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Assessing coastal vulnerability: Development of a combined physical and economic index

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ABSTRACT

As a consequence of climate change, coastal communities worldwide are subject to increased risk from sea-level rise and more intense storms. Therefore, it is important for coastal managers to have focused site specific data on present and predicted climate change impacts in order to determine shoreline vulnerability. There are few UK studies that characterise coastal vulnerability, while nearly all global work has concentrated on geomorphological and to a lesser extent, socio-economic aspects. In response, the present study developed a new Physical Coastal Vulnerability Index (PCVI) and applied it to eleven UK sites, seven in England, three in Wales and one in Scotland. PCVI results were then compared and contrasted with a new Fiscal Coastal Vulnerability Index (FCVI), which enabled coastal areas to be visually classified in one of four categories to inform relative risk. Both indices were subsequently integrated into a Combined Coastal Vulnerability Index (CCVI). Results showed that Great Yarmouth and Aberystwyth were highly vulnerable, while Llanelli and Lynmouth were least vulnerable, and the importance of integrating both indices is demonstrated by modified overall vulnerability assessments. Therefore, CCVI provides a simple to use shoreline monitoring tool which is particularly suitable for assessment of risk. The indices support coastal planning, including intervention or no active intervention policies, and thereby benefitting a range of stakeholders. CCVI works at local, regional and international scales, and identifies vulnerable locations. Consequently, these indices will inform management strategies to improve coastal resilience under various sea level rise and climate change scenarios.

1. Introduction

Coastal zones are highly dynamic and are susceptible to natural hazards, due to the diverse climatic changes that are occurring around the world (Zsamboky et al., 2011; Arkema et al., 2013). The world's coastlines have different geographical characteristics that influence the generation of trade and other coastal activities and make significant contributions to the economies of countries (Kantamaneni, 2016a). Increases in coastal disasters, particularly flood events, impose large socio-economic costs, particularly in populated estuaries, low-lying coastal urban areas, and islands, and these are important communal hotspots of vulnerability (Hinkel et al., 2010). Threats to coastlines occur where substantial growth on the land near the sea is affected by shape and biophysical features (Carter, 2013), while Newton et al. (2012) introduced a syndrome-based method of assessing coastal vulnerability that emerged from concerns related to the impacts of climate variations on coastal zones, suggesting that multiple stressors impact coastal systems worldwide in several ways. The impacts of regional and global climate changes, sea-level rise, and weather fluctuations, alongside terrestrial processes, represent serious threats to all coastal communities (Oliver-Smith, 2009; Handmer et al., 2012). Global trends in sea-level rise have an effect on the UK, particularly along the Norfolk and Suffolk coastlines in southeast England, where records show a historic rising trend (Doody and Williams, 2004; Pye and Blott, 2006; Brooks et al., 2012). According to UNEP (2013), the UK coast has been strongly altered, and the UK's shoreline is one of the most degraded of any country in the world. Therefore, coastal vulnerability assessments are very important when consideration is given to the management and future development of coastal regions, both in the UK and elsewhere across the globe.

Considerable literature exists from around the world on geomorphological and physical coastal vulnerability (Gornitz and Kanciruk, 1989; Gornitz, 1990; Gornitz et al., 1994; Abuodha and Woodroffe, 2010; Balica et al., 2012; Kumar and Kunte, 2012; Wang et al., 2014;

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Pramanik et al., 2016; Nguyen et al., 2016; Islam et al., 2016). However, there are few corresponding studies on socio-economic vulnerability (Cutter et al., 2003; Vincent, 2004; Schröter et al., 2005; Rygel et al., 2006; Hahn et al., 2009). Similarly, there are UK studies (McLaughlin et al., 2002; McLaughlin and Cooper, 2010; Denner et al., 2015; Kantamaneni, 2016a; Kantamaneni, 2016b), but none assess combined physical and economic vulnerability. Therefore, the present study assesses the physical and economic vulnerability of eleven UK sites of varying physical and economic characteristics; the locations chosen from academic articles and reports of flooding and loss. By assessing and integrating each site's Physical Coastal Vulnerability Index (PCVI) and Fiscal Coastal Vulnerability Index (FCVI), analyses will enable the comparing and contrasting of physical, economic and combined vulnerabilities from multiple perspectives, including ranking of the eleven vulnerable UK coastal areas.

2. Study areas

Consistent with the work of Kantamaneni (2016b), eleven vulnerable coastal sites in the UK with diverse anthropogenic, physical and socio-economic characteristics have been selected for coastal vulnerability assessment. Of these sites, seven are in England, three are in Wales, and one is in Scotland (Table 1; Fig. 1).

