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Assessing and mapping regional coastal vulnerability for port environments and coastal cities

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Abstract

Complex hazards associated with climate change are increasing the vulnerability of urban coastal areas around the globe. This was particularly evident in the UK during the winter of 2013–14 when many coastal areas and infrastructure suffered from unprecedented storms, flooding and erosion. Given the value and importance of urban environments, there is a real need to assess the vulnerability of towns and cities on the United Kingdom (UK) coastline on the basis of the latest projected climate scenarios. Accordingly, a modified Physical Coastal Vulnerability Index (PCVI) was developed in which beach width and coastal slope are considered the most critical physical parameters. The PCVI can be used to rank spatial coastal cells into four classes of vulnerability (from extremely low to high) and to map coastal vulnerability using GIS. As a case study, this approach was applied to the city of Southampton; one of the key port and trade cities in the UK, with results indicating that 38% of the city's coastline is highly vulnerable, and more than 50% moderately vulnerable. The work demonstrates that the methodological framework can be used as a planning tool for coastal management and, based on the availability of suitable data, can be adapted for estuarine or coastal and port environments without any geographical limits. Newly developed coastal vulnerability maps can be used by coastal engineers, managers and other decision makers to implement rigorous shoreline management planning as well as supporting risk, and disaster management policy and procedures.

Keywords Physical coastal vulnerability index (PCVI) · Vulnerability mapping · Geographic information systems (GIS) · Estuarine environments · Port and coastal cities

Introduction

Coastal zones and estuarine regions are densely populated hotspots of vulnerability (Nicholls et al. 2007; Halpern et al. 2008; Newton and Weichselgartner 2014; Wolters and Kuenzer 2015) being socio-economically, ecologically, and environmentally vital, whilst susceptible both to natural and anthropogenic hazards (Bollmann et al. 2010; Higgins et al. 2013). Climate induced hazards such as sea level rise, floods, and storm surges increase the pressure on coastal estuarine regions particularly in low-lying areas (Macintosh 2013; Spalding et al. 2014; Tavares et al. 2015; Sperotto et al. 2016). Currently, more than 10% of the global population lives in low-elevation coastal zones below the 10 m elevation range (McGranahan et al. 2007). Exacerbated by uneven climatic variations across the globe (Nicholls et al. 2007; Zsamboky et al. 2011), allied anthropogenic processes such as abridged sediment supply to river deltas, frequently intensify the local susceptibility connected with sea level rise (Nicholls and Cazenave 2010). Increased coastal disasters, particularly storm attacks with high winds, significantly affect the socio-economic costs, in such regions (Hinkel et al. 2010; Kron 2013) with an increasing proportion of coastal populations affected by severe storm events in recent decades (Brown et al. 2016;). Adger (2006) emphasised that evaluating vulnerability is the initial step to notify policy makers of the fundamental causes of coastal disasters. While Newton et al. (2012) introduced a syndrome method of coastal vulnerability assessment that identified the multi-stressors impact on global coastal systems. Systematic coastal vulnerability assessments, therefore, represent important tools in driving

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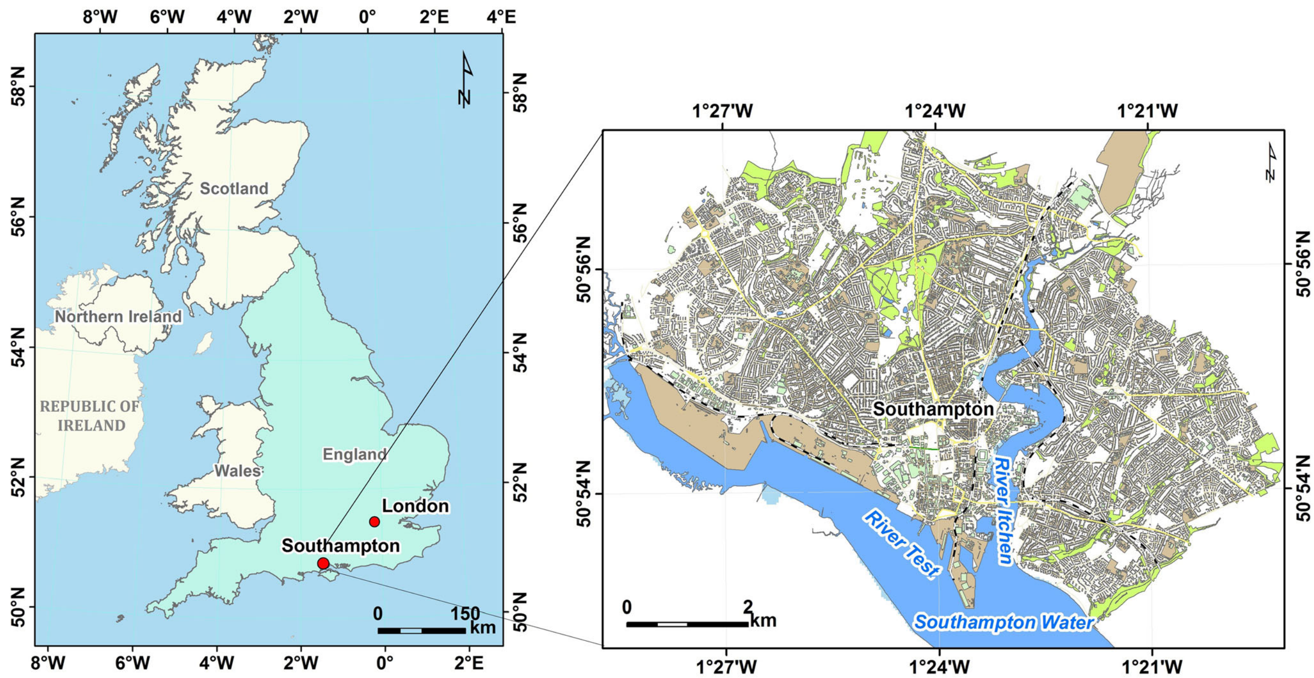


Fig. 1 Study area

forward coastal management and the consideration of future development options for coastal regions globally.

Coastal vulnerability indices allow variables to be rated in a computable manner, indicating the relative vulnerability of coastlines to physical changes such as climate change and other associated factors. In producing statistical data, it can emphasise areas of high coastal vulnerability and places where the effects of climate change and sea-level rise are anticipated to be greatest (Pethick and Crooks 2000; Rani et al. 2015). Globally, there is a considerable amount of literature now on geomorphological coastal vulnerability studies such as, inter alia, the work by Gornitz and Kanciruk 1989; Gornitz 1991; Gornitz et al. 1994; Abuodha and Woodroffe 2010; Palmer et al. 2011; Balica et al. 2012; Pramanik et al. 2015; Islam et al. 2016; and Kantamaneni et al. 2017. Similarly, there is a more limited body of literature detailing the vulnerability of coastal environments in the UK, such as the work of McLaughlin et al. (2002); McLaughlin and Cooper (2010); and Denner et al. (2015). In addition, Fitton et al. (2016, 2018) evaluated coastal erosion vulnerability of the Scottish coastline by developing both a Physical Susceptibility Model (UPSM) and the Coastal Erosion Susceptibility Model (CESM), with these studies assessing erosion vulnerability with regard to both physical and socio-economic aspects. Similarly, Kantamaneni (2016a, b) and Kantamaneni et al. (2018) have developed studies also assessing UK case study sites from both economic and physical perspectives. No studies to date however were found to have evaluated more specifically the coastal susceptibility of UK urban and port cities taking into account their particular physical structures. There is a real need to develop such a

