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Challenges for coastal management and conservation under climate change in South Africa

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Introduction

Climatic and environmental changes in the 21st century are increasingly impacting the properties and dynamics of different types of physical environments globally, in particular mountains, lowland rivers and coasts. These changes may also then trigger downstream responses by the ecosystem and geosystem resources and services that are provided in these landscapes to human society. Predicting the outcomes of future changes in different physical environments has implications for the sustainable development, resource management and conservation of these environments and their properties. This is particularly the case along coastlines because these lie at the forefront of climate change impacts, at the interface of land and sea (Kron 2013). However, the precise impacts that climate change may have upon any coastline will depend on its physical properties and the nature of the climate forcings that affect it. For example, an increase in coastal storm frequency and associated wind speeds and storm wave height can lead to more extensive coastal flooding and more rapid coastal erosion (Johnson et al. 2015). However, a rocky coastline will respond to coastal storms in a very different way to a sandy one, even if the climate forcing is the same.

Such scenarios of coastal responses to future climate change are not merely hypothetical; they have implications for the effectiveness of coastal management and conservation policies to meet these future needs (Colenbrander 2019). Ensuring that government-led strategic environmental management is fit for purpose is a key challenge. In South Africa, as in many other countries, the existing legislative, policy and administrative frameworks for coastal environmental management were established several decades ago and under different environmental as well as societal and governance structures and values that may be inappropriate for present and future needs (e.g. eds. Fuggle & Rabie 1992; Goble et al. 2014). This means that the purpose of environmental management and its ultimate goals, especially in managing sensitive and rapidly changing environments such as coasts, need to be reassessed in the light of anticipated future environmental management issues and priorities.

The aim of this study is to identify the key environmental issues that coastal management in South Africa needs to focus on in the coming decades under the increasing influence of anthropogenic climate change. This aim is achieved through a horizon-scanning approach that is commonly used in the field of foresight studies, in which future risks can be identified and projected. Horizon scanning can, therefore, inform the development of future policies relevant to environmental decision-making (Bengston, Kubik & Bishop 2012; Vecchiato 2012).

In detail, this article outlines (1) the methodological approach taken to identify the major issues of relevance in this study, (2) the application of coastal biophysical systems to understand the interconnections that exist between these issues and (3) how these lead to the identification of coastal management challenges. Finally, the article identifies some key strategies by which these issues can be addressed. This analysis can inform government, industry, local communities and coastal managers on the most appropriate ways to future-proof the coast and protect its natural resources, assets and services.

Methodological approach of this study

This study takes a horizon-scanning approach in which emerging issues affecting the coastal zone in South Africa over the next decades are identified. This is achieved by examining the relevant peer-reviewed literature and other contextual information, such as from the Intergovernmental Panel on Climate Change (IPCC). Once the major coastal challenges have been identified through this process, their impacts on coastal properties and dynamics are then identified. The final step is to consider the implications of any changes in coastal properties and dynamics for future

management and conservation; it does not consider the adequacy of existing coastal management strategies to address these issues. This is ultimately an important step because appropriate and timely government and management action can decrease coastal risk and hazard impacts, whereas inappropriate or delayed (or no) action will not achieve this and may actually increase societal and environmental risks. The research approach adopted here is therefore founded on coastal science rather than following previous horizon-scanning studies that use an iterative but subjective Delphi process of expert opinions (e.g. Rudd 2015) or that use a public participatory approach to guide policy (Glavovic 2006). The approach adopted in this study has been previously applied to coastal environments in the Arctic (Gormley et al. 2023) and New Zealand (Macinnis-Ng et al. 2024) and with respect to water systems management (Dunn et al. 2015) and ecological conservation (Kark et al. 2016).

Coastlines as systems

Coastlines can be considered as *sedimentary systems* through the ways in which sediment moves within coastal or littoral cells by waves, tides and wind (Johnson et al. 2015). The outcomes of sediment movement are spatial and temporal patterns of net erosion and deposition and the distinctive morphometric patterns of coastal landforms that reflect these sediment mass budget changes (Cooper, Hooke & Bray 2001). Although this has been, historically, the fundamental basis on which coastal scientists have considered the sediment dynamics of coasts (Rosati 2005), a better viewpoint of coasts is as *integrated biophysical systems*, in which there is feedback between coastal geomorphic, sedimentary, biological and chemical properties and processes that interact with each other to influence the development of coastal environments (Knight 2024a). Examples of these interactions include:

- Changes in beach geometry and grain size patterns that result from changes in wave regime, longshore sediment supply and river discharge
- Landslides and rockfalls from cliffs that protect the cliff foot, reducing the rate of future coastal erosion
- Weathering rates and processes on rocky coasts that can affect biodiversity through juvenile recruitment, as well as change rock surface microtopography and roughness through bioweathering and bioerosion
- Sediment infilling, changes in water body chemistry and water quality within estuaries and in back-barrier lagoons as a result of changing water and sediment input towards the coast by hinterland rivers
- Environmental pollution affecting water quality and aquatic organisms, especially within estuaries and associated with fine sediments
- Vegetation succession and soil development on sand dunes.

