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A Review of the Hydrodynamic Drivers Influencing Coastal Erosion and Hazard Assessments in South Africa

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ABSTRACT

Coastal areas hold immense value, but development and coastal hazards pose significant threats to such areas. Extreme climate events accelerate erosion, inundate wetlands, and contaminate resources. Coastal erosion, exacerbated by sea-level rise and storms, requires innovative management. South Africa's coastal communities and resources are faced with managing the impacts of sea level rise, increased coastal floods and related infrastructure damage. This review identifies hydrodynamic drivers influencing coastal erosion and hazard assessments in South Africa. Key hydrodynamic factors, such as sea-level rise, storm surges, tidal range, wave energy, and wave climate in the context of South Africa are identified and discussed. The review evaluates existing approaches, highlights gaps, and offers recommendations for future research. The review concludes by stressing the need for further research to enhance our understanding of these drivers and their implications for coastal erosion and hazard assessments in South Africa. This knowledge is deemed crucial for devising effective coastal management strategies and adapting to climate change impacts.

KEYWORDS: COASTAL EROSION, HAZARD ASSESSMENTS, HYDRODYNAMIC DRIVERS, SEA-LEVEL RISE

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INTRODUCTION

Coastal regions encompass an extensive economic, social, cultural, and spiritual spectrum that deeply resonates with diverse stakeholders and communities (Neumann et al., 2017, Pervaiz & Hummel, 2023). Given their immense importance, the protection and preservation of these areas are integral to the pursuit of sustainable coastal development. Government bodies, academia, and involved stakeholders have shown an increasing worry about the ramifications of development on the coastal environment. Alongside this, the rising anthropogenic pressures on coastal resources and their management, climate change continues to intensify its claim for immediate attention and action.

The escalating occurrence of extreme coastal climate events like accelerated coastline erosion, inundation of wetlands and estuaries, contamination of freshwater resources, and threats to socio-economic activities and infrastructure demand urgent mitigation measures (Hereher, 2015: 342). Moreover, coastal erosion as a hazard is yielding destructive consequences for human life and the natural world (Yincan et al, 2017). These detriments, alongside the escalating infrastructural cost, are predicted to rise owing to climate change effects such as sea-level rise and storm surges (Smith et al., 2013, Pervaiz & Hummel, 2021).

These crises necessitate innovative and holistic solutions for coastal management, especially considering the extensive coastal area, growing population, increasing development pressure, heightened storm intensities and frequencies, and scarce resources available for mitigation and adaptation strategies. Ultimately, the vulnerability of coastlines to erosion is influenced by physical elements such as geology, sea-level rise rates, historic shoreline evolution, coastal slopes, tidal range (Thieler & Hammar-Klose, 2000), coastal geomorphology, hydrodynamics, climate, and human activities (Łabuz, 2015).

While all aforementioned physical factors are essential, this review primarily focuses on the hydrodynamic drivers affecting coastal erosion assessments. These include sea-level rise, tidal levels, and range, tidal current velocities, and wave energy and transformation among others. The role of coastal hydrodynamics is becoming increasingly crucial as it adapts and responds to the effects of climate change (Stansby, 2013, Ahmad & Eisma, 2023). In regions like the South African coast, coastal erosion poses a significant threat due to the consequences of sea-level rise from climate change and high-energy waves (Theron et al., 2010).

Given the urgency of these challenges, there is a need for deeper exploration of the hydrodynamic drivers of coastal erosion along the South African coast. Therefore, this review aims to identify and delve into these drivers to aid comprehensive coastal erosion assessments along the South African Coasts. This research's insights can then inform best practice methods for considering and modeling hydrodynamic drivers in coastal erosion hazard assessments, thereby promoting improved management and assessment of coastal erosion hazards, and fostering enhanced resilience amidst climate change.

Initially, this study will offer a concise overview of various coastal erosion assessment methodologies and models. Subsequently, it will scrutinize the extent to which these models incorporate hydrodynamic considerations. Furthermore, the study will evaluate South African coastal hazard assessment approaches and their limitations, gaps, and needs concerning hydrodynamic considerations. Ultimately, the review concludes with recommendations for future research in this crucial field.

OVERVIEW OF COASTAL EROSION ASSESSMENTS

The inward movement of the shoreline towards the land caused by permanent deficit transportation of coastal sediment away from an area by waves, currents, wind, and/or human activities is termed as 'coastal erosion' (British Geological Survey, 2012). Coastal erosion assessments quantify the movement and changing the position of the coast. The quantification of coastal erosion in terms of shoreline position change is fundamentally important to relief and development agencies, coastal scientists, engineers, and managers (Douglas & Crowell, 2000). More particularly so when they are engaged with sustainable coastal management and engineering design to mitigate, manage, and prevent permanent coastal and seawater encroachment, beach erosion, disasters, and hazards (Prasad & Kumar, 2014).

The effects of coastal erosion have furthermore received a lot of attention from climate change impact literature. This is not surprising as coastal erosion as a climate change linked hazard is increasingly triggering disastrous outcomes for both human life and the natural environment (Yincan et al, 2017). Although coastal erosion has always contributed to the forming of the existing coastlines (Van Rijn, 2011), the rate of coastal erosion and its increased infrastructural cost are expected to intensify due to effects associated with climate change (Smith et al., 2013) as well as due to the rise in exposure expected with global coastal population growth. Increasing coastal erosion is demanding innovative, predictive, and integrated approaches to coastal assessment and management, especially considering the vast area of coast, a growing coastal population, increasing development pressure, increasing storm intensities and frequencies, and limited resources available for mitigation and adaptation measures.

Towards addressing the above-mentioned demand for improved coastal erosion hazard assessments various contributing factors to coastal erosion have been progressively included and investigated. Assessments and research have been practically concerned with the constant changes in geological, geomorphological, hydrodynamic, biological, climatic, and anthropogenic factors that lead to coastal erosion hazards and impacts that stem from such changes (Łabuz, 2015). The way these factors have been assessed and modeled have likewise been increasingly researched and various methods have been developed.

A variety of analytical assessment methods have been proposed and developed to detect coastal erosion induced shoreline change. The range of erosion assessment methods can largely be divided into two approaches, namely deterministic and probabilistic. The deterministic process was introduced by Pelnard-Considere in 1956 through his equation for determining future coastline position evolvement

(Reeve & Fleming, 1997). It was predominantly used in assessing coastal erosion and related processes, which is especially evident in assessments done by Shand, et al. (2015) and Mariani, et al. (2012) on segments of Australian and New Zealand coastlines, as well as various studies regarding dune erosion on the Dutch coastline, such as assessments done by van Gent, et al. (2008) and Vellinga (1986). This method produces the expected erosion hazard setback by dividing and accordingly assessing independent components before combining them, the method often includes aspects or measurement error allowance (Shand, et al., 2015). It is largely based on the mean erosion rates caused by a single, dominant failure mechanism (Dong & Guzzetti, 2005) and accordingly follows a one-line model (Reeve & Fleming, 1997). Deterministic techniques subsequently have the advantage of allowing for clear interpretation and manageable data updates but fall short in some crucial areas of coastal erosion predictions induced by a combination of both natural - and anthropogenic factors (Shand, et al., 2015).