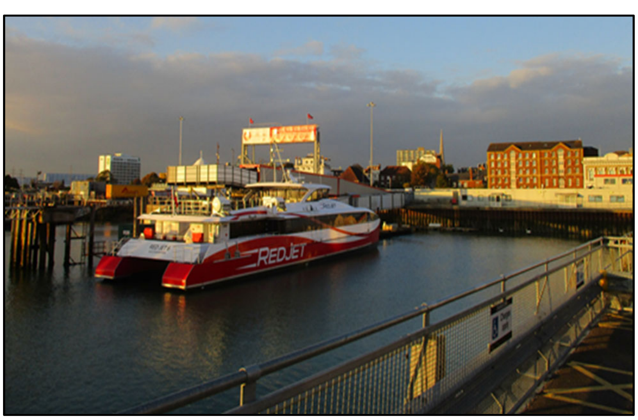
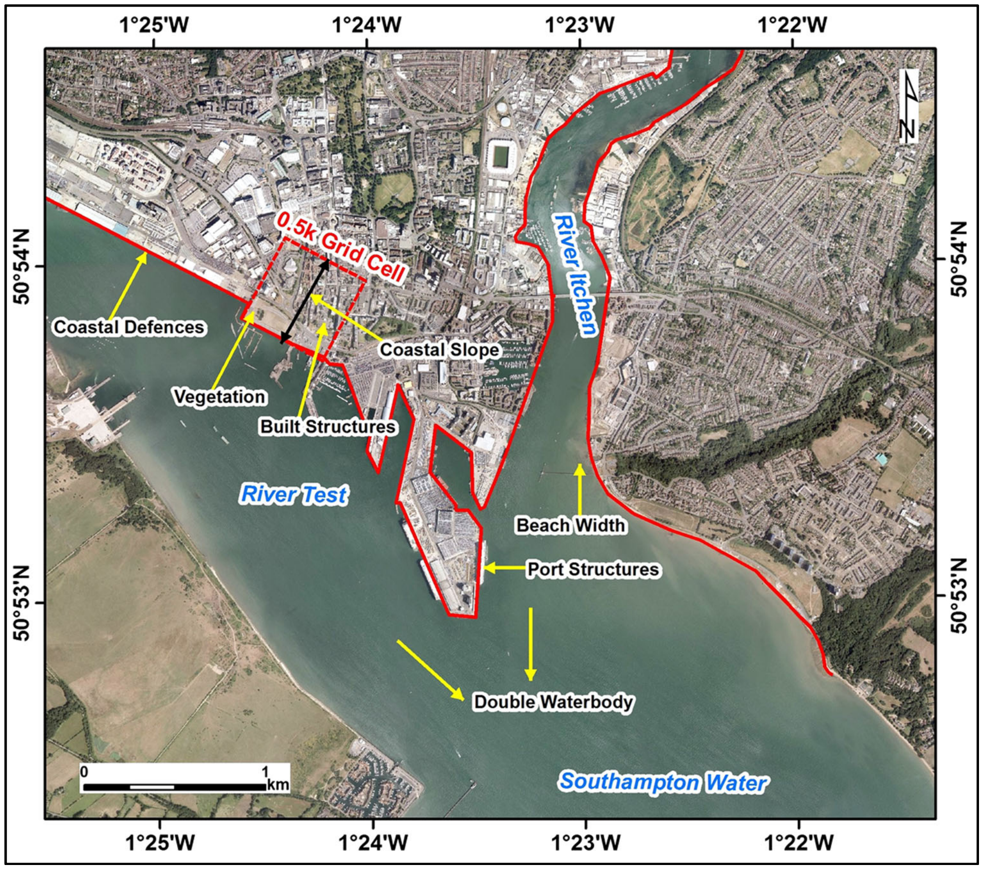


Fig. 2 Port and coastal infrastructure at Southampton

Table 1 Physical parameters

Designated Symbol	Physical Parameters
P_a	Beach width
P_b	Coastal slope
P_c	Distance of vegetation behind the back beach
P_d	Distance of built structures behind the back beach
P_e	Coastal defences
P_f	Additional weighting for an estuarine environment (Double River waterbody)
P_g	Additional weighting for port *(Additional weightage scores were added directly for CVI index score)*

Fig. 3 Transect line and 0.5- km coastal cell with all parameters marked



means therefore and apply this to these important economic and strategic coastal areas. As such, and on the basis of the latest climate scenarios, this study assessed the vulnerability of Southampton, through the development and application of a modified Physical Coastal Vulnerability Index (PCVI) so as to generate spatial coastal vulnerability maps using GIS.

Study area

Southampton is a maritime city and urban area with significant infrastructure and harbour activities, located on the south coast of the United Kingdom. As one of the UK's busiest ports, it is also known as the cruise capital of Europe. Positioned between 50°54.237′ N Latitude and 1°24.2568′ W Longitudes (Fig. 1), the city covers 51.81km^2 and has the population of 249,500 is anticipated to grow to 252,600 by 2035 (Southampton City Council 2015). The city lies at the northern tip of Southampton Water, which is a deep-water estuary, joining the Rivers Test, Itchen and Hamble to the Solent estuarine complex. The city centre is situated between the River Test, which runs along the western edge of the city and the River Itchen, which separates Southampton in two parts: east and west (PUSH 2016a, b). The city 's land area is >50 km^2 and 80% of the land is already developed. Southampton city has >35 km coastal frontage of which major % is low lying area (Southampton City Council 2015). The study area has high fiscal value with over four million people visiting the city every year and contributing significantly to the national and sub local economies. In addition, the port of Southampton contributes >£1.7 billion GDP every year to the national economy (Atkins 2011).

Physical geography

Other than relatively deep water access to the sea through Southampton Water and the Solent, one of the key drivers for Southampton's port development has been the advantageous 'double high tide' that effectively extends the period of high water in the tidal cycle, thereby increasing the length of time available for shipping and port operations. This along with the city's situation being in close proximity to both the UK's south coast market, as well as Northern Europe, has meant that the port has proved successful in attracting international trade and shipping. As a result of the Eastern and Western Dock developments, a significant coastal frontage is covered by maritime industries along with residential and commercial properties (Fig. 2). Of the waters that provide the coastline for Southampton, the River Test is heavily bounded by the existing port infrastructure and watershed developments (Townend 2007) with much of the land having been reclaimed as a result of works that began in the 1890s (Witherick 1981). The reclamation however has impacted on the

