Plan and CBA 2 are the areas of high biodiversity with a high level of irreplaceability. In Figure 2.7 (Shaw *et al*, 2019), the mouth of the Kromme River and the Marina has been identified as CBA 1 and the coastline of St Francis Bay has been identified as CBA 2.

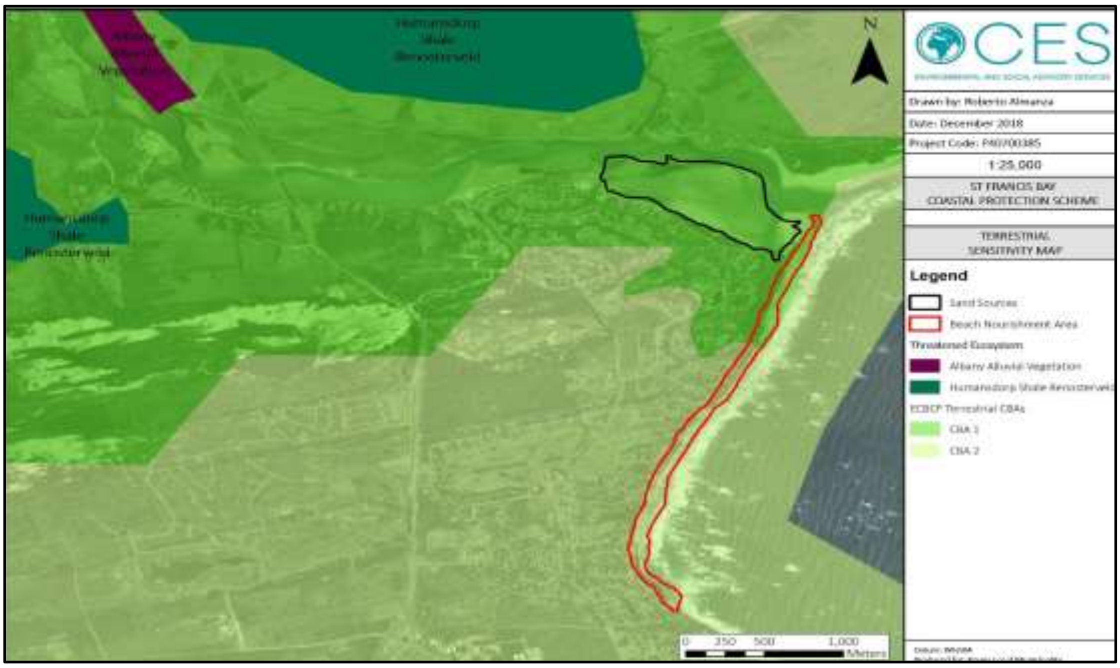


Figure 2.7: The Critical Biodiversity Areas (CBAs) of St Francis Bay

Source: Shaw *et al.*, 2019

- National Environmental Management Act: Protected Areas Act

The Protected Areas Act aims to protect and conserve ecologically viable areas that are "representative of biological diversity", in its natural landscapes and seascapes (Shaw *et al*., 2019; van der Linde & Feris, 2010). The Act also provides for the management of these areas, co-operative governance and public participation. This Act must, in relation to any protected area, be interpreted and applied in conjunction with the Biodiversity Act.

Objectives of the Protected Areas Act as stated by van der Linde & Feris (2010):

a) "To provide, within the framework of the National Environmental Management Act, for the declaration and management of protected areas;
b) To provide for co-operative governance in the declaration and management of protected areas;
c) To promote sustainable use of protected areas for the benefit of people, which would preserve the ecological character of the areas; and
d) To promote the participation of local communities in the management of protected areas, where appropriate."

The Kromme Estuary is ranked as the 17th most important estuary in South Africa, as stated by Shaw *et al*. (2021). The estuary is not considered to be located within a protected area, although it is part of the list of desired protected areas. The estuary is considered to be in a fair state of health

(Whitfield, 2000; Coastal and Environment Services, 2006; Shaw *et al*, 2021) although the estuary is in need of rehabilitation. The high need for rehabilitation includes water quality, water quantity and the clearance of alien vegetation.

- National Environmental Management Act: Air Quality Act (Act No. 39 of 2004)

The Air Quality Act regulates air quality in order to protect the environment. The Act provides standards for regulating air quality monitoring, management and control by the government (Almanza *et al*., 2019; van der Linde & Feris, 2010). This Act also provides for specific air quality measures.

Objectives of the Air Quality Act as stated by van der Linde & Feris (2010):

a) "To protect the environment by providing measures for:
    i. Protection and enhancement of the air quality in the Republic,
    ii. Prevention of air pollution and ecological degradation; and
    iii. To secure ecologically sustainable development, while promoting economic and social development.
b) To give effect to Section 24(b) of the Constitution to enhance the quality of air for securing an environment that is not harmful to the health and well-being of people."

2.6. Conclusion

Coastal zones are considered to represent the most important interface between humans and the oceans (Visbeck *et al*., 2013). Coastal zones are sensitive areas as these systems support a large proportion of the world's proportion. Due to the attractiveness of coastal zones, significant human interventions have occurred in these areas. Coastal development is a critical driver of change. Coastal zones are experiencing rapid development and this development is unavoidable as it is considered economical and good for the well-being of coastal communities. Major changes in coastal settlement patterns have occurred in the past decades, resulting in enormous changes to the dynamics occurring in these fragile systems.

The coastal zone forms part of a major ecological corridor due to the presence of Critical Biodiversity Areas and Ecological Support Areas. This corridor is an important area for climate change adaptation, as it will buffer landward areas from impacts of sea-level rise and storm surges. The ecological components of the coastline include beach habitat, shifting dune systems and vegetated dune ecosystems. The loss of biodiversity, with the changes in temperature and rainfall, will affect the ecosystems which will in turn determine the ability of ecological infrastructure to deliver ecological and social services.

With coastal hazards and human interventions, this has formed complex interactions and therefore has led to increased levels of "risk, exposure and sensitivity of coastal communities and their environment" and this raises their vulnerability (Visbeck *et al*., 2013). In this Chapter, various domains were considered within the PED nexus relevant to a coastal zone such as St Francis Bay. These components included the headland-bypass dunefield; climate change; the local economy; social well-being; inequality and political governance.

The development of the nexus conceptual framework is vital to clarify complex relationships across the various sectors and thus provide a foundation for further analysis. The complexity of the nexus model increases the ability to better represent nexus interlinkages. The nexus concept emphasizes the importance of connections and feedbacks that occur within the nexus. With this understanding of the nexus and the relationships among the components of the nexus model, is important for developing environmental management plans and to ensure the sustainability of the town. Complex systems provide a theoretical framework in order to understand that the components need to be examined as a whole and not only the individual components.

The DPSIR framework integrates the knowledge across the various disciplines, in this case a coastal zone, and formulates policies therefrom. The framework creates a visual representation of the relationships among the disciplines, expressing a complex scenario. The Millennium Ecosystem Assessment examines the impact of humans on their surrounding environment and in turn how ecosystem services influence human well-being. This therefore has an impact on the sustainability of the town as well as the management options that need to be implemented to ensure the best outcome for the environment and the people. These two frameworks contain a methodological approach and presentation style that can be applied to the case of a complex system of St Francis Bay in the following Chapter.

The IDP and National legislation provide a legal framework that promotes ecological sustainable development. These acts include the Integrated Coastal Management Act, Biodiversity Act, Protected Areas Act and the Air Quality Act. The NEMA acts are applicable to coastal zones, in the case of St Francis Bay, and provide a foundation for the research applied in the methodology in the following Chapter and these results are further explored in the following chapters.

Decision-making to promote sustainable development for the coastal interface must be integrative across the dimension of social and ecological systems (Singh *et al*., 2021). Coastal zones are complex social-ecological systems, which is characterized by constant change. Due to the increase in development in rural communities or informal settlements, this requires careful sustainable development planning and design, which is aimed at decreasing socio-economic pressure, and ensures that ecosystems are maintained for the continued use by the communities that depend on them.

CHAPTER 3: STUDY AREA AND METHODOLOGY

3.1. Introduction

This chapter provides a description of the study sites' history and geography. It offers background to geology, climate and vegetation of St Francis Bay as well as the change of the dune systems and the Kromme River. The methodology that was applied in this research is explained. The methodology followed a quantitative and qualitative approach.

The primary objective of the study is to identify the various components in St Francis Bay which are linked to the population, development and the environment, and the costs and consequences that arise from these dynamics. The study aims to determine the complex linkages which exist among these components in order to create a PED nexus model. The severity and significance of the consequences will further be explored. To conclude the chapter are limitations that occurred through the methodology.

3.2. Study Area: St Francis Bay

As mentioned in the Study Area in Chapter 1, St Francis Bay is a low-lying town located along the South African South coast in the Eastern Cape Province. The town is part of the Kouga Municipality. St Francis Bay is neighboured by Cape St Francis, Humansdorp and Jeffrey's Bay. The bay has an artificial sand spit constructed between the Marina and the mouth of the Kromme River and the ocean. The town is a tourist destination due to the surfing zones, watersports, fishing and guesthouses.

3.2.1. History of St Francis Bay

In 1575, a Portuguese sailor Manuel de Mesquita Perestrelo sighted the area of St Francis Bay whilst exploring the coastline. In 1744, migrant stock farmers and Cape Dutch hunters explored the Cape and this led to the permanent establishment of the settlers (Simpson, 2007). According to Simpson (2007) one of the earliest land-grants in the area, in 1765, was Jacobus Kok on a farm beside the Seeikoei River. This house (completely enclosed by additions) still exists on the farm Aloe Ridge between St Francis Bay and Jeffreys Bay. The arrival of the Dutch in the Cape lead to an end of the Khoisan hunter-gatherers. In 1771, no stock farmer was allowed to move beyond the Gamtoos River and therefore the area between the Kromme and sea began to fill up (Logie, n.d.).

From 1795 to 1803 and 1803 to 1806 the Cape fell under the British military rule and became a British colony. During this time, a number of families were "struggling to make a living in the bush-covered dunes south of the Kromme" as stated by Logie (n.d.). After more than a decade in 1820, more settlers moved to the Cape and began to earn an income through making slaked lime from shells as well as leather goods such as saddles and harnesses (Simpson, 2007). Up until 1953, most of the land in the St Francis Bay area was utilized for agricultural purposes by the settlers. The settling in the St Francis Bay area by the Europeans excluded and marginalised other local and indigenous populations from establishing and expanding their own settlements. This socio-political tension is relevant for the PED analysis in Chapter 5 of the dissertation.

In 1954, Leighton Hulett bought a piece of land in the fishing village and established a fishing camp for visitors (St Francis Bay, 2022). In 1956, a small township consisting of 51 plots was setup to prevent the movement of the dunes of the Sand River and at the same time Leighton began to lay down branches of *Acacia cyclops* (Rooikrans) and *Acacia saligna* (Port Jackson Willow) to prevent this movement (Logie, n.d.). From here, people bought land from the Huletts and built their own properties. Hulett planned to build channels along the river in order to make it accessible for resident's boats (Lehmkuhl, 2008; Grant, 2015). Trenches were therefore dug in order to drain the ground and the soil was deposited on the banks to heighten the surface level of the land (Simpson, 2007; Grant, 2015). These heightened banks would later be stabilized by alien vegetation to act as a defensive barrier to reduce erosion from occurring and to prevent the banks from being washed away from wave action.

The town flourished from a fishing village to a popular tourist destination (Figure 3.1). The Huletts hoped to keep the idea of a "fishing-village look" for the town and therefore houses followed a specified architecture with white walls and grey thatched roofing or grey tiles (St Francis Bay, 2022). In 1960, formal development of the village occurred (La Cock & Burkinshaw, 1996) and the development of the Santereme and St Francis on Sea took place. By 1976 the initial canal system was complete with eastern and western outlets to the river. The bridge across the Kromme River was completed in 1979 and the bridge across the Sand River was also completed in 1979. A harbor and the corresponding facilities were constructed at Port St Francis in 1995 (Figure 3.2) for the fishing industry. At the same time, work began on a number of apartments in the harbour area.

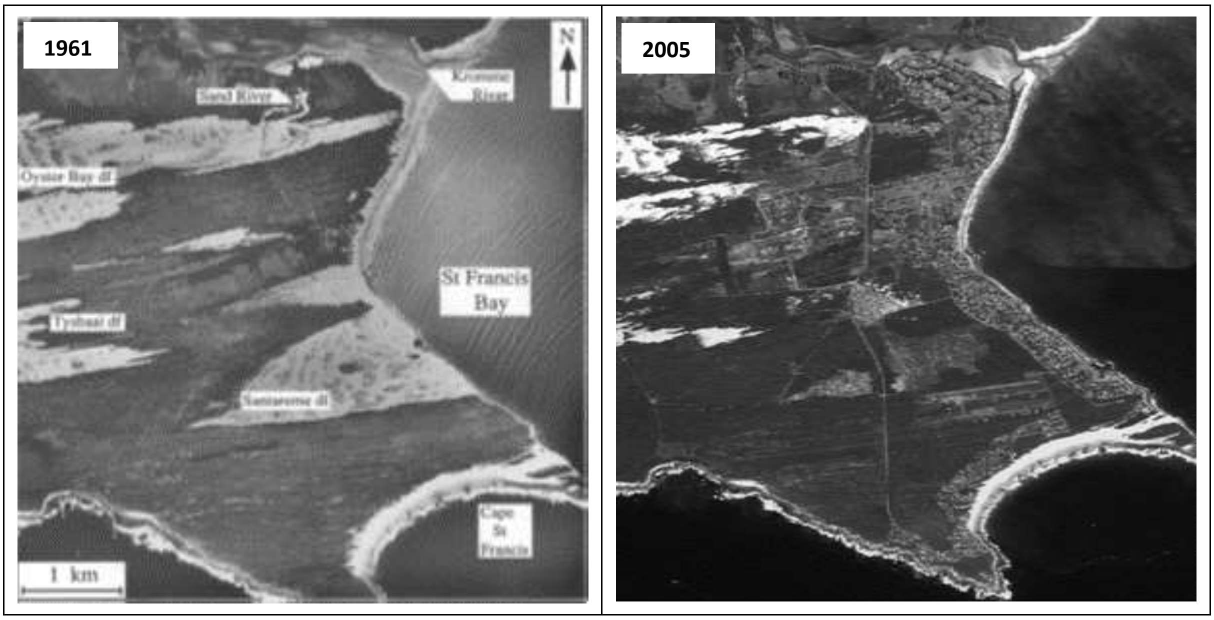


Figure 3.1: St Francis Bay in 1966 and 2005. Source: Harris, 2018

Figure 3.2: Harbour at Port St Francis. Source: Author, 2022

3.2.2. Geology of St Francis Bay

St Francis Bay is characterised by relatively flat terrain, which slopes towards the Kromme and Sand River channels. The area of St Francis Bay is underlain by the Paleozoic rocks of the Cape Supergroup, which consists mainly of quartzite and the sandstones of the Table Mountain Group (Goudini Formation) (Cowling *et al.,* 2019). These quarzitic sandstones were deposited along the coastal plains of the Agulhas Sea 510-400 million years ago. North of Cape St Francis, the coastline is underlain by Devonian-aged rocks of the Bokkeveld Group (Claaseen, 2015). The Schelm Hoek Formation, which is the most recent aeolian deposits of the Algoa Group, is characterised by unconsolidated, calcareous sands combined with locally developed paleosols and Late Stone Age middens (Almanza *et al*., 2019). The overlying sediments comprise of the Holocene aeolianites which are deposited on Pleistocene calcarenites (Nahoon Formation) (Cowling *et al.,* 2019). The headlands are formed by the resistant quartzite of the Table Mountain Group.

3.2.3. Headland Bypass Dunefields

Two headland-bypass dunefields are active in St Francis Bay, namely, the Oyster Bay dunefield and the Thys Bay dunefield (Figure 3.3). The Oyster Bay dunefield is active over a length of approximately 14km, with a width that varies from 500m to 1,200 m. The Thys Bay dunefield has a length of about 5km and a width between 150m and 1000m. A third dunefield, the Santareme dunefield, was stabilised during the 1970s and 1980s to enable development to occur in the area (La Cock & Burkinshaw, 1996). A small headland-bypass system is present at the most eastern point of headland, approximately 600m in length. These active dunefields form a thin veneer of sediment over the headland (McLachlan *et al.,* 1994). The headland of Cape St Francis provides protection to St Francis Bay town and along with the orientation of the town this results in the swell conditions in the bay differing from the open coastline (Anderson, 2012).

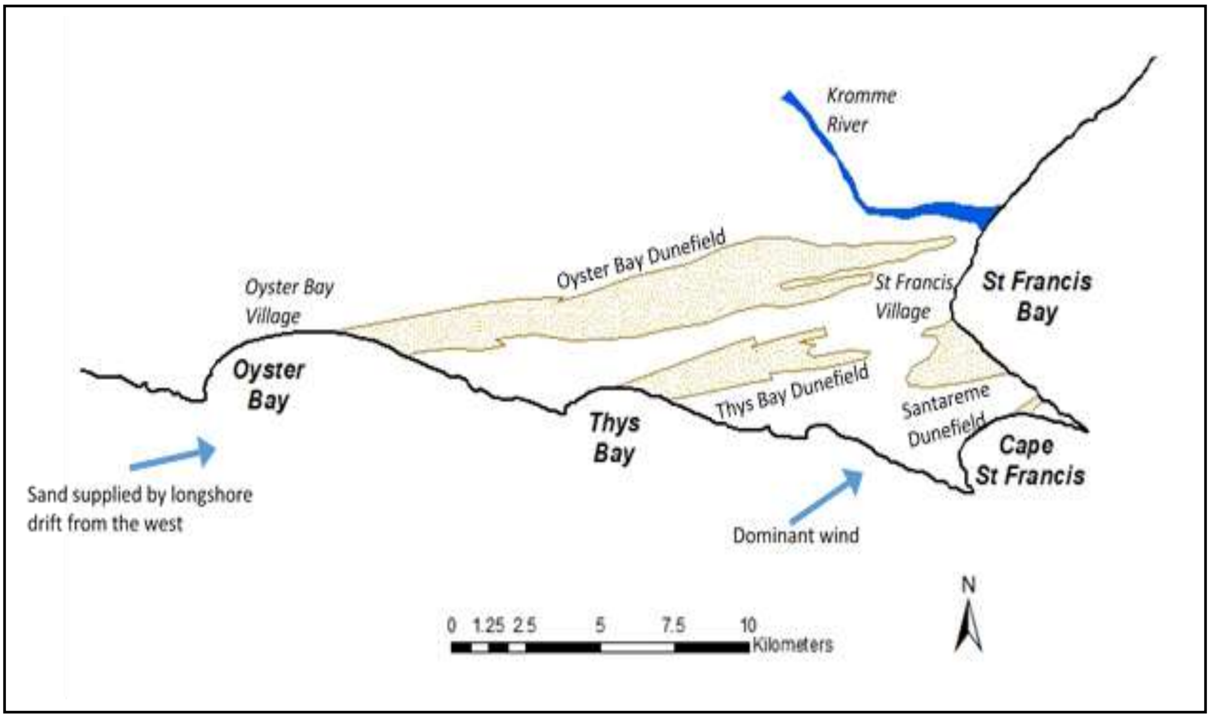


Figure 3.3: Headland sand bypass dunefields in St Francis Bay and Cape St Francis

Source: Adapted from McLachlan *et al*., 1994

3.2.4. Kromme River Estuary

The Kromme Estuary is approximately 14km in length with a width of 80m (Snow & Adams, 2006), and the Kromme River is 110km long. The estuary mouth is permanently open to the ocean. The Kromme River separates the north fertile shale soil from the south less rich sandstone (Cowling, 2011). Two dams have been constructed on the Kromme River, the Churchill dam (built in 1943) and the Impofu Dam (built in 1983). The dams have a combined storage capacity of storing ca 133% of mean annual run-off of the Kromme catchment (Almanza *et al.,* 2019). The dams have reduced river flow and have resulted in the water becoming more saline towards the head of the estuary (Snow & Adams, 2006).

The tributaries that join with the Kromme River include the Sand River, Klein River, Huis River and Brakfontein River. The Sand River, a small tributary of the Kromme River, drains the eastern section of the Oyster Bay Headland dunefield. The mouth of the Sand River migrated "approximately 4km upstream in the Kromme River" (La Cock & Burkinshaw, 1996). A sand spit of about half a kilometre long extends from the south bank of the estuary, between the ocean and the Marina. A marina has been developed on the west bank near the mouth of the river. The Kromme River is ephemeral in nature with minimal flow and when the river floods, it results in devastation. The Kromme Estuary supports recreational activities including fishing, waterskiing, canoeing, boat cruisers and swimming (Adams, 2001).

As stated in Section 2.5.2. above, the Kromme Estuary is ranked as the 17th most important estuary in South Africa (Shaw *et al*., 2021). The Estuarine Health Index Score calculated for the Kromme Estuary based on its present ecological status is 49 (Almanza *et al.,* 2019), and this results in a present Ecological Status of D – largely modified (Table 3.1). The Kromme Estuary has been identified as a Desired Protected Area (Figure 2.7). Due to the impact of the two dams along the river, it is recommended that the estuary should be ecological status of C – moderately modified system. This is where a loss of natural habitat and biota has occurred, but the basic ecosystem functions are predominately unchanged (Almanza *et al.,* 2019). The estuary is considered to be in a fair state of health.