The use of average values by the deterministic approach, however, not only excludes the consideration of rare, large-magnitude events but also that of the considerable variety of factors that could contribute to more localized coastal erosion events (Dong & Guzzetti, 2005). Furthermore, the deterministic approach for evaluating coastal erosion largely does not include the intensive consideration of uncertainty (Wainwright, et al., 2015; Shand, 2015). Due to the availing uncertainty present in current coastal processes and the associated climate change, it is crucial that this uncertainty should form part of coastal planning and decision making (Wainwright, et al., 2015).

As Douglas & Crowell (2000) support, the approximations of erosion rates are calculated in various ways, including the endpoint rate (EPR) and linear regression rate (LRR) methods, but should always account for the variety of uncertainties present in, for example, measurements and historical model analyses through an added quantity of erosion. This is where the use of the EPR and LRR techniques fall short in a deterministic approach. The EPR model assumes that the observed historical regression rates will continue in the future and accordingly utilizes this data to predict future regression rates, as in the study by Mukhopadhyay, et al. (2012) on shoreline regression and erosion on the Puri Coast in the Bay of Bengal, India. The LRR model, implemented in Adarsa & Bhattacharya's (2013) coastal erosion vulnerability assessment around the Midnapur-Balasore Coast in India, among others, uses available data to find a line which contains the comprehensive minimum of the squared distance to the shoreline (Hedge & Akshava, 2015; Mukhopadhyay, et al., 2012). Accordingly, these techniques mostly require no knowledge of sediment transport, wave interference, or disaster events because it assumes that the cumulative effect of the foregrounded processes is indicated in the shoreline position history (Mukhopadhyay, et al., 2012). Considering the above-mentioned shortfall and the increased rate of climate change Wainwright, et al. (2015) rightly emphasizes that a range of approximations of different probabilities of coastal erosion factors should be considered for a more transparent method of conveying possible future scenarios to be put in place. This is in line with what the probabilistic techniques look like.

Barnes (2017) notes that, in the case of Australia, coastal movement processes and hazard studies are currently largely based on and moving towards data analysis as well as numerical and parametric modeling through probabilistic methods. The probabilistic method, developed by van der Graaff (1986) has become much more prominent than the traditional process of deterministic methods with regards to coastal erosion assessments in recent decades (Shand, et al., 2015). This includes Hall, et al.'s (2002) model which considers both the rate of erosion as well as the size thereof. Additionally, it observes both the likelihood and consequence of hazard occurrence (with the inclusion of areas likely affected, such as existing development, as well as those potentially affected, such as new or potential development) which moves away from single value prediction and limited understandings (Shand, et al., 2015). The probabilistic method also utilizes stochastic simulation, as done by both den Heijer, et al., (2012) in the case of dune failure along the Dutch coast and Dong & Guzzetti (2005) regarding soft-cliff erosion in England, which accounts for a distribution of values for each parameter to include the anticipated variations and uncertainties that are not considered in the single value-producing deterministic methods (Shand, et al., 2015; Reeve & Fleming, 1997). The Monte-Carlo technique is accordingly implemented, which is based on a deterministic process model, to combine these parameters which produce a probabilistic prediction of coastal erosion processes (Shand, et al., 2015; Reeve & Fleming, 1997). Accordingly, it uses both stochastic (probabilistic) variables and deterministic (fixed value) variables to provide valuable recognition of the actual coastal erosion probabilities (den Heijer, et al., 2012; Shand, et al., 2015).

The variety of erosion modeling methods largely follow two analytical approaches, one being numerical modeling and the other being spatial analysis. As with the beach and dune erosion assessment through a probabilistic framework in the Menorca Island, Western Mediterranean by Enriquez, et al. (2019) numerical modeling utilizes atmospheric and oceanographic hindcast data to better understand and assimilate spatially defined oceanic processes for forecasting purposes (Bonetti et al., 2013). Numerical modeling is especially helpful when and where data about the impact and response of the coastal processes are lacking. This process can be divided into two primary models namely empirical (data-driven) and process-based numerical models (Hansen, 2016). While empirical models involve developing a mathematical model that recreates a set of observations to then be used predictively, the process-based numerical models consider the various pertinent physical processes (including wave propagation, wind, wave breaking, currents, and sea-level variations) which contribute to coastal erosion (Hansen, 2016). These respective models are often used, as in the case of Callaghan, et al. (2008), in combination to create a more considered model. It is important to note, however, that the application of these currently available numerical models are restricted in considering climate change as they generally simulate processes existing at a single spatial-temporal scale (Enriquez, et al., 2019; Le Cozannet, et al., 2014; Ranasinghe, et al., 2012).

Whereas numeric modeling focuses on examining the physical coastal dynamic processes, the spatial analysis' approach is focused on the analysis and representation of vulnerability to the hazard (Bastos, et al., 2016). Spatial analysis approaches, based on Geographical Information Systems, is an integrated approach wherein remote sensed imagery and data of variables that affect coastal erosion are jointly analyzed. Spatial analysis has significantly advanced the understanding and monitoring of various coastal dynamic processes and features. Its integrated approach has allowed for analysis of - and investigation into the interrelationship between various coastal elements and processes. Numerous spatial analysis methods for assessing coastal erosion and shoreline changes have been developed and applied. The straightforward inundation of static topography, the Bruun rule, as used within a probabilistic framework by Ranasinghe, et al. (2012) to assess the coastal erosion of Narrabeen Beach in Sydney, Australia, that extrapolates shoreline displacement rates from historic aerial imagery, and simple automated detection mathematical models based empirical observations, such as the End Point Rate (EPR) model (Mukhopadhyay et al., 2012) are examples of only a few of them.

As asserted by Bonetti, et al. (2013) it is valuable to note that the combination of both numerical modeling and spatial analysis techniques in coastal erosion assessments have potential in providing more valid evaluations than they would independently. For the development of both deterministic and probabilistic models, however, it is essential to acquire high-resolution series of coastal retreats and to obtain the frequency-size statistics of the retreats from the data (Dong, 2005)

The latest modus operandi of spatial analysis generally consists of a ranked-based coastal vulnerability to erosion index assessments. These indexes are focused on identifying segments of the coast that are more vulnerable to coastal erosion (Alexandrakis et al., 2010). These indexes are constructed, and their segments are calculated by ranking and combining various, geographic, oceanographic, and natural process variables and data that affect erosion within coastal systems and presenting them on a map. Variables include, amongst others, coastal geomorphology, coastal slope, rate of sea-level rise, mean significant wave height, mean tidal range, and sediment budget (Gornitz, 1991; Hereher, 2015; Özyurt & Ergin, 2010; Thieler & Hammar-Klose, 1991; Tragaki et al., 2018)Although their methodology highlights those regions in which the various effects of sea-level rise may be the greatest, the method yields numerical data that cannot be directly equated with particular physical effects (Thieler & Hammar-Klose, 2000). Another shortcoming of the model is that it does not consider the impacts of human manipulation of the coastal environment on the physical processes of the impacts of sea-level rise (Özyurt & Ergin, 2010). Accordingly, the coastal erosion hazard assessment in coastal vulnerability indexes is generally not encompassing of all the erosion parameters and subsequently, a coastal vulnerability index should not currently be read as a coastal erosion hazard assessment.