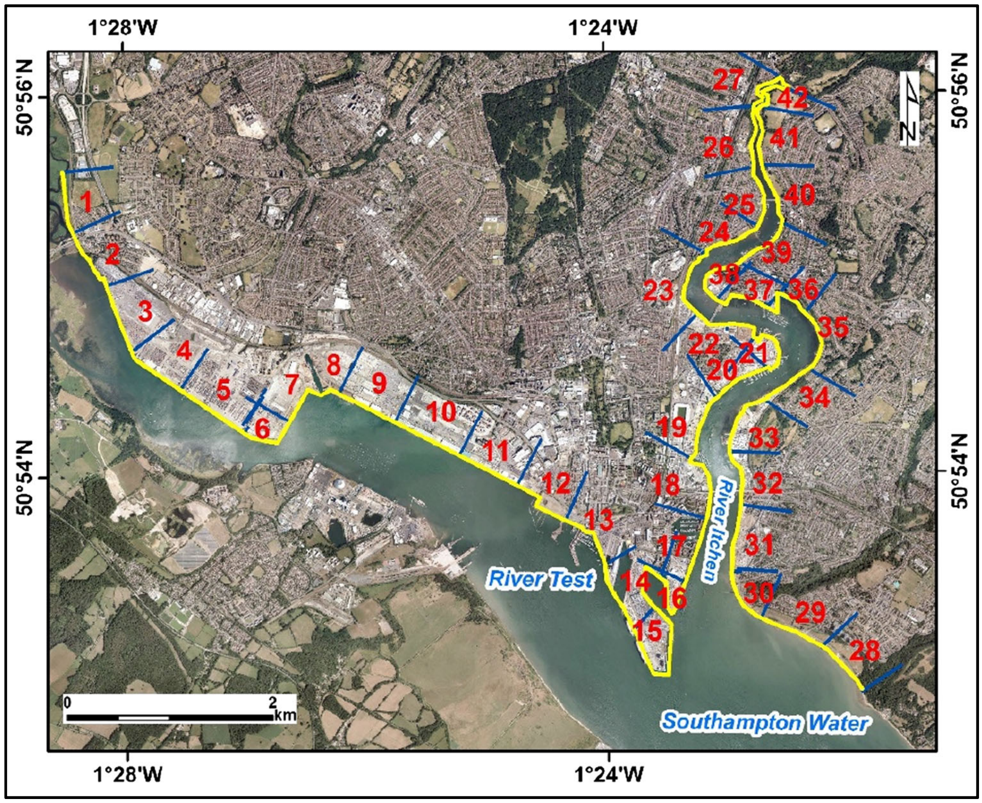


Fig. 4 Transect line and 0.5-km coastal cells

hydrodynamic and sediment movement within the estuary (Townend 2007; French 2008; Pye and Blott 2014) and accordingly influenced the estuarine morpho-dynamics (Quaresma et al. 2007; Rossington et al. 2011; Hopley 2014) with surface waves of the rivers Test and Itchen. These rivers' waves are significantly less than Southampton Water waves due to the consequence of further restrictions, continuous changes in river orientation and artificially constructed infrastructures such as bridges, quays and piers (ABPmer 2012). Rivers Test and Itchen, and their estuarine interactions along with infrastructure developments (Fig. 2) and cumulatively influence the tidal environment and then ultimately affect the flood risk within the Southampton City region (Neal and Davies 2003). With the highest wave fetch at all types of tidal conditions in River Itchen is >700, and however, it is lower than Southampton water. Currently, Southampton City region is vulnerable to tidal/coastal, river, surface water, sewer and groundwater flooding (ABPmer 2012). The probability and possible impact of each kind of flooding differ significantly and vary geographically. Coastal and surface water flooding poses the highest risk due to the consequence of tide locking when heavy rainfall events occur (Priest et al. 2011; Jha et al. 2012). Though human-made coastal defences cover less area, most of the Southampton coastline is protected to a large degree by the port and its physical structures.

Methodology and materials

The basic concept of Kantamaneni et al.'s (2018) coastal vulnerability index (CVI) has been adapted for the current study and modified by adding additional weighting scores for

Table 2 Physical parameter ratings associated with different levels of physical vulnerability

	Physical vulnerability value			
Physical Parameter	Extremely Low (1)	Low (2)	Moderate (3)	High (4)
Beach width (P_a)	> 150 m	100–150 m	50-100 m	< 50 m
Coastal slope (P_b)	> 12%	12–8%	8–4%	< 4%
Distance of vegetation behind the back beach (P_c)	> 600 m	200–600 m	100–200 m	< 100 m
Distance of built structures behind the back beach (P_d)	>600 m	200–600 m	100 m – 200 m	< 100 m
Coastal defences (P_e)	> 50%	20–50%	10% – 20%	< 10%

Table 3 Vulnerability level ratings grouped by total relative vulnerability score

Total relative vulnerability score	Vulnerability
>15	Very low
15–17	Low
18–20	Moderate
21–24	High
25–28	Very high

specific parameters relating to the estuarine environment and the physical structure of the port. This modification reflects the physical estuarine environment and port, which makes this specific study distinctive. In total five physical parameters were used to estimate physical coastal vulnerability, as shown in Table 1. In applying this methodology, transect lines were drawn a perpendicular to the coast at 0.5 km spacing (Fig. 3). The back beach was used as a proxy baseline, with measurements extending to a line drawn 0.5 km inland approximately parallel to the baseline and as far as mean low water in a seaward direction. Subsequently, detailed measurements based upon each parameter were recorded along each transect line using a 0.5 km cell, as shown in Figs. 3 and 4. The index values were then imported into ArcGIS to generate coastal vulnerability GIS maps.

Physical parameters measurement

Beach width was measured from the back beach (Fig. 3) coordinates to the mean low water level (MLW) mark, using the Ordnance Survey spatial dataset and the Getmapping Plc aerial maps. The coastal slope is an important physical parameter in coastal vulnerability assessment studies because, the degree of flatness of a coastal region determines the vulnerability of the coast to inundation. Lower slope areas are highly susceptible to erosion and higher slope regions (steep) are less susceptible (Sterr et al. 2000; Thieler 2000). For the current study, Google Earth Pro maps have been used to obtain coastal elevation (coastal slope) values (Fig. 3). A distance of 500 m was selected to measure the distance of vegetation behind the back beach for the current study (Fig. 3). In areas where the foliage did not spread beyond built structures, the vegetation was measured to that point. Built structures, such as paths, roads, and railways, were measured for their widths and deducted from the total vegetation if there were significant expanses of vegetation beyond these structures (Denner et al. 2015; Fig. 3). A distance of 500 m was also selected to measure the distance of built structures, such as paths, roads, railways, and private and commercial buildings, behind the back beach. In areas where the foliage was encountered, the vegetation was measured, and the total vegetation was deducted from the built structure expanse (Kantamaneni et al. 2018; Fig. 3). A large amount of Southampton frontage is covered by quay areas of the port, which offers protection from flooding, erosion and storm surges. As such, for the purpose of this study, port and harbour structures are considered to be coastal defences even though that is not their primary purpose. Coastal defences were measured based upon the percentage of shoreline coverage within each cell (Kantamaneni et al. 2018; Fig. 3). The three parameters (distance of vegetation, distance of built structures and coastal defences) were all measured using the Getmapping Plc aerial maps.