Table 3.1: Ecological Categories to describe estuary ecosystem health

Estuarine Health Index Score	Present Ecological State (PES)	Description
91-100	A	Unmodified, natural
76-90	B	Largely natural with few modification
61-75	C	Moderately modified
41-60	D	Largely modified
21-40	E	Highly degraded
0-20	F	Extremely degraded

Source: Turpie *et al*., 2012

3.2.5. Climate and vegetation

St Francis Bay receives rainfall year-round, with more rainfall occurring during the winter months (Figure 3.4) (La Cock & Burkinshaw, 1996). Marked seasonality occurs with the wind trajectories, where in winter, the wind blows from west to southwest and is driven by the northward trajectory of the westerly belt (Fitchett *et al.,* 2016). In summer, the wind blows easterly to southeast when the atmospheric circulation is dominated by the tropical easterlies. St Francis Bay is situated in a zone where the climate transitions between the sub-tropical and Mediterranean climate (St Francis Bay, 2014). The town is associated with an average maximum summer temperature of 23°C, whereas in winter the average maximum temperature is in the region of 16°C (Figure 3.5).

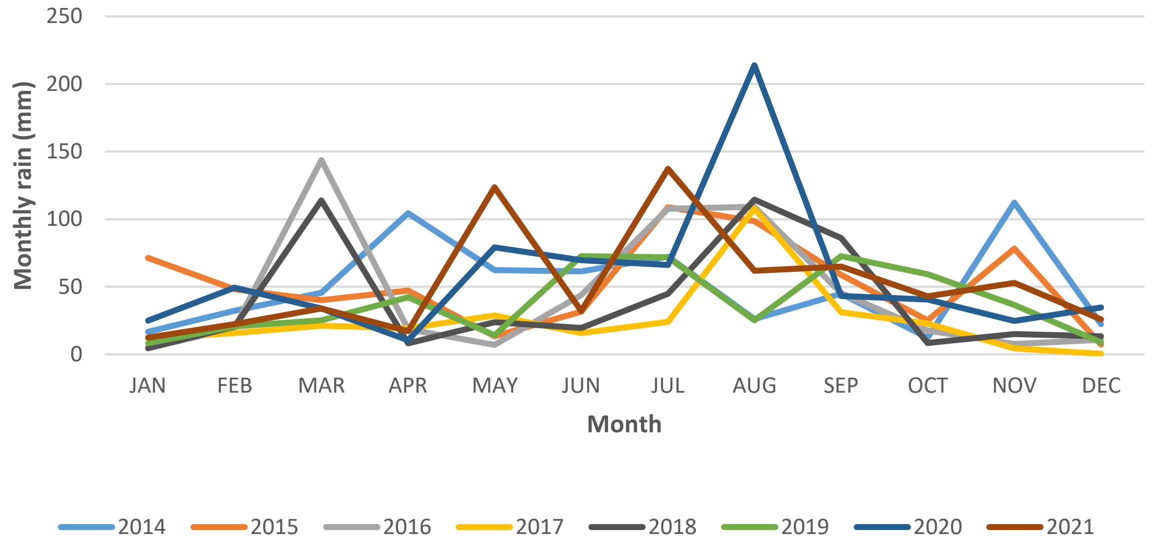


Figure 3.4: Average Monthly Rainfall for St Francis Bay from 2014 to 2021, measured at 08:00.

Source: South African Weather Office, 2022

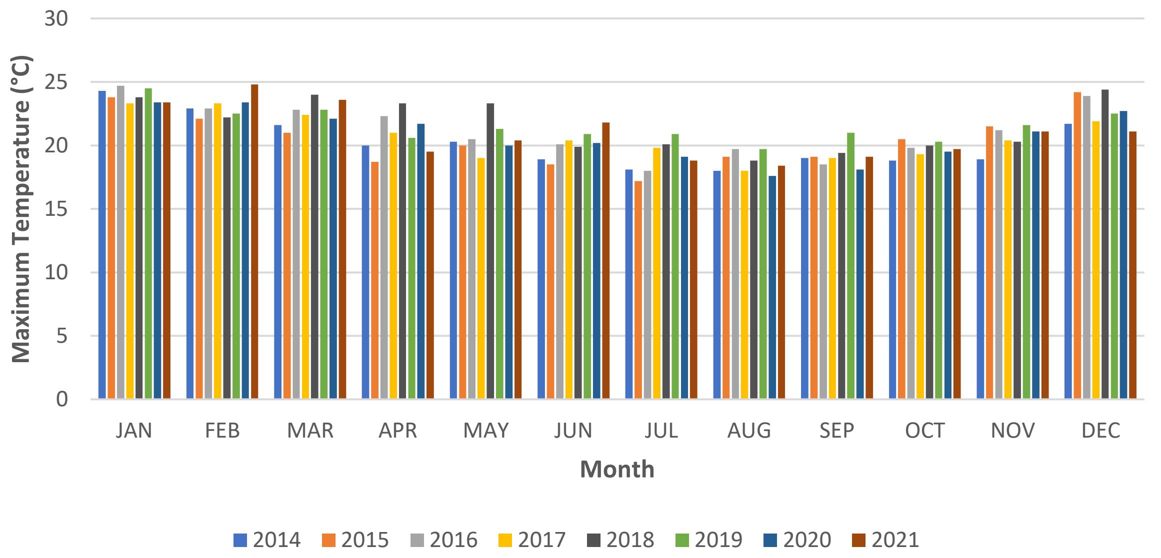


Figure 3.5: Average Monthly Maximum Temperature for St Francis Bay from 2014 to 2021, measured at 08:00 Source: South African Weather Office, 2022

The Bay and the vegetation of the dunes are located in the Cape Floristic Region, with the main vegetation types of Fynbos and Thicket. The Fynbos vegetation is dominated by species endemic to the Holocene such as *Restio eleocharis* and *Metalasia muricata* (Cowling *et al*., 2019). The dune thicket is dominated by species of tropical origin such as *Rapanea gilliana* and *Maytenus procumbens* (Cowling *et al*., 2019).

3.3. Methodology

The study focuses on the population-environment-development interface which exists in St Francis Bay and the subsequent consequences from the relevant linkages. Information about the population aspect refers to demographic and social standings, urbanization and human well-being. The environmental aspect refers to bio-physical information. Information with regards to the development aspect includes urban development, informal settlements, economic development (tourism), economic growth and infrastructural development.

3.3.1. Mixed Methods

The methodology applied in this research consists of a mixed methods approach, combining elements of quantitative and qualitative approaches (Figure 3.6). By applying this approach, it enables a greater degree of understanding to be created compared to if a single method was applied to the study. Qualitative and quantitative data are collected and analysed in a sequential manner that integrates the two forms of data (Almalki, 2016). The quantitative method produces numerical data and statistics whereas the qualitative method generates textual data and presents observed patterns (Elkatawneh, 2016). As stated by Shorten & Smith (2017) using a mixed methods approach in research, uncovers “relationships that exist between the intricate layers of our multifaceted research questions.” This is applicable to this dissertation as the aim and objectives are to understand the complex and complicated linkages that exist among the components of the PED nexus. The approach to applying simultaneous use of the methods provides the potential to identify the hidden features that exist in a system.

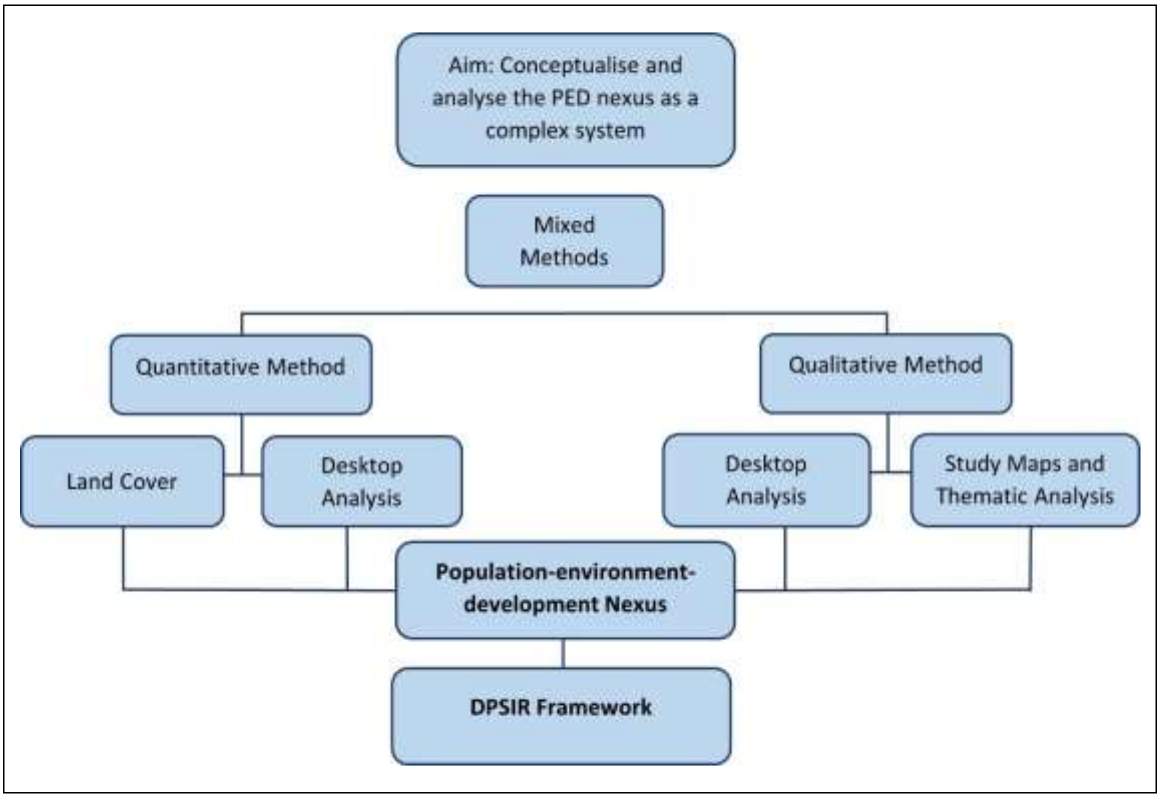


Figure 3.6: Flow diagram of the methodology

3.3.2. Quantitative Method

Quantitative data is used to measure the differences between groups and variables (Jansen & Warren, 2020) and data is expressed by numbers or statistics. The quantitative approach applied to the study of St Francis Bay included a time-sequential series map with a statistical table of landscape features that changed over a certain time-period in the Bay. A desktop analysis was applied and included statistical information with regards to the Special Rating Area (SRA) for rates and levies in St Francis Bay, the cost and duration of the mitigation options to restore the beaches in St Francis Bay and household services status in the Bay. The projected sea-level rise in the Eastern Cape is also included.

3.3.2.1. Time-sequential series

Geographical Information Systems (GIS) and remote sensing were used in order to assess the time-sequential patterns of change with regards to sediment movement across the St Francis Bay headland and the changes in the landscape of the town. Complexity is a challenging concept for theoretical modelling. The nonlinear category is appropriate as it evolves over a large range of timescales and length-scales (Paun *et al.*, 2020). With this, small changes in the initial conditions or external environment can have unpredictable consequences in the outcomes of the system (Aritua *et al.*, 2009), and so can be modelled. The macroscopic behaviour of nonlinear dynamics emerges from the complex interactions of microscale components and modifies the interactions between the microscopic components (Richardson *et al*., 2017). By understanding these interactions, the nonlinear approach can be applied to the various other categories of complex systems. This facilitates a transdisciplinary approach to research.

Longitudinal studies present a repeated measure to follow a particular area over prolonged periods of time, over years or decades (Caruana *et al*., 2015). These studies are observational in nature, with quantitative or qualitative data being collected, where no external influence is applied (Caruana *et al*., 2015). A characteristic feature of longitudinal research, according to Gravlee *et al*. (2009) is a focus on processes of change, stability and continuity through time. The advantages of this method include the ability to identify and relate events to certain exposures in order to establish a sequence of events and follow the various changes over time. In contrast, a disadvantage includes the potential for inaccuracy in the conclusion (Caruana *et al*., 2015).

A time-series is a set of numbers that measures the status of an activity over time. In some situations, only a few variables are observed in terms of measured time-series. The approach is to focus on the few variables which have been observed, the macroscopic variables, while the remaining microscopic variables are represented to a lesser extent (Qualitative) (Hassanibesheli *et al*., 2020). The time-series analysis models the behavior of complex systems based on observed time-series by separating the system's behaviour between observed macroscopic and hidden microscopic variables. This method is a representation of a part of reality. The simultaneous use of the methods provides the potential to explore various interactions between components (Gear *et al*., 2018). Nonlinearity foregrounds the multiple scales at which macroscopic components interact with microscopic components to produce feedback loops and produce various outcomes of a system, creating complexity.

Aerial images were obtained over a 36-year period for the following years: 1984, 1990, 2000, 2010 and 2020. Aerial images prior to 2010 were geospatially referenced in order for the lineation of landscape features to occur. The images were projected to the Transverse Mercator projection, referenced to the World Geodetic System (WGS) 1984 datum. ArcGIS 10.2 software was used to identify and delineate the landscape features of the area. Classifications that were mapped include: urban development, informal settlements, coastal beaches, headland bypass dunefields, the golf course, and the Sand and Kromme River. These were used to represent how the area of St Francis Bay changed over the 36-year period. The 1984 image represents St Francis Bay transitioning into a development state, whereas the 2020 image represents the present state of the area. The area covered by each landscape feature was obtained by the ArcGIS 10.2 software, where the area was recorded in hectares in Microsoft Excel. The area percentage change of the landscape features in St

Francis Bay was calculated from 1984 to 2020. By assessing the time-sequential patterns of the Bay, it allows for a link to be established between the increase in development and consequently the impacts on the environment.

3.3.2.2. Desktop Analysis

Desktop research involves collecting data from existing resources. Desktop studies refer to a study that is carried out through research, rather than through physical investigations. These studies can provide an initial understanding of the subject in question and identify potential risks which may occur in the study. The disadvantages and advantages are described by Wasko (2019). Disadvantages of desktop analysis include copyright and the restricted use of secondary data and data validity as data may be outdated. In contrast to this, the advantages of desktop analysis are that the data may be more readily available and analyses can be conducted for complete datasets.

For the study, desktop analysis data was collected in the form of statistics. Existing research and assessment reports were consulted in order to obtain statistical information with regards to the rates and levies of properties in St Francis Bay and the costs of the conceptual options to protect the coastal zone. The household services status in St Francis Bay was also included. The projected rise of sea level around St Francis Bay was obtained online. This data was obtained from NASA EARTHDATA and was projected until 2150. The data was composed of three different scenarios, relative to a baseline of 1995-2014. The medium data of the scenarios was used to determine the rate of sea-level rise (Appendix A). The following is the description as described by NASA EARTHDATA: "in the SSP3-7.0 pathway, the medium to high reference scenario resulted from no additional climate policy under the SSP3 socioeconomic development narrative. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions. In the SSP1-1.9 pathway, it holds warming to approximately 1.5°C above 1850-1900 in 2100 after slight overshoot (median) and implies net zero CO2 emissions around the middle of the century. In the SSP1-2.6 pathway, it stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero emissions in the second half of the century." With the quantitative research, the data was recorded in a table format in order for comparisons to be made and for the research questions to be carried out. This was to support the research question of the consequences and the costs which result from these linkages. Links were allowed to be observed between the domains of St Francis Bay.

3.3.3. Qualitative Method

Qualitative data presents data in a descriptive manner. A desktop analysis was applied with regards to the economic and socio-economic status of the town. This included the percentage of people in each age as well as the education levels of these residents in St Francis Bay. The type of sector in which people work, the employment status and the monthly income of these residents were also included. The total tourism spending and the Gross Domestic Profit (GDP) in the Kouga Municipality were compared and the Human Development Index (HDI) was applied. Percentages were used in the graphs instead of the raw numbers as the percentages allowed for easier comparisons to be made with regards to the whole population of St Francis Bay. Study maps were also produced in order to assess management solutions and a thematic analysis was applied to form the basis of the nexus model.

3.3.3.1. Desktop Analysis

In qualitative research, desktop analysis was applied as data was collected from existing research and assessment reports were consulted in order to obtain information in relation to the education and housing/dwelling performance in St Francis Bay. Information regarding employment, income and tourism in St Francis Bay was obtained from Statistics SA. The data was obtained from three websites that incorporated the information from Statistics SA and this data was combined with the available data obtained from Statistics SA via email. The data was presented in graph format to allow for comparisons to be made. By using this method, it allowed for links to be observed in the *Population* component of St Francis Bay. This was then applied to the nexus.

3.3.3.2. Qualitative Desktop Study Maps

A qualitative map expresses the absence or presence of various features of the land and does express the information with numbers. Satellite aerial imagery (dated 2021) was obtained for the St Francis Bay area. The .KML files for the boundary of St Francis Bay were obtained from the Census 2011 website (https://census2011.adrianfrith.com/place/268011). Manifold System 8.0 software was used to map the various regional frameworks in the Eastern Cape. The relevant mapping databases and bioregional plans that have been assessed for the site area include the following: National Vegetation Map 2018 (NVM, 2018), Mucina & Rutherford (2006) and National Biodiversity Assessment (NBA, 2019); where this provides a description of vegetation types, species (including endemic) and vegetation unit conservation status. The Eastern Cape Biodiversity Conservation plan (ECBCP, 2019) provides critical biodiversity areas in the Eastern Cape. The Garden Route Biodiversity Sector Plan identifies the Critical Biodiversity Areas along the Garden Route coast.

3.3.3.3. Thematic Analysis

MAXQDA can be applied for mixed methods data analysis. MAXQDA provides insights into qualitative data sets without suggesting the interpretation of the data. Software programs for qualitative data allows for easy sorting, structuring and analyzing large amounts of text and other data to occur (MAXQDA, n.d.). The advantages of MAXQDA include the ability to work with a range of data formats (Bothwell, 2019). This can therefore analyse text documents.

The Literature Review was analysed by thematic analysis to reveal components in the data. The responses were recorded in MAXQDA Analysis Software. The program allowed for coding of the text, into major theme codes of Development, Population and Environment. This software allowed for trends to be identified within the sources of the Literature Review. Codes were created in order to group and form themes in the data set. Thematic analysis identified and analysed themes within the data to find which themes occur most often throughout the data set and which themes are most important to answer the research questions (Harper & Thompson, 2011). From this, sub-components were identified to examine the linkages.

3.3.4. Limitations of the Methodology

It is assumed that all the information that was used, such as GIS datasets and satellite imagery for the quantitative and qualitative methods was correct at the time of mapping for the project. Statistical data was obtained from the 2011 Census as data from the recent census, 2021, was not available for the study site of St Francis Bay. This data is considered available but outdated. The data obtained is assumed to be correct as the three websites where statistical information for the 2011 Census for the desktop study in Section 3.3.3.1 was obtained and the data received from Statistics SA via email corresponded in order to produce Figures 4.3 to 4.10. Satellite imagery that was used as the baseline for the time-lapse series as well as the study maps may not be the most recent imagery on Google Earth due to when the software updates the images.

CHAPTER 4: RESULTS

4.1. Introduction

This section presents the findings of the research conducted in St Francis Bay. The research was comprised of quantitative and qualitative methods. The quantitative method focused on the change of landscape features, in the form of a time lapse series, over a 36-year time period in St Francis Bay. This method included a desktop analysis of rates and levies of properties in St Francis Bay and the costs and construction duration of conceptual options to maintain the coastline. The projected sea-level rise for St Francis Bay in 2150 was included. The qualitative method included a desktop analysis where various statistics of the St Francis Bay were described: education, housing, employment, income, tourism income and the Human Development Index (HDI). The statistics that were included were based on the available information online and the data obtained from Stats SA via email. The method focused on themes extracted from the Literature Review by using software that identifies topics most commonly used in the Literature Review, thus indicating the importance of certain concepts within the study and how it applies to the nexus and DPSIR framework.

4.2. Quantitative Data

Quantitative data is information that can be expressed by numbers. The data that is generated can be transformed into statistics (Using Qualitative & Quantitative Geographic Data, 2020). It can be used to measure the differences between groups and the differences between variables (Jansen & Warren, 2020). The following sections present quantitative data in the form of numbers and statistics which are applicable to St Francis Bay coastal zone. A time-sequential map was produced to illustrate and present the percentage change on the landscape of St Francis Bay due to development. Statistical information with regards to rates and levies, construction costs of mitigation options, socio-economic and well-being and the projected rate of sea-level is also presented.

4.2.1. Time-sequential series

The time-sequential series map is qualitative in nature but produced a statistical table of landscape features that changed over a certain time period in the Bay. This method establishes a sequence of events as mentioned previously and follows change over time (Caruana *et al*., 2015). A separation of macroscopic and microscopic variables occurred (Gear *et al*., 2018). The human-made and natural landscape features in St Francis Bay are shown in Figure 4.1. The most significant change that occurred in St Francis Bay was the increase of development and the subsequent loss of the headland bypass dunefield. In 1984, there was small urban development growth in the town and the continued growth of the golf course from previous years. Some of the Santareme Dunefield is present in 1984, with the Oyster Bay Dunefield extending eastwards towards the R330. The Impofu dam wall was constructed in 1983 and is situated along the Kromme River. From 1990, the development of St Francis Bay increased from 1984. The Oyster Bay and Thysbaai Dunefield decreased in area, with the Santareme Dunefield no longer present at this time. There was a slight increase in the golf course in St Francis Bay. The R330 altered its route as compared to 1984.