This viewpoint of coastal biophysical systems is advantageous because it describes the co-relationships between different coastal properties that, when taken together, better describe coastal morphodynamics and their controls. In addition to these scientific advantages, this understanding can also lead to more effective coastal management; for example, one cannot best conserve coastal biodiversity without understanding how plants and animals are linked to coastal soils, rocks, waves and tides. A biophysical systems approach is also useful in the context of global climate change because it can help describe how different coastal properties respond to climate forcing, e.g. their geomorphological sensitivity (Knight 2024b).

Challenges for the South African coast in the 21st century

Based on themes that are most commonly identified in the global literature, including the IPCC (Wong et al. 2014), and with specific reference to South Africa, some key challenges for coastal systems, and therefore for management of those systems, can be identified using the horizon-scanning approach adopted in this study (Table 1). Each of these challenges takes place in a specific environmental and societal context; thus, the same 'challenge' may be manifested differently in different places.

As indicated in Table 1, these challenges do not take place in isolation but are rather connected to each other, both conceptually and in reality, through a systems framework (Figure 1a). The key drivers of geomorphic change and sensitivity in coastal environments in South Africa are storms and sea-level rise, because these are the main forcing factors that then initiate secondary (downstream) responses in these environments (Rosati 2005). However, the impacts of these drivers will depend on the type and characteristics of the coastline under consideration: sandy and rocky coasts have different sensitivities and will respond in different ways to climate forcing and will give rise to different societal and environmental risks (Knight 2024a). In addition, the relationships shown in Figure 1a are not exhaustive and other factors such as population change and socioeconomic priorities may also change how coastal systems work or are perceived and managed.

A heat index of environmental risks (Figure 1b) can be used to indicate the most significant drivers of coastal change in South Africa, as expressed by the degree to which these drivers pose risks to the workings and dynamics of coastal systems. This qualitative analysis is based on the driving factors and morphodynamic behaviours of different coastlines, as described in the literature, and through an understanding of the biophysical systems context in which specific coastlines operate. For example, sandy beaches in KwaZulu-Natal Province are highly sensitive to coastal storms (Corbella & Stretch 2012); thus, they are at high risk with respect to increased storm frequency (Figure 1b). However, different beaches recover from storm erosion over different timescales, and this is strongly influenced by management practices and the degree of urbanisation at that beach (Corbella & Stretch 2012). Apart from the major physical and climatic forcing factors, human factors such as tourism are also significant. This is because tourism (overpopulation) goes alongside

TABLE 1: Major coastal challenges in the 21st century (broadly in order of importance; see text), globally and with specific reference to South Africa.