Technical description of methodology

Detailed measurements based upon each parameter were recorded along each transect. Additional weightings to account for the estuarine environment (double river water body) and port were also offered. With rankings applied, these values were then summed for each location to provide a relative CVI score using comparative PCVI formula as follows;

$$PCVI = P_a + P_b + P_c + P_d + P_e + P_f \quad + P_g \tag{1}$$

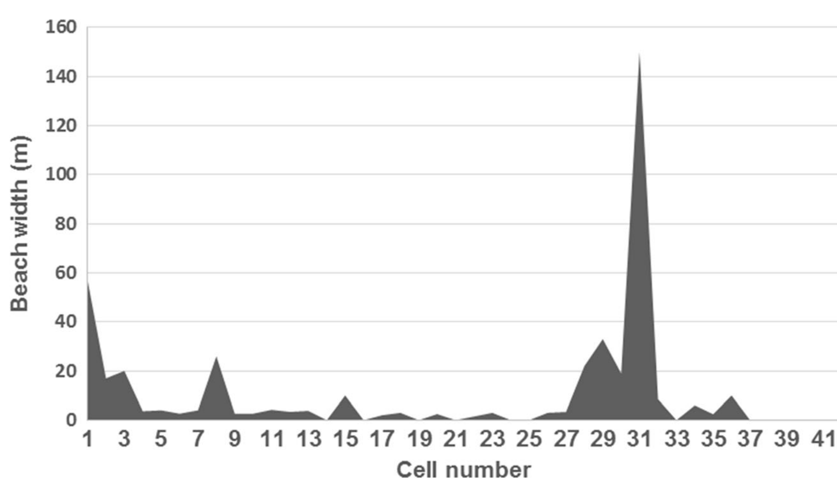


Fig. 5 Graphical representation of beach width (m)

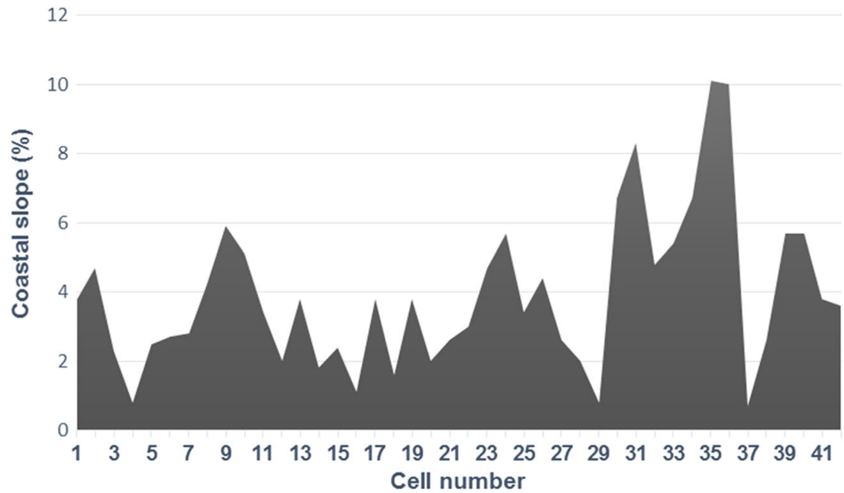


Fig. 6 Graphical representation of coastal slope (%)

Table 2 details physical thresholds for each parameter assigned a ranking score between 1 and 4. Accordingly, each cell was assigned a CVI value for all physical parameters (Table 1) that varied from 1 (extremely low) to 4 (high). Simple summation of individual rankings provided a total relative vulnerability score i.e. relative $PCVI = P_a + P_b + P_c + P_d + P_e + P_f + P_g$ where P_a = beach width vulnerability score, P_b = coastal slope vulnerability score, P_c = distance of vegetation vulnerability score, P_d = distance of built structures vulnerability score, P_e = coastal defences vulnerability score P_f = additional weighting for estuarine environment, P_g = additional weighting for port environment.

Data gathered for each cell were rated for levels of vulnerability. The total relative vulnerability score varied from 5 (minimum) to 28 (maximum – after adding additional weighting scores). These scores were compared with Table 3 in order to categorise the total relative level of physical vulnerability for each cell. The total relative vulnerability scores were then ranked from very low to very high vulnerability as shown in Table 3.

Results

Coastal cell measurements were taken by the procedures described in the methodology section by subdividing each coastline frontage into 0.5 km cells. In total, 42 cells along 21 km of coastline were identified (Fig. 4). By using mathematical formula (eq. 1), five physical parameters for each cell were assessed. Descriptive results with appropriate graphs are discussed in the following sections.

Physical parameters analysis

There are moderate variations between the 42 cells in respect to the associated index values. The average beach width was 12 m, which lay between the maximum value of 150 m recorded for cell 31 and the minimum value of 0.01 m recorded for cells 33 and 37 (Fig. 5). Due to the land reclamation for port construction, no much difference was found in between the values of MLW and MHW levels. The average coastal slope was 3.5%, which lay between the maximum value of 10% recorded for

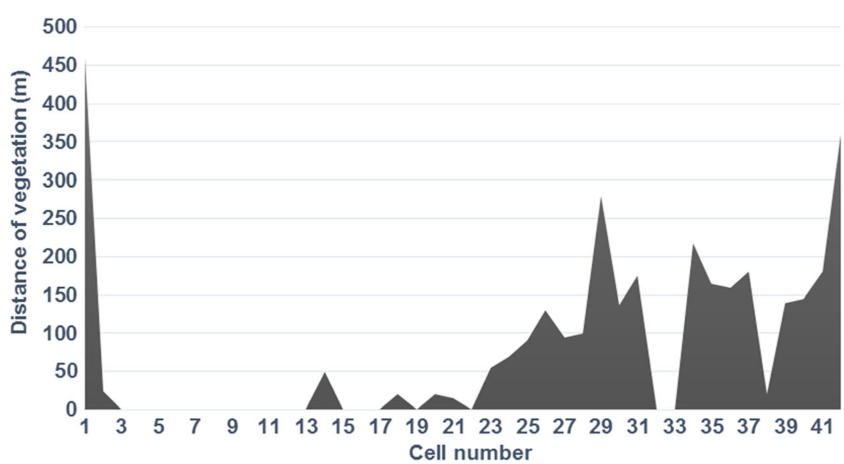


Fig. 7 Graphical representation of distance of vegetation behind the back beach (m)

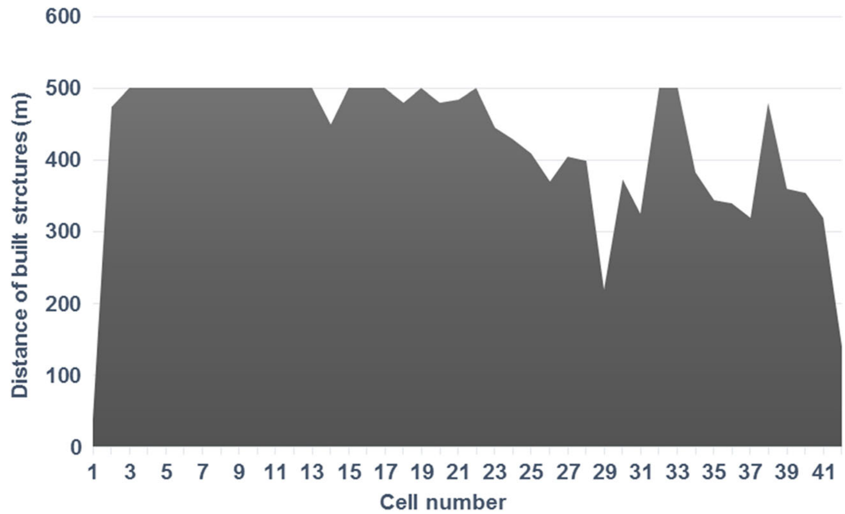


Fig. 8 Graphical representation of built structures behind the back beach (m)

cells 35 and 36, and the minimum value of 0.7% recorded for cell 37 (Fig. 6).