Over the next ten years, by 2000, there was a continued expansion of the St Francis Bay town. There was a decrease in the Oyster Bay and Thysbaai Dunefield. Informal settlements started to build-up in the Bay area. The golf course also increased in area. The R330 altered its route again, passing the newly formed informal settlements, towards Cape St Francis. Port St Francis became present on the landscape, with the harbor construction which took place in 1995. In 2010, the St Francis Links Golfing Estate was developed. There was a continued growth in development, with a decrease in the Oyster Bay and Thysbaai Dunefield. The two dunefields decreased in width. The informal settlement along the R330 increased in size. The current state of St Francis Bay in 2020 has seen an increase in development and the informal settlement from 2010. The Oyster Bay and Thysbaai Dunefield continued to decrease in width and length. Between 1984 and 2020, the Sand River had altered course during the time period and the mouth of the Sand River has shifted along the Kromme River.

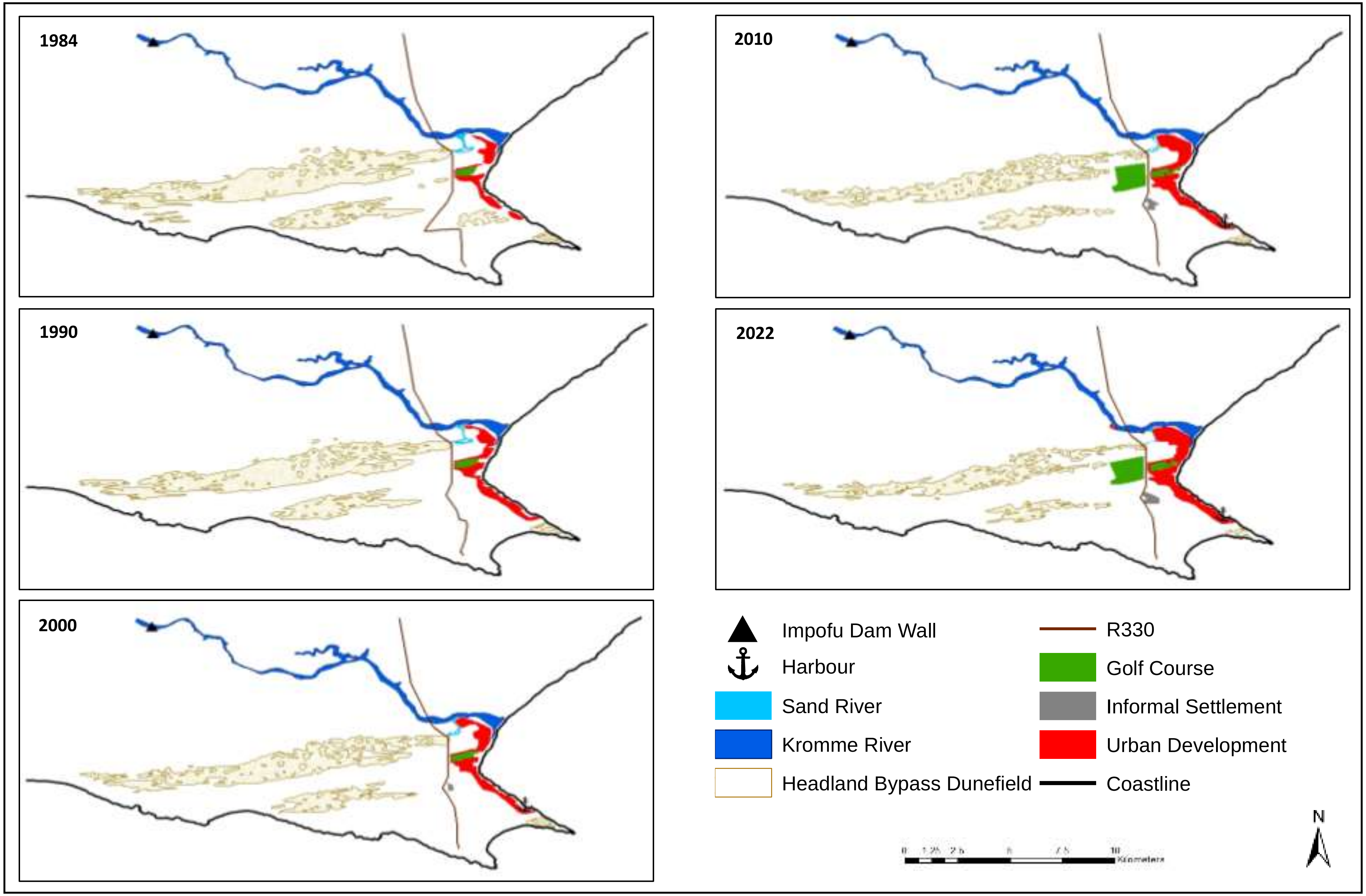


Figure 4.1: Time-lapse series of the landscape changes in St Francis Bay 1984 to 2022

Table 4.1 was generated from the time-lapse series map data to highlight the percentage change of the St Francis Bay landscape over the 36 year time period. The Oyster Bay and Thys Bay Dunefields decreased by 51.5% between 1984 and 2020. The golf course had the highest increase in change by 100% from 1984 to 2020. The informal settlement had an increase in area from 1984 to 2020 but no percentage change occurred as the informal settlement was not established in 1984. The urban development in St Francis Bay increased by 48.6% from 1984 to 2020.

Table 4.1: The percentage change of the landscape features in St Francis Bay from 1984 to 2022

Landscape Features	1984 (hectares)	2022 (hectares)	Area changed (hectares)	Percentage change (%)
Headland Bypass Dunefield	2095.2	1015.9	1079.3	51.5
Golf Course	24	211.3	187.3	780.4 (100)
Informal Settlement	0	25.2	25.2	0.0
Urban Development	245.6	365	119.4	48.6

4.2.2. Desktop Analysis

The Special Rating Area (SRA) for St Francis Bay in Table 4.2 below indicates the costs of rates and levies based on the 2016 / 2017 rates to raise money to restore part of the town's infrastructure and beaches. Properties with a low value of R1 million have low rates and levies compared to properties with a high value of R10 million which have high rates and levies.

Table 4.2: The approximate rate and levies based on the valuation of properties

Value	Rates	Levy
R1 million	R548	R274
R2 million	R1105	R552
R2.5 million	R1383	R692
R3 million	R1662	R836
R5 million	R2775	R1388
R10 million	R5559	R2779

Source: St Francis Property Owners, 2017

The cost estimates and the duration of construction of the mitigation options proposed to restore the St Francis Bay beaches are indicated in Table 4.3. Beach Nourishment is the most cost-effective option at R72 000 000 and the construction is the least amount of time of 16 months. This requires more maintenance. Offshore breakwaters are the most expensive option presented at R363 000 000 and has the longest construction duration of 58 months. This requires less maintenance. The Groynes offer an estimate between R86 000 000 and R191 000 000, with the least amount of construction duration at 23 months and the longest at 30 months.

Table 4.3: The cost and construction duration of the conceptual options to maintain the St Francis coastline.

Conceptual Options	Cost	Construction Duration (months)
Beach Nourishment	R72 000 000	16
Beach Nourishment and Headland Structure of Long Groynes	R174 000 000	30
Beach Nourishment and Headland Structure of Short Groynes	R86 000 000	23
Beach Nourishment and Groyne Fields	R191 000 000	26
Offshore Breakwaters	R363 000 000	58

Source: WorleyParson Group, 2018

In St Francis Bay (Table 4.4), 1 125 households had formal housing and 516 households had informal housing. All 1 665 households had access to piped water. 1461 households had access to flushing toilets, 6 households had a pit toilet, and 15 households had no access to sanitation. 1 515 households had energy for electricity and 1 296 households had energy for cooking whereas 150 households had other forms of energy for electricity and 369 households had other forms of energy for cooking. 1 602 households have access to refuse removal at least once a week, 33 households made use of a communal refuse dump and 12 households used own refuse dump.

Table 4.4: Household services within the St Francis Bay area.

Characteristics	Number	%
Number of households	**1 665**	
Access to housing		
Formal	1 125	67.6
Traditional	15	0.9
Informal	516	31
Other	9	0.5
Access to water		
Access to piped water	1 665	100
No Access to piped water	-	-
Access to sanitation		
Flush toilet	1 461	87.7
Chemical	18	1.1
Pit toilet	6	0.4
Bucket	105	6.3
Other	57	3.4
None	15	0.9
Energy for lighting		
Electricity	1 515	91
Other	150	9
Energy for cooking		
Electricity	1 296	77.8
Other	369	22.2
Access to refuse removal		
Removed by local authority at least once a week	1 602	96.2
Removed by local authority less often	9	0.5
Communal refuse dump	33	2
Own refuse dump	12	0.7
No rubbish disposal	3	0.2
Other	3	0.2

Source: Statistics SA, 2011

The data presented below was obtained from NASA EARTHDATA and was projected until 2150 (Figure 4.2). See Appendix A NASA EARTHDATA for the Eastern Cape – Port Elizabeth. The SSP3-7.0 pathway has an expected 0.23m rise in 2050, 0.72m rise in 2100 and 1.27m rise in 2150. The SSP1-1.9 pathway has an expected 0.2m rise in 2050, 0.39m rise in 2100 and 0.6m rise in 2150. In the SSP1-2.6 pathway, in 2050 there was an expected rise of 0.2m, in 2100 a rise of 0.45m and in 2150 a rise of 0.72m.

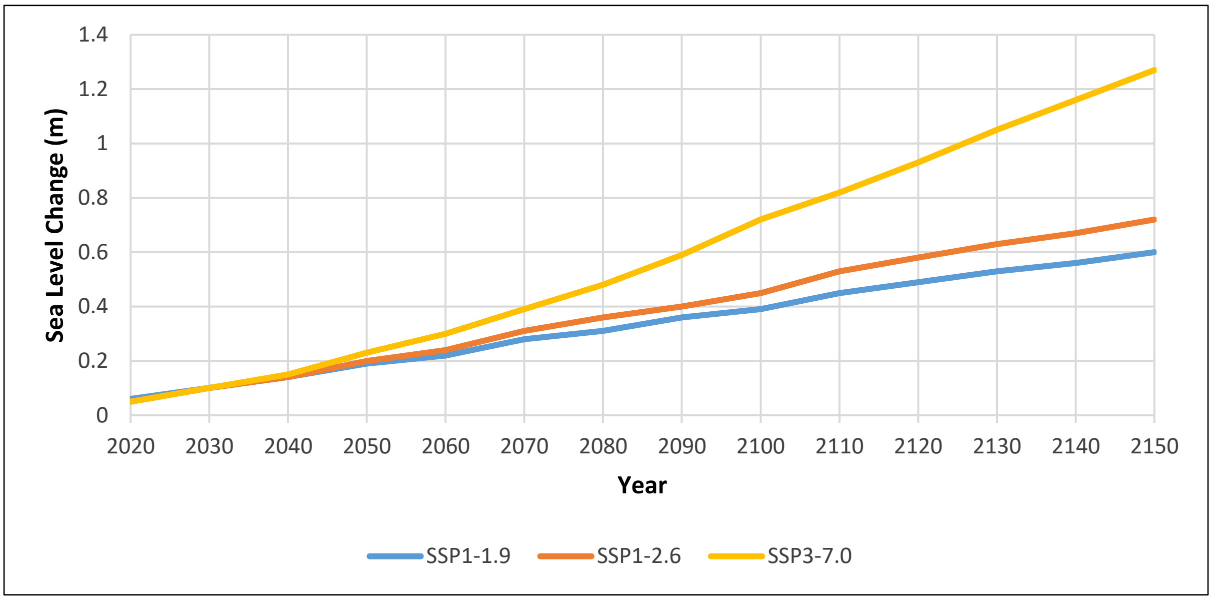


Figure 4.2: Estimated sea-level rise in the Eastern Cape from 2020 to 2150.

4.3. Qualitative Data

The following sections present data in the form of visual context which are applicable to the St Francis Bay coastal zone. Information regarding the ages, education and employment of residents are presented as well as monthly income. The tourism spent in Kouga Municipality, the Gross Domestic Profit (GDP) and HDI in the Municipality are also presented. The NEMA Acts that are applicable to coastal zones are presented below in order to present mitigation options and development plans if future development is to continue. The population data in Figures 4.3 to Figure 4.7 are presented as a percentage of the total population (4 933 people) in St Francis Bay. Using percentages in the representation of the Bay allows for easier comparisons to be made among the social indicators and an easier understanding of the dynamics occurring in the population.

4.3.1. Desktop Analysis

The percentage of people in the various age groups as seen in each zone in Figure 1.3 is indicated in Figure 4.3 below (Stats SA, 2011). The percentage in each age group in each of the three zones is part of the total population of the St Francis Bay town (4 933 people). The highest percentage of people living in the Sea Vista zone are between the ages of 65 to 69 (1.11%) and the lowest percentage of people living in the zone are above the age of 85 (0.12%). The highest percentage of people living in the St Francis Bay zone are between the ages of 25 to 29 (11.98%) and the lowest percentage of people living in the zone are above the age of 85 (0.26%). The highest percentage of people living in the St Francis Links are between the ages of 60 to 65 (0.10%). Within the St Francis Bay area, the highest percentage of people (12.30%) in the Bay area between the ages of 25 to 29 and the lowest percentage are those above the age of 85 at 0.39%

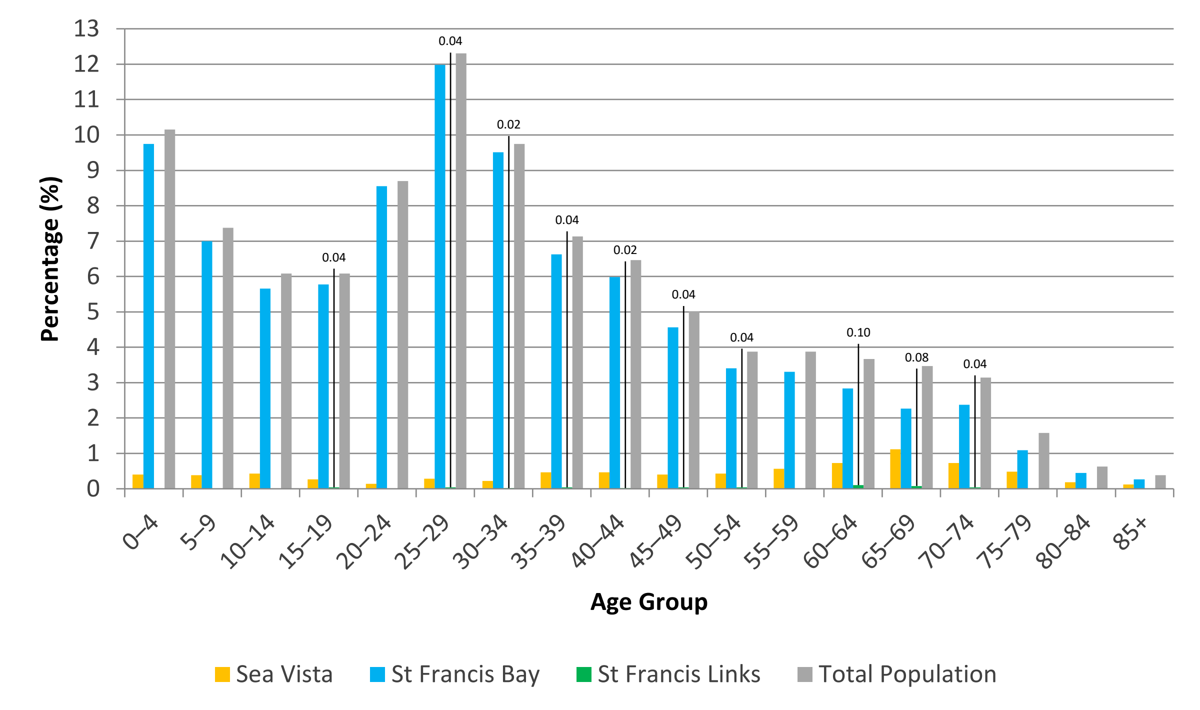


Figure 4.3: The percentage of people in each age group in the various zones in the St Francis Bay area

In the St Francis Bay area, with a population of 4 933 people have various levels of education (Figure 4.4) (Stats SA, 2011). From the people living in the area, 28.34% had some secondary education, with 9.85% of people having a higher education level. The lowest percentage of people, with 1.82%, had no schooling or formal education.

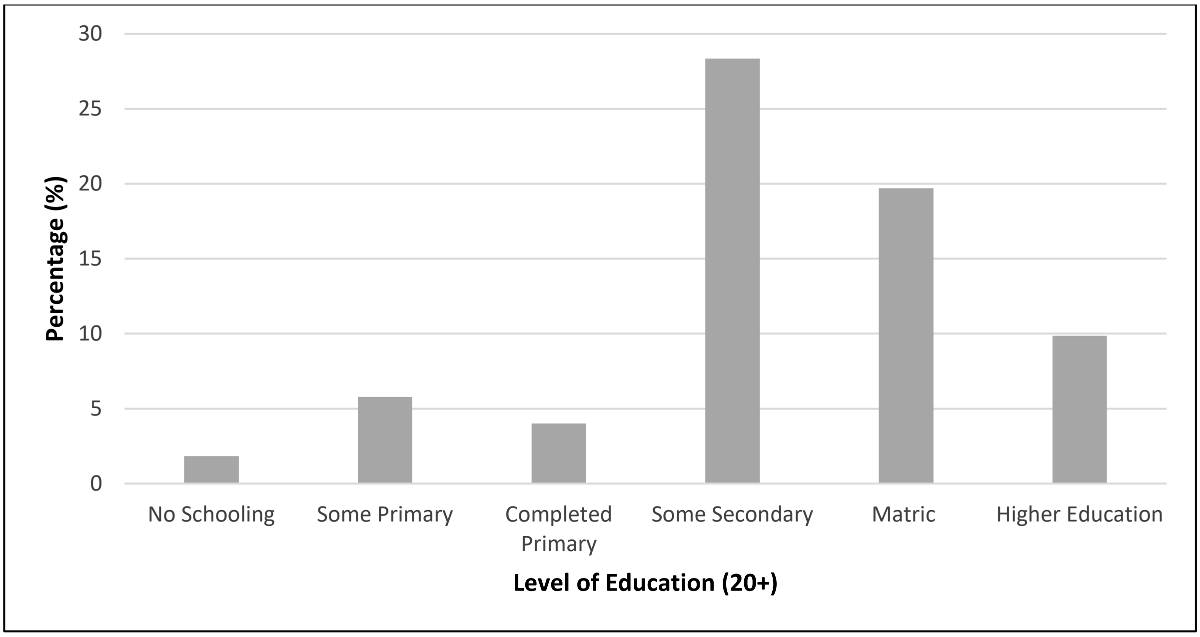


Figure 4.4: Education levels of residents in St Francis Bay.

The percentage of people in the different sectors as seen in each zone in Figure 1.3 is indicated in Figure 4.5 below (Stats SA, 2011). The percentage in each sector in each of the three zones is part of the total population of the St Francis Bay town (4 933 people). In each zone of the St Francis Bay area (Figure 1.3), three sectors of work exist: the formal sector, informal sector and private households. The highest percentage of people in the Sea Vista zone work in the formal sector (1.84%) with the lowest percentage working in informal sector (0.30%). The highest percentage of people in the St Francis Bay zone work in the formal sector (24.33%) and the lowest percentage of people work in the informal sector (1.66%). The highest percentage of people working in the St Francis Links are in the formal sector with 0.18% of people, with none working in the private household sector. Within the St Francis Bay area, the highest percentage of people in the Bay are working in the formal sector at 26.35% and the lowest percentage of people are working in the informal sector at 2.01%.

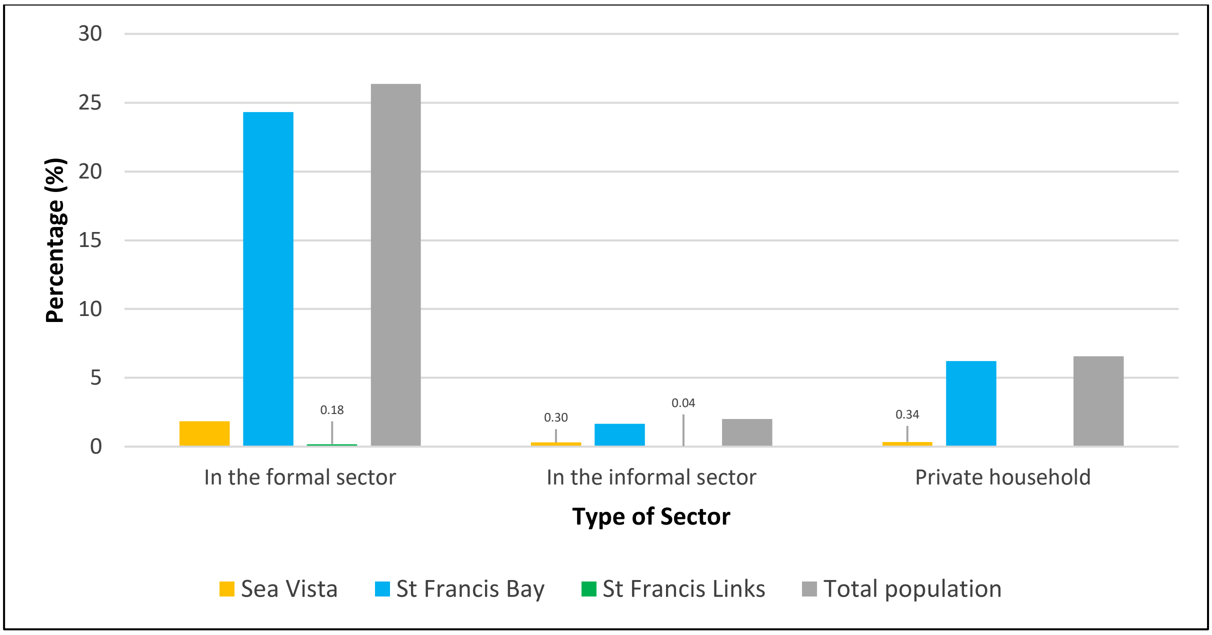


Figure 4.5: The type of sector in which the percentage of people work in each zone in the St Francis Bay area

The percentage of people in the different employment status as seen in each zone in Figure 1.3 is indicated in Figure 4.6 below (Stats SA, 2011). The percentage in each employment status in each of the three zones is part of the total population of the St Francis Bay town (4 933 people). The highest percentage of people in the Sea Vista zone have an employment status of employed (2.21%) with the lowest percentage either being unemployed or discouraged from seeking work at 0.18%. The highest percentage of people in the St Francis Bay zone have an employment status of employment (32.50%) whereas the lowest percentage of people are discouraged from seeking work (3.32%). The highest percentage of people in the St Francis Links have an employment status of employed (0.20%) where the lowest percentage of people are unemployed and discouraged from seeking work. Within the St Francis Bay area, the highest percentage of people in the Bay are employed at 34. 91% and lowest percentage of people are discouraged from seeking work at 3.51%. The unemployment rate for the town of St Francis Bay (all zones) is 32.2%.