In considering all of the above assessment methods and techniques, a few gaps are present in the development of a fully encompassing coastal erosion hazard assessment. The consideration of sediment supply, for instance, needs more in-depth consideration. While the minority of assessments such as Corbella & Stretch (2012) consider sediment supply, although very briefly and of surface-level value, others such as den Heijer, et al. (2012) and Enriquez, et al. (2019) don't consider sediment supply in their studies. With regards to sediment, the seasonal variations of its movement might also need deeper consideration, as is evident in the lack of thorough investigation thereof in studies such as those of Mujabar & Chandrasekar (2013) and Mukhopadhyay, et al. (2012).

Enriquez, et al. (2019) notes that with the investigation of continuous, long-term shoreline movement, sea-level rise is considered as the main hydrodynamic driver, neglecting various other factors, including wave movement and variations. Towards enhancing effective assessment and prediction, hydrodynamic drivers should be increasingly researched, assessed, and modeled. This review will accordingly continue to further investigate the presence and pertinence of hydrodynamic drivers in coastal erosion hazard assessments.

THE ROLE OF HYDRODYNAMIC DRIVERS IN COASTAL EROSION ASSESSMENTS

The continuous landward movement of the shoreline due to the ongoing transportation of coastal sediment from a specific area, influenced by waves, currents, wind, or human activities, is defined as 'coastal erosion' (British Geological Survey, 2012). Evaluating this movement and the subsequent changes in coastline positioning is vital to organizations dealing with disaster management and coastal development, coastal scientists, and engineers (Douglas & Crowell, 2000). This relevance is even more pronounced in cases of sustainable coastal management and engineering design aimed at mitigating and preventing permanent beach erosion, coastal and seawater intrusion, and associated hazards (Prasad & Kumar, 2014).

Climate change literature has significantly spotlighted the impacts of coastal erosion. Such focus aligns with the rising occurrences of disastrous outcomes linked to coastal erosion, intensified by climate change, affecting human life and the natural environment (Yincan et al, 2017). Though coastal erosion plays a part in shaping existing coastlines (Van Rijn, 2011), the rate and infrastructural cost of coastal erosion are projected to escalate due to climate change effects (Smith et al., 2013), compounded by the increased exposure due to the growth in global coastal populations. The call for innovative, predictive, and integrated approaches to coastal assessment and management is rising in response to these challenges.

To meet the increased demand for improved coastal erosion hazard assessments, researchers and practitioners have progressively included various contributing factors to coastal erosion in their studies. They have been particularly focused on continuous changes in geological, geomorphological, hydrodynamic, biological, climatic, and anthropogenic factors that result in coastal erosion hazards and subsequent impacts (Łabuz, 2015). There is an increasing body of research into how these factors are assessed and modeled, and a number of methods have been developed.

Among the range of methods proposed to detect coastal erosion-induced shoreline changes, two key approaches emerge: deterministic and probabilistic. The deterministic approach, introduced by Pelnard-Considere in 1956, has been widely used in assessing coastal erosion and associated processes (Reeve & Fleming, 1997). Despite its clear interpretation and manageable data updates, the deterministic approach falls short in predicting coastal erosion driven by a combination of natural and anthropogenic factors (Shand, et al., 2015).

The deterministic approach's use of average values also overlooks the consideration of rare, large-magnitude events and localized coastal erosion events driven by a variety of factors (Dong & Guzzetti, 2005). More importantly, it does not sufficiently consider the inherent uncertainties in evaluating coastal erosion (Wainwright, et al., 2015; Shand, 2015). Given the current uncertainties in coastal processes and associated climate change, it's imperative to incorporate these uncertainties into coastal planning and decision making.

The probabilistic approach, developed by van der Graaff (1986), has grown more prevalent in recent decades in coastal erosion assessments (Shand, et al., 2015). This method includes models that consider the erosion rate and its size, the likelihood and consequence of hazard occurrence, and anticipates variations and uncertainties, making it more robust than the deterministic approach (Shand, et al., 2015; Reeve & Fleming, 1997).

However, both deterministic and probabilistic models require the acquisition of high-resolution series of coastal retreats and the frequency-size statistics of these retreats from the data (Dong, 2005). For a more valid evaluation of coastal erosion, it is beneficial to use a combination of numerical modeling and spatial analysis techniques (Bonetti, et al., 2013).

The most recent approach in spatial analysis generally involves ranking-based coastal vulnerability to erosion index assessments. These indexes are focused on identifying the coastline segments most vulnerable to coastal erosion (Alexandrakis et al., 2010). However, it is crucial to note that these indexes do not consider the impacts of human manipulation on the coastal environment, and thus, cannot be directly equated with particular physical effects (Thieler & Hammar-Klose, 2000).

In relation to the methods and techniques discussed above, several gaps still exist in the development of a comprehensive coastal erosion hazard assessment. For instance, the role of sediment supply in erosion needs a more in-depth consideration. Seasonal variations in sediment movement might also need deeper consideration.

Moreover, continuous, long-term shoreline movement studies generally consider sea-level rise as the primary hydrodynamic driver, often neglecting various other factors, including wave movement and variations (Enriquez, et al., 2019). To enhance effective assessment and prediction, hydrodynamic drivers should be further researched, assessed, and modeled. The following section of this review will thus delve into the significance of hydrodynamic drivers in coastal erosion hazard assessments.

CONCLUSION

A broad examination of coastal erosion assessment strategies and models has revealed the importance of integrating a diverse array of coastal erosion factors for a clearer, more comprehensive outcome. This investigation has reaffirmed the need to widen the scope of hydrodynamic elements affecting coastal erosion and the necessity to blend varying methodologies such as deterministic and probabilistic approaches, along with spatial analysis and numeric modeling techniques, a view supported by Bonetti, et al. (2013).

Our investigation into the role of hydrodynamic factors in coastal erosion risk and vulnerability assessments has shown a significant need for deeper insights into these drivers, particularly in the face of climate change and rising sea levels (Almar, et al., 2015; Chowdhury, et al., 2019; Cranfield Murtlock, 2015; Stansby, 2013). This necessitates addressing existing shortcomings in the understanding of hydrodynamic drivers like wave direction, storm frequency and increase, and swash zone related parameters. Importantly, future research should strive to incorporate comprehensive considerations of wave climate, including the wave direction change expected with climate shifts.

South African case studies offer a unique vantage point, showing a higher attention to wave direction compared to global studies. However, even in these studies, wave direction change has not been treated as a physical variable. An inclusion of the expected wave direction change, as pointed out by Hemer et al. (2010), could significantly enhance the efficacy of coastal erosion assessments along the South African coasts. Other factors, like storm frequency increase and swash zone dynamics, could benefit from more focus. Similarly, more than half the studies in South Africa have overlooked sea-level rise as a physical variable, highlighting a need for greater consideration of this climate change factor.

The anticipation of decreasing occurrences of big wave inducing events, like tropical cyclones, and increasing average wind velocities, both due to climate change (Habets, 2015; Malherbe et. al., 2015; Theron & Rossouw, 2008), are also significant considerations that have been less addressed in South African assessments. Incorporating these along with a measurement of uncertainty in wave height increase would provide a holistic view of the effects of hydrodynamic drivers on coastal erosion at a regional level.

The data-related challenges - the lack of accurate satellite and wave buoy data sets over extended historical periods (Habets, 2015), and the need to consider this data to obtain precise insights - underline the requirement for a robust and extensive study of coastal erosion assessments, including a meticulous examination of hydrodynamic drivers, specifically on the South African scale.