The average distance of vegetation behind the back beach was 137 m, which lay between the maximum value of 459 m recorded for cell 1, and the minimum value of 15 m recorded for cell 21 (Fig. 7). Due to the rapid urbanisation and land reclamation, the Southampton coastal frontage is heavily commercialised and populated (Hampshire City Council 2014). Accordingly, most of the land within one km from the coast is composed of transportation links, port infrastructure, and commercial and residential properties (Southampton City Council 2016). The average distance of built structures behind the back beach was 454 m, which lay between the maximum value of 500 m recorded for cells 17 and the minimum value of 41 m in cell 1, and majority % of the cells contained built structures (Fig. 8). The average recorded coastal defence coverage was 83%, which lay between the maximum value of 100% that represents coverage of 20 cells and the minimum value of 24% recorded for cell 2. Importantly, coastal defence structures were absent from 63% of the cells (Fig. 9).

PCVI and analysis of total relative vulnerability scores

Overall, 42 cells were critically analysed by applying PCVI. After the analysis of five parameters, additional weightage scores were also added to those values. As shown in Figs. 10 and 11, considerable variations exist between the 42 cells with respect to their index values. The average value was 20.8, which corresponds to the moderate category. However, the maximum PCVI value (25) was obtained for cell 23, while the lowest (16) was obtained for cell 22. More than 55% (n = 24) of cells were rated as having the moderate vulnerability, and 38% (n = 16) of the cells were rated as high vulnerable. The overall CVI scores clearly indicated that 38% of Southampton coastline has high physical coastal vulnerability using current climate scenarios. It also noted that a considerable number of high valued infrastructure such as port, roads, and properties, are located along highly vulnerable coastal segments.

In addition, results suggested that cells without port structures were more vulnerable than cells which have

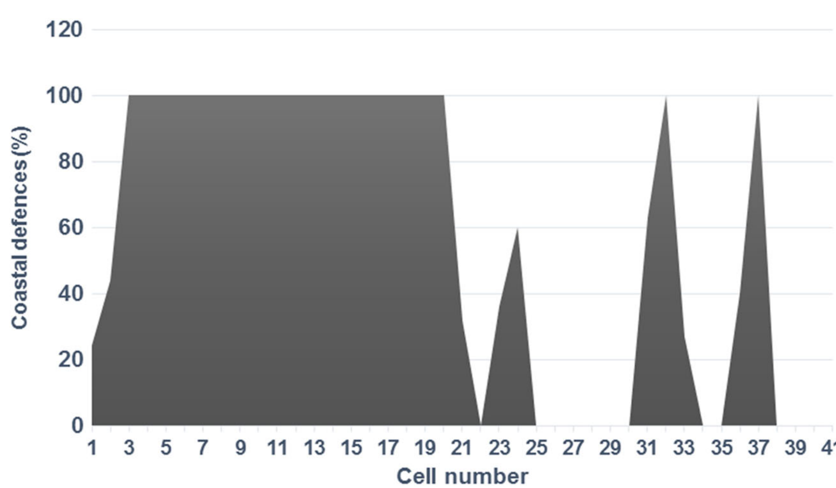


Fig. 9 Graphical representation of coastal defences (%)

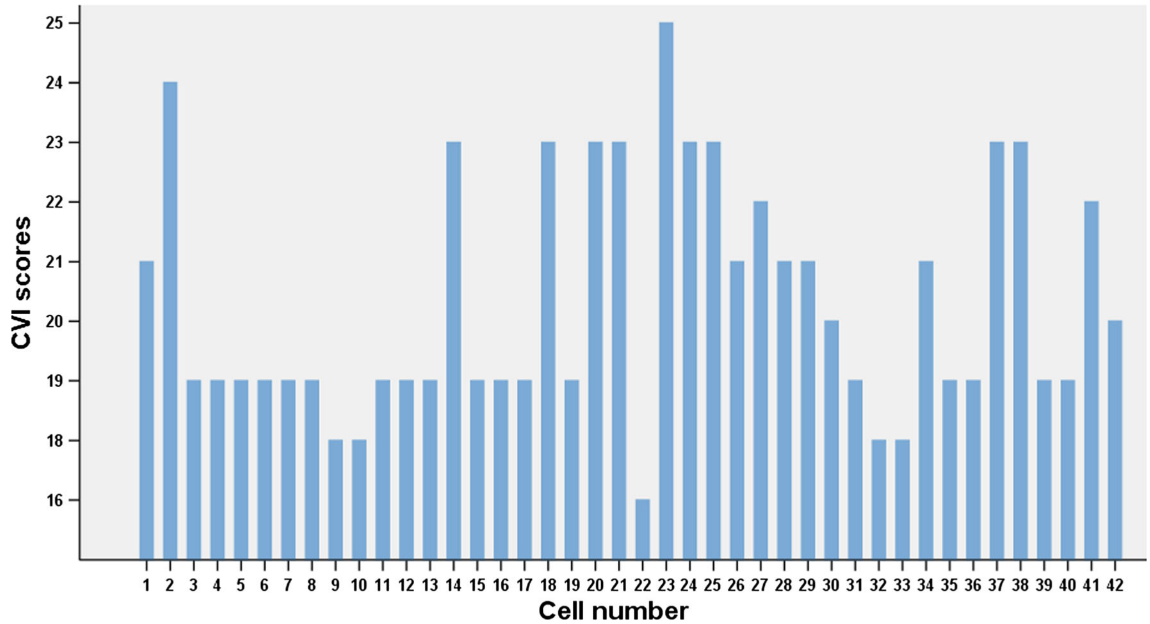


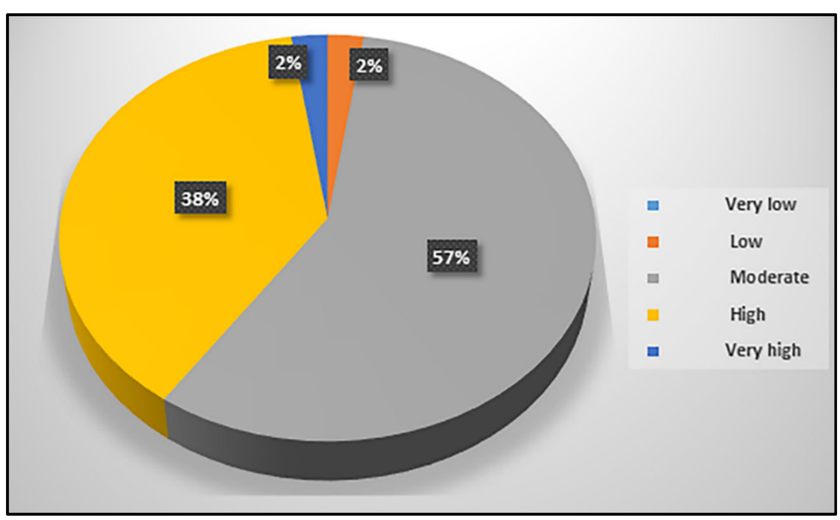
Fig. 10 Graphical representation of cumulative CVI scores

port structures, whilst 20% of cells showed only minor variations between MLW and MHW levels. For this reason, most of the measurements fell between high and moderate categories, with very few cells classified as being either very high or very low in terms of relative vulnerability (Fig. 12).