Global challenge	Why and how it may impact a coastline	Why and where it is of relevance to South Africa
Sea-level rise	• **Drivers:** Global hydrological changes, increased ocean water temperature and glacier melt caused by increased global temperatures. • **Major impacts:** Enhanced coastal flooding and erosion, coastal squeeze where the coastal plain is constrained, and aquifer salinisation.	• **Relevance:** All coastlines are potentially vulnerable to sea-level rise, including in South Africa, which has an extensive coastline. • **Localities of concern:** Along all coastlines but especially at large river mouths, along unconsolidated sandy or muddy coasts, where there is an extensive coastal plain at low elevation, or where areas are subsiding.
Increased storm/cyclone frequency	• **Drivers:** Increased atmospheric energy and sea-surface temperatures under climate change, leading to invigorated atmospheric circulation and pressure gradients and changing weather patterns more generally. • **Major impacts:** Strong winds, large waves, meteorological surges and high precipitation across the coastal zone as storms make landfall.	• **Relevance:** South Africa is very commonly affected by subtropical storms (from the Indian Ocean) and low-pressure cells/cut-off lows (from the Southern Ocean) and these already cause significant impacts to communities and the environment, especially along coastlines. • **Localities of concern:** northeastern coastlines in South Africa, in KwaZulu-Natal Province and on adjacent coasts in Mozambique. Storms associated with cut-off lows mainly affect the Southern Cape coasts of Eastern Cape Province.
Enhanced shoreface erosion	• **Drivers:** Sea-level rise and under large wave conditions. • **Major impacts:** Beach narrowing (coastal squeeze), seaward sediment export, shoreface steepening.	• **Relevance:** Sandy beaches and embayments are particularly sensitive to net erosion; coastal squeeze also affects rock-bound estuaries that have very limited capacity for landward migration. • **Localities of concern:** Sandy beaches, embayments and estuaries; erosion can be enhanced where there is disruptive coastal infrastructure; examples noted in the literature include around the ports of Durban and Richards Bay.
Coastal flooding	• **Drivers:** Sea-level rise, increased storminess, coastal subsidence. • **Major impacts:** Enhanced coastal erosion, flooding of land and infrastructure, and changes in estuarine/backbarrier environments.	• **Relevance:** Low-lying areas are most sensitive to flooding from a number of different causes, making this a common outcome of climate change. • **Localities of concern:** Low elevation areas, areas located immediately landward of any barriers (beaches and sand dunes) where water can pond, and areas within and immediately upstream of estuaries or lagoons.
Environmental pollution	• **Drivers:** Agriculture, industry and urbanisation within catchments; changes in rainfall (extreme wet/dry events or periods) in the coastal hinterland, poor waste management from urban centres, soil erosion. • **Major impacts:** Eutrophication/hypoxia and decreased water quality within coastal lagoons/estuaries, land degradation, decreased environmental quality and loss of ecosystem services and resources.	• **Relevance:** Existing environmental impacts are amplified by climate change, in particular temperature and rainfall, in shallow water systems and in muddy environments. • **Localities of concern:** Rivers, estuaries and lagoons where shallow water exists; water and air pollution; and waste production around urban areas.
Aquifer salinisation	• **Drivers:** Sea-level rise, groundwater overexploitation, land subsidence. • **Major impacts:** Groundwater contamination.	• **Relevance:** Salinisation limits water availability, which is a particular issue in South Africa generally and in rapidly urbanising areas. • **Localities of concern:** Along sandy coasts where marine water is able to penetrate inland, especially along a wide intertidal zone.
Biodiversity loss	• **Drivers:** Land use change by urbanisation, transition to agriculture and ecological responses to climate and environmental change. In the marine environment, changes in ocean circulation and upwelling can lead to changes in marine productivity and biodiversity. • **Major impacts:** Loss of ecosystem services, agricultural production and carbon storage.	• **Relevance:** Many areas of the South African coast fall within biodiversity hotspots or are ecologically sensitive; urbanisation, mining and agriculture are the main disturbance factors. • **Localities of concern:** Aquatic biodiversity in particular within estuaries and lagoons, including native molluscan and mangrove species.
Invasive species	• **Drivers:** Climate change, import of exotic species, weak biosecurity, destabilised ecosystems. • **Major impacts:** Decreased biodiversity, decreased ecosystem services, increased likelihood of species endangerment.	• **Relevance:** Can impact on some native species in some locations and along coasts; this may particularly include intertidal molluscan and plant species found along rocky coasts and in estuaries. • **Localities of concern:** Most commonly along estuaries and lagoons and along rocky coasts, particularly within the intertidal zone where it has been well documented, but can also affect sand dunes and other environments.
Coastal engineering	• **Drivers:** Socioeconomic development in coastal communities, infrastructure development (ports/harbours, reclamation, groynes, sea walls), channel dredging and the building of new housing developments and tourist facilities. • **Major impacts:** Changes in the nearshore energy regime can reduce the coastal erosion rate or shift its location, decrease sediment supply and transport, decrease the area of muddy substrates and increase environmental pollution.	• **Relevance:** Urban and tourist development along coasts goes along with hard and soft engineering, so this is an outcome of coastal socioeconomic development. • **Localities of concern:** Around growing coastal population centres, around river mouths, especially near ports and tourist towns in KwaZulu-Natal, Eastern Cape and Western Cape provinces.
Coastal urbanisation	• **Drivers:** Socioeconomic development in coastal communities, increasing population number and density, and increased demand for environmental resources. • **Major impacts:** Increased environmental pollution, population pressure on resources and coastline features such as beaches and dunes.	• **Relevance:** Coastal urban development is taking place rapidly in South Africa, especially in smaller rural towns. • **Localities of concern:** Small coastal towns throughout South Africa, in particular in KwaZulu-Natal, Eastern Cape and Western Cape provinces, as suburban areas spread.
Coastal subsidence	• **Drivers:** Groundwater and oil/gas extraction, urbanisation and infrastructure development. • **Major impacts:** Increased coastal flooding.	• **Relevance:** Groundwater extraction from unconsolidated Quaternary coastal plain sediments. • **Localities of concern:** May be limited to some localised and highly urbanised areas, especially where reclamation has taken place, and on urbanised coastal plains or river floodplains.
Tourism	• **Drivers:** Socioeconomic development in coastal communities, ecotourism. • **Major impacts:** Exploitation of environmental resources, increased waste and pollution and land degradation associated with trampling and overuse of dunes and other ecosystems may be associated with second homes, holiday resorts, etc., which commonly have negative effects on local residents.	• **Relevance:** A key socioeconomic activity in many rural areas of South Africa but may be unregulated, poorly planned and give rise to many negative and unsustainable environmental impacts. • **Localities of concern:** Mainly associated with coastal urban settlements and where coastal environments and climates are conducive to tourist recreation activities, especially along sandy coasts.
Sand mining	• **Drivers:** Mining for aggregate, minerals. • **Major impacts:** Land degradation and pollution, soil erosion, land and soil clearance, decreased biodiversity and changes in sediment systems.	• **Relevance:** Many sand mines are recorded, some of which are illegal and are commonly unregulated, with wide-ranging negative environmental impacts affecting sand dunes, beaches and river mouths. • **Localities of concern:** Along sand-dominated coasts, mainly along the west coast, Southern Cape and northern KwaZulu-Natal regions.