In sum, this review accentuates the need for improved, comprehensive coastal erosion assessments by addressing the identified gaps, reinforcing the importance of including a wider range of hydrodynamic drivers, and highlighting the potential of specific regional studies. To successfully address coastal erosion, it is crucial that future research follows a comprehensive, multi-faceted approach, while also considering the impacts of climate change and data-related challenges.

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D.E.F.G.: Methodology; Software; Formal Analysis; Investigation; Writing – review & editing;
H.I.: Supervision; Resources; Project Administration; Funding Acquisition; Writing – review & editing.

REFERENCES

Adarsa, J. & Bhattacharya, A., 2013. Assessment of Coastal Erosion Vulnerability around Midnapur-Balasore Coast, Eastern India, using Integrated Remote Sensing and GIS Techniques. Journal of the Indian Society of Remote Sensing, 41(3), pp. 675-686.

Ahmad, J., & Eisma, J. A., 2023. Capturing small-scale surface temperature variation across diverse urban land uses with a small unmanned aerial vehicle. Remote Sensing, 15(8), 2042.

Alexandrakis, C. & Poulos, S., 2014. A Holistic Approach to Beach Erosion Vulnerability Assessment. Scientific Report, 4(6078), pp. 1-8.

Almar, R.; Kestenare, E.; Reyns, J.; Jouanno, J.; Anthony, E.J.; Laibi, R.; Hemer, M.; Du Penhoat, Y.& Ranasinghe, R. 2015. Response of the Bight of Benin (Gulf of Guinea, West Africa) Coastline to Anthropogenic and Natural Forcing, Part1: Wave climate variability and impacts on the longshore sediment transport. Continental Shelf Research, Volume 110, pp. 48-59.

Bakhtyar, R.; Barry, D.A.; Li, L.; Jeng, D.S. & Yeganeh-Bakhtiary, A. 2009. Modeling Sediment Transport in the Swash Zone: A Review. Ocean Engineering, 36(9-10), pp. 767-783.

Barnes, M., 2017. How to Choose an Appropriate Coastal Hazard Mapping Spatial Scale, Gold Coast, Australia: CoastAdapt.

Bastos, L., Bio, A. & Iglesias, I., 2016. The Importance of Marine Observatories and RAIA in Particular. Frontiers of Marine Science, Volume 3:140.

Bonetti, J.; da Fontoura Klein, A. H.; Muler, M.; De Luca, C. B.; da Silva, G. V.; Toldo Jr., E. E. & Gonzalez, M. 2013. Spatial and Numerical Methodologies on Coastal Erosion and Flooding Risk Assessment. In: C. Finkl, ed. Coastal Hazards. Coastal Research Library, vol 1000. Dordrecht: Springer, pp. 423-442.

Boruff, B., Emrich, C. & Cutter, S., 2005. Erosion Hazard Vulnerability of US Coastal Counties. Journal of Coastal Research, 21(5), pp. 932-942.

British Geological Survey, 2012. UK Geohazard Note: Coastal Erosion. Natural Environmental Research Council.

Butt, T. & Russel, P., 2000. Hydrodynamics and Cross-Shore Sediment Transport in the Swash Zone of Natural Beaches: A Review. Journal of Coastal Research, 16(2), pp. 255-268.

Cai, F.; Su, X.; Liu, J.; Li, B. & Lei, G. 2009. Coastal Erosion in China under the Condition of Global Climate Change and Measures for its Prevention. Progress in Natural Science, Volume 19, pp. 415-426.

Callaghan, D. P., Nielsen, P., Short, A. & Ranasinghe, R., 2008. Statistical Simulation of Wave Climate and Extreme Beach Erosion. Coastal Engineering, 55(5), pp. 375-390.

Callaghan, K., Engelbrecht, J. & Kemp, J., 2015. The Use of Landsat and Aerial Photography for the Assessment of Coastal Erosion and Erosion Susceptibility in False Bay, South Africa. South African Journal of Geomatics, 4(2), pp. 65-79.

Casas-Prat, M., 2015. Effects of Climate Change on Wave Climate and Consequent Coastal Impacts: Application to the Catalan Coast (NW Mediterranean Sea). s.l.: Ph.D Thesis. Polytechnic University of Catalonia, Barcelona.

Chardon-Maldonado, P., Pintado-Patino, J. & Puleo, J., 2015. Advances in Swash-Zone Research: Small-Scale Hydrodynamic and Sediment Transport Processes. Coastal Engineering, Volume 15, pp. 8-25.

Chowdhury, P., Ranjan Behera, M. & Reeve, D., 2019. Wave Climate Predictions along the Indian Coast. International Journal of Climatology, 39(11), pp. 4531-4542.

Corbella, S. & Stretch, D., 2012b. Decadal Trends in Beach Morphology on the East Coast of South Africa and Likely Causative Factors. Natural Hazards and Earth System Sciences, Volume 12, pp. 2515-2527.

Corbella, S. & Stretch, D., 2012c. The Wave Climate on the KwaZulu-Natal Coast of South Africa. Journal of the South African Institution of Civil Engineering, 54(2), pp. 45-54.

Corbella, S. & Stretch, D., 2012. Shoreline Recovery from Storms on the East Coast of South Africa. Natural Hazards and Earth System Sciences, Volume 12, pp. 11-22.

Corbella, S. & Stretch, D., 2014. Directional Wave Spectra on the East Coast of South Africa. Journal of the South African Institution of Civil Engineering, 56(3), pp. 53-64.

Corbella, S. & Stretch, D. D., 2012a. Predicting Coastal Erosion Trends using Non-stationary Statistics and Process-based Models. Coastal Engineering, Volume 70, pp. 40-49.

Cranfield Murtlock, T., 2015. Wave Climate and Coastal Change in Southeast Australia. Sydney: Ph.D Thesis, Macquarie University.

de Boer, W.; Mao, Y.; Hagenaar, G.; de Vries, S.; Slinger, J. & Vellinga, T. 2019. Mapping the Sandy Beach Evolution around Seaports at the Scale of the African Continent. Journal of Marine Science and Engineering, 7(5), p. 151.

den Heijer, C., Baart, F. & van Koningsveld, M., 2012. Assessment of Dune Failure along the Dutch Coast Using a Fully Probabilistic Approach. Geomorphology, Volume 143-144, pp. 95-103.

Dong, P. & Guzzetti, F., 2005. Frequency-Size Statistics of Soft Cliff Erosion. Journal of Waterway, Port, Coastal, and Ocean Engineering, 131(1), pp. 37-42.

Doran, K.S.; Stockdon, H.F.; Sopkin, K.L.; Thompson, D.M. & Plant, N.G. 2013. National Assessment of Hurricane-Induced Coastal Erosion Hazards: Mid-Atlantic Coast, Reston, Virginia: U.S. Geological Survey.

Douglas, B.C. & Crowell, M. 2000. Long-term shoreline position prediction and error propagation. Journal of Coastal Research. 16(1):145–152.

Enriquez, A. R., Marcos, M., Falquez, A. & Roelvink, D., 2019. Assessing Beach and Dune Erosion and Vulnerability Under Sea Level Rise: A Case Study in the Mediterranean Sea. Frontiers in Marine Science, 6(4), pp. 1-12.

Fourie, J.; Ansorge, I.; Backeberg, B.; Cawthra, H.C.; MacHutchon, M.R. & van Zyl, F.W. 2015. The Influence of Wave Action on Coastal Erosion along Monwabisi Beach, Cape Town. South African Journal of Geomatics, 4(2), pp. 96-109.