Discussion

The world's coastlines are under increasing physical, environmental, and socio-economic pressures that are often at the forefront of discussions and of great concern to all stakeholders. Therefore, a better understanding of the magnitude of change and physical consequences is vital. An assessment of physical vulnerability allows coastal areas to be evaluated according to a range of physical parameters though the selection of these physical parameters can be complex. In order to ensure a comprehensive assessment of Southampton coastline, a modified PCVI was developed by adapting the methodology of Kantamaneni et al. (2018) by adding two additional weighting scores. The width of a beach impacts the physical coastal vulnerability of the coastline, with wider beaches being less susceptible and narrow beaches more vulnerable to the diversity of coastal hazards (Gopalakrishnan et al. 2011). Previous studies such as Denner et al.'s (2015) study in the Llanelli area of Wales,

Fig. 11 Relative coastal vulnerability and its distribution



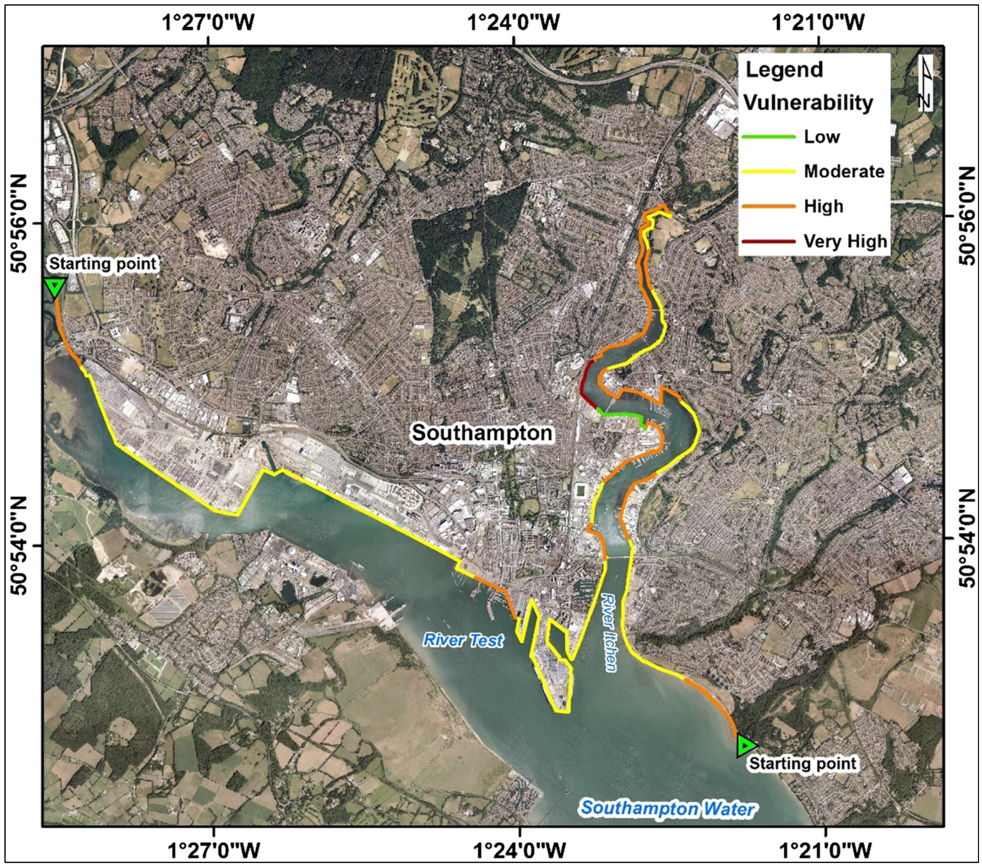


Fig. 12 Southampton coastal vulnerability map

showed that the deep-water channels had a great impact upon flooding; and the beach width as an important parameter for evaluating vulnerability. For this study, beach width has clearly narrowed, due to the urbanisation of Southampton and the expansion of coastal infrastructure since the sixteenth century, as shown in Fig. 13.

The PCVI evaluation results revealed that 38% of the Southampton coastline is highly vulnerable and > 50% is moderately vulnerable. Coastal cells at the lower end of the coast have the highest vulnerability due to the lack or robust coastal defences. However, the majority of the coastal cells did not have vegetation, and these cells are more vulnerable than cells that have vegetation. The highest PCVI value was 25, and the lowest was 16 which suggests that a considerable number of cells subject to damage from storms and associated factors. The expansion of infrastructure has increased the vulnerability pressures and ultimately leads to even greater loss from flooding and storm damage (Wadey et al. 2012). Much of the properties (commercial and residential) are located within 0.7 km of the shoreline (Fig. 14), therefore, predicted upsurges in storm occurrences and associated flooding events that often result in shoreline damage in this region. Additionally, due to the low-lying area, Southampton is exposed to flood risk from both sea and rivers; while climate change induced hazards such as sea level rise (up to 1 m over the next 100 years in the Southampton Itchen area) and high tides will further increase the flood risk in this region (Smith et al. 2014; Pye and Blott 2014; Hampshire City Council 2014).

The present study details the first application of the physical coastal vulnerability index (PCVI) for the Southampton coast and has revealed variations in the intensity of coastal vulnerability for 42 coastal cells. This model is useful as it highlights coastal cells where several effects of diverse factors may be the highest. Besides, five physical parameters and additional weighting scores could be easily modified based on the availability of suitable data. Meanwhile, developed coastal vulnerability GIS maps illustrate the intensity of the susceptibility of various coastal cells by highlighting different colours along the Southampton coast, which can be used to identify the magnitudes of coastal vulnerability without having technical knowledge. The results of this research will improve understanding of physical consequences of changing environmental conditions, particularly in highly populated, low-lying and urban areas, and may be used to inform the effective planning of coastal management strategies in both physically and/or economically important regions.