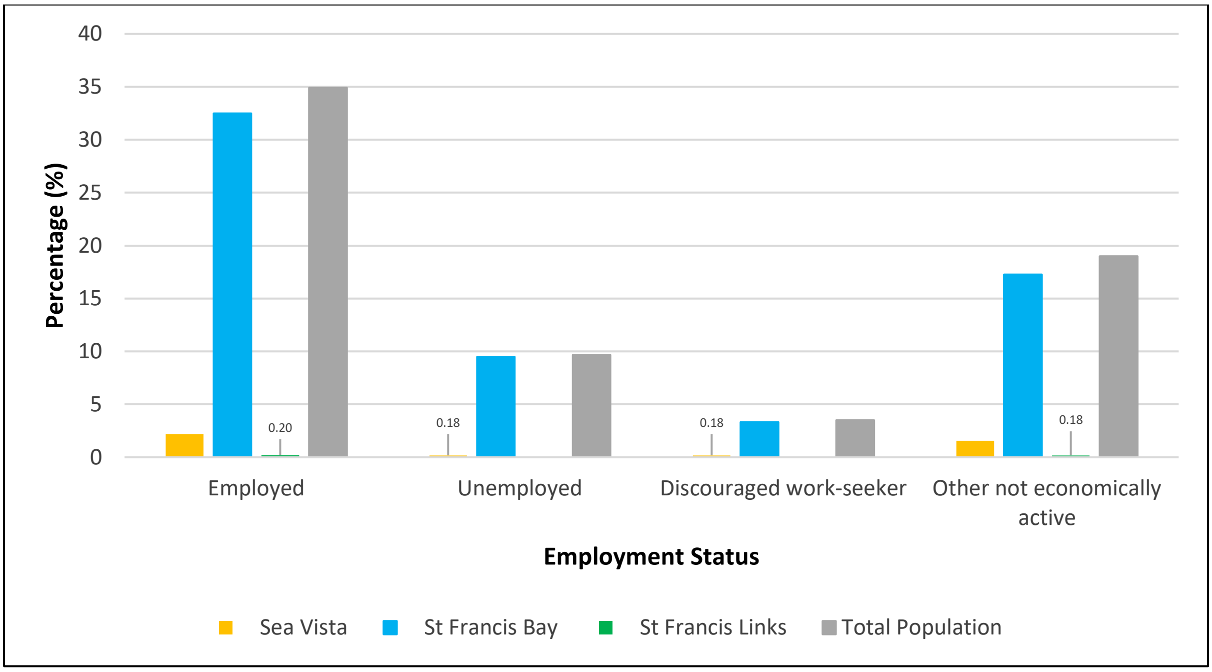


Figure 4.6: The employment status and the percentage of people which work in each zone in the St Francis Bay area.

The monthly income of all the individuals in the St Francis Bay area (Stats SA, 2011) is indicated in Figure 4.7. This includes all three zones as seen in Figure 1.3 as a whole. Of the total population 36% of individuals receive no income, 4.6% of individuals receive a monthly income between R 6 401 - R 12 800 and 0.5% of individuals receive an income of above R 102 401.

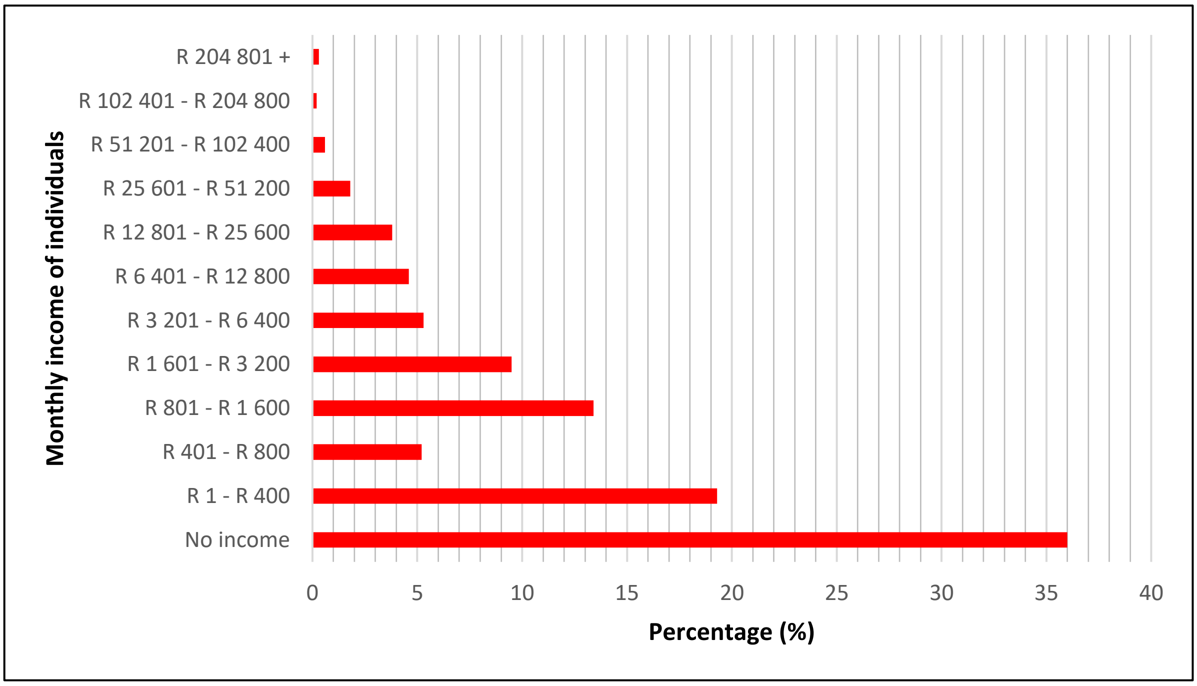


Figure 4.7: Individual monthly income of residents in St Francis Bay area

Kouga Local Municipality had a total tourism spending (Figure 4.8) of R675 million in 2016 with an average annual growth rate of 4.5% since 2006 (R433 million) (ECSECC, 2016). According to Figure 4.8, there has been a gradual growth in tourism spending the region over a 10-year period.

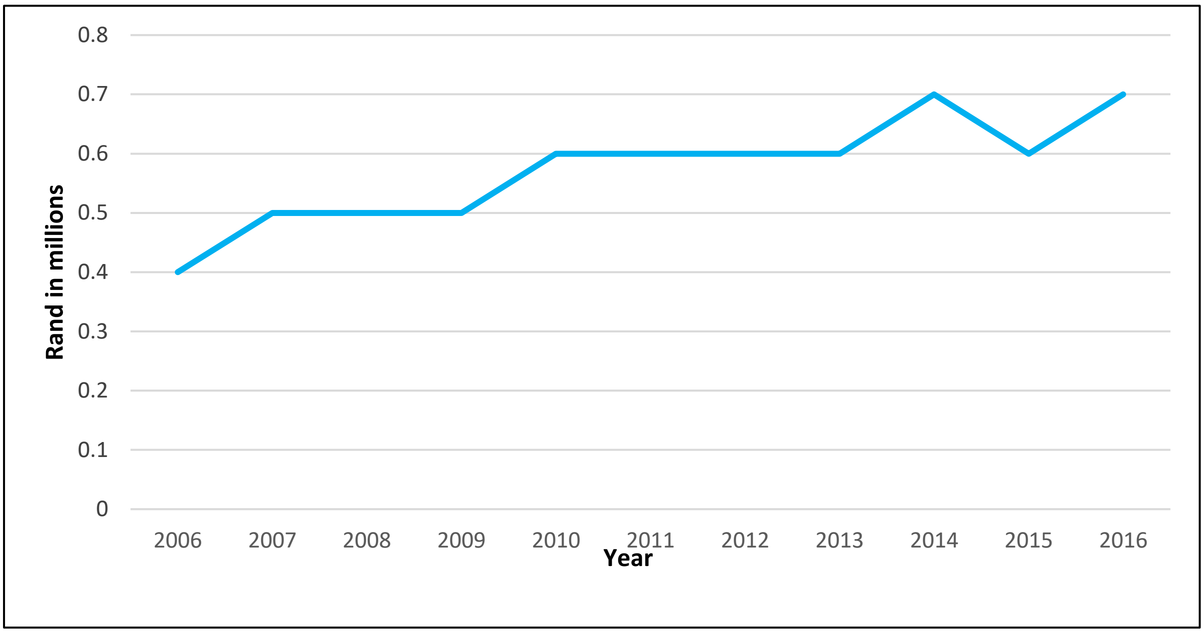


Figure 4.8: Total tourism spending in the Kouga Municipality.

In Kouga Municipality, the tourism spending as a percentage of the Gross Domestic Profit (GDP) (Figure 4.9) in 2016 was 6.4%, with a linear decline from 2006 with a tourism spending of 13% (ECSECC, 2016) over the 10-year period. The unemployment in St Francis Bay, as seen in Figure 4.6 above, also contributes to the decline in GDP.

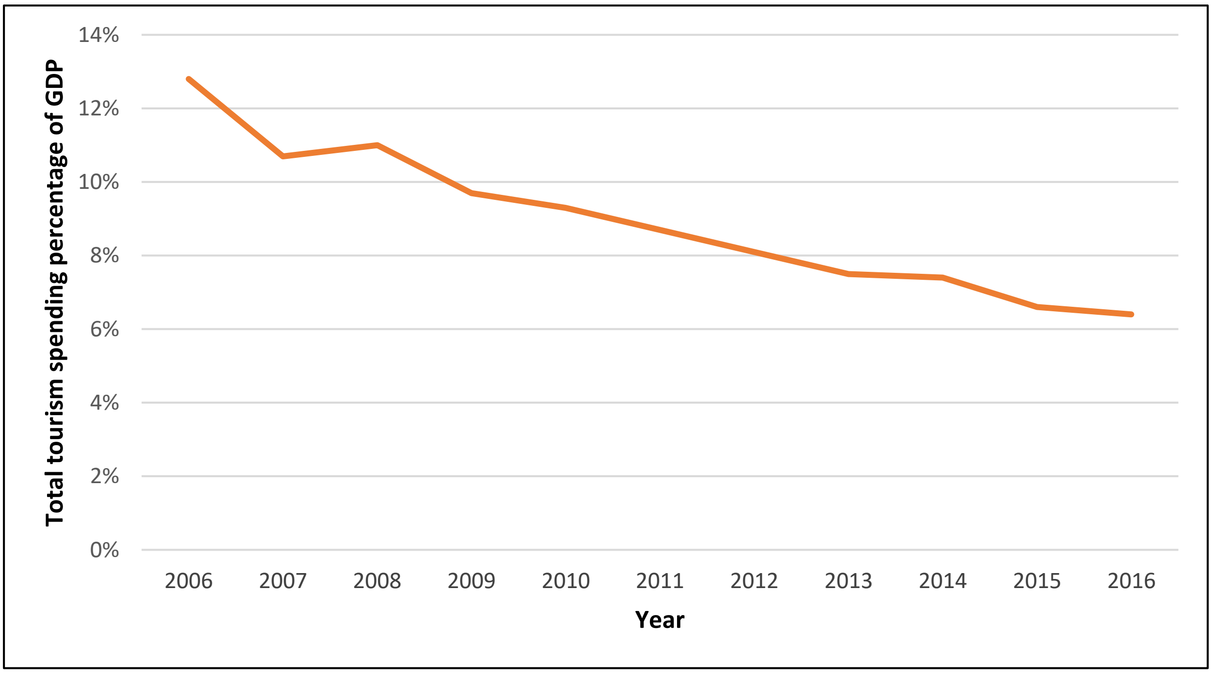


Figure 4.9: Total tourism spending as a percentage share of the GDP.

From Figure 4.8 and 4.9, it can be concluded that as the tourism spending increased in the Kouga Municipality increased over the 10 year period, the GDP of the Kouga Municipality decreased in this time period. Between 2008 and 2009 South Africa experienced a recession when the country was caught up in the global financial crisis.

The HDI of a place is expressed on a value between 0 and 1. The higher a place's human development, the higher the HDI value. The HDI of St Francis Bay (Figure 4.10) was 0.58 in 1990, declined to 0.57 in 2005 and increased to 0.62 in 2015. The trend remained constant between 0.55 and 0.65 over the 25-year period. As the HDI remained constant at approximately 0.59 this indicates that St Francis Bay has a medium level of human development

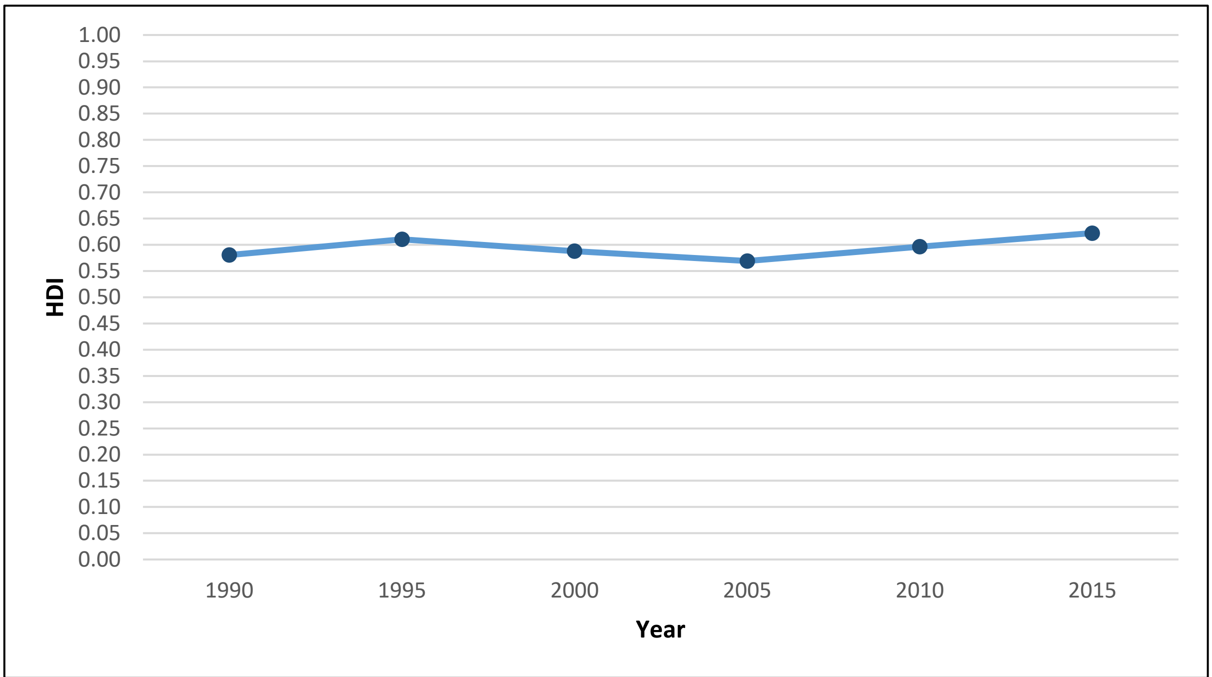


Figure 4.10: The HDI of St Francis Bay

4.3.2. Qualitative Desktop Study Maps

- Vegetation of South Africa, Lesotho and Swaziland Map (VegMap, 2018)

According to the VegMap (2018) mapping resources, the majority of St Francis Bay has been identified as St Francis Dune Thicket (Figure 4.11). According to the National Biodiversity Assessment (NBA 2018), St Francis Dune Thicket is classified as *Least Concerned* and has a conservation target of 19%. St Francis Dune Thicket is also *Poorly Protected*. Surrounding the Kromme River is Albany Alluvial Vegetation (Figure 4.11). Albany Alluvial Vegetation is classified as *Endangered* and has a conservation target of 31%. Albany Alluvial Vegetation is listed as a *Threatened Ecosystem* in terms of the National Environmental Management: Biodiversity Act (10 of 2004) as it is *Poorly Protected*. Additional to the Albany Alluvial Thicket, is the Elands Forest Thicket surrounding the Kromme River

(Figure 4.11). The Elands Forest Thicket is classified as *Least Concerned* and has a conservation target of 19% and is *Poorly Protected*. Towards the south of St Francis Bay is the Cape Seashore Vegetation (Figure 4.11). The Cape Seashore Vegetation is classified as *Least Concerned* and has a conservation target of 20%. This vegetation is *Well Protected* as it is located in the Cape St Francis Nature Reserve. The Humansdorp Shale Renosterveld (Figure 4.11) is classified as *Vulnerable* and has a conservation target of 29%. Humansdorp Shale Renosterveld is *Not Protected*.

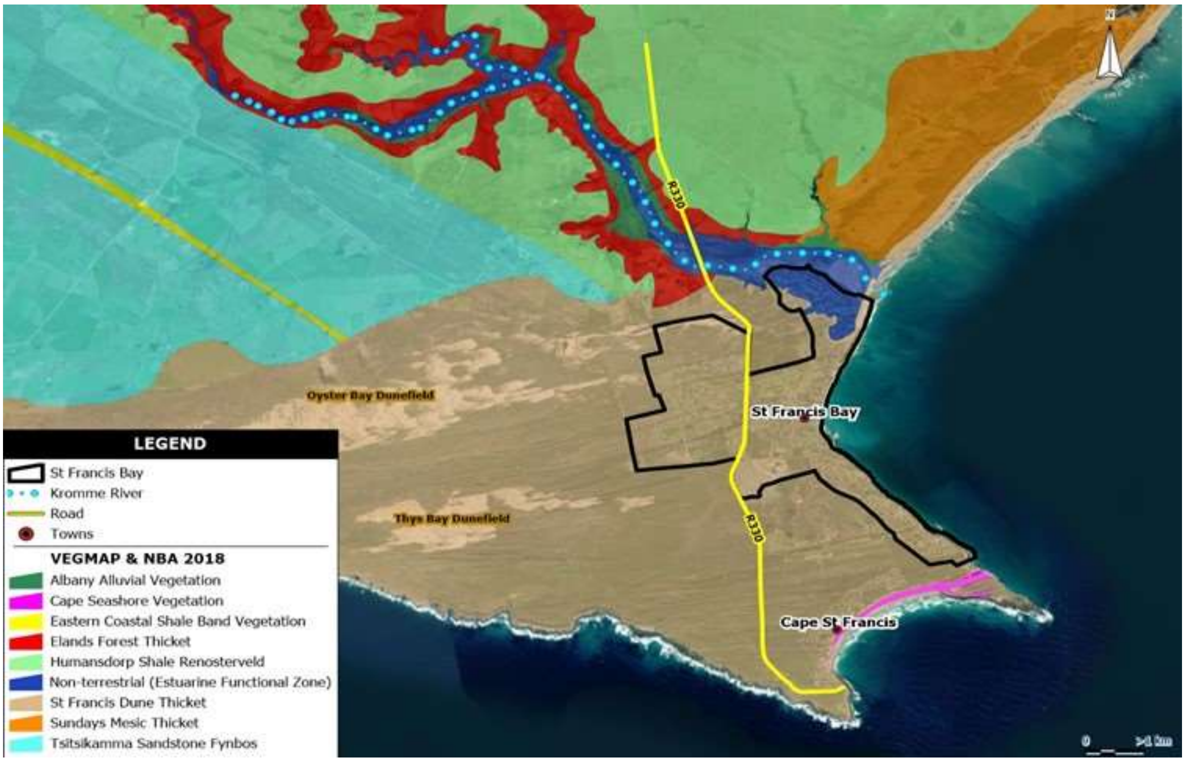


Figure 4.11: Vegetation on St Francis Bay, in terms of the VegMap (2018) mapping resources

- Eastern Cape Biodiversity Conservation Plan (ECBCP, 2019)

In terms of the ECBCP 2019 Terrestrial mapping resources, St Francis Bay town has been identified as a no CBA (Critical Biodiversity Area) or ESA (Ecological Support Area) zone (red in Figure 4.12). This indicates that there is no natural habitat remaining as these areas in the Figure are where settlements occur in the Bay, as the layer stays within the boundary of St Francis Bay.

