Introduction

Globally, the coastal environment is increasingly becoming more susceptible to the effects of coastal erosion and extreme weather events. This is largely due to the fact that this environment is a popular destination for residence, leisure and recreation, with more then a third of eastern and southern Africa’s populations residing within 100km of the coast (UNEP/Nairobi Convention Secretariat, 2009). As development pressure increases the natural functioning of the coast is lost (O’Connor et al., 2009). Changes in the natural functioning of the coast coupled with the threat of future sea-level rise and climate change make it imperative that coastal managers gain a better understanding as to the vulnerability of the coast to these events (Palmer et al., 2011). Kumar et al., 2010, define vulnerability as the inherent risk that an environment, such as the coastal zone, faces as a result of its predisposition to be affected, or to be susceptible to damage.

This need to assess and understand coastal vulnerability has long since been identified, Gornitz and Kanciruk (1989) undertook what was a pioneering study of (natural) features and processes on the coast and considered what would enhance or reduce coastal impact from sea-level rise. They focused on two aspects, the exposure to inundation and to erosion, and identified seven variables (coastal relief, lithology and landforms, and relative changes in sea level, shoreline movement, tidal range and exposure to large waves) for hazard assessment. The approach was later applied to the South African coast (Hughes and Brundrit, 1992). Beaches, estuaries and lagoons were identified as potentially high risk environments because of their unconsolidated soft sediments, low relief and wide inland exposure. It should be noted that such areas account for more than 50% of the South African coast. Global climate change and its direct link to sea-level rise along the South African coast (Mather et al., 2009) has resulted in increased concern as to the future impacts to the coast and thus the vulnerability of the coast. Thus recent studies have sought to provide greater resolution and detail, and have also tended to include socio-economic indicators. Geographic Information Systems are now valuable tools for incorporating comparative statistics into detailed studies. In a World Bank Policy Research Working Paper, Dasgupta et al., 2009, gave a comparative analysis of the impacts of sea level rise and, in particular, the intensification of storm surges for developing countries worldwide. Indicators for coastal populations, settlements, economic activity and the extent of wetland ecosystems, established which developing countries are most at risk, and recognised that some countries are far more vulnerable than others from these impacts of climate change. Whilst South Africa, overall, is not considered highly vulnerable, the Eden District was ranked third in Africa for urban areas at risk from intensification of storm surges. This confirms the conclusion reached by Hughes and Brundrit (1995) that low-lying areas of the southern Cape are at risk from more frequent intrusions of extreme events into sheltered back lagoons containing developed infrastructure and services. The variation in risk along the coast emphasises the need for higher resolution studies of vulnerability along the entire coast.

A Coastal Vulnerability Index for KwaZulu-Natal (KZN) is considered to be one of the most important social and economic assets for the province. However, the 580km coast is an area exposed to the increasing challenges of coastal erosion, sea-level rise and extreme events. Thus there is a need to know what is potentially at risk, which led to the development of a Coastal Vulnerability Index (CVI), which was undertaken as a desktop study based on available data. The CVI assesses the relative physical vulnerability of the coast. This paper outlines the broad technique used to determine the CVI for KZN, which identifies zones of risk, and assesses its implications for coastal management in the province. Physical vulnerability was determined by means of identifying indicators of risk, with beach width, dune width and distance to the 20m isobath being identified as the most critical indicators. Furthermore, social, economic and ecological factors were assessed in relation to the findings of the physical CVI. The study showed that 30% of the coast was at risk, 47% at moderate risk and 23% at high risk to potential damage and impact as a result of future coastal erosion and storm events. A suite of management options have been proposed for each risk category and it is anticipated that these will better inform coastal management on the ground. It is further anticipated that the information derived from the CVI, coupled with future modelling, will inform the determination of coastal set-back lines in KZN.