Gornitz, V., 1991. Global Coastal Hazards from Future Sea Level Rise. Global & Planetary Change, 3(4), pp. 379-398.

Habets, F.C. 2015. Project South Durban: Understanding the Sediment Transports and Budgets around the Durban DigOut Port, South Africa. MSc Thesis, Delft University of Technology, Delft. Available: http://resolver.tudelft.nl/uuid:7a1b1778-60cb-4d94-bd86-ff262efe92da [Accessed 20 March 2020]

Hall, J. W., Meadowcroft, I. C., Lee, E. M. & van Gelder, P. H. A. J. M., 2002. Stochastic Simulation of Episodic Soft Coastal Cliff Recession. Coastal Engineering, 46(3), pp. 159-174.

Hansen, J., 2016. The Use of Modelling Tools to Assess Local Scale Inundation and Erosion Risk, Gold Coast, Australia: CoastAdapt, National Climate Change Adaptation Research.

Harris, L., 2008. The Ecological Implications of Sea-Level Rise and Storms for Sandy Beaches in KwaZulu-Natal. MSc Thesis, University of KwaZulu-Natal, Westville: s.n.

Harris, L., Nel, R., Smale, M. & Schoeman, D., 2011. Swashed Away? Storm Impacts on Sandy Beach Macrofaunal Communities. Estuarine, Coastal and Shelf Science, 94(3), pp. 210-221.

Hedge, A. V. & Akshava, B. J., 2015. Shoreline Transformation Study of Karnataka Coast: Geospatial Approach. Aquatic Procedia, 4(2015), pp. 151-156.

Hemer, M., Church, J. & Hunter, J., 2010. Variability and Trends in the Directional Wave Climate of the Southern Hemisphere. International Journal of Climatology, Volume 30, pp. 475-491.

Hereher, M., 2015. Coastal vulnerability assessment for Egypt's Mediterranean coast. Geomatics, Natural Hazards & Risk, 6(4), pp. 342-355.

Horikawa, K. e., 1988. Nearshore Dynamics and Coastal Processes: Theory, measurement, and predictive models. s.l.: University of Tokyo Press.

Jones, S., 2018. Oceans & Coasts. State of Environment Outlook Report for the Western Cape Province: Executive Summary, Cape Town: Western Cape Government: Environmental Affairs and Development Planning.

Komar, P., Marra, J. & Allan, J., 2002. Coastal Erosion Processes and Assessment of Setback Distances. In: L. &. W. L. Ewing, ed. Solutions to Coastal Disasters '02. Reston, Virginia, US: American Society of Civil Engineers, pp. 808-835.

Łabuz, T.A. 2015. Environmental Impacts —Coastal Erosion and Coastline Changes. In Second Assessment of Climate Change for the Baltic Sea Basin. T.B.I.A. Team, Ed. Springer, Cham. 381–396. DOI: 10.1007/978-3-319-16006-1.

Landim Dominguez, J. & Pinto Bittencourt, A., 1996. Regional Assessment of Long-term Trends of Coastal Erosion in Northeastern Brazil. Anais da Academia Brasileira de Ciencias, 68(3), pp. 355-372.

Le Cozannet, G.; Garcin, M.; Yates, M.; Idier, D. & Meyssignac, B. 2014. Approaches to Evaluate the Recent Impacts of Sea-Level Rise on Shoreline Changes. Earth Sciences, Volume 138, pp. 47-60.

Luo, S., Wang, H. & Feng, C., 2013. An Integrated Risk Assessment of Coastal Erosion based on Fuzzy Set Theory along Fujian Coast, Southeast China. Ocean & Coastal Management, Volume 84, pp. 68-76.

MacHutchon, M., 2015. Geophysical Monitoring of Coastal Erosion and Cliff Retreat of Monwabisi Beach, False Bay, South Africa. South African Journal of Geomatics, 4(2), pp. 80-95.

Malherbe, J., Engelbrecht, F.A. & Landman, W.A. 2013. Projected Changes of Tropical Cyclone Climatology and Landfall in the Southwest Indian Ocean Region under Enhanced Anthropogenic Forcing. Climate Dynamics 40 (2867-2886). Available: DOI:10.1007/s00382-012-1635-2. [Accessed 20 March 2020]

Mariani, A.; Shand, T.; Carley, J. T.; Goodwin, I. D.; Splinter, K.; Davey, E. K.; Flocard, F. & Turner, I. L. 2012. Generic Design Coastal Erosion Volumes and Setbacks for Australia, Hobart, Tasmania: Antarctic Climate and Ecosystem Cooperative Research Centre.

Merlotto, A., Bertola, G. & Piccolo, M., 2016. Hazard, Vulnerability, and Coastal Erosion Risk Assessment in Necochea Municipality, Buenos Aires Province, Argentina. Journal of Coastal Conservation, Volume 20, pp. 351-362.

Mortlock, T., Goodwin, I., Mc Aneney, J. & Roche, K., 2017. The June 2016 Australian East Coast Low: Importance of Wave Direction for Coastal Erosion Assessment. Water, 9(2), pp. 121-143.

Mujabar, P.S. & Chandrasekar, N., 2013. Coastal Erosion Hazard and Vulnerability Assessment for Southern Coastal Tamil Nadu of India by using Remote Sensing and GIS. Natural Hazards, Volume 69, pp. 1295-1314.

Mukhopadhyay, A; Mukherjee, S; Mukherjee, S; Ghosh, S; Hazra, S & Mitra, D. 2012. Automatic Shoreline Detection and Future Prediction: A case study on Puri COast, Bay of Bengal, India. European Journal of Remote Sensing, 45(1), pp. 201-213.

Musekiwa, C., Cawthra, H., Unterner, M. & van Zyl, F. W., 2015. An Assessment of Coastal Vulnerability for the South African Coast. South African Journal of Geomatics, 4(2), pp. 123-137.

Neumann, B., Ott, K. & Kenchington, R. 2017. Strong sustainability in coastal areas: a conceptual interpretation of SDG 14. Sustainability Science. 12(6):1019–1035. DOI: 10.1007/s11625-017-0472-y.

Özyurt, G. & Ergin, A. 2010. Improving Coastal Vulnerability Assessments to Sea-Level Rise: A New Indicator-Based Methodology for Decision Makers. Journal of Coastal Research. 262:265–273. DOI: 10.2112/08-1055.1.

Palmer, B.J.; Van der Elst, R.; Mackay, F.; Mather, A.A.; Smith, A.M.; Bundy, S.C.; Thackeray, Z.; Leuci, R. & Parak, O. 2011. Preliminary Coastal Vulnerability Assessment of KwaZulu-Natal, South Africa. Journal of Coastal Research, Issue Special Issue 64, pp. 1390-1395.

Prasad, D.H. & Kumar, N.D. 2014. Coastal Erosion Studies — A Review. 2014(March):341–345.

Pervaiz, F., & Hummel, M., 2021. Evaluation of Climate Change and Urbanization Impacts on Bridges in Harris County, Texas. World Environmental and Water Resources Congress 2022, 499–507.

Pervaiz, F., & Hummel, M. A., 2023. Effects of Climate Change and Urbanization on Bridge Flood Vulnerability: A Regional Assessment for Harris County, Texas. Natural Hazards Review, 24(3), 04023025.