Pathways within the boundary and areas surrounding the boundary and the Kromme River are identified as CBA 1 (Figure 4.12). A CBA 1 should be maintained in a natural state (or near-natural state) that secures the retention of biodiversity pattern and ecological processes (ECBCP, 2019). These biodiversity features are beyond their limits of acceptable change. CBA 2 (Figure 4.12) also occurs in surrounding areas of the boundary. CBA 2 should be maintained in a natural state (or near-natural stated) that secures the retention of biodiversity pattern and ecological processes (ECBCP, 2019). ESA 1 and ESA 2 surround the Kromme River (Figure 4.12). ESA 1 should be maintained in a functional state i.e., a semi-natural state such that ecological function and ecosystem services are maintained. ESA 2 should maintain current land use where no intensification occurs (ECBCP, 2019).

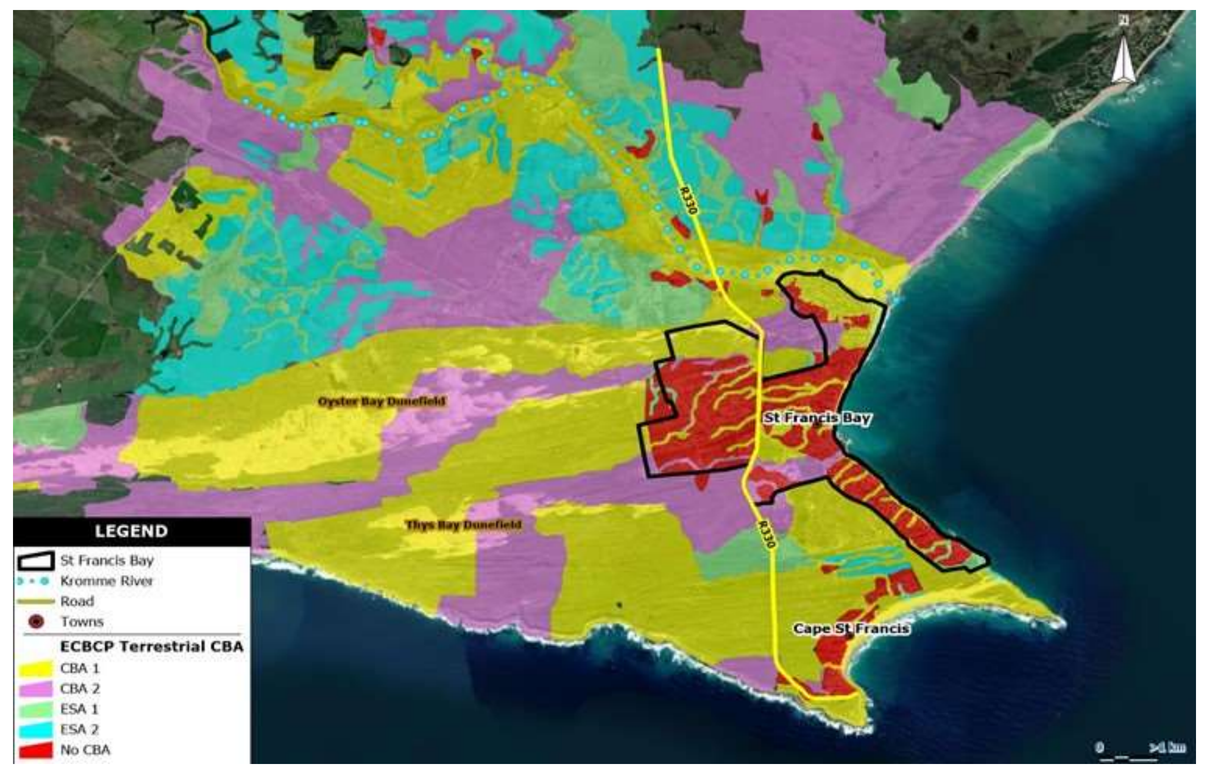


Figure 4.12: St Francis Bay, in terms of the ECBCFP 2019 Terrestrial mapping resources.

In terms of the ECBCP 2019 Aquatic mapping resources, St Francis Bay has mostly been identified as ESA 1 (Figure 4.13), associated with the Kromme River. According to the ECBCP Handbook (2019), sites identified as Aquatic ESA 1 should be maintained in a functional state i.e., a semi-natural state such that ecological function and ecosystem services are maintained (ECBCP, 2019). Ecosystems that are natural/ near-natural should be maintained and those that are moderately degraded / disturbed should be restored (ECBCP, 2019). Running along the Kromme River, the ECBCP 2019 mapping resources has identified the area as CBA 1 (Figure 4.13). A CBA 1 should be maintained in a natural state (or near-natural stated) that secures the retention of biodiversity pattern and ecological processes (ECBCP, 2019).

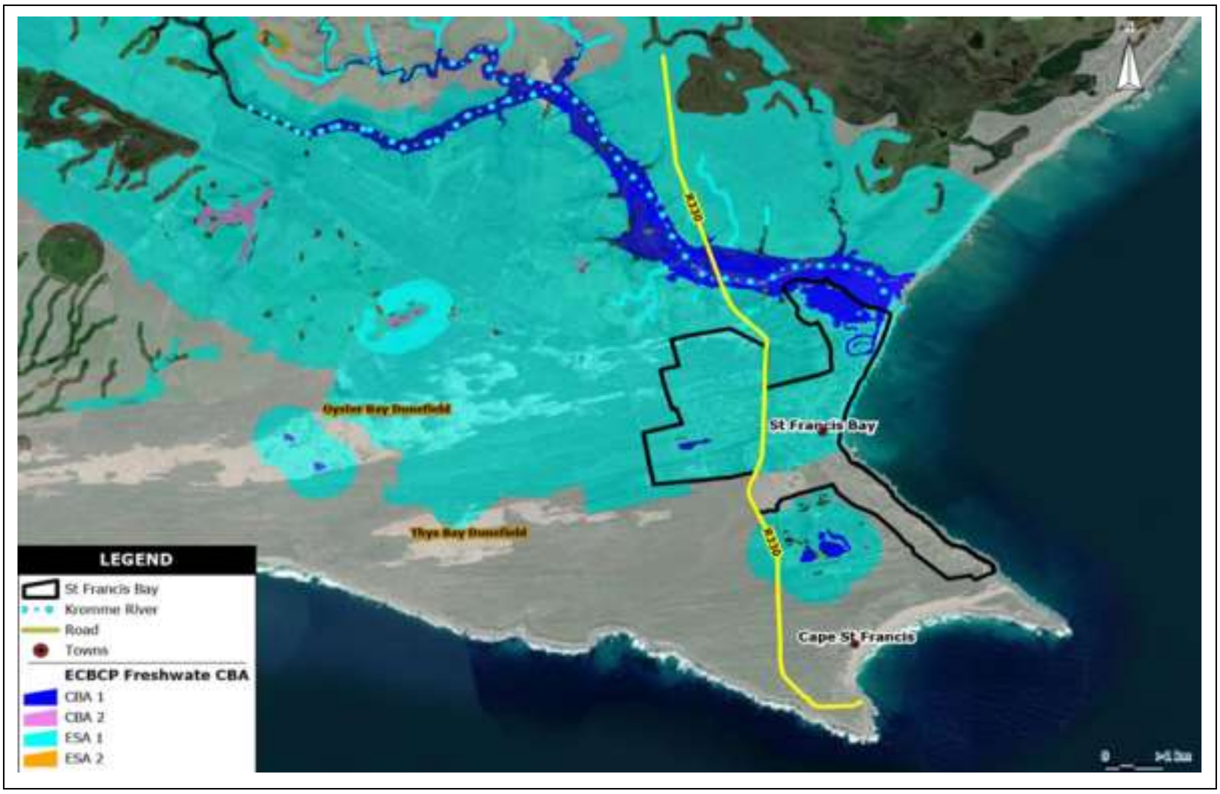


Figure 4.13: St Francis Bay, in terms of the ECBCP 2019 Aquatic mapping resources

- Garden Route Biodiversity Sector Plan

The Garden Route Biodiversity Sector Plan identified St Francis Bay as mostly CBA, with some areas as ESA (Figure 4.14). The area is critical for maintaining corridors, linkages and ecological processes and is critical for maintaining coastal processes.

Figure 4.14: St Francis Bay, in terms of the Garden Route Biodiversity Sector Plan CBA and ESA.

According to the Garden Route Biodiversity Sector Plan, areas surrounding the boundary of St Francis Bay are degraded (Figure 4.15). These areas are considered to be already transformed or degrade and play an important role in supporting CBAs.

Figure 4.15: St Francis Bay, in terms of St Francis Bay, in terms of the Garden Route Biodiversity Sector Plan Transformed areas.

4.3.3. Thematic Analysis

A thematic analysis was applied to the Literature Review of the study. The larger the word in the cloud, the more frequently is appeared in the literature. In Figure 4.16: coastal, development, complex, system and components are the most frequently used word in the Literature Review. Other frequently used words include environment, population, tourism and framework. From this Figure and the previous figures, a trend can be formulated with regards to certain themes occurring in the study and the relationships that exist among the themes.

Figure 4.16: MAXQDA Word Cloud of themes extracted from the Literature Review.

4.4. Conclusion

The quantitative and qualitative data that was presented in the previous sections are applicable to St Francis Bay as a coastal zone and presents both statistical and descriptive information. The data relates to the various economic, social, and environmental aspects of the town and the components which are formed as a result.

The time-sequential maps and accompanying data presents how the landscape of St Francis Bay has drastically changed over a short period of time and this results in consequences occurring to the natural environment, namely the headland dunefield and the beach. The social data presents inequalities occurring in the town of St Francis Bay and with the change in landscape and climate change, these areas are most likely to experience the worst outcomes. A change in sea-level is likely to occur over the next few decades with resultant consequences. Mitigation options with regards to reducing beach erosion were given and what it would cost to implement the various options. The data also presents the inequalities among the different sectors of the town, in terms of well-being, education and income. Qualitative maps were created in order to determine protection zones, protected flora and the landscape change in terms of degraded land in the Bay.

The data presented in this Chapter, as well as the Literature Review, creates the basis in conceptualizing the approach of complex systems in the form of a nexus model. In the following Chapter, the PED nexus has been modelled in the context of St Francis Bay and will further explore how the components are interlinked. The nexus explores the linkages which occur among the components and the costs and consequences which arise from these. From the presented data, management solutions can be created and implemented in order to reduce the predicted costs and consequences that may occur in the town of St Francis Bay. This is also to protect the natural environment and the species (fauna and flora) that occur in these zones. By understanding how the components are interlinked, this highlights the importance of sustainable development in coastal zones, thus ensuring the well-being of future generations.

CHAPTER 5: DISCUSSION

5.1. Introduction

The study analyzes the complex linkages which exist at the population-environment-development nexus and the cost and consequences which result from these linkages in St Francis Bay. The complexity of the interactions between the population, environment and development components are represented in the PED-nexus model, as explored in Section 2.2 (Figure 5.1). The following nexus diagram was created from the quantitative and qualitative data presented in the previous chapter and from the information described in the Literature Review (Chapter 2). Nexus approaches can identify synergistic effects and co-benefits that might otherwise be missed in complex systems and help detect and minimize harmful trade-offs (Liu *et al.,* 2018).

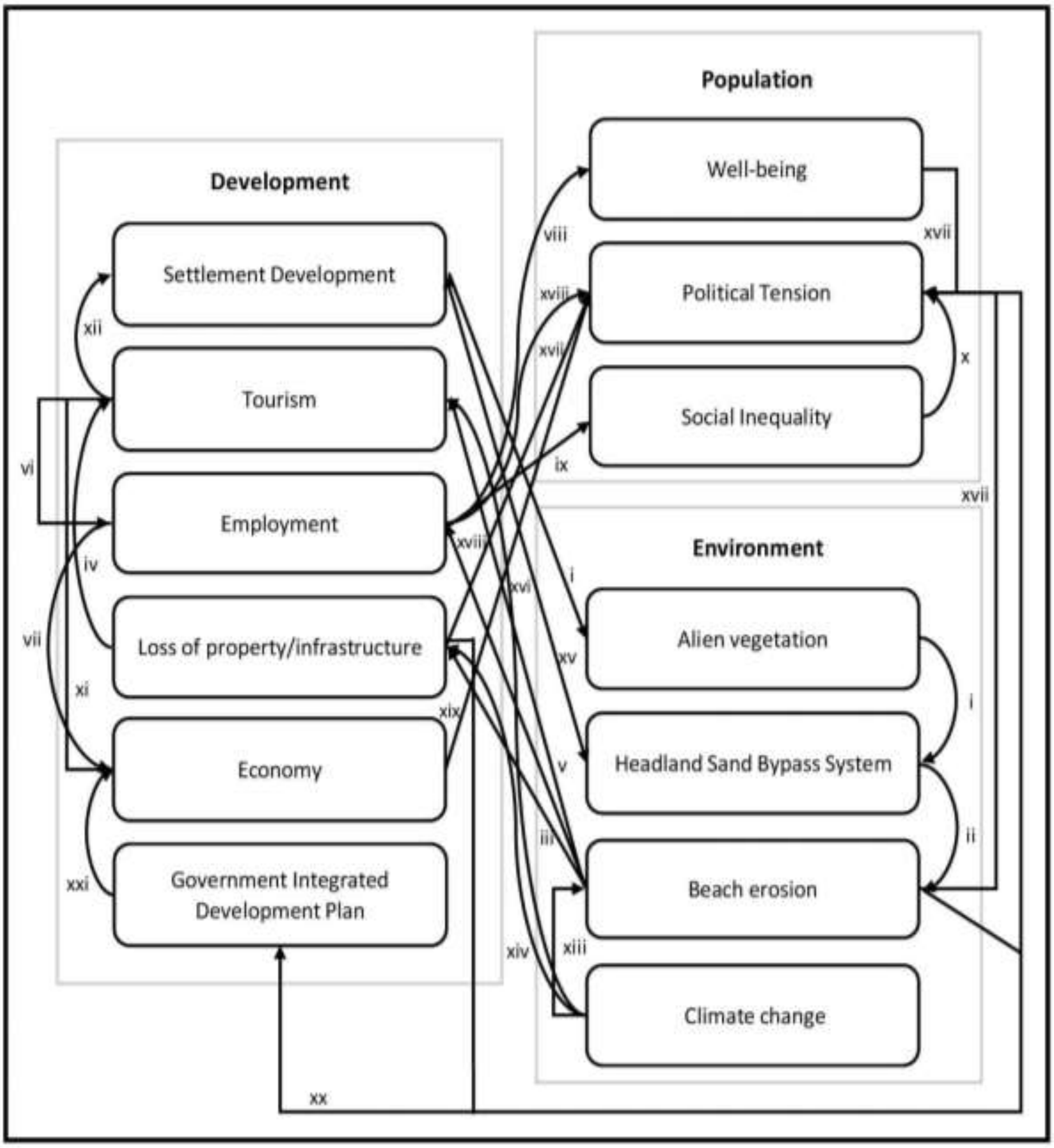


Figure 5.1: Representation of the population-environment-development nexus in St Francis Bay

5.2. Population-environment-development Nexus

The above population-environment-development nexus pathways are described below make the complexity more accessible and enhance the understanding of the nexus. The statements will be accounted for in the Chapter.

i. As the settlements developed from the 1960s (La Cock & Burkinshaw, 1996), alien vegetation was introduced to the Headland Bypass Dunefield to prevent further movement of sediment from the dunefield towards the developing town of St Francis Bay (Figure 5.2).
ii. The prevention of sediment movement from the dunefield contributed towards the occurrence of beach erosion along the coastline (Figure 5.3).
iii. With properties and infrastructure constructed close to the coastal zone and the increasing rate of erosion, beach erosion resulted in the loss of these infrastructures (Phillips & Jones, 2006) as the buildings would collapse due to unstable support. Coastal erosion may damage transport infrastructure by flooding or eroding roads. This infrastructure has been paid for by residents through rates and taxes (Table 4.2).
iv. Due to the loss of property/infrastructure, this may limit the number of tourists that the town can accommodate.
v. Beach erosion may impact the tourism sector as there are fewer beaches for tourists to enjoy (Fitchett *et al*., 2016).
vi. The impact on tourism may in turn have an impact on employment. With less tourism, there is a loss of job opportunities, ranging from hospitality to entertainment. In contrast to this, tourism may also lead to an increase in employment opportunities.
vii. Due to a loss of jobs, a decrease in the economy would occur.
viii. The increased unemployment rates will have an impact on the local well-being of the residents. The well-being is affected due to anxiety resulting from a loss of property, loss of income and displacement (Creel, 2003). An increase in employment opportunities will therefore influence the well-being of residents as they will be able to live better lives.
ix. With unemployment, this may contribute to inequalities in the town as residents cannot afford the luxury houses on the marina and village and will live on the outskirts of the town (Figure 5.4).
x. Inequality will lead to political tension towards the government to deliver basic needs and services to the township.

From points vi to x, a positive feedback system is occurring. In this process, the feedback system worsens the effects of the first disturbance. This increases in magnitude through the system.

xi. Tourism can contribute to the economy of the town, as with an increase in tourism (Figure 5.5), the economy increases, whereas a decrease in tourism will lead to the economy declining (GhulumRabbany *et al*., 2013).

xii. With an increase in tourism, developments will likely increase to accommodate the growing tourist population.

xiii. Climate change is predicted to result in sea-level rise as well as increased storm surges (Fitchett *et al.,* 2016). This results in an enhancement of beach erosion (Theron *et al.,* 2010) (Figure 5.6).

xiv. With climate change and the increased storm surges, the rising water after heavy rain can cause devastating damage to infrastructure, such as bridges and roads, which is the access road into the town (Figure 5.7)

xv. Due to the increase of residents in the coastal zones, dune systems are being destroyed in the process of providing residential development, tourist resorts, and recreational areas. Dunefields will have an impact on development as the sediment movement may block the development (McLachlan *et al*., 1994). During strong winds, the sand blows onto the road, causing hazardous conditions for motorists (Figure 5.8).

xvi. As climate change is occurring and changing weather patterns, this will have an influence on the attraction of coastal zones to tourists as well as the entertainment factor (Senevirathna *et al.,* 2018*)*.

xvii. Beach erosion, loss of property, and well-being may result in political tension. Residents are concerned with the changes occurring around them and require assistance from those in the local authority. Political and social tensions may arise as a result of the measures undertaken to address coastal erosion (McLachlan *et al*., 1994). Large investments required in coastal zones may not be considered an appropriate economic response by people.

xviii. Coastal erosion may unfavorably affect people’s income. Erosion on or nearby a property can result in a reduction in the value or price of the property. The loss of property will arise if coastal protection works are not undertaken. The reduced productivity of businesses that rely on infrastructure which is affected by erosion or which incur costs in mitigating erosion, will have a knock-on effect on the local economy.

xix. The economy in the town can lead to political tension as a decrease in the economy may have residents concerned as to how economic activities will continue in the town and mitigation methods will be implemented.

xx. Due to this increase in tension, beach erosion and loss of property/infrastructure, integrated development plans will need to be implemented in order to present a plan of action for the future and how to improve the town.

xxi. The integrated development plan will have an impact on the economy as it will cost money to restore the town, however, once the plans have been put into action, this will hopefully bring income back into the town.

Various linkages exist at the Population-environment-development interface as seen from the pathways described above. The reciprocal dynamics exist where one component affects another component (Laspidou *et al.,* 2018), such as loss of property/infrastructure on tourism or the impact of climate change on beach erosion. Feedback loops exist where a component has a ripple effect on more than one component in the system (Laspidou *et al.,* 2018), such as with developments increasing, alien vegetation was introduced to the dunefields which led to beach erosion and influenced other components.

Figure 5.2: Vegetation planted on the Oyster Bay Dunefield, entering St Francis Bay.

Source: Author, 2022

Figure 5.3: Coastal erosion occurring along the coastline of St Francis Bay.

Source: Author, 2022

Figure 5.4: Informal settlement on the outskirts of St Francis Bay.

Source: Author, 2022

Figure 5.5: Tourism in St Francis Bay along the beaches and the Marina.

Figure 5.6: Erosion caused by heavy rainfall and storm surges.

Source: Author, 2022

Figure 5.7: Damage to the bridge and roads in St Francis Bay after heavy rainfall.

Figure 5.8: Strong winds blowing sand onto the road. Source: Author, 2022

Globally, coastal populations and infrastructures are experiencing high-risk conditions due to coastal erosion (Veloso-Gomes *et al.,* 2008). According to Neumann *et al.* (2015) coastal settlements, infrastructure and economies could be severely impacted by flooding, coastal erosion and shoreline relocation. Due to the high-energy wind environment, according to McLachlan *et al.* (1994), headland-bypass dune systems tend to be "non-accretionary" in the long-term and thus play an important role in maintaining the sand budget by transporting sand between bays. Since 1845, natural driftsands posed a threat to the development of human settlements and have since been stabilized in St Francis Bay in order to support the increase in development and the associated increase in the economy (Avis, 1989). In New South Wales, Australia, strong swells have led to erosion which has resulted in the partial collapse of buildings. Structures such as harbours, breakwaters and groins which disrupt sand transport, may lead to severe erosion as these withdraw down-drift beaches of sand (Brown & McLachlan, 2002).

Freire *et al.* (2009) state that buildings have been constructed very close to the shoreline and therefore are threatened by erosional processes (as seen in Figure 5.9 A). In Spain, large-scale urban development carried out on the foredunes during tourism rise in the seventies destroyed the Spanish dune systems (Gomez-Pina *et al.,* 2002). As a result of such massive dune occupation, most of the Spanish coastline has shown signs of erosion. In Mauritius, beach erosion threatens coastal roads and tourist hotels, and will be accelerated by sea-level rise (Ragoonaden, 1997).