Abstract

The coastal zone of KwaZulu-Natal (KZN) is considered to be one of the most important social and economic assets for the province. However, the 580km coast is an area exposed to the increasing challenges of coastal erosion, sea-level rise and extreme events. Thus there is a need to know what is potentially at risk, which led to the development of a Coastal Vulnerability Index (CVI), which was undertaken as a desktop study based on available data. The CVI assesses the relative physical vulnerability of the coast. This paper outlines the broad technique used to determine the CVI for KZN, which identifies zones of risk, and assesses its implications for coastal management in the province. Physical vulnerability was determined by means of identifying indicators of risk, with beach width, dune width and distance to the 20m isobath being identified as the most critical indicators. Furthermore, social, economic and ecological factors were assessed in relation to the findings of the physical CVI. The study showed that 30% of the coast was at risk, 47% at moderate risk and 23% at high risk to potential damage and impact as a result of future coastal erosion and storm events. A suite of management options have been proposed for each risk category and it is anticipated that these will better inform coastal management on the ground. It is further anticipated that the information derived from the CVI, coupled with future modelling, will inform the determination of coastal set-back lines in KZN.
this event as frequent as 10 to 12 years (Mather, 2008), making it critical for government to be better informed and better prepared for future events of this nature. Given the insight of historical vulnerability assessments and the limitations of available data to assess coastal vulnerability in KZN, an indicator of vulnerability was developed. The Coastal Vulnerability Index (CVI) assesses the relative physical coastal vulnerability of the coast and determines a relative degree of vulnerability for small sections of the coast as: risk, moderate risk or high risk respectively. This assessment also considers social, economic and ecological factors by identifying indicators and assessing them in relation to the findings of the CVI to determine which populations and associated infrastructure are potentially at risk. The CVI is packaged essentially as an interactive tool which allows coastal managers to view and assess the vulnerability for sections of the KZN coast. This paper outlines the broad technique used to determine the relative CVI for KZN and assesses its implications for coastal management in KZN.

Study Area
This research focuses on the KZN coastal zone, South Africa, which is some 580km in length (Figure 1). The coast is relatively straight, with few bays and no islands or offshore barriers to provide protection. About 80% of the coast comprises stretches of sandy beach, with the rest being characterised by intermittent rocky outcrops (Palmer et al., 2011).

The warm climate and waters, the availability of flat land with high aesthetic value, the concomitant lifestyle, tourism, wealth for coastal retirement and an increase in holiday homes along the KZN coast have resulted in large areas of urban development with high population densities (DEAT, 1999; Palmer et al., 2011). Primarily along the southern sections of coast, development has been intense and often been poorly planned, frequently increasing the area’s vulnerability (Palmer et al., 2011). It should be noted that urban development is not evenly distributed along the coast, with almost no development in the far north, in the iSimangaliso Wetland Park (a proclaimed World Heritage Site of 332 000 hectares).

![Figure 1: Location of the KwaZulu-Natal coastal zone (Palmer et al., 2011)](image)

Method
Relative physical vulnerability
This method divides the coast into 50m by 50m cells and rates each in terms of its degree of vulnerability as a result of the identification and examination of key indicators of physical vulnerability (Palmer et al., 2011). Indicators are considered to be useful in vulnerability assessments as they can be used in identifying and monitoring changes in vulnerability over time and space, which results in improved knowledge as to the underlying processes resulting in vulnerability (Rygel, O’Sullivan and Yarnal, 2006).

The method was undertaken as a quick, desktop means of assessing the vulnerability of the KZN coast. Thus the list of parameters used is kept short in order to focus on only the most important and easily assessed parameters (Palmer et al., 2011). The assessment started with seven physical parameters, which after review by specialists was reduced to five core parameters namely: beach width, dune width, percentage rocky outcrop, distance (width) of vegetation behind the back beach and distance to the 20m isobath. Where beach width was calculated as from transect length, dune width was determined as the width of the dunes behind the back beach. The distance to the 20m isobath was calculated from the nearest point of the 20m isobath from the back beach, percentage outcrop was determined as the percent of rocky outcrop exposed
along a transect and distance of vegetation behind the back beach was determined as the width of vegetation behind the back beach (Palmer et al., 2011).