Puleo, J.A.; Blenkinsopp, C.; Conley, D.; Masselink, G.; Turner, I.L.; Russel, P.; Buscombe, D.; Howe, D.; Lanckriet, T.; McCall, R. & Poate, T. 2014. Comprehensive Field Study of Swash-Zone Processes. I: Experimental Design with Examples of Hydrodynamic and Sediment Transport Measurements. Journal of Waterway, Port, Coastal and Ocean Engineering, 140(1), pp. 14-28.

Ramsay, D., 2011. Coastal Erosion and Inundation due to Climate Change in the Pacific and East Timor, s.l.: Department of Climate Change and Energy Efficiency, Government of Australia.

Ranasinghe, R., Callaghan, D. & Stive, M. J., 2012. Estimating Coastal Recession due to Sea Level Rise: Beyond the Bruun rule. Climatic Change, Volume 110, pp. 561-574.

Ranga Rao, V.; Ramo, K.; Dash, S. K.; Patra, S.; Vishnuvardhan, K.; Damodara Raa, V. & Mohan, R. 2015. A Study on Hydrodynamic Behaviour of SW Coast of India – Implication to Ecosystem Model. Procedia Engineering, Volume 116, pp. 746-754.

Rautenbach, C., Theron, A., Joubert, W. & van Niekerk, L., 2017. Coastal Zone. In: C. Davis-Reddy & K. Vincent, eds. Climate Risk and Vulnerability: A Handbook for Southern Africa. 2nd ed. Pretoria: CSIR, pp. 91-99.

Reeve, D. & Fleming, C. A., 1997. A Statistical-Dynamical Method for Predicting Long Term Coastal Evolution. Coastal Engineering, 30(3-4), pp. 259-280.

Rijn, L. v., 2011. Coastal Erosion and Control. Ocean & Coastal Management, 54(12), pp. 876-887.

Shand, T; Reinein-Hamill, R; Kench, P; Ivamy, M; Knook, P & Howse, B. 2015. Methods for Probabilistic Coastal Erosion Hazard Assessment. Auckland, New Zealand, Engineers Australia, and IPENZ.

Smith, A.M.; Mather, A.A.; Bundy, S.C.; Cooper, J.A.G.; Guastella, L.A.; Ramsay, P.J. & Theron, A. 2010. Contrasting Styles of Swell-driven Coastal Erosion: Examples from KwaZulu-Natal, South Africa. Geological Magazine, 147(6), pp. 940-953.

Smith, A., Guastella, L.A., Mather, A.A., Bundy, S.C. & Haigh, I.D. 2013. KwaZulu-Natal coastal erosion events of 2006/2007 and 2011: A predictive tool? South African Journal of Science. 109(3–4):1–4. DOI: 10.1590/sajs.2013/20120025.

Souza, C., 2001. Coastal Erosion Risk Assessment, Shoreline Retreat Rates, and Causes of Coastal Erosion along the State of Sao Paulo Coast, Brazil. Pesquisas em Geociencias, 28(2), pp. 459-474.

Stansby, P., 2013. Coastal Hydrodynamics - Present and Future. Journal of Hydraulic Research, 51(4), pp. 341-350.

Stronkhorst, J.; Levering, A.; Hendricksen, G.; Rangel-Buitrago, N. & Rosendahl Appelquist, L. 2018. Regional Coastal Erosion Assessment based on Global Open Access Data: A case study for Colombia. Journal of Coastal Conservation, Volume 22, pp. 787-798.

Theron, A. & Rossouw, M., 2008. Analysis of Potential Coastal Zone Climate Change Impacts and Possible Response Options in the Southern African Region. Pretoria, Science Real and Relevant: 2nd CSIR Biennial Conference.

Theron, A.; Rossouw, M.; Barwell, L.; Maherry, A.; Diedericks, G. & de Wet, P. 2010. Quantification of Risks to Coastal Areas and Development: Wave Run-up and Erosion. s.l.: CSIR Conference 2010.

Thieler, E. & Hammar-Klose, E., 1991. National Assessment of Coastal Vulnerability to Sea-level rise; U.S. Atlantic Coast, Reston: USGS.

Thieler, E. & Hammar-Klose, E., 2000. National Assessment of Coastal Vulnerability to Sea-level Rise; Preliminary Results for the U.S. Pacific Coast, Reston: USGS.

Tragaki, A., Gallousi, C. & Karymbalis, E. 2018. Coastal hazard vulnerability assessment based on geomorphic, oceanographic, and demographic parameters: The case of the Peloponnese (Southern Greece). Land. 7(2). DOI: 10.3390/land7020056.

Van der Graaff, J., 1986. Probabilistic Design of Dune; an example from The Netherlands. Coastal Engineering, Volume 9, pp. 479-500.

Van Gent, M.R.A.; van Thiel de Vries, J.S.M.; Coeveld, E.M.; de Vroeg, J.H. & van der Graaff, J. 2008. Large-scale Dune Erosion Tests to Study the Influence of Wave Periods. Coastal Engineering, Volume 55, pp. 1041-1051.

Van Rijn, L., 2013. Leo van Rijn - Sediment. [Online] Available at: https://www.leovanrijnsediment.com/papers/Coastalhydrodynamics2013.pdf[Accessed 15 March 2020].

Vellinga, P., 1986. Beach and Dune Erosion during Storm Surges. Ph.D Thesis, Delft University of Technology.

Wainwright, D. J.; Ranasinghe, R.; Callaghan, D. P.; Woodroffe, C. D.; Jongejanf, R. & Dougherty, A. J. 2015. Moving from deterministic towards probabilistic coastal hazard and risk. Coastal Engineering, Volume 96, pp. 92-99.

Wigley, R., 2011. Geohazards in Coastal Areas, Cape Town, South Africa: Council for Geoscience.

Yincan, Y.E. et al, 2017. Coastal Erosion. In Marine Geo-Hazards in China reference. Elsevier. 269–296. DOI: 10.1016/B978-0-12-812726-1.00007-3.

Zacharioudaki, A. & Reeve, D., 2011. Shoreline Evolution under Climate Change Wave Scenarios. Climatic Change, Volume 108, pp. 73-105.

ALBRIGHT, R., CALDEIRA, L., HOSFELT, J., KWIATKOWSKI, L., MACLAREN, J. K., MASON, B. M., NEBUCHINA, Y., NINOKAWA, A., PONGRATZ, J., RICKE, K. L., RIVLIN, T., SCHNEIDER, K., SESBOUE, M., SHAMBERGER, K., SILVERMAN, J., WOLFE, K., ZHU, K. & CALDEIRA, K. 2016. Reversal of ocean acidification enhances net coral reef calcification. Nature, 531, 362-365.

NATALIO, L. F., PARDO, J. C. F., MACHADO, G. B. O., FORTUNA, M. D., GALLO, D. G. & COSTA, T. M. 2017. Potential effect of fiddler crabs on organic matter distribution: a combined laboratory and field experimental approach. Estuarine, Coastal and Shelf Science, 184, 158-165.

ROBERTS, J. M., WHEELER, A. J. & FREIWALD, A. 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. Science, 312, 543- 547.