Figure 5.9: (A) Houses constructed close to the shore in St Francis Bay. (B) Houses constructed in the Marina in St Francis Bay, vulnerable to sea-level rise. Source: Author, 2022

Population growth and development are critical drivers of change in the coastal zone and therefore generate high pressure on ecosystems, including marine and terrestrial, and natural resources through increased utilization and pollution (Neumann *et al.,* 2015). Coastal growth, land conversion and urbanization are related to increased exposure to a rise in people. Sea-level rise and related effects, which increase levels of risk will lead to vulnerability along the coastlines and in populated deltas (Figure 5.9 B) (Neumann *et al.,* 2015). Nonlinear dynamics offers new tools to quantify, model and predict the behaviour of complex systems (Willy *et al.,* 2003). It is critical to understand the complexity of relevant components in order to enhance the viability of coastal systems. This includes the mitigation of the consequences which arise from the linkages. By understanding the multiple components that manifest in a reciprocal fashion regarding the consequences of what is shown in the time series, links to the feedback category of complex systems, creating a nexus.

The beach offers recreational and tourism points as well as offers coastal protection by reducing wave energy (Almanza *et al.,* 2019). Erosion has led to a decrease in the width of the beach, particularly in St Francis Bay. The net shoreline retreat along St Francis Bay beach has been "approximately 30-50m over the past 30 years", where the retreat is "1-1.5m per annum" (Shaw *et al.,* 2019). The retreat has resulted in the erosion of the vegetated sand spit occurring, along with increased storm surges, leading to ecological impacts on the dune system. This therefore has a ripple effect on the future impacts on social infrastructure and property.

Tourism can create employment, attract visitors, and generate opportunities (Figure 4.9) in areas where economic activity may be restricted, as well as provide social opportunities to the local community, as stated by Dodds (2010). Coastal protection costs (Table 4.3) are more than the market value of undeveloped rural land. Coastal protection works are therefore likely to be prioritized in areas with higher land value. This may lead to inequality in areas with lower land values, where residents will be at greater risk of the social effects of displacement. Various social effects can impact the well-being of the community. Displacement can contribute to problems of overcrowding on the remaining land, depending on how much suitable land remains and how well the resettlement is managed. Mental health issues including anxiety can arise from the loss of property, income, displacement from homes and the uncertainty of risk (Feris, 2014).

The Human Development Index serves as a frame of reference for both social and economic development. The HDI for St Francis Bay in 2015 is 0.62 as seen in Figure 4.10. According to Radovanovic (2011), St Francis Bay has a medium level of human development. As the HDI measures health, education and standard of living, the system has been criticized for not including ecological considerations. The HDI has neglected to incorporate the links to sustainability by not investigating the impacts on the natural system of activities that could potentially contribute to national income, and therefore the HDI (Neumayer, 2012). The Human Development Report 2020 proposed an adjustment for the Human Development Index. This is to recognise links between human development and biophysical boundaries. The HDI presents more information compared to the GDP. Compared to GDP, the HDI places a greater emphasis on human development, as it considers the quality of life and not only the production capacity of a country (Radovanovic, 2011).

Feris (2014) argues that people should consider the nexus of poverty and environmental degradation. Those who are living in poverty are the ones who are experiencing the most from environmental changes. This is seen in Figures 4.4, 4.5, 4.6 and 4.7 of Chapter 4 of the Results. They are experiencing a "loss of sense of place and solastalgia" (Feris, 2014). Solastalgia is considered to be present within South African law with regards to the conservation of protected areas and environmental impact studies (Feris, 2014). The principles of the National Environmental Management Act call for the consideration of people's values and the research of potential impacts on these values. Sense of place is a necessary concept to be understood with regards to social sustainability at various micro- and macro- levels.

Peng *et al.,* (2016) state that coastal environments encourage several positive psychological benefits and behaviours that promote the well-being of the residents and tourists. The advantages of living near the coast are strongly associated with positive outcomes with a reduction in negative outcomes (Peng, et al., 2016). Human psychology and behaviour are dependent on current social stimuli as well as characteristics and behaviour of the environment. If human behaviour causes the living ecosystem to fall out of balance, this will have a serious effect on people's psychology and behavior (Peng *et al.,* 2016).

According to St Francis Property Owners (2016), the Sea Vista Township has approximately 472 brick-built houses and approximately 1,000 shacks. Assuming that there is an average of 3 people per dwelling (Stats SA, 2011), the population of the township is approximately 4,500 people. Assuming that 1 out of 3 people in each dwelling is a job seeker, there are approximately 2,300 seekers in the township. These are mostly unemployed, poorly skilled workers who are looking for casual wage jobs in order to survive (Figure 4.6). St Francis therefore needs to create about 3,000 jobs as well as the housing and skills base of these people. This will require better education to take place in the town.

In a newspaper article published by Rogers (2022), a ruling was announced that the SRA (Table 4.2) in St Francis Bay would be annulled was welcomed by some residents it is said the initiative was unfair as a "third of the ratepayers" were bearing the costs of the projects which came about from the funds, many of which are pensioners. Opposing this, some residents state that the SRA is needed to address serious issues such as rising crime, crumbling roads, and beach erosion as the municipality was not maintaining these. As stated by the Concerned Residents Association, 1 600 residents were paying the SRA levy for the benefits to be enjoyed by 4 500 residents, where the people that benefit the most are those with "homes in the canals and on the beachfront."

The CBA map, Figure 2.7 of section 2.5.2 of the Literature Review, identifies areas that have been irreversibly transformed through development, such as urban development and agriculture. These areas can no longer contribute to the biodiversity of the area (Holness & Bradshaw, 2009). The CBA 1 identified in this map corresponds the CBA 1 mapped in Figure 4.12 of the Results Chapter. There are however small patches of land (partially transformed or degraded land) that have been classified as

ESAs or CBAs. This is due to these exceptions supporting the surrounding biodiversity in some manner.

As seen in Figure 4.11 in Chapter 4 and mentioned in Section 3.2.5 in Chapter 2, St Francis Bay is predominately covered in Thicket and Fynbos. With regards to the conservation targets of the vegetation types in Figure 4.11, it is important to note where the transition boundary is with certain vegetation types and where the vegetation type is listed on the NBA. This will indicate what vegetation type is suitable for development, the level of protection of the vegetation type and whether it is suitable for construction to proceed. Also, with the water courses (Figure 4.13) and the level of protection, it allows for mitigation strategies to be developed to conserve the water as well as the biodiversity which occurs in the surrounding areas. Knowing which areas are CBA and ESA in terms of St Francis Bay, allows for specific management objectives to be drawn up to be integrated into the IDP.

Management objectives of CBA categories include and quoted by the ECBCP, 2019:

- "CBA 1: Ecosystems and species must remain intact and undisturbed. If land use activities are unavoidable in these areas, an offset must be designed (Figures 4.12; 4.13 and 4.14).
- CBA 2: Ecosystems and species must remain intact and undisturbed. There is flexibility in the landscape to achieve biodiversity targets. If land use activities are unavoidable in these areas and depending on the condition of the site, set-aside areas must be designed in the layout and implemented.
- ESA 1: These areas are not required to meet biodiversity targets but these still perform essential roles, such as connectivity and ecosystem service delivery. Ecosystems that are moderately disturbed/degraded should be restored.
- ESA 2: These areas have already been subjected to severe or irreversible modification. These areas are not required to meet biodiversity targets but still perform some functions with essential roles, such as connectivity and ecosystem service delivery. ESA 2 areas should not undergo any further deterioration in ecological function."

As a large portion of the Garden Route is already transformed, most of the remaining areas are of high conservation value. The CBA maps (Figures 4.12, 4.13 and 4.14) aims to guide sustainable development in St Francis Bay by providing a combination of biodiversity information in order to inform decision-makers (Holness & Bradshaw, 2009). This serves as a reference for various planning procedures, advising which areas in the Bay can be developed, and which areas are of critical biodiversity value as well as their support zones that should be protected against any impacts (Holness & Bradshaw, 2009). This thus ensures appropriate land use and planning for the "best possible long-term benefits and to promote integrated management of natural resources" as stated by Holness & Bradshaw (2009). The IDP integrates planning at the relevant municipal level. IDP may include an Integrated Environmental Management Plan to ensure compliance with environmental legislation. Components of an Integrated Environmental Management Plan may include according to the ECBCP (2019): 1) State of Environment Reporting (informed by CBAs and ESAs); 2) Assessment of biodiversity and ecosystems (including CBAs and ESAs); 3) Socio-economic needs of the populace; 4) Identification of environmental programmes and plans, including CBAs and ESAs; and 5) Action plans, for integration into the IDP, for projects such as remediation/restoration and sustainable resource use opportunities.

The Kouga Integrated Development Plan 2017-2022 listed various objectives in the report. Development needs by Ward 12 which apply to St Francis Bay include the upgrade of sewerage systems and wastewater plants, dune encroachment, rehabilitation of the dumping site, maintenance of bridges over the canals, roads upgrades and the maintenance of the launching site at the Kromme River (Kouga Municipality IDP, 2017). A Priority Project list was created for Ward 12 (Table 5.1) to determine which projects need to be attended to first.

Table 5.1: Priority Project list of Ward 12, including St Francis Bay

Project	Priority
Road maintenance	1
Management of the Zeeikoei River Mouth	2
Bush clearing	3
Beach and spit maintenance	4
Bucket system in lower Kwanomzamo	5
Coastal Management Plan	6
Wastewater plant - St Francis Bay	7

Source: Kouga Municipality IDP, 2017

5.3. Driver-Pressure-State-Impact-Response Framework

As mentioned in section 2.2.2 of the Literature Review and as stated by Bowen and Riley (2003), it is important for a link to be acknowledged between social and ecological systems and the interactions involved in these systems. As mentioned in Chapter 2, the DPSIR framework presents a visual representation of the cause and effects of the relationships which exist among components in society and the environment (Smaling & Dixon, 2006; Tscherning *et al.,* 2012). From the mixed methods approach in the methodology and the PED-nexus in Section 5.2, the DPSIR Framework was created for St Francis Bay in Figure 5.10 below and was adapted from Figure 2.2, to identify the links between systems. With the information obtained from the framework, it can contribute to management plans along the coastal zone and mitigate the anthropogenic activities and the environmental and socio-economic consequences which arise in these zones (Gari *et al.,* 2015).

For the St Francis Bay area, the driving forces are human and economic activities and development in order to support the population. These activities therefore exert pressure on the environment due to land-use change over the 36-year period in St Francis Bay and the increasing population change over the years. From this, the state of the environment will experience a change. As land-use change occurs, there is an alteration of the direction of the headland dunefield (McLachlan *et al.,* 1994) for roads and infrastructure to be built. This leads to impacts on the environment to take place. Physical changes may occur such as beach erosion or socioeconomic functions may change as a result of the impact of beach erosion on tourism. A response will arise from impacts on the environment and society. This will include management policies being updated and enforced or alternative methods such as beach nourishment will be implemented in order to reduce erosion. The response may thereafter create feedback to the drivers, pressures, state and impact.

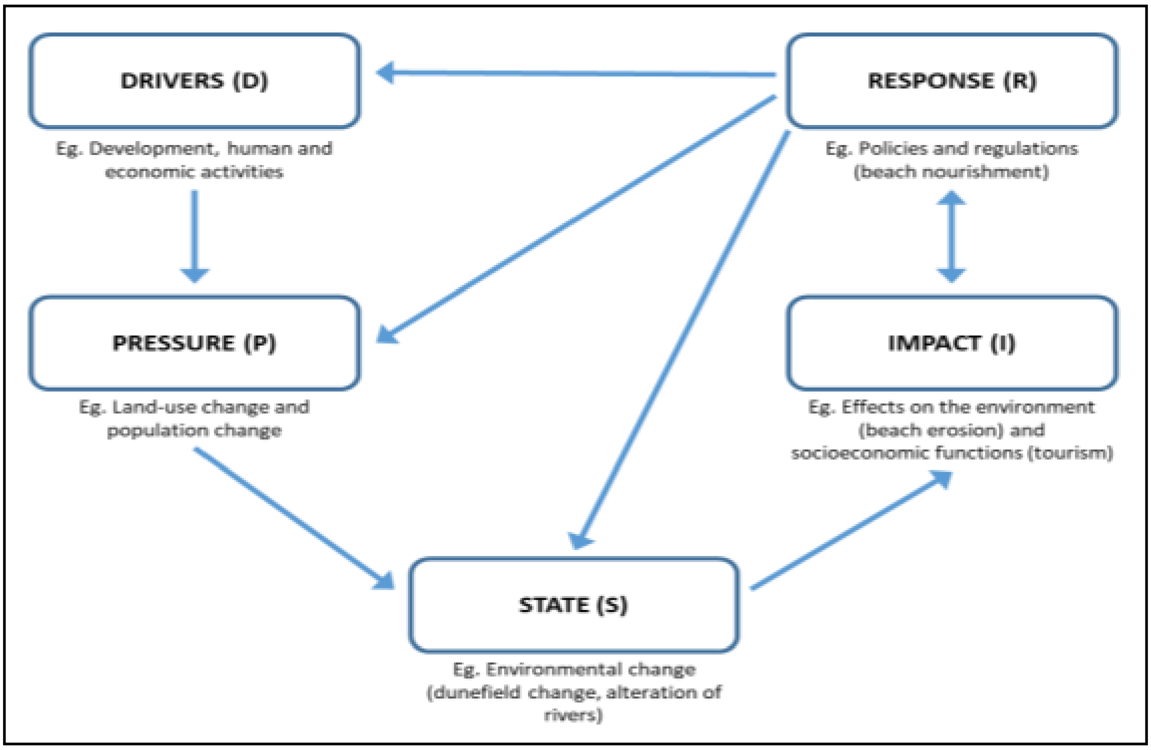


Figure 5.10: DPSIR Framework of St Francis Bay.

5.4. The Thyspunt Nuclear Plant impact on St Francis Bay

Thyspunt is located on the coastal shoreline of the Eastern Cape, between Oyster Bay and Cape St Francis and is 12km west of St Francis Bay (Figure 5.11). The sites have been identified as suitable locations for a nuclear reactor to be constructed, with other possible locations at Duynefontein and

Bantamsklip. Thyspunt is considered the more suitable site due to lower construction costs and lower seismic risk (Eskom, 2010).

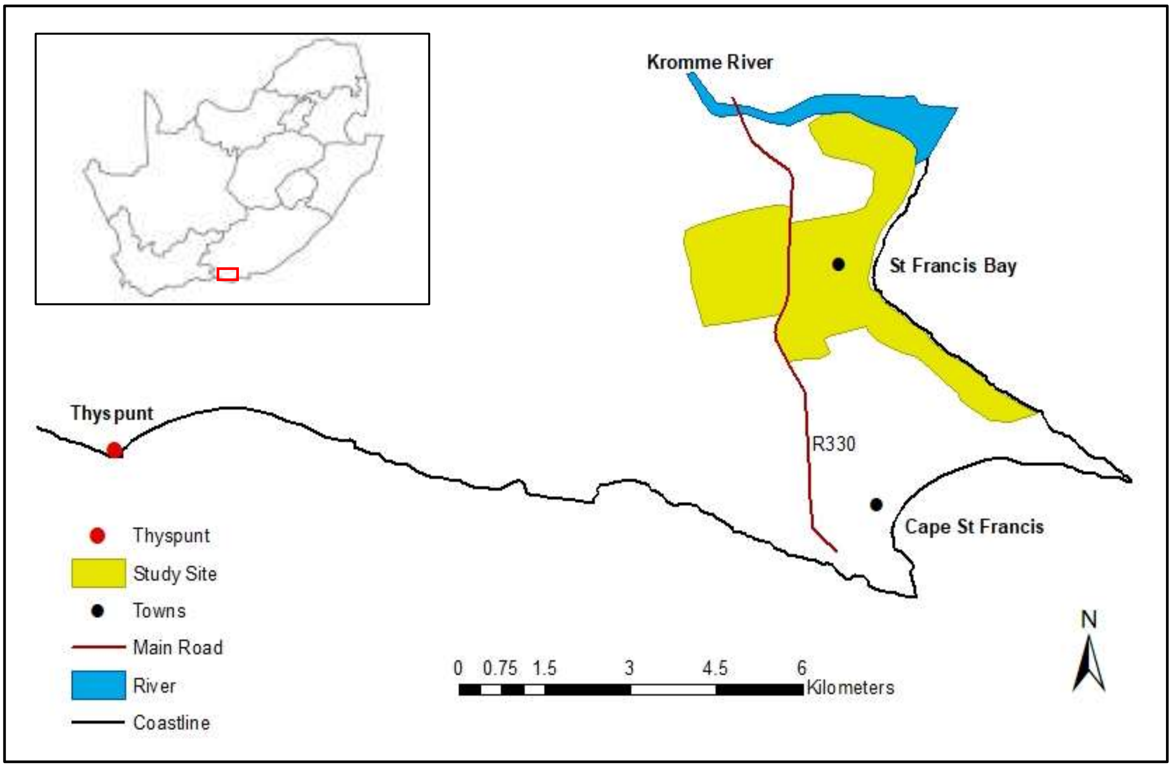


Figure 5.11: Thyspunt location in relation to the study site.

As stated by Van Wyk (2013), South Africa is placing great pressure on energy generation to attain socioeconomic growth through infrastructure development. South Africa's main energy source utilized is of coal. The Nuclear Siting Investigation Programme (NSIP) started in the 1980s by identifying and ranking candidate sites that were suitable for new nuclear installation development in expectation of the rise in energy consumption. This was to secure sites before development occurs in these areas, preventing their selection and use. Following an Environmental Impact Assessment (EIA) by Eskom in 2015, Thypsunt was identified as the ideal site to build a new nuclear reactor.

A massive influx of investment and growth is expected with the nuclear reactor as the station could produce up to 8000MW of power. The need for expanding energy supply in South Africa has become heavily prominent due to an increase in population. With the cost of electricity rising and power outages occurring over the past few years, are placing economic strain on economic growth in South Africa. Residents in surrounding townships of Thyspunt state that the nuclear power station will create "general and technical jobs for the community" (Mail & Guardian, 2012; Nkosi & Dikgang, 2018).

Concerns about the location of the nuclear site include historical and cultural significance as archaeological and paleontological resources are in danger due to the reactor impact. There are long-term effects that are being ignored, and these include a person's mental health and well-being (Nkosi & Dikgang, 2018). The proposed nuclear station may have a negative effect on the local economy as tourists may choose to not visit Thyspunt and the surrounding areas due to construction and the operation of the nuclear power station.

This influences one's sense of place as stated by Feris (2014) and Creel (2003) in section 2.3.6 of the Literature Review. Socio-ecological systems can exhibit complex behaviour as stated by Pollard *et al.* (2011). As with St Francis Bay and the Thyspunt nuclear plant, there is an introduction of new attributes (Table 2.2) that can contribute to the existing complexity of St Francis Bay. This includes multilevel dynamics with more involvement from the government and the municipality to increase energy supply with the current low supply of coal resulting in power outages and the unpredictable emergence which may arise from chemical systems and if a system breakdown occurs.

Complex systems present a concept of self-organisation, such as with St Francis Bay, as coastal zones are stressed complex systems (Hopkins *et al.,* 2011). Self-organisation, as stated by Green *et al.* (2008), is the emergence of order in a system by internal processes, and the construction of Thyspunt in a close radius to St Francis Bay is the introduction of an external force into a complex system. With this introduction of a new component in the system, it will result in a change in the nexus as to how the components interact will alter and change the relationships which form from these interactions. This has an impact on the feedback concept of complex systems as links among the components will change and have a ripple effect throughout the nexus. The feedback concept will therefore not be able to control the system (Ladyman *et al.,* 2013), leading to the system becoming disorganized.

Thyspunt is an example of how a component can alter the stable notion of a complex system (Figure 5.1). As Thyspunt Nuclear Plant is an external component, a possible complexity in the nexus may occur: the real estate surrounding the Thyspunt area and St Francis Bay may change as residents do not want to be within a close radius if the power plant does explode or the chemical effects which may arise from the plant. This will have an impact on tourism in the Kouga Municipality, leading to a decrease in the tourist economy. With a decline in the economy, further inequalities and the well-being of residents in St Francis Bay may arise as residents on the outskirts of the town cannot afford to relocate if a malfunction does occur at the plant. Further pressure will be placed on the municipality and the government within this scenario.

Thyspunt Nuclear Plant has raised many questions of concern with regards to the well-being of humans, tourism and thus the economy, as well as political tensions among residents within the area. With the Thyspunt nuclear plant, there is an introduction of new attributes which contribute to the existing complexity of St Francis Bay. This may lead to a rise in costs to conserve the interests of all those who are involved and impacted by the consequences. Thyspunt is an example of how a complex system can be altered with a component and demonstrates how the pathways are interlinked.

5.5. Coastal Management Solutions for the St Francis Bay Nexus

These are the proposed management solutions based on the information which was generated throughout the assessment. As seen from Figure 5.1 in Section 5.2 previously, St Francis Bay is an example of a complex system. From this PED model there have been subsequent costs and consequences that have taken place in the past decades and may continue into future decades. Table 4.3 demonstrates the costs that would ensue in order to mitigate the beach erosion that has been created from the expanding development of the town, causing the headland dunefield to decrease in size and therefore interrupting sediment transport from the dunefield to the beach.