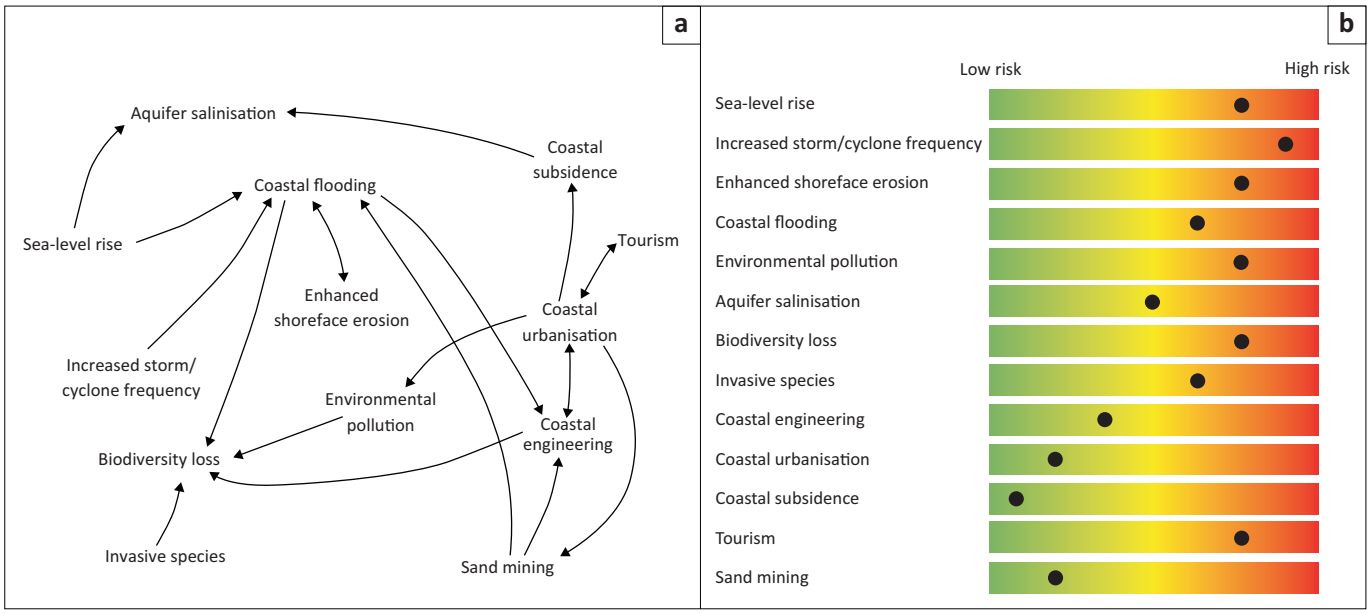

FIGURE 1: (a) Flow diagram showing the interconnections that exist between the major challenges for coastal systems in South Africa in the 21st century, as listed in Table 1. The direction of the arrow indicates which factor exerts an influence upon another; for example, sea-level rise exerts an influence upon aquifer salinisation. (b) Qualitative heat index representation of environmental risks to the coastline of South Africa in the 21st century.