The data required for this assessment was extracted from orthophotographs. For the northern and southern coasts (Figure 1), imagery was captured post the 2007 storm event in late 2007/early 2008 with accuracy to standard deviation m.s.e. (mean squared error) of 0.25m. For the central coast, mosaic imagery captured in 2007 supplied by the coastal authority (eThekwini Municipality) was used (Figure 1).

Identified parameters offer different responses or degrees of protection depending upon the magnitude, type and nature of the impact. Therefore each parameter was weighted individually according to its value and corresponding perceived level of risk. In order to have a degree of validation of this data, a comparison to historic data from known past coastal erosion events was undertaken. The weighting of individual parameters, as outlined in Table 1, was (1) extremely low, (2) low, (3) moderate or (4) high depending on its value and range (Palmer et al., 2011).

Table 1: Rating of physical parameters (Source: Palmer et al., 2011)

<table>
<thead>
<tr>
<th>Physical Parameter</th>
<th>Extremely Low (1)</th>
<th>Low (2)</th>
<th>Moderate (3)</th>
<th>High (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach width</td>
<td>&gt; 150m</td>
<td>100 – 150m</td>
<td>50 – 100m</td>
<td>&lt; 50m</td>
</tr>
<tr>
<td>Dune width</td>
<td>&gt; 150m</td>
<td>50 – 150m</td>
<td>25 – 50m</td>
<td>&lt; 25m</td>
</tr>
<tr>
<td>Distance to 20m isobath</td>
<td>&gt; 4km</td>
<td>2 – 4km</td>
<td>1 – 2km</td>
<td>&lt; 1km</td>
</tr>
<tr>
<td>Distance of vegetation behind the back beach</td>
<td>&gt; 600m</td>
<td>200 – 600m</td>
<td>100 – 200m</td>
<td>&lt; 100m</td>
</tr>
<tr>
<td>Percentage outcrop</td>
<td>&gt; 50%</td>
<td>20 – 50%</td>
<td>10 – 20%</td>
<td>&lt; 10%</td>
</tr>
</tbody>
</table>

Beach width, dune width and distance to the 20m isobath were identified as being the most critical indicators. This was based on specialist input using the premise that the wider the beach, the more wave energy it is able to dissipate, and that dune width provides protection in terms of being a proxy for the amount of sediment available to ‘buffer’ against erosion (Palmer et al., 2011). While the distance to the 20m isobath relates to wave energy, the greater the distance to this isobath, the greater the time to allow for dissipation of wave energy (Mather, Stretch and Garland, 2010). Specialists determined that cells scoring high (4) on all three of these sites needed to be weighted additionally by four in order to highlight the potential risk of these cells. Furthermore, it was determined that due to the sensitive nature of estuaries, cells that crossed estuary mouths were to be weighted additionally by four (Palmer et al., 2011). Lastly cells that portrayed evidence of historical erosion were weighted by a factor of four.

Based on the scoring and weighting, each cell received a total relative vulnerability score out of a possible 32:

\[
\text{Relative CVI} = a + b + c + d + e + f + g + h
\]

Where \(a\) = beach width vulnerability score, \(b\) = dune width vulnerability score, \(c\) = distance to 20m isobath vulnerability score, \(d\) = percentage outcrop vulnerability score, \(e\) = distance of vegetation behind the back beach vulnerability score, \(f\) = additional weighting of highly vulnerable sites (if \(a\), \(b\) and \(c\) = 4), \(g\) = additional weighting if the cell intersects an estuarine area, \(h\) = historical erosion site (Palmer et al., 2011).