The coastal zone is important from environmental, economic and social views (Veloso-Gomes *et al.,* 2008). As stated by Silva *et al.,* (2007), the management of coastal zones is a complex issue. Management of coastal zones should be conducted in an integrated, sustainable manner to be able to mitigate challenges arising from the dynamic environment (Calvao *et al.,* 2013). Mitigation is of vital consideration when forming and creating policies for sustainable development and therefore requires integrated and coordinated management policies (Veloso-Gomes *et al.,* 2008).

The following sections demonstrate the consequences which have transpired in St Francis Bay in the form of a historical timeline from 1960 when large-scale development took place, through the various floods, fires and erosion events over the decades until a storm event in 2021. Included in this timeline are different EIA reports presenting mitigation options to reduce beach erosion. Following the timeline, mitigation strategies from the EIA reports are presented in terms of reducing beach erosion in St Francis Bay.

5.5.1. Historical Timeline of St Francis Bay

As seen from the timeline of St Francis Bay (Figure 5.12) and the time-lapse series map (Figure 4.1), most of the development in the town occurred from 1960 (McLachlan *et al.,* 1994). This was the beginning of what soon became rapid development on the peninsula, as towns such as Cape St Francis and Oyster Bay increased in size. As more tourists were visiting the town and people were relocating to the town as well, there was a need for more houses and more infrastructures to be built. This had a ripple effect on the surrounding environment and society.

Multiple fires occurred over the years from 1988 to 2019, which left devastating after-effects on the houses as well as the well-being of the residents. This could be caused by run-away bushfires due to the alien vegetation that has been planted to stabilize the dunes. The fire would catch on from the thatch, which most of the houses in St Francis Bay have, and spread from house to house.

Over the past two decades, due to climate change, heavy rainfall and storm surges have caused devastating damage to houses and roads. Infrastructure, such as the bridge and parking areas (Figures 5.6 and 5.7), have collapsed from these weather events and subsequently, the erosion of the coastal zone also impacts this. The damage to houses and infrastructure from fires as well as from climate events, contributes a large cost to the town as repairs need to occur within a certain amount of time for the residents and tourists, and the impact on their well-being and the economy.

Due to change in the course of the Sand River, caused by the alteration of the Oyster Bay Dunefield and the increasing development in St Francis Bay, has led to more frequent flooding of the river after heavy rainfall. The original mitigation strategy to prevent beach erosion was beach nourishment and this proved inadequate (Shaw *et al.,* 2019). Therefore, after this, groynes were introduced as a strategy in order to prevent beach erosion. As seen from Table 4.3, the groynes have a greater cost to construct as compared to beach nourishment. Various EIAs have been conducted to evaluate the impact of these mitigation strategies and compare the costs and alternatives of these strategies. These EIAs also carry a cost in order to be conducted with regards to specialists and time.

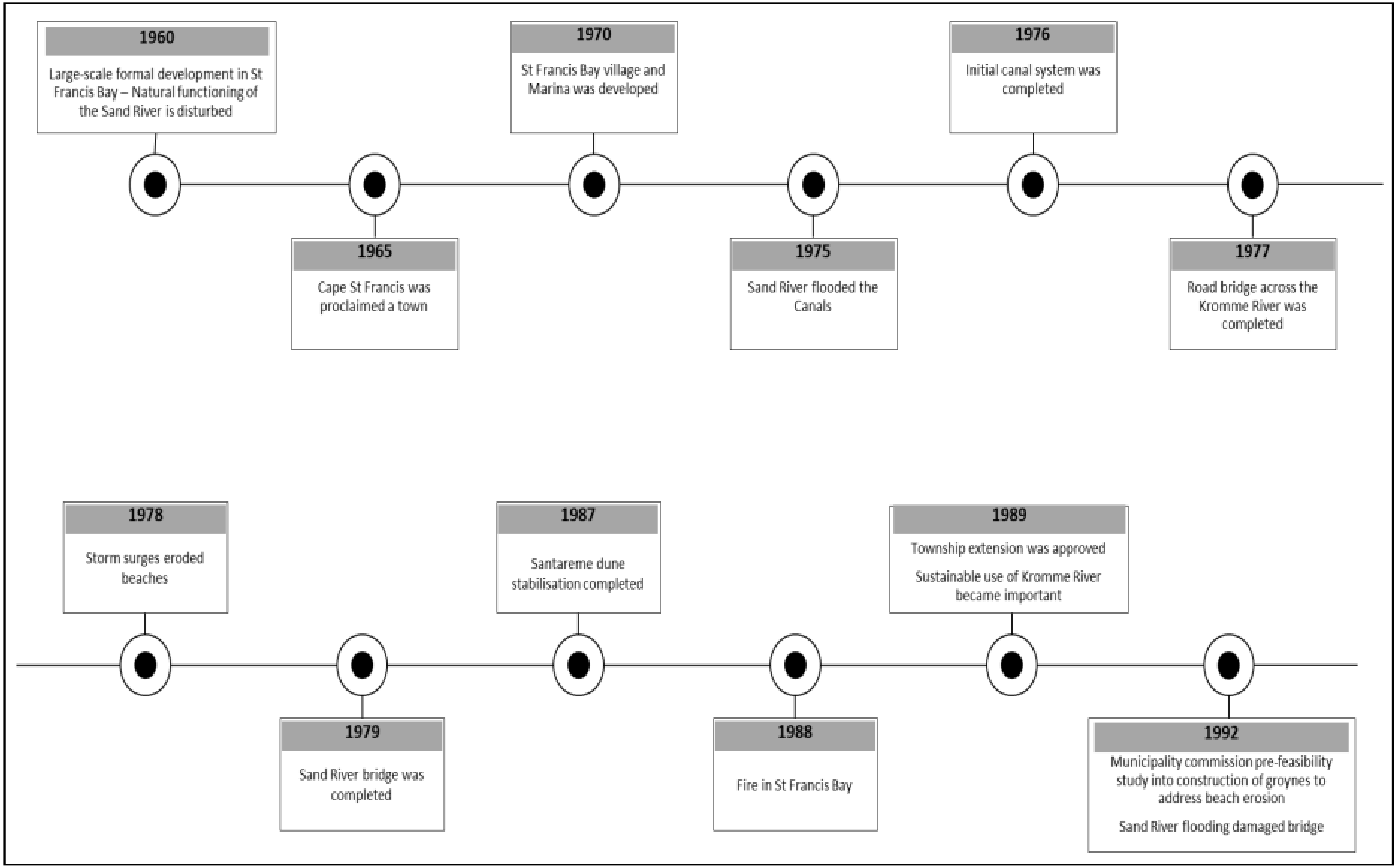


Figure 5.12: Historical time of St Francis Bay From 1960 until 2021

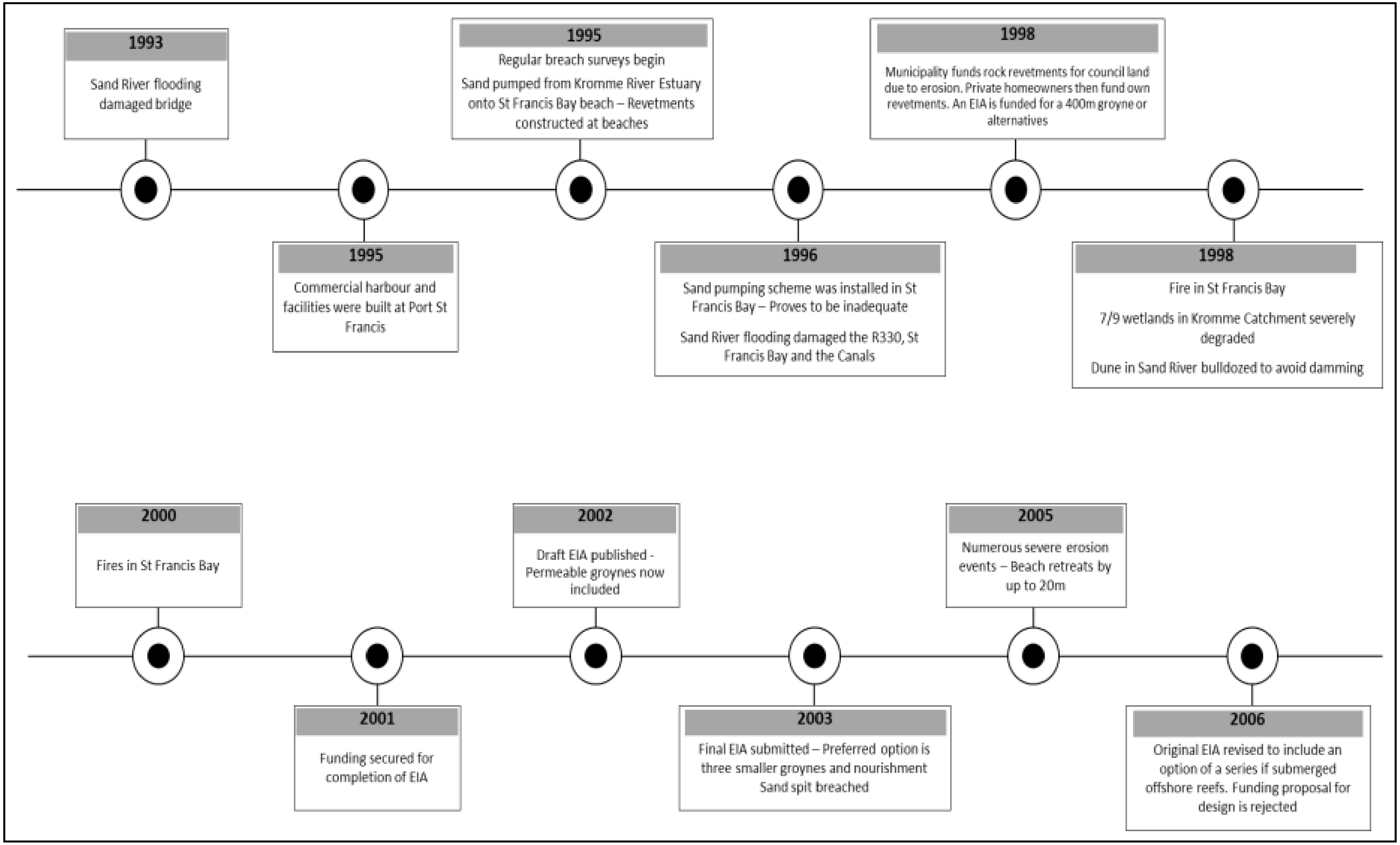
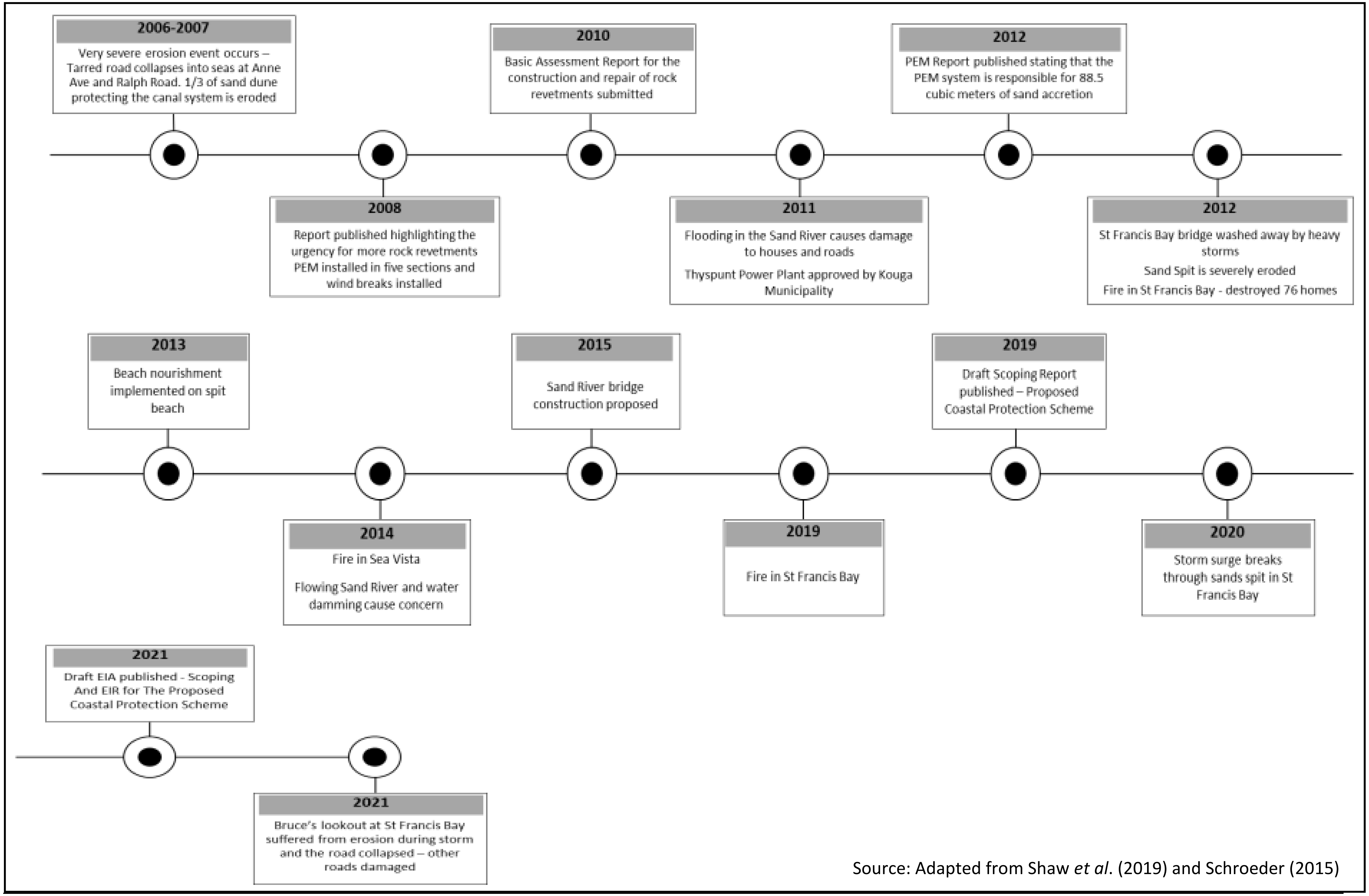


Figure 5.12: Historical time of St Francis Bay From 1960 until 2021



Source: Adapted from Shaw *et al*. (2019) and Schroeder (2015)

Figure 5.12: Historical time of St Francis Bay From 1960 until 2021

5.5.2. Mitigation Strategies Applicable to beach erosion in St Francis Bay

Managing coastal zones requires intensive multi-sectoral efforts by government institutions, the private sector and community groups (Creel, 2003). The various conceptual management options are described by the WorleyParson Group (2018). The costs and construction duration of these management options have been presented in Table 4.3 in Chapter 4.

- Sand Spit

The sand spit (Figure 5.13) in St Francis Bay has been under pressure for the past few years, as seen in Figure 5.13, as erosion is estimated to be a meter a year for the last 40 years (Mortimer, 2020). The spit is vulnerable to strong storms and swells. As the dunefields were stabilized for development to occur, there is no sand to nourish the beach and the spit. This contributes to the vulnerability of the spit. In 2020, a spring high tide surged through the spit in St Francis Bay, which separated the million-rand houses along the Marina from the ocean. Excavated sand from lower down the beach was brought in to fill the gap in the spit. The breaching of the spit poses a threat to infrastructure, properties and the local economy (Mortimer, 2020) as described in Figure 5.1 and the corresponding description in section 5.2 in Chapter 5.

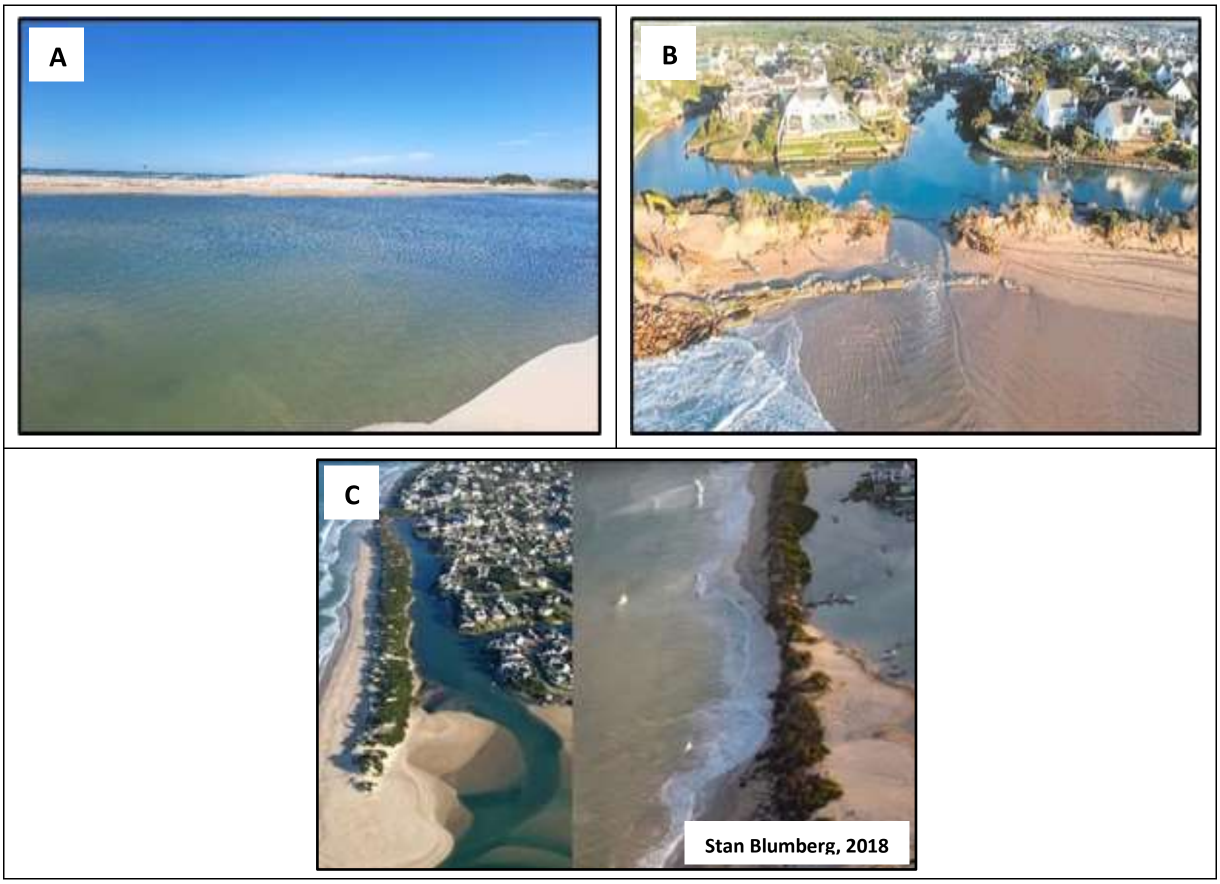


Figure 5.13: (A) Sand spit in May 2021. (B) Sand spit breached after stormy seas in July 2020. (C) The erosion of the spit in St Francis Bay, with 2018 on the right.

- Beach Nourishment

Beach nourishment (Figure 5.14) is considered less of an environmentally intrusive method as compared to other methods and the most cost-effective (Table 4.3) in order to prevent the coastline of St Francis Bay from experiencing additional erosion. This solution is to artificially nourish the beach with sediment from suitable sources, such as the Kromme estuary, where sand is imported to the eroding beach. With the additional sand input, it will provide extra protection against erosion as incoming waves will dissipate its energy before reaching the shoreline (Shaw *et al*., 2019). The identification of a suitable source is based on an area where sand will consist of a similar grain size to that of the beach and is feasible to extract (Figure 5.14), such as from upstream river. In 1996, beach nourishment operations were initiated where sand was dredged from the Kromme River estuary. Beach nourishment requires a large volume of initial nourishment on the beach to set a base to allow for a wider beach crest. The maximum volume of sand which will need to be sourced is “approximately 854 000m^3” and will be transported either by a dredger, truck or pipeline system (Almanza *et al*., 2019). Long-term maintenance will be required in order to maintain the optimum beach level.