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491 *Table 1 Overview of global coastal erosion hazard, risk and vulnerability assessments*

Study	Purpose of the Study	Parameters Considered	Hydrodynamic Drivers Considered
Regional Assessment of Long-term Trends of Coastal Erosion in Northeastern Brazil (Landim Dominguez & Pinto Bittencourt, 1996)	Long Term Coastal Erosion Trend Evaluation	Geology (formations, terraces, beach rocks, lagoonal deposits, dune deposits, and coral reefs) and hydrodynamics	Sea level rise, wave climate (seasonal directions & height), and tidal range
An Integrated Risk Assessment of Coastal Erosion based on Fuzzy Set Theory along Fujian Coast, Southeast China (Luo, et al., 2013)	Coastal Erosion Risk Assessment	Geology (erodibility in coastal substrates) and hydrodynamics	Sea level rise, wave height, storm surge, tidal range
Regional Coastal Erosion Assessment based on Global Open Access Data: a case study for Colombia (Stronkhorst, et al., 2018)	Coastal Erosion Assessment	Geological layout, sediment balance, vegetation, storms, and hydrodynamics	Wave climate (height) and tidal range.
Coastal Erosion Risk Assessment, Shoreline Retreat Rates, and Causes of Coastal Erosion Along with the State of Sao Paulo Coast, Brazil (Souza, 2001)	Coastal Erosion Risk Assessment	Geomorphology, sediment balance, and hydrodynamics	Sea level rise, wave regime (increased storminess), current circulation, and tidal range

Erosion Hazard Vulnerability of US Coastal Counties (Boruff, et al., 2005)	Coastal social and erosion hazard vulnerability index	Geomorphology (erodibility), sediment balance, coastal slope, social vulnerability variables, and hydrodynamics	Sea level rise, wave height, and tidal range.
Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS (Mujabar & Chandrasekar, 2013)	Coastal vulnerability index	Geology, geomorphology, shore configuration, beach width, gradient and composition, drainage/estuaries, sediment balance, and hydrodynamics	Sea level rise, wave height, and tidal range
A Holistic Approach to Beach Erosion Vulnerability Assessment (Alexandrakis & Poulos, 2014)	Coastal vulnerability index	Geomorphology, beach morphology, wind climate, sedimentology, and hydrodynamics	Sea level rise, mean sea level, wave climate (wave breaking height & angle, significant wave height, wave period, and closure depth), and tidal range
National Assessment of Hurricane-Induced Coastal Erosion Hazards: Mid-Atlantic Coast (Doran, et al., 2013)	Coastal erosion hazard assessment.	Beach morphology (dune crest and toe, shoreline position and beach slope) and hydrodynamics.	Wave setup and swash, wave height and period, and tide and storm surge.

Hazard, vulnerability, and coastal erosion risk assessment in Necochea Municipality, Buenos Aires Province, Argentina (Merlotto, et al., 2016)	Coastal erosion hazard, risk, and vulnerability assessment	Coastal geomorphology, sediment supply, erosion/accretion rate, and hydrodynamics	Storm waves (height, frequency, duration).

Table 2 Overview of South African based coastal erosion hazard, risk, and vulnerability assessments

Study	Purpose of the Study	Parameters Considered	Hydrodynamic Drivers Considered
The Influence of Wave Action on Coastal Erosion along Monwabisi Beach, Cape Town (Fourie, et al., 2015)	Coastal Erosion Assessment	Coastal retreat rate, geological substrate, and hydrodynamics	Wave climate (significant wave height, maximum wave height, extreme wave heights, wave seasonality, wave direction, and storm waves)
An Assessment of Coastal Vulnerability for the South African Coast (Musekiwa, et al., 2015)	Coastal Vulnerability Index	Beach geomorphology, geology, elevation to chart datum, beach width, distance to 20m isobaths, anthropogenic activities, and hydrodynamics	SLR, wave climate (maximum wave height, mean wave height), and tidal range
Predicting Coastal Erosion Trends using Non-stationary	Coastal Erosion Hazard Prediction Model	Storm duration, storm frequency increase, dune height above	SLR, wave climate (maximum wave height, wave height, wave

Statistics and Process-based Models (Corbella & Stretch, 2012a)		mean sea level, cross-shore distance offshore, hydrodynamics	duration, wave peak, wave period, and wave angle in storm events), and water level.
Preliminary Coastal Vulnerability Assessment for KwaZulu-Natal, South Africa (Palmer, et al., 2011)	Coastal Vulnerability Index	Beach width, dune width, distance to 20m isobaths, the distance of vegetation behind the back beach, percentage rocky outcrop	
Decadal Trends in Beach Morphology on the East Coast of South Africa and Likely Causative Factors (Corbella & Stretch, 2012b)	Coastal Erosion Assessment	Beach gain, beach loss, wind trends, storm frequency, duration and calm period, and hydrodynamics	SLR, wave climate (maximum wave height, maximum significant wave height, average significant wave height, maximum peak period, average peak period, peak energy frequency, average direction), and tidal range
Quantification of Risks to Coastal Areas and Development: Wave Run-up and Erosion (Theron, et al., 2010)	Coastal Vulnerability & Risk Assessment	Geomorphology, geology, coastal slope, erosion/accretion rate, ground cover, wave exposure, foredune buffer volume/ height, and hydrodynamics	SLR, wave climate (wave height), and tidal range
Mapping the Sandy Beach Evolution around Seaports at the Scale of the African Continent (de Boer, et al., 2019)	Coastal Impact Map	Coastline orientation, sediment sources & sinks, natural sheltering setting, coastal protection (cross-shore & longshore structures),	Wave climate (mean wave direction)

		breakwater length, port construction date, and hydrodynamics	
Geophysical Monitoring of Coastal Erosion and Cliff Retreat of Monwabisi Beach, False Bay, South Africa (MacHutchon, 2015)	Coastal Erosion Assessment	Nearshore & coastal morphology, wind patterns, and hydrodynamics	Wave climate (mean significant wave height, mean peak wave period, wave angle, and wave run-up), tidal range, and nearshore, and surface currents.
Contrasting Styles of Swell-driven Coastal Erosion: Examples from KwaZulu-Natal, South Africa (Smith, et al., 2010)	Coastal Erosion Assessment	Geomorphology, nearshore bars, erosion, coastline recovery, wind speed variation, wind direction variation, storm type, and hydrodynamics	Wave climate (significant shallow wave height, maximum swell height, highest significant offshore swell, swell morphodynamics, swell direction), tidal height & state, water level dynamics, currents, and storm surge
The Use of Landsat and Aerial Photography for the Assessment of Coastal Erosion and Erosion Susceptibility in False Bay, South Africa (Callaghan, et al., 2015)	Coastal Erosion Assessment	Shoreline evolution and landcover change	
Geohazards in Coastal Areas (Wigley, 2011)	Physical Vulnerability Index	Geomorphology, shoreline erosion, and accretion rates, coastal slope, and hydrodynamics	Rate of relative SLR, mean tidal range, mean wave height

Swashed away? Storm impacts on sandy beach macrofaunal communities (Harris, et al., 2011)	Coastal Erosion Assessment	Beach intertidal width, beach intertidal elevation, mean sand grain size, sediment fall velocity, dean's parameter, beach index, beach state index, beach deposit index, sorting, skewness, kurtosis, and hydrodynamics	Wave breaker height, wave period, swash period, mean tide range, and relative tide range

MAIN EXAMPLES OF REFERENCING LITERATURE

JOURNALS: PRINT AND ONLINE.

ONE AUTHOR

In-text example: (Schneider, 2015).