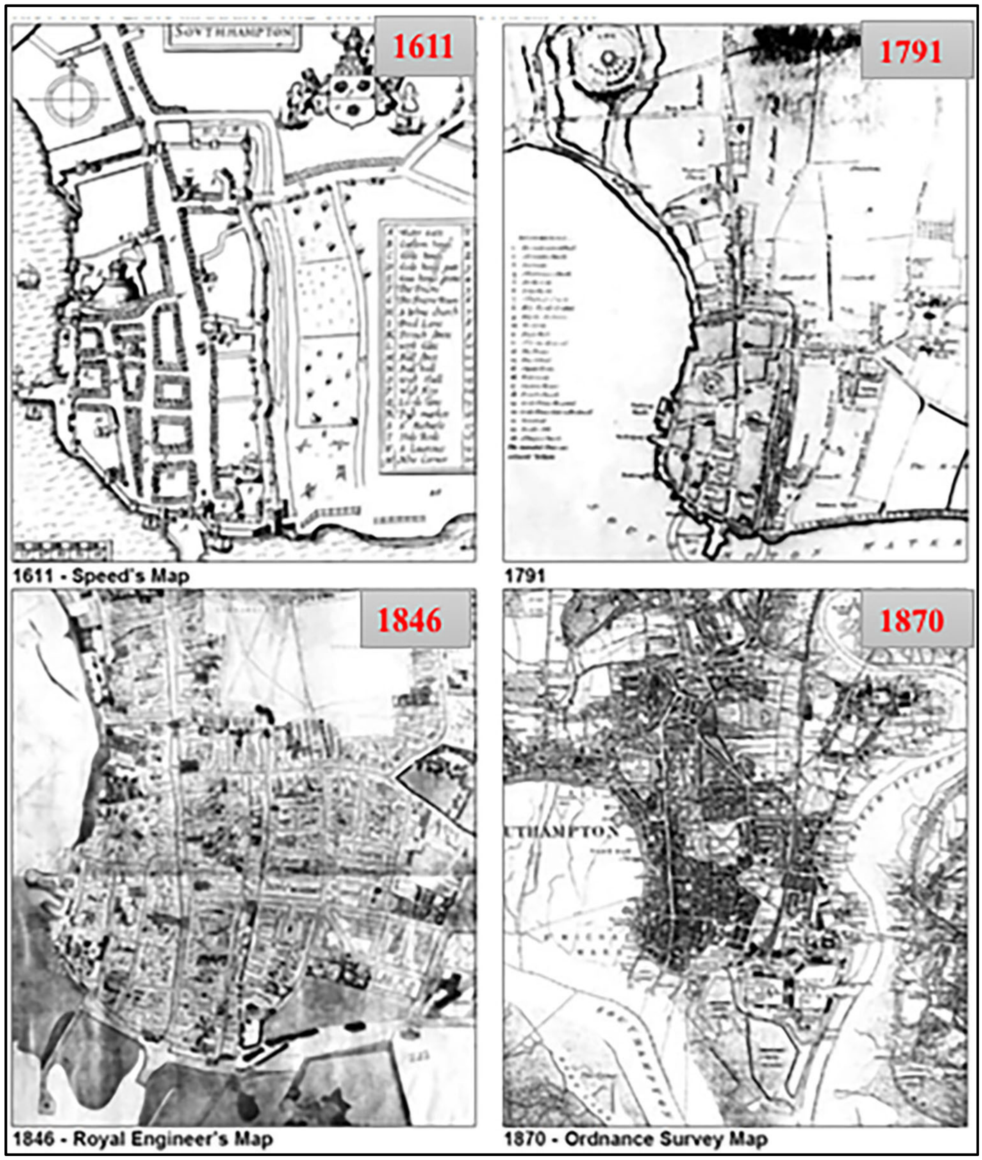


Fig. 13 Urbanisation trends in Southampton. Source: Southampton City Council 2016

Fig. 14 Coastal properties of Southampton

Conclusion

The systematic determination of coastal vulnerability represents an important step forward in developing effective planning measures to combat a predicted increase in coastal hazards associated with climate change. The modified PCVI model outlined in this paper represents an adaptation of previous work carried out by Kantamaneni et al. (2018) and incorporates additional weighting scores to help quantify specific coastal environments, such as port cities. The selection of physical parameters used to develop a PCVI was complex, due to the number of driving forces that operate within specific coastal environments. Overall results showed that the most critical physical parameters affecting vulnerability along Southampton coastline were the coastal slope and beach width; whilst 38% of coastline is highly vulnerable, with more than 50% being moderately vulnerable. The use of PCVI to ascertain the intensity of the vulnerability of spatial coastal cells can categorise vulnerability and, therefore, provide support for coastal decision makers with regard to shoreline planning and redevelopment. The methodological framework can be adapted for estuarine, urban, port or coastal environments without any geographical limits based on the availability of suitable data.

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Compliance with ethical standards

Conflict of interest This manuscript has not been previously published and is not under consideration in the same or substantially similar form in any other peer-reviewed media. To the best of my knowledge, no conflict of interest, financial or other, exists.