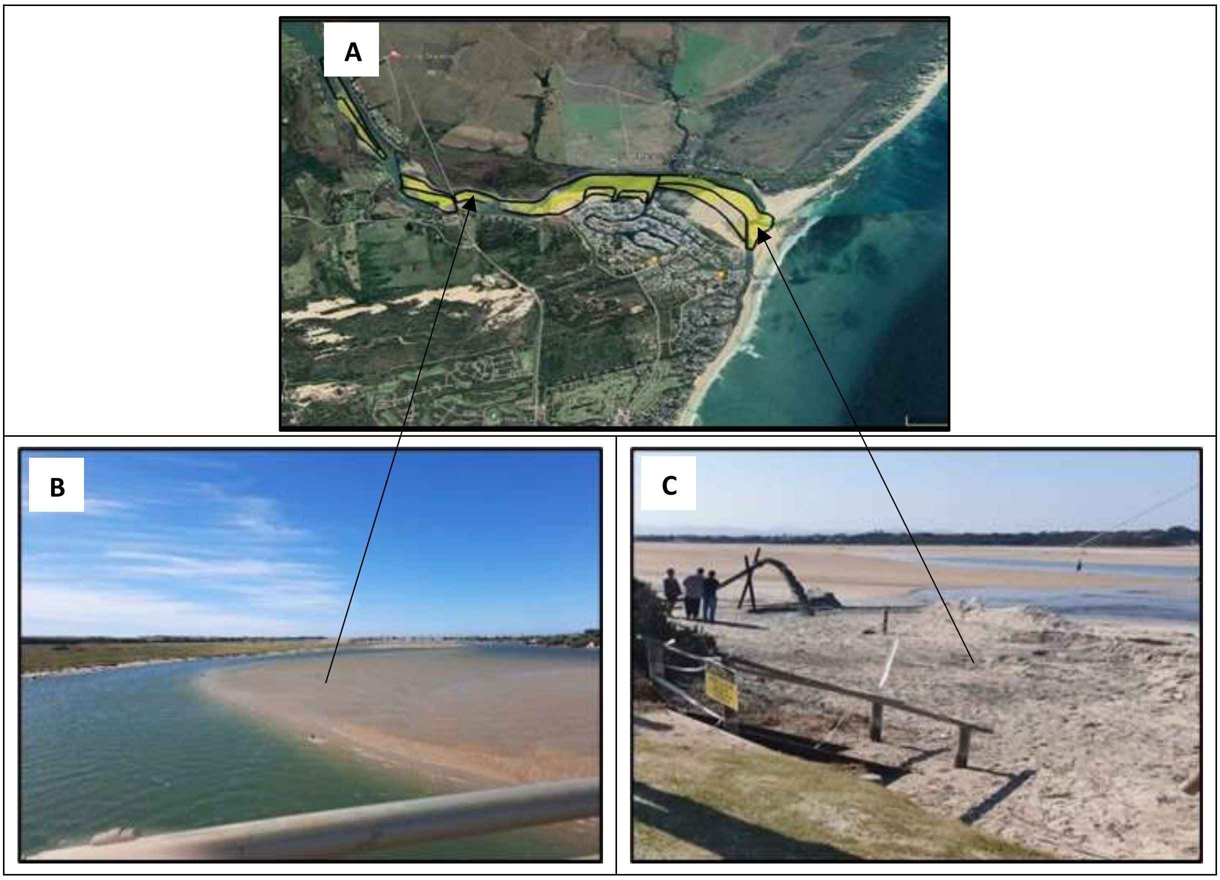


Figure 5.14: (A) Shows the dredging areas in St Francis Bay. (B) The zone at the bridge entering St Francis Bay. (C) The dredging zone at the Kromme River mouth.

- Groyne Field and Nourishment

Groynes (Figure 5.15(B)) require a large volume of rocks as well as require additional site investigations to confirm their adequacy and stability. These structures are used when the wave direction is “oblique to the shoreline and sediment transport is longshore dominant” (Almanza *et al.*, 2019). The groynes will extend from the back end of the beach and reach a length of “between 170m and 200m offshore” as stated by Almanza *et al*. (2019). Groynes offer a small reduction in wave energy. A maximum of approximately 41 550m^3 of rock material will be required for the proposed groynes. It has been stated that this conceptual option is not considered to be the most feasible solution for the coastline of St Francis Bay and is more costly than beach nourishment (Table 4.3).

- Detached Breakwaters and Nourishment

Offshore breakwater structures (Figure 5.15(C)) provide a high level of coastal protection and retention of sediments on the beaches. The construction of breakwaters is the most expensive conceptual option presented in Table 4.3. These structures would have a negative visual impact on the coastline, especially for the tourists in St Francis Bay. Breakwaters require a substantial volume of sediment and this would be difficult to construct due to the need for offshore marine equipment. This structure is considered less favourable for implementation.

Figure 5.15: Conceptual options for St Francis Bay. (A) Beach nourishment, (B) Groynes and beach nourishment and (C) Detached breakwaters and nourishment.

Source: WorleyParson Group, 2018

From the various conceptual management options as described by the WorleyParson Group (2018) above, in Table 5.2 it presents the advantages and disadvantages of these coastal structures as described by Williams *et al*. (2018).

Table 5.2: Advantages and disadvantages of different coastal defense structures.

Types	Advantages	Disadvantages
Sand Dunes	• Aids with energy dissipation • Creates wildlife value	• Susceptible to erosion
Groynes	• Encourages sedimentation and deposition of sand • Limits loss of sediment • Construction is easy	• Requires sediment supply • High maintenance costs • Interrupts traversing of beach
Seawalls	• Effective in preventing erosion • Can resist severe exposure • Safe for public use	• Poor energy absorption • Expensive
Offshore Structures	• Promotes beach build-up • Less beach maintenance is required • High level of coastal protection	• Costly • Large volume of sand nourishment required • Large visual impact • Water quality reduction • High level of environmental impact on marine system
Beach Nourishment	• Aesthetically attractive • Least environmental impact • Soft solution	• Requires periodic maintenance which can be costly • Sand expected to be lost more rapidly

Source: Almanza *et al*., 2019 & Williams *et al*., 2018

5.6. Implications at the St Francis Bay interface

The Integrated Coastal Management Act provides a holistic management approach to the coast as an integrated system, with the participation of stakeholders to ensure the protection of the environment and promote sustainable development (Department of Environmental Affairs, 2008). Principles of the ICM include economic development (coastal economic development opportunities must be improved to meet needs and promote well-being), social equity (ensure that present and future generations have the right to equality and freedom) and ecological integrity (the health and productivity of coastal ecosystems must be maintained and rehabilitated) as noted by the Department of Environmental Affairs (2008). The ICM focuses on regulating human activities in coastal zones in order to ensure the protection of coastal ecosystems. By identifying the linkages that exist between the attributes of the PED nexus in St Francis Bay, it will aid in the development of policies for environmental management in coastal zones and so promote sustainability in the town.

Dunefields were artificially vegetated due to an unawareness or unfamiliarity of the relationships that exist between the beach and dune systems with regards to coastal sediment transport resulting in beach erosion. The environmental implications of dunefield modification were not considered due to an insufficient understanding of the functioning of dune systems (McLachlan *et al.,* 1994). This has therefore resulted in implications with implementing environmental management options as these occurred decades ago.

Various implications exist for the coastal zone of St Francis Bay. The Oyster Bay Dunefield is well established due to invasive plant species, and it is therefore too late to reactivate the dunefield (McLachlan *et al*., 1994). This failed reactivation is also due to settlement development in Oyster Bay and St Francis Bay. As mentioned in Table 4.3 in the Results Section, coastal protection is expensive and construction is time-consuming. Construction may cause further damage to the coastline and 'green zones' surrounding the construction sites as coastal protection zones are built. Whilst coastal protection plans need approval and inclusion from the municipality and residents, beach erosion will continue and worsen the coastline for management.

5.7. Conclusion

Complex linkages exist at the population-environment-development nexus as seen from the nexus model and various cost and consequences result from these linkages in St Francis Bay. Coastal zone growth, land conversion and urbanization are related to an increase in people in these zones. Population growth and development are considered critical drivers of change in coastal zones and therefore generate high pressure on coastal ecosystems and natural resources. Several components exist in St Francis Bay and each component has a ripple effect on other components. These are interlinked in a complex manner and the consequences resulting from the changes in the linkages can lead to high costs occurring for St Francis Bay.

The human interface, in the form of development, with the dunefields has had a negative effect on the surrounding environment. This has contributed to the erosion of the St Francis Bay beach. The building of Santareme on the Santareme dunefields has directly impacted the replenishment of sand on the beach as the development prevented sand from the dunefield moving to the beach. All three dunefields are diminishing in size due to the need for the development of infrastructure in the towns to support the growing number of residents and tourists. Sand from the Oyster Bay Dunefield, which used to reach the beach directly pre-1960, is now washed into the Kromme River. This has caused implications in the Kromme River as sedimentation is increasing in the River mouth, creating difficulties for boats to cross the River. Excessive sediment deposits can also alter and degrade habitats as well as change the flow and depth of rivers over time.

Coastal settlements, infrastructure and economies could be severely impacted by flooding, coastal erosion and shoreline relocation as a result of climate change. Buildings have been constructed close to the shoreline in order for “better views” to be obtained for residents and tourists and therefore are threatened by erosional processes. Although the erosion has contributed to a reduction in the width of the beach, St Francis Bay remains a popular tourist attraction. The resulting tourism has the capacity to create employment, attract visitors, and generate opportunities in areas where economic activity may be restricted, as well as provide social opportunities to the local community. Coastal environments encourage positive psychological benefits and behaviours that promote the well-being of residents and tourists and therefore reduce political tension. Although, those who are living in poverty are the ones who are experiencing the most from environmental change. It is therefore important to consider all those who fall within the town, how they are impacted by various changes which could occur in the nexus, and how they can be impacted from this.

Environmental management is at the human-environment interface, and the trade-offs which need to be made should be when environmental, social and economic attributes are considered (King *et al*., 2018). Inappropriate development and use of the land around a complex headland bypass dunefield system, has disastrous effects, including the destruction of infrastructure and the local economy, as seen by the St Francis Bay nexus. Various EIAs have been conducted and implemented within the St Francis Bay area in order to mitigate the consequences which have arisen over the past decades due to development. This has led to high costs for the mitigation strategies to be implemented to reduce beach erosion as well as to maintain or rebuild houses and roads. The nonlinear dynamics applied in the project offers new tools to quantify, model and predict the behaviour of complex systems. It is critical to understand the complexity of relevant components in the coastal zone in order to enhance the viability of coastal systems. This includes the mitigation of the consequences which may arise from the linkages of the nexus and the manner that can promote sustainability.

CHAPTER 6: SYNTHESIS

6.1. Introduction

The aim of this research was to conceptualise and analyse the PED nexus as a complex system in St Francis Bay and the costs and consequences that result from these complex linkages. Components of the PED nexus included development, tourism, employment, the economy, well-being, inequality, beach erosion and climate change to name a few. The aim was investigated through the presentation and exploration of quantitative and qualitative data and the formation of a PED model applicable to St Francis Bay. The model presents the complex linkages that exist in the dynamic coastal zone and that a ripple effect occurs from one component to another.

This chapter aims to conclude this study of the complex linkages of a PED nexus. This conclusion will be twofold: firstly by focusing on the findings of this research with regards to beach erosion and the development that has taken place at a rapid rate in the town and the mitigation strategies which are recommended in order to reduce the changing landscape. The social aspect of the town is also explored. Furthermore, recommendations for improvements for future research will also be discussed.

6.2. Synthesis of the study

Coastal zones create complex interface ecosystems between the population and the biophysical environment. Coastal zones are considered as vulnerable due to sensitive ecosystems. The natural environment is increasingly under pressure because of socio-economic factors such as population growth rates and increased land use. Development in coastal zones is unavoidable and can be considered good for the economy and well-being of coastal communities if effectively managed. Due to the exposed nature of St Francis Bay, with the complex interaction between the coastal and estuarine processes, has resulted in the removal of sediment and therefore has led to beach erosion over the past decades.

St Francis Bay has a complex inter-relationship at the population-environment-development interface. Each sub-component within the nexus has an impact or influence under the same main component or it may affect another sub-component. The linkages which arise from the interactions among the components may lead to positive or negative impacts, depending on how the town manages the problems it is currently facing. Complexity theory focuses on understanding the interactions among system components at different levels and times.

The nexus concept addresses the long-term relationships among the population, environment, and population. The St Francis Bay landscape has altered drastically over the past 60 years. Changes to the landscape include stabilisation of the dunefield through alien invasive species and an increase in development. The increase in the golf course and informal settlement also contributed to the altered landscape. Beach erosion poses a threat to recreation and tourism and therefore the economy of the region.

St Francis Bay beaches have suffered from significant erosion events over the past decades. The stabilization of the headland bypass system in 1970s has been considered one of the contributing factors of erosion. Due to the ignorance of the artificial vegetation of the headland dunefields has resulted in coastal erosion. The environmental implications of the dune modification were not taken into account from the lack of understanding of the interdependence of the beach and dune systems. This has led to a reduction in sediment supply to the beaches, and the construction of the Impofu dam has also restricted sand movement. This has resulted in a rapid retreat of the shoreline. The attractive coastal lifestyle has resulted in the disproportionate development of shorelines as compared to inland areas. Economic and social opportunities arising in the town are causing coastal ecosystems to be degraded.

Coastal systems are mostly impacted by human activities and are most threatened by global climate change. St Francis Bay is situated at a low altitude, therefore the greatest threat that the town will experience is that of sea-level rise. Physical interactions along coasts and inland, such as dredging, the damming of rivers and river deltas, extraction of liquids and gases from the ground, land reclamation, habitat modification, and coastal engineering have a great impact the coastal environment.

Projects are currently in place, such as an Integrated Development Plan and the Integrated Coastal Management Plan, to help minimize the effects of the population and development on the environment. This is to reduce the social inequalities in the town, decrease beach erosion along the coastline, and increase the economy in the town by maintaining properties and infrastructure. Residents are contributing to the maintenance of the infrastructure along roads and buildings. The ICM Act sets a new approach in order to manage coastal resources to promote social equity, the sustainable use of coastal resources as well as protecting the natural environment.

Coastal zones are anticipated to degrade in future decades due to pollution, overexploitation, climate change, and infrastructure development thus leading to a loss of biodiversity and ecosystem services. This therefore requires integrated actions to mitigate these changes (Turner *et al*., 1996; Lam *et al*., 2020). In order for a decrease in beach erosion to occur, mitigation options would need to be continued and maintained for the implementation process to succeed. The management interventions should work with the dynamic nature of the coastline. With erosion slowing down, it would allow some of the components of the nexus to re-establish. Changes in St Francis Bay will not take place in a short period of time as prolonged damage to the town has occurred. Over time, it is hoped that St Francis Bay will be able to live up to its former glory.

Beaches and dunefields form interdependent components of the coastal system. The results of the study show that the population-environment-development nexus can be interpreted in various pathways as it is a highly intricate system. Many components are involved in the process and this provides information that decision-makers require when planning new and existing activities in the coastal zone. In the study, it is demonstrated that the sustainability of the settlement relies on the understanding of such linkages. Management issues arising from the study have been identified and the strategies must be understood by municipal officials, stakeholders, community members and residents.

The results illustrate how critical levels of beach erosion are connected amidst an intricate reciprocal nexus. Coastal zones are exposed to a variety of coastal hazards and human development. Understanding complexity with regards to the ecosystem will improve society's ability to protect, manage and predict the impacts of environmental change. This demonstrates that the sustainability of a town, such as St Francis Bay, hinges on the understanding of the linkages of a complex nexus system. By acknowledging this complexity, this allows for better preparation for the emergence and opportunity adaptation in the coastal zone.

6.3. Recommendations for future research

The recommendations for future research for this study would be the use of more recent census data (if available) as it would greatly enhance the status of St Francis Bay as well as the inequalities that are present in the town at the current moment. The census data that was obtained in 2021 will provide insights and demonstrate the change in the past decade with regards to the rapid development in the town and the present state of the beaches. By conducting semi-structured interviews would also provide greater insight into the complex dynamics of St Francis Bay and the perspective of those who are experiencing the ripple effects of the nexus.

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APPENDIX

- NASA EARTHDATA for the Eastern Cape – Port Elizabeth

The data present in Figure 4.2 (page 59) was composed of three different scenarios, relative to a baseline of 1995-2014. The medium data of the scenarios was used to determine the rate of sea-level rise. This is the grey row in the table below. The following is the description as described by NASA EARTHDATA: "in the SSP3-7.0 pathway, the medium to high reference scenario resulted from no additional climate policy under the SSP3 socioeconomic development narrative. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions. In the SSP1-1.9 pathway, it holds warming to approximately 1.5°C above 1850-1900 in 2100 after slight overshoot (median) and implies net zero CO2 emissions around the middle of the century. In the SSP1-2.6 pathway, it stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero emissions in the second half of the century."

psmsl_id	process	confidence	scenario	quantile	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150
820	total	medium	ssp119	5	0.025	0.059	0.08	0.113	0.129	0.156	0.166	0.184	0.163	0.198	0.209	0.219	0.225	0.231
820	total	medium	ssp119	17	0.038	0.075	0.102	0.142	0.165	0.199	0.22	0.249	0.249	0.282	0.302	0.32	0.335	0.35
820	total	medium	ssp119	50	0.056	0.1	0.138	0.188	0.224	0.275	0.312	0.36	0.394	0.448	0.488	0.525	0.562	0.596
820	total	medium	ssp119	83	0.077	0.133	0.186	0.253	0.312	0.385	0.447	0.521	0.584	0.663	0.728	0.79	0.852	0.911
820	total	medium	ssp119	95	0.093	0.16	0.228	0.313	0.388	0.482	0.563	0.656	0.744	0.832	0.917	0.999	1.08	1.159
820	total	medium	ssp126	5	0.021	0.05	0.078	0.113	0.134	0.167	0.186	0.206	0.215	0.252	0.271	0.288	0.303	0.317
820	total	medium	ssp126	17	0.034	0.069	0.103	0.146	0.175	0.217	0.247	0.278	0.302	0.342	0.371	0.397	0.423	0.447
820	total	medium	ssp126	50	0.054	0.098	0.143	0.2	0.244	0.305	0.356	0.404	0.454	0.527	0.578	0.627	0.674	0.72

820	total	medium	ssp126	83	0.076	0.132	0.194	0.272	0.339	0.422	0.501	0.578	0.656	0.767	0.848	0.927	1.005	1.082
820	total	medium	ssp126	95	0.093	0.161	0.238	0.334	0.42	0.528	0.629	0.729	0.828	0.95	1.052	1.153	1.25	1.35
820	total	medium	ssp245	5	0.021	0.051	0.086	0.132	0.165	0.207	0.253	0.295	0.336	0.369	0.41	0.449	0.487	0.524
820	total	medium	ssp245	17	0.034	0.071	0.111	0.165	0.207	0.259	0.316	0.37	0.425	0.466	0.518	0.57	0.62	0.668
820	total	medium	ssp245	50	0.054	0.1	0.151	0.218	0.276	0.35	0.428	0.504	0.585	0.672	0.752	0.832	0.91	0.986
820	total	medium	ssp245	83	0.077	0.136	0.202	0.288	0.372	0.476	0.583	0.696	0.817	0.953	1.073	1.19	1.308	1.422
820	total	medium	ssp245	95	0.094	0.166	0.246	0.35	0.455	0.584	0.719	0.855	1.013	1.165	1.313	1.459	1.604	1.748
820	total	medium	ssp370	5	0.018	0.053	0.089	0.145	0.196	0.254	0.313	0.381	0.455	0.477	0.546	0.614	0.682	0.746
820	total	medium	ssp370	17	0.032	0.07	0.114	0.177	0.235	0.303	0.373	0.458	0.55	0.585	0.668	0.752	0.833	0.91
820	total	medium	ssp370	50	0.052	0.098	0.154	0.229	0.302	0.39	0.484	0.593	0.722	0.816	0.933	1.05	1.164	1.274
820	total	medium	ssp370	83	0.074	0.131	0.205	0.3	0.397	0.514	0.644	0.794	0.969	1.113	1.276	1.437	1.596	1.753
820	total	medium	ssp370	95	0.092	0.159	0.249	0.363	0.482	0.627	0.784	0.972	1.188	1.353	1.553	1.753	1.948	2.141
820	total	medium	ssp585	5	0.02	0.055	0.097	0.155	0.213	0.282	0.359	0.448	0.536	0.547	0.626	0.701	0.772	0.836
820	total	medium	ssp585	17	0.035	0.074	0.123	0.19	0.257	0.337	0.422	0.525	0.633	0.663	0.757	0.848	0.932	1.01
820	total	medium	ssp585	50	0.055	0.104	0.166	0.247	0.33	0.43	0.541	0.672	0.81	0.92	1.053	1.181	1.302	1.416
820	total	medium	ssp585	83	0.077	0.142	0.22	0.323	0.434	0.566	0.718	0.896	1.087	1.283	1.474	1.658	1.839	2.011

820	total	medium	ssp585	95	0.095	0.171	0.267	0.389	0.524	0.688	0.872	1.097	1.334	1.565	1.8	2.033	2.256	2.476
820	total	low	ssp126	5	0.021	0.05	0.078	0.113	0.134	0.167	0.186	0.206	0.215	0.252	0.271	0.288	0.303	0.317
820	total	low	ssp126	17	0.034	0.069	0.103	0.146	0.175	0.217	0.247	0.278	0.302	0.342	0.371	0.397	0.423	0.447
820	total	low	ssp126	50	0.058	0.103	0.152	0.212	0.261	0.322	0.376	0.427	0.48	0.556	0.614	0.672	0.73	0.79
820	total	low	ssp126	83	0.088	0.159	0.25	0.35	0.445	0.547	0.652	0.764	0.881	1.001	1.119	1.235	1.359	1.485
820	total	low	ssp126	95	0.103	0.193	0.318	0.451	0.576	0.711	0.867	1.036	1.21	1.386	1.558	1.734	1.904	2.077
820	total	low	ssp585	5	0.02	0.055	0.097	0.155	0.213	0.282	0.359	0.448	0.536	0.547	0.626	0.701	0.772	0.836
820	total	low	ssp585	17	0.035	0.074	0.123	0.19	0.257	0.337	0.422	0.525	0.633	0.663	0.757	0.848	0.932	1.01
820	total	low	ssp585	50	0.058	0.109	0.172	0.258	0.352	0.466	0.598	0.759	0.936	1.118	1.33	1.56	1.812	2.087
820	total	low	ssp585	83	0.091	0.174	0.291	0.442	0.632	0.866	1.141	1.447	1.775	2.096	2.403	2.907	3.856	4.891
820	total	low	ssp585	95	0.106	0.221	0.391	0.599	0.845	1.152	1.529	1.964	2.461	3.013	3.605	4.252	4.921	5.623