**Social, economic and ecological components**

As stated, this assessment tries to address social, economic and ecological factors by identifying indicator features and assesses them in relation to the findings of the physical CVI. This provides an indication as to which populations and associated infrastructure and properties are potentially at risk. The features considered were broken down into social, economic and ecological as shown in Table 2. **Social** features are those which relate to people’s use of and benefits they receive from the coast, both for subsistence, residence and for recreation and leisure. **Economic** features relate to areas of commercial activity i.e. the strategically important infrastructure which supports an area and contributes to economic income for the KZN province. **Ecological** features related to ecologically sensitive and important areas along the KZN coast which should be conserved in order to ensure long-term functioning of natural coastal areas, thus contributing to the sustainability of the system.
Table 2: Social, economic and ecological components and number of sites assessed in the CVI study (Adapted from Palmer et al., 2011)

<table>
<thead>
<tr>
<th>Social Resources</th>
<th>Number of sites</th>
<th>Economic Resources</th>
<th>Number of sites</th>
<th>Ecological Resources</th>
<th>Number of sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsistence harvesting*</td>
<td>10</td>
<td>Sugarcane</td>
<td>231</td>
<td>Turtle nesting sites*</td>
<td>2</td>
</tr>
<tr>
<td>Subsistence fishing*</td>
<td>19</td>
<td>Forest plantations</td>
<td>105</td>
<td>Protected areas</td>
<td>72</td>
</tr>
<tr>
<td>Subsistence farming</td>
<td>229</td>
<td>Commercial farms</td>
<td>472</td>
<td>Estuary mouths*</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dune mining</td>
<td>3</td>
<td>Bird sanctuary sites*</td>
<td>12</td>
</tr>
<tr>
<td>Recreational areas</td>
<td></td>
<td>Commercial &amp;</td>
<td>538</td>
<td>Marine Protected Areas (MPAs)*</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>industrial properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sports areas</td>
<td>226</td>
<td>Roads</td>
<td>543</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat launch sites*</td>
<td>47</td>
<td>Railways</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishing hotspots*</td>
<td>121</td>
<td>Piers*</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal public property (CPP)</td>
<td>147</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Residential erven</td>
<td>48156</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Resources falling directly in the littoral active zone

Results

Physical vulnerability

Figure 2: Range of vulnerability scores for the KZN coast

Figure 2 shows the distribution of CVI scores out of a possible 32, it is evident the lowest recorded score is 9 and the median of the data is 17. The information presented in Figure 2 was used to ‘group’ or rank vulnerability scores into three categories in order to simplify the interpretation for management. The three categories were risk, moderate risk and high risk. The distribution of the CVI scores was used to determine the ranges for the categories, resulting in risk being from 9-14, moderate risk being from 15-20 and high risk being from 21 – 32. For the assessment risk was defined as the lowest potential to be impacted or damaged as a result of coastal erosion or extreme storm event, meaning that these sections of coast are at some risk to damage. Due to the dynamic nature of the KZN coast it was determined that no sections of the coast could be at no risk, and thus the lowest category considered was risk. This study showed that 30% of the coast was at risk, 47% at moderate risk and 23% at high risk to potential damage and impact as a result of future coastal erosion or extreme storm events.
Social, economic and ecological vulnerability

Figure 3: Percentage of social, economic and ecological resources located within or adjacent to cells of high risk

Social, economic and ecological resources located in or across the littoral zone (identified in Table 2) were considered at relatively higher risk if all, or a proportion of them, fell within or adjacent to cells of high risk. Figure 3 shows what percentages of these features are located within or adjacent to cells of high risk, and this is important for management going forward. It is also important to note that proximity to the coast is important, particularly in terms of infrastructure, where developments to close to the high water mark are at greater risk to damage than those located inland (Figure 4). Areas of concern are swimming beaches (98% at high risk), turtle nesting sites (100% at high risk) and bird sanctuary areas (100% at high risk).