References

ABPmer (2012) Southampton City Council Coastal Flood and Erosion Risk Strategy, Proposal10793. Available at https://www.southampton.gov.uk/policies/southampton%20coastal%20strategy%20-%20appendix%201a%20-%20conceptual%20understanding_tcm63-365040.pdf Accessed on 10.10.2014
Abuodha PA, Woodroffe CD (2010) Assessing vulnerability to sea-level rise using a coastal sensitivity index: a case study from Southeast Australia. J Coast Conserv 14:189–205
Adger WN (2006) Vulnerability. Glob Environ Chang 16:268–281
ATKINS (2011) Economic impact of the port of the Southampton. Availiable at Economic_Impact_of_the_Port_of_Southampton_-_Final_Reportpdf Accessed on 12. 12.2016
Balica S, Wright NG, van der Meulen F (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Nat Hazards 64:73–105
Bollmann M, Bosch T, Colijn F, Ebinghaus R, Froese R, Guessow K, Khalilian S, Krastel S, Koertzinger A, Lagenbuch M, Latif M (2010) World ocean review 2010: living with the oceans
Brown J, Ciavola P, Masselink G, McCall R, Plater A (2016) Preface: monitoring and modelling to guide coastal adaptation to extreme storm events in a changing climate. Nat Hazards Earth Syst Sci 16:463–467
Denner K, Phillips M, Jenkins R, Thomas T (2015) A coastal vulnerability and environmental risk assessment of Loughor estuary, South Wales. Ocean Coast Manag 116:478–490
Fitton JM, Hansom JD, Rennie AF (2016) A national coastal erosion susceptibility model for Scotland. Ocean Coast Manag 132:80–89
Fitton JM, Hansom JD, Rennie AF (2018) A method for modelling coastal erosion risk: the example of Scotland. Nat Hazards 91:931–961
French J (2008) Hydrodynamic modelling of estuarine flood defence realignment as an adaptive management response to sea-level rise. J Coast Res 24:1–12
Gopalakrishnan S, Smith MD, Slott JM, Murray AB (2011) The value of disappearing beaches: a hedonic pricing model with endogenous beach width. J Environ Econ Manag 61:297–310. https://doi.org/10.1016/j.jeem.2010.09.003
Gornitz V (1991) Global coastal hazards from future sea level rise. Palaeogeogr Palaeoclimatol Palaeoecol 89:379–398
Gornitz V, Kanciruk P (1989) Assessment of global coastal hazards from sea level rise. Oak Ridge National Lab, TN (USA)
Gornitz VM, Daniels RC, White TW, Birdwell KR (1994) The development of a coastal risk assessment database: vulnerability to sea-level rise in the US southeast. J Coast Res:327–338
Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A global map of human impact on marine ecosystems. Science 319:948–952
Hampshire City Council (2014) Coastal Communities 2150 Adaptation Plan For the Community of Southampton Itchen Avaliable at http://solentforum.geodata.soton.ac.uk/current/CCATCH/Southampton_Itchen/SouthamptonAdaptationPlan.pdf
Higgins S, Overeem I, Tanaka A, Syvitski JP (2013) Land subsidence at aquaculture facilities in the Yellow River delta, China. Geophys Res Lett 40:3898–3902
Hinkel J, Nicholls RJ, Vafeidis AT, Tol RS, Avagianou T (2010) Assessing risk of and adaptation to sea-level rise in the European Union: an application of DIVA. Mitig Adapt Strateg Glob Chang 15:703–719
Hopley EC (2014) The impact of changing sediment budgets on an industrialised estuary: a case study of Southampton water. University of Southampton, UK
Islam MA, Mitra D, Dewan A, Akhter SH (2016) Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh–a geospatial approach. Ocean Coast Manag 127:1–15
Jha AK, Bloch R, Lamond J (2012) Cities and flooding: a guide to integrated urban flood risk management for the 21st century. World Bank Publications
Kantamaneni K (2016a) Coastal infrastructure vulnerability: an integrated assessment model. Nat Hazards 84:139–154
Kantamaneni K (2016b) Counting the cost of coastal vulnerability. Ocean Coast Manag 132:155–169
Kantamaneni K, Du X, Aher S, Singh RM (2017) Building blocks: a quantitative approach for evaluating coastal vulnerability. Water 9:905
Kantamaneni K, Phillips M, Thomas T, Jenkins R (2018) Assessing coastal vulnerability: development of a combined physical and economic index. Ocean Coast Manag 158:164–175. https://doi.org/10.1016/j.ocecoaman.2018.03.039
Kron W (2013) Coasts: the high-risk areas of the world. Nat Hazards 66:1363–1382
Macintosh A (2013) Coastal climate hazards and urban planning: how planning responses can lead to maladaptation. Mitig Adapt Strateg Glob Chang 18:1035–1055
McGranahan G, Balk D, Anderson B (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environ Urban 19:17–37
McLaughlin S, Cooper JAG (2010) A multi-scale coastal vulnerability index: a tool for coastal managers? Environmental Hazards 9:233–248
McLaughlin S, McKenna J, Cooper J (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497
Neal C, Davies H (2003) Water quality fluxes for eastern UK rivers entering the North Sea: a summary of information from the Land Ocean interaction study (LOIS). Sci Total Environ 314:821–882
Newton A, Weichselgartner J (2014) Hotspots of coastal vulnerability: a DPSIR analysis to find societal pathways and responses. Estuar Coast Shelf Sci 140:123–133
Newton A, Carruthers TJ, Icely J (2012) The coastal syndromes and hotspots on the coast. Estuar Coast Shelf Sci 96:39–47

Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Science 328:1517–1520

Nicholls RJ et al (2007) Coastal systems and low-lying areas. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 315–356

Palmer B et al. (2011) Preliminary coastal vulnerability assessment for KwaZulu-Natal, South Africa J Coast Res :1390

Pethick JS, Crooks S (2000) Development of a coastal vulnerability index: a geomorphological perspective. Environ Conserv 27:359–367

Pramanik M, Biswas S, Mukherjee T, Roy A, Pal R (2015) Sea level rise and coastal vulnerability along the eastern coast of India through geo-spatial technologies. J Geophys Remote Sensing 4:2

Priest SJ, Parker DJ, Hurford A, Walker J, Evans K (2011) Assessing options for the development of surface water flood warning in England and Wales. J Environ Manag 92:3038–3048

PUSH (2016a) Partnership for urban south hampshire -strategic flood risk assessment – 2016 Update Available at: https://maps.hants.gov.uk/push/Reports/PUSH_SFRA_SCC_Guidance_for_Upload.pdf 2016 Accessed on 30.11.2016

PUSH (2016b) Partnership for urban south hampshire: strategic flood risk assessment, final report. December, 2007, Atkins, 109pp.2007. Partnership for urban south hampshire: strategic flood risk assessment, final

Pye K, Blott SJ (2014) The geomorphology of UK estuaries: the role of geological controls, antecedent conditions and human activities. Estuar Coast Shelf Sci 150:196–214

Quaresma VS, Bastos AC, Amos CL (2007) Sedimentary processes over an intertidal flat: a field investigation at Hythe flats, Southampton water (UK). Mar Geol 241:117–136

Rani NS, Satyanarayana A, Bhaskaran PK (2015) Coastal vulnerability assessment studies over India: a review. Nat Hazards 77:405–428

Rossington S, Nicholls R, Stive M, Wang Z (2011) Estuary schematisation in behaviour-oriented modelling. Mar Geol 281:27–34

Smith A, Martin D, Cockings S (2014) Spatio-temporal population modelling for enhanced assessment of urban exposure to flood risk. Applied Spatial Analysis and Policy :1–19

Southampton City Council. Southampton statistics (2015). Avaliable at https://www.southampton.gov.uk/council-democracy/council-data/statistics Accessed on 10.10.2016

Southampton City Council. Southampton current urban form (2016). Avaliable at https://www.southampton.gov.uk/policies/4%20The%20Current%20Urban%20Form.pdf Accessed on 20.04.2017

Spalding MD, Ruffo S, Lacambra C, Meliane I, Hale LZ, Shepard CC, Beck MW (2014) The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. Ocean Coast Manag 90:50–57

Sperotto A, Torresan S, Gallina V, Coppola E, Critto A, Marcomini A (2016) A multi-disciplinary approach to evaluate pluvial floods risk under changing climate: the case study of the municipality of Venice (Italy). Sci Total Environ 562:1031–1043

Sterr H, Klein R, Reese S (2000) Climate change and coastal zones: an overview of the state of the art on regional and local vulnerability assessment. Citeseer

Tavares AO, dos Santos PP, Freire P, Fortunato AB, Rilo A, Sá L (2015) Flooding hazard in the Tagus estuarine area: the challenge of scale in vulnerability assessments. Environ Sci Pol 51:238–255

Thieler ER (2000) National assessment of coastal vulnerability to future sea-level rise. No. 076-00. In: US geological survey

Townend I (2007) A conceptual model of Southampton Water Prepared for the Estuary Guide as a case study support document by I Townend, online available at: http://www.estuary-guide.net/pdfs/southampton_water_case_study.pdf

Wadey MP, Nicholls RJ, Hutton C (2012) Coastal flooding in the Solent: an integrated analysis of defences and inundation. Water 4:430–459

Witherick M (1981) Port developments, port-city linkages and prospects for maritime industry: a case study of Southampton Cityport industrialization and regional development. Pergamon Press, Oxford, pp 113–132

Wolters ML, Kuenzer C (2015) Vulnerability assessments of coastal river deltas-categorization and review. J Coast Conserv 19:345–368

Zsamboky M, Fernández-Bilbao A, Smith D, Knight J, Allan J (2011) Impacts of climate change on disadvantaged UK coastal communities. Joseph Rowntree Foundation, York