2.1. Description of study area locations

Spurn Head, primarily has the form of a sand and shingle spit covered by dunes, together with an area of till and alluvium to the north (May and Hansom, 2003). Contributing to the spit's sediment budget, low till cliffs are being eroded at rates in excess of 2.5 m yr-1 at its northern end. Macro-tidal tides with a tidal range of 6 m influence sediment deposition along the frontal lobe of the spit that can erode at rates of between 1 m and 2 m yr-1 (Quinn et al., 2009). The lack of any type of coastal defences make this region more vulnerable to erosion. ***Hallsands***, a combination of gravel extraction, high wave energy and high tide conditions have resulted in rapid coastal erosion, which makes Hallsands one of the most heavily eroded sites in the UK. ***Lynmouth,*** severe coastal flooding events often cause damage in the Lynmouth area, due to rapid climatic change scenarios (Scrase and Sheate, 2005). Changes in land use and management, urban development in the catchment and sea-level rise cumulatively affect the frequency and magnitude of flooding in this area (Enviornemt Agency, 2012). ***Happisburgh,*** coastline is exposed to waves from multiple directions, and it is especially vulnerable to storms generated from the north, as there is no fetch limitation in this direction (Thomalla and Vincent, 2003). Storm waves erode the glacial till at the base of the cliffs, causing collapse and rapid erosion; more than 260 metres of coastline has retreated in recent years (BGS, 2014). Existing costal defences (wooden revetments) are not strong enough to protect the coast from different varieties of hazards in this area. ***Dawlish,*** coastal strip is more than 6 km in length between Teignmouth and Dawlish has been highly vulnerable to recurrent closures due to high sea waves and storm attacks since it was constructed. This became especially apparent during the 2013/12 winter storms when the sea was breached and properties were damaged (Dawson et al., 2016). In the last 2000 years, the sea-level rise along the south coast has been ~0.9 mm/yr. (Dawson, 2012).

Great Yarmouth, a low-lying coastal town constructed on a spit, which is made up of varying proportions of sand and gravel. The region has a history of coastal flooding, and this situation is not helped by the fact that the river Yare separates the spit from the mainland at its western end (Nicholls et al., 2007). Landslides and erosion are common problems in this area. ***Skegness***, is a coastal town in Lincolnshire district in England. It has been subject to erosion and general retreat for several centuries (Dugdale and Vere, 1993). The high water table and low-lying landscape of this region, in conjunction with the increased risk associated with sea-level rise, postglacial adjustment (forebulge collapse) and storm surges, intensify the area's physical vulnerability to the effects of climate change (Zsamboky et al., 2011). ***Benbecula,*** exposed to North Atlantic Ocean winter storms and waves (Wolf and Woolf, 2006; Dawson et al., 2007). Accordingly, high waves and coastal erosion are the most significant problems in this area, and it is one of the highly eroded sites in the UK (Kantamaneni and Phillips, 2016). ***Aberystwyth*** coastal strip is > 2 km long and is mostly reinforced by hard sea defences. The sea front, which is exposed to south-westerly storm waves, has a history of erosion and sea defence breaches that spans several decades. The most recent storms occurred in late 2013 and early 2014, during which the coastlines of the UK were severely affected by an exceptional run of winter storms, culminating in serious coastal damage and widespread flooding (Slingo et al., 2014). ***Port Talbot,*** coastline is backed either by natural dune systems or retaining structures, but many of the commercial and residential properties built in this relatively low lying area are at risk of flooding. Strong winds and tides generated in the Bristol Channel contribute to a high-energy wave environment (Allan et al., 2009). Prevailing winds emanate from the southwest; the macro-tidal environment has a spring tidal range 7.5 m (Phillips and Crisp, 2010), and storm waves > 5.5 m with periods > 8.5 s are not uncommon in this region (Thomas et al., 2015). ***Llanelli,*** coastline is mostly backed by coastal defences and recent storm events have severely damaged the coastal paths and rail infrastructure and caused damage to several newly constructed dwellings (Denner et al., 2015). It is acknowledged that continuous flooding in the area has resulted from increases in impervious surfaces that resulted from the construction of new developments, increases in the sewage base load caused by housing stock expansion, and the co-occurrence of high tides with heavy rainfall (CCC, 2007).

Table 1
Vulnerable coastal sites chosen for detailed assessment.

England	Wales	Scotland
Spurn Head	Port Talbot	Benbecula
Skegness	Llanelli	
Happisburgh	Aberystwyth	
Great Yarmouth		
Hallsands		
Dawlish		
Lynmouth		

3. Methodology

A severe storm and extreme wave event coinciding with an equinox caused significant infrastructure damage along the KwaZulu-Natal (South Africa) coast. Subsequently, Palmer et al. (2011) developed a literature based PCVI by assessing five physical factors that affect shoreline vulnerability, i.e. beach width, dune width, distance to 20 m isobath, distance of vegetation behind back beach and percentage rock outcrop. These were given scores based on predefined thresholds with parameter and estuary weightings completing the assessment framework. This framework was then applied to 50 m by 50 m cells along the KwaZulu-Natal shoreline, which gave a measure of relative shoreline vulnerability based on an 'very low', 'low', 'moderate' and 'high' scoring system (1–4). Denner et al. (2015) modified this for the Loughor Estuary (Wales, UK) by dividing 11 km of the coastline into 100 m × 10 m cells and subsequently ranking relative vulnerability according to 'very low', 'low', 'medium', 'high' and 'very high'. Consequently, they were able to identify relative coastal risk along different segments of the Loughor Estuary. Denner et al. (2015) methodology retained Palmer et al. (2011) five physical factors, but in the current study, a new PCVI was developed which integrated two additional physical parameters: 'distance of built structures behind the back beach' and 'sea defences'. These parameters affect shoreline vulnerability and their thresholds were determined from expert opinion. Consequently, Table 2 details the