Figure 4: Impact on structures, influenced by distance from the high-water mark, building a is more likely to be damaged than building b, due to its location (Palmer et al., 2011)

Discussion

The physical vulnerability assessment, or CVI, was based on easily identifiable and extractable parameters in the form of a desktop assessment. As a result five key parameters were considered as indicators for the assessment of physical vulnerability. All five parameters were evaluated individually and those that were considered to be critical were weighted additionally. The results were ‘validated’ by comparing the data for the KZN coast to data from sites of known historic erosion (Palmer et al., 2011). Evidence shows that the KZN coast has historically experienced erosion damage and it is likely that events such as that experienced in 2007 will occur again (Smith et al., 2010). Consequently it is expected that sites with relatively higher CVI...
will be at the highest risk to damage (Palmer, et al., 2011). It is therefore imperative that coastal managers have the ability to improve planning and are better prepared for future events so that management can be more proactive.

It is anticipated that the CVI will serve as an innovative interactive management tool. The coast was divided into three categories of risk, being risk, moderate risk and high risk. In terms of social, economic and ecological features, only those that are within or in close proximity to cells of high risk where assessed in detail in order to determine what would be lost or damaged should future extreme events occur. From a social aspect, swimming beaches are of the greatest concern which also has a potential economic impact. If the swimming beaches are damaged tourists income will be adversely affected. Thus coastal manages need to maintain these beaches and be ready to deal with and implement emergencies responses to damage as required. From an ecological point, turtle nesting sites and bird sanctuary areas are of greatest concern, this is exacerbated by the fact that there only a few of these sites, thus they need particularly careful management.

In addition to the assessment of social, economic and ecological features in high risk areas different management criteria were developed for each category. Sites that score risk are considered to be at lower risk than areas which score moderate risk or high risk. These sites still have the potential to be impacted or damaged, but the likelihood is lower than in areas falling into higher risk categories. These sites are likely to have a lower vulnerability/risk rating because the physical parameters are in good condition – e.g. vegetation behind the back beach, beach width, dune width, outcrop and distance to the 20m isobath respectively. If developments in these areas are approved they may increase the vulnerability of these areas. Hence it is imperative that any new development be set-back appropriately so as to maintain the natural functioning of the coast in these areas. Sites which score moderate risk are at higher risk than areas of risk, but lower than areas of high risk. There is a good likelihood of these sites being damaged as a result of coastal erosion or extreme weather events. It is recommended that the options of retreat and defence be explored as existing infrastructure may be damaged. New developments in areas adjacent to sites within this risk category should be set-back sufficiently to ensure that they are not damaged. If there is insufficient space for set-back or retreat then alternative sites for the development should be considered. Areas classified as high risk are considered to be the most susceptible to the effects of erosion and are most likely to be impacted should sea-level rise or extreme events occur. Some of these areas have been historic erosion hotspots. Existing developments in these areas have a high likelihood to be damaged as a result of such events. It is recommended that the options of retreat and defense be explored as existing infrastructure may be damaged. New developments in areas adjacent to sites with this risk category should be set-back sufficiently to ensure that they are not damaged. If there is insufficient space for set-back or retreat then alternative sites for the development should be considered.

Way Forward
The assessment identifies three zones of risk which have been related to management actions and it also identifies key social, economic and ecological features that are potentially at risk. Features which are located directly in the littoral active zone are easy to manage in terms of risk, as they are either in a very high vulnerability area or not and management interventions can be clearly defined to manage this. However, management in urban areas where infrastructure is slightly set-back from the coast is more difficult to deal with as it is unlikely that there is room for retreat (Palmer, et al., 2011; Mather, Roberts and Tooley, 2010). Thus management interventions need to be carefully planned and implemented effectively, and some interventions could include the use of Coastal and Shoreline Management Plans.

This assessment has been done as a snapshot to identify potential risk and vulnerability to the coastal zone of KZN, so as to start informing better management. The CVI will be refined in order to better assess the zone of impact and this will be done by considering coastal elevation, predicted sea-level rise and shoreline change (Palmer, et al., 2011). It is further hoped that the information derived from the CVI, coupled with future modeling, will inform the determination of coastal set-back lines and in turn contribute to better coastal management in KZN.
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