Reference List Example:

SCHNEIDER, E. K. 2015. Trajectory analysis of the mechanism for westward propagation of Rossby waves. *Journal of the Atmospheric Sciences*, 72, 2178-2182. doi:10.1175/JAS-D-14-0242.1

TWO AUTHORS

In-text example: (Fruman and Achatz, 2015).

Reference List Example:

FRUMAN, M. D. & ACHATZ, U. 2015. Validation of large-eddy simulation methods for gravity wave breaking. *Journal of the Atmospheric Sciences*, 72, 3537- 3562.

THREE OR MORE AUTHORS

In-text examples: (Roberts et al., 2006); Natalio et al. (2017); Albright et al. (2016).

Reference List Examples:

ROBERTS, J. M., WHEELER, A. J. & FREIWALD, A. 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science*, 312, 543- 547.

NATALIO, L. F., PARDO, J. C. F., MACHADO, G. B. O., FORTUNA, M. D., GALLO, D. G. & COSTA, T. M. 2017. Potential effect of fiddler crabs on organic matter distribution: a combined laboratory and field experimental approach. *Estuarine, Coastal and Shelf Science*, 184, 158-165.

ALBRIGHT, R., CALDEIRA, L., HOSFELT, J., KWIATKOWSKI, L., MACLAREN, J. K., MASON, B. M., NEBUCHINA, Y., NINOKAWA, A., PONGRATZ, J., RICKE, K. L., RIVLIN, T., SCHNEIDER, K., SESBOUE, M., SHAMBERGER, K., SILVERMAN, J., WOLFE, K., ZHU, K. & CALDEIRA, K. 2016. Reversal of ocean acidification enhances net coral reef calcification. *Nature*, 531, 362-365.

BOOKS: PRINT AND ONLINE

ONE AUTHOR

In-text example: (Lurton, 2010).

Reference List Example:

LURTON, X. 2010. An introduction to underwater acoustics: principles and applications, Berlin, Springer - Verlag.

TWO AUTHORS

In-text example: (Jakobse and Ozhigin, 2011)

Reference List Example:

JAKOBSE, T. & OZHIGIN, V. K. 2011. *The Barents Sea: ecosystem, resources, 23 management,* Trondheim, Tapir Acad. Press.

THREE OR MORE AUTHORS

In-text examples: Liu et al. (2015); (Mann et al., 2000); Quintell et al. (2015).

Reference List Examples:

LIU, Y., KERKERING, H. & WEISBERG, R. H. 2015. *Coastal ocean observing systems*, Amsterdam, Academic Press.

MANN, J., CONNOR, R. C., TYACK, P. L. & WHITEHEAD, H. 2000. *Cetacean societies: field studies of dolphins and whales*, Chicago, University of Chicago Press.

QUINTRELL, J., LUETTICH, R., BALTES, B., KIRKPATRICK, B., STUMPF, R. P., SCHWAB, D. J., READ, J., KOHUT, J., MANDERSON, J., MCCAMMON, M., CALLENDER, R., TOMLINSON, M., KIRKPATRICK, G. J., KERKERING, H. & ANDERSON, E. J. 2015. The importance of federal and regional partnerships in coastal observing. In: LIU, Y., KERKERING, H. & WEISBERG, R. H. (eds.) *Coastal ocean observing systems*. Boston: Academic Press.

CHAPTER IN A SINGLE AUTHOR BOOK

In-text example: Bourdieu (2011).

Reference List Example:

BOURDIEU, P. 2011. In front of the camera and behind the scenes. *On television*. Cambridge: Polity.

MAPS IN-TEXT EXAMPLES:

(Bourillet et al., 2012);

(Center for Coastal Monitoring and Assessment and Program and Coastal Services Center, 2001)

Reference List Examples:

BOURILLET, J. F., DE CHAMBURE, L., LOUBRIEU, B., BRETON, C. & MAZE, J. P. 2012. *Geomorphological map from Blackmud canyon to Douarnenez canyon*. Scale : 1 / 1000 000 (N 46 degree) Mercator projection Ellipsoid WGS84. Versailles: Editions Quae. 1 map.

CENTER FOR COASTAL MONITORING AND ASSESSMENT (US). BIOGEOGRAPHY PROGRAM & COASTAL SERVICES CENTER (US). 2001. *Benthic habitats of Puerto Rico and the U.S. Virgin Islands.* Silver Spring: U.S. National Oceanic and Atmospheric Administration.

CORPORATE AUTHORS

493 **In-text examples:** (University of Chicago Press, 2010); (BSI, 1985); (ISO, 1997); (WHO, 1993)

Reference List Examples:

UNIVERSITY OF CHICAGO PRESS. 2010. *The Chicago manual of style*. 16th ed. Chicago: University of Chicago Press.

BSI (British Standards Institution) 1985. *Specification for abbreviation of title words and titles of publications.* London: BSI.

ISO (International Organization for Standardization) 1997. *Information and Documentation—Bibliographic References. Part 2, Electronic Documents or Parts Thereof. ISO 690-2*. New York: American National Standards Institute.

WHO (World Health Organization) 1993. *WHO editorial style manual*. Geneva: World Health Organization.

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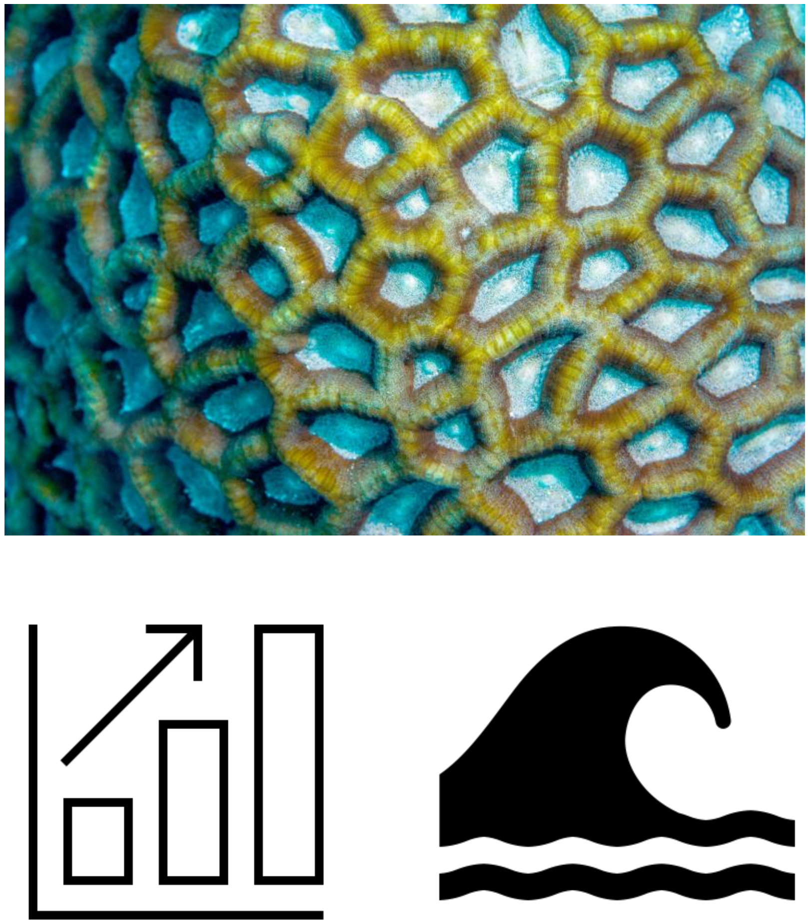

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