coastal engineering and urbanisation as tourist infrastructure is developed, but, while the latter two are strongly framed today in the context of sustainability (Malan & Swart 1997), tourist presence can lead to significant unanticipated environmental and ecological impacts even in locations away from hotels, car parks, restaurants and other tourist facilities (Goliath, Mxunyelwa & Timla 2018). This highlights the importance yet also the uncertainty of direct and indirect human activities on coastal risk. In addition, some of these major coastal challenges operate on a global scale, are effectively irreversible and cannot be easily mitigated (e.g. sea-level rise), whereas others are because of human agency alone and therefore can be better managed or mitigated by appropriate policies (e.g. sand mining).

A way forward: Application of biophysical systems approaches to coastal management and conservation

Coastal landscape management and conservation is based on identifying and then protecting specific geographical areas that are demarcated with rigid and fixed boundaries. This approach, while bureaucratically easier and the conventional approach taken for spatial management, commonly fails to adequately mitigate against conservation and environmental threats because this approach does not view or manage landscapes as biophysical systems (Knight & Grab 2024). Treating landscapes as integrated biophysical systems can help understand how they may respond to these ongoing changes. This is because this approach can consider how the biological (ecological and biogeochemical) as well as physical (geomorphic and hydrologic) elements of landscapes interact with each other and may experience change through feedback processes. Thus, understanding landscapes as systems can yield a better understanding of their net responses to forcing, such as from anthropogenic climate change in the 21st century. Some previous studies have identified problems with existing coastal policy and legislation to manage these changes (e.g. Colenbrander 2019; Dube, Nhamo & Chikodzi 2022; Goble et al. 2014; Palmer et al. 2011).

Some recommendations on how to future-proof coastal management and conservation under climate change in South Africa can be identified:

- Review the boundaries of protected areas of different types to ensure that they adequately identify and include the key elements for which protection was originally done
- Have a plan to monitor coastal change from geomorphic, ecological and other perspectives, along different types of coasts in different locations
- Focus on nature-based solutions to build coastline resilience in a more cost-effective and integrated way; for example, encouraging the growth of sand dune vegetation to stabilise the dune face and reduce erosion
- Develop climate-resilient tourism plans and sustainable development strategies through collaboration with politicians, business owners, local residents and other stakeholders in coastal towns and cities
- Develop an annually updated risk matrix heat map product so that local communities and stakeholders can better understand the status of coastal risk
- Communicate with, involve and empower the public and local communities in monitoring, remediation (e.g. litter picking) and environmental enhancement (e.g. tree planting).

Studies are already identifying the threats posed by coastal change on protected areas (e.g. Knight & Grab 2024), and

these impacts are likely increasing. However, moving forward, landscape management and conservation in all types of environmental settings in South Africa need to consider not only the role of climate change in landscape processes and properties but also how they influence each other in a biophysical systems context. It is this approach that is best able to future-proof valued landscapes against ongoing climate and environmental changes.

Conclusion

Coastlines globally can be considered as biophysical as well as human systems, and the spatial and temporal evolution of coastlines can be considered as the outcomes of these systems in operation. Significant challenges face the South African coast as a result of ongoing climate change as well as socioeconomic, infrastructural and planning development issues. Together, these give rise to increased risk of negative impacts on coastal systems. In the context of sustainable development in South Africa, minimising the impacts of climate change risks on sensitive environments such as coastlines is a critical management priority (Dube et al. 2022). However, this requires an understanding of the interconnected climatic and anthropogenic drivers and their varied impacts upon coastal systems, but this knowledge is often lacking. A result is that coastal managers and other decision-makers commonly lack the datasets or knowledge necessary to develop appropriate policies or to enact these in a suitable way in different coastal settings or in addressing different coastal risks (Colenbrander 2019). In addition, coastal systems are not static or at equilibrium: they will continue to evolve in possibly unanticipated ways over the coming decades under ongoing change and in response to changing socioeconomic and political conditions. Despite being areas of higher overall risk, in South Africa, coastal population growth, tourism development and future enhanced heating and lack of water inland may push more people towards the coast in coming decades. This also has to be considered in assessing future risk and coastal management priorities.

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Author's contributions

J.K. declares that they are the sole author of this research article.

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Data availability

The author confirms that the data supporting the findings of this study are available within the article and in published articles cited in the text.

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