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Risk Assessment of Storms in Coastal Zones: Case Studies from Cartagena (Colombia) and Cadiz (Spain)

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Nelson Rangel-Buitrago
Faculty of Basics Sciences, Physics Program
University of Atlántico
Barranquilla
Colombia

Giorgio Anfuso
Department of Earth Sciences
University of Cádiz
Cádiz
Spain

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Dedicated to the memory of
José Ángel Martínez del Pozo (Cuenca)
An exceptional scientist, a great friend

Preface

A scientific consensus exists regarding the significant impacts of global climate change processes over coastal zones. These include sea level rise, variability in the patterns of rainfall and runoff and changes in frequency, intensity and duration of storms. The study of the relationships existing between littoral transformation and climate change—with associated hazards, vulnerabilities and risks—represents the first step in the design of coastal zones adaptation plans. Procedures used for the determination of hazards, vulnerabilities and risks can be classified according to different aspects but the establishment of a concise classification presents a difficult task where limits between classes are not strict. In this sense, a detailed methodology for evaluation and characterization of hazard, vulnerability and risk associated with storms, was developed, tested and applied in different coastal sectors of Colombia and Spain. This methodology takes into account physical, social, economic, ecological and heritage aspects. The analysis was made by a semi-quantitative approximation method, applying variables associated with intrinsic coastal zone properties and storm-related hazards. The variables were combined into different indexes, which were merged into a single normalized index that allows determination of coastal hazards, vulnerability and risk to storms. Results obtained in both coastal systems reveal that there are several vulnerable areas affected by extremely high erosion rates. Hazard, vulnerability and risk maps generated with this methodology can be used as a guideline contributing to the determination of causes, processes and consequences derived from storm-associated processes. Moreover, as several stakeholders are involved, efficient management of the coastal system is imperative and careful interventions are urgently needed to avoid irreversible negative impacts on both coastal systems. The information derived by the use of the proposed methodology in this work may have direct applications in future coastal development plans and, at the same time, can assist decision-makers in the implementation of preventive management strategies for most sensitive areas.

Nelson Rangel-Buitrago
Giorgio Anfuso

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Contents

Chapter 1
Introduction

Recent studies, i.e. Crowell et al. (2007) and World Resources Institute (2010), indicated that 20 % (1,409 million) of the world population lives within 25 km of the coastline and 40 % (2,818 million) within less than 100 km—a coastal strip representing only 20 % of the global land surface. This area hosts 100 % of the population of Denmark, 99 % of the UK, 88 % of Sweden, 79 % of Italy and 45 % of Spain. Such a concentration of population and activities in coastal zones leads to an increase in vulnerability to coastal hazards (Adger et al. 2005).

Additionally, coastal occupation has been greatly increasing in the past few decades especially due to coastal tourism-related activities (Klein et al. 2004; Jones and Phillips 2011). Tourism is now one of the world largest industries (Houston 1995, 2008) and the coverage of built-up areas in the first kilometer coastal strip along several European regions of the Mediterranean Sea exceeds 45 % (EEA 2006). As a result, along the world's coastlines, human activities and infrastructures have been exposed to the impact of constant erosion processes, as well as time located events, such as, great storms and hurricanes that have caused important economic losses and scores of deaths (Bacon and Carter 1991; Komar and Allan 2008). Furthermore, any environmental impact may be significant in future years due to ongoing coastal development (Brown and McLachlan 2002) and predicted climatic change processes (IPCC 2007; Anfuso and Nachite 2011; Jones and Phillips 2011).

In order to reduce the impacts of climate change, it is important to provide realistic analyses of the expected processes (IPCC 2014). Recent research on climate change effects on coastal zone has been almost completely dedicated to the impacts of sea level rise associated with the global warming (Komar and Allan 2008; Phillips and Crisp 2010). Important issues that must also be taken into account are the knowledge and trend of wave climate, and occurrence and distribution of extreme waves and storms (Keim et al. 2004) which have been increased in the last decades (Komar and Allan 2008; Soomere 2008). In a scenario of rising sea levels and increasing wave heights, the coastline will suffer huge impacts in terms of erosion and flooding especially with respect to low-lying regions that may partly or entirely disappear (Hanson and Larson 2008).

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Over 70 % of the shorelines around the world are retreating (Maio et al. 2012), and on the eastern barrier beach U.S. coast, nearly 86 % have experienced erosion during the past century. Coastal areas of megacities, such as New York and Boston are highly vulnerable to coastal flooding and extreme erosional events (Clark et al. 1998; Kirshen et al. 2007). These include destruction, damage to human structures, deterioration or the complete disappearance of ecosystems (Kirshen et al. 2007) and the submergence and destruction of sensitive archeological sites and associated cultural resources (Shaw et al. 1998). As example, in Bangladesh, a typhoon in 1970 gave rise to more than 9 m storm surge producing 220,000 fatalities and huge damages; a cyclone struck Myanmar along the Andaman Sea in 2008 killing 130,000 peoples. Recently, in 2012, hurricane Sandy caused 80 fatalities in the Caribbean and affected 1.8 million peoples in Haiti.

Deadly disasters do not exclusively affect undeveloped countries (Li and Li 2011). The "Halloween Nor'easter" of 1991 inflicted over US$1.5 billion in damages in Massachusetts (Cooper et al. 2005) and Hurricane Katrina caused 1,833 fatalities and more than $100 billion of economic losses from combined coastal and river flooding. Europe is not exempt from this kind of situations; as an example, in 1953, a North Sea storm caused more than 1,800 fatalities in The Netherlands and Cyclone Klaus in 2009 reached winds of 150 km/h and caused 31 victims in the Northern Spain and Southern France. In UK, the storms/floods occurred in the 2007 and the December 2013/January 2014 period, respectively caused $4.5 and 1.5 billion damages; although Penning-Rowsell (2014) has argued that the economic risk has overestimated the actual costs by four to five times.

Risk assessments provide information on the pressure to which the coastal zone is exposed as well as its adaptive capacity (Small and Nicholls 2003). In these kinds of assessments, it is important to examine interacting physical attributes and socioeconomic, conservational and archeological–cultural characteristics. Within this context, the considerable amount of information that must be integrated and processed requires an organized working methodology in order to show spatial relationships between the hazard phenomenon and the elements at risk.

The evaluation of coastal risk is a key issue in the geosciences field and a huge literature exists detailing system responses to perturbation. Methodologies used to assess coastal risk can be classified according to different characteristics but establishment of a succinct classification results many times in a hard task where limits between classes are not strictly defined (Di Paola et al. 2011). This intrinsic littoral risk is determined using different information such as physical and ecological coastal features, human occupation, present and future shoreline trends, etc. (Gornitz 1991; Gornitz et al. 1997; Cooper and McLaughlin 1998; Anfuso and Martinez 2009; McLaughlin et al. 2002; McLaughlin and Cooper 2010). First studies have employed single approach methods (i.e. Bruun rule, Bruun 1962; UNEP Methodology, Carter et al. 1994) but have progressively evolved and been superseded by more recent techniques due to improved consideration of physical and non-physical factors, as well as the associated uncertainties, has given rise to more consistent methods (i.e. USGS-CVI, Gornitz et al. 1994; SURVAS, Nicholls and De la Vega-Leinert 2000; Benassai et al. 2009). Their associated risk maps have been obtained for several coastal sectors around the world (LOICZ 1995; Cooper and McLaughlin 1998; Kelly 2000). Specifically, recent works have been focused on the determination of coastal risk related to the specific impacts of storms and hurricanes (Burzel et al. 2010; Carrasco et al. 2012; Ceia et al. 2010; Di Paola et al. 2011; Li and Li 2011; Maio et al. 2012; Raji et al. 2013).

Taking into account the above observations, reliable assessment and mitigation tools to reduce coastal erosion and flooding are urgently required. The determination of coastal susceptibility or vulnerability is an important instrument for managers/planners for coastal preservation, protection and development, as vulnerability outcomes provide baseline information and a scientific basis for any envisaged coastal erosion management plan and mitigation measures dealing with sustainability aspects (Williams et al. 1998).

This booklet deals with a methodological approach to risk determination for sand and cliff coasts to storm impacts by the use of matrixes concerning physical parameters, socio-economic activities, ecological and historic resources. The approach is based on the selection and evaluation of three types of variables: (i) the forcing variables contributing to storm-induced erosion, (ii) dynamic variables that determine the resilience to erosion (Susceptibility) and (iii) the vulnerable targets grouped in three different contexts (socio-economic, ecological and heritage). These are combined into two separate indices, the Hazard Index (combining forcing and susceptibility) and the Vulnerability Index, which together constitute the Coastline Risk to Storms Index as a single numerical measure of the risk for a given area. The proposed methodology has been tested in two coastal areas located in the Caribbean Sea (Cartagena, Colombia) and the Atlantic Ocean (Cadiz, Spain). Both areas record an important flow of tourists associated with the “sun, sea and sand market” which also represents an economic recourse for the hinterland (Williams et al. 2001; Rangel 2013). Additionally, the methodology can be easily applied in different coastal areas around the world where basic information on the delineated parameters is available.

References

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309:1036–1039

Anfuso G, Martinez JA (2009) Assessment of coastal vulnerability through the use of GIS tools in South Sicily (Italy). Environ Manage 43:533–545

Anfuso G, Nachite D (2011) Climate change and the Mediterranean Southern Coasts. In: Jones A, Phillips MC (eds) Disappearing destinations: climate change and future challenges for coastal tourism. CAB International, Wallingford

Bacon S, Carter DJT (1991) Wave climate changes in the North Atlantic and the North Sea. Int J Climato 11:545–558

Benassai G, Chirico F, Corsini S (2009) Una metodologia per la definizione del rischio da inondazione costiera. Studi Costieri 16:51–72

Brown AC, McLachlan A (2002) Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. Environ Conserv 29:62–77

Bruun P (1962) Sea level rise as a cause of shore erosion. J Wat Har Div 88:117–130

Burzel A, Dassanayake D, Naulin M, Kortenhaus A, Oumeraci H, Wahl T, Mudersbach C, Jensen J, Gönnert G, Sossidi K, Ujeyl G, Pasche E (2010) Integrated flood risk analysis for extreme storm surges (XTREMRISK). COPRI, Shangai

Carrasco AR, Ferreira Ó, Matias A, Pacheco A, Freire P (2012) Short-term sediment transport at a backbarrier beach. J Coast Res 27(6):1076–1084

Carter TR, Parry ML, Nishioka S, Harasawa H (1994) Technical guidelines for assessing climate change impacts and adaptation. University College and Centre for Global Environmental Research, Tskuba

Ceia F, Patricio J, Marquez J, Alveirinho-Dias J (2010) Coastal vulnerability in barrier islands: the high risk areas of the Ria Formosa (Portugal) system. Ocean Coast Manage 53:478–486

Clark GE, Moser SC, Ratick SJ, Dow K, Meyer WB, Emani S, Jin W, Kasperson JX, Kasperson RE, Schwarz HE (1998) Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA., USA. Mitig Adapt Strat Gl 3(1):59–82

Cooper JAG, McLaughlin S (1998) Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. J Coast Res 14:512–524

Cooper C, Fletcher J, Fyall A, Gilbert D, Wanhill S (2005) Tourism: principles and practice. Pearson, Oxford

Crowell M, Scott E, Kevin C, McAfee S (2007) How many people live in coastal areas? J Coast Res 23(5):3–5

Di Paola G, Iglesias J, Rodriguez G, Benassai G, Aucelli P, Pappone G (2011) Estimating coastal vulnerability in a meso-tidal beach by means of quantitative and semi-quantitative methodologies. J Coast Res SI 61:303–308

EEA (2006) The changing face of Europe's coastal areas. In: Breton F, Meiner A (eds) EEA report no. 6. Office for official publications of the European Communities, Luxembourg

Gornitz V (1991) Global coastal hazards from future sea level rise. Palaeogeogr Palaeocl 89: 379–398

Gornitz VM, Daniels RC, White TW, Birdwell KR (1994) The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast J Coast Res 12: 327–338

Gornitz VM, Beaty TW, Daniels RC (1997) A coastal hazards data base for the U.S. West coast. Oak Ridge National Laboratory, Oak Ridge

Hanson H, Larson M (2008) Implications of extreme waves and water levels in the southern Baltic Sea. J Hydraul Res 46(2):292–302

Houston JR (1995) The economic value of beaches. US Army Corp of Engineering

Houston JR (2008) The economic value of beaches—2008 update. Shore and Beach 76(3):22–26

IPCC (2007) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change, IPCC, Geneva

Jones A, Phillips M (2011) Disappearing destinations. CABI, London

Keim BD, Muller RA, Stone GW (2004) Spatial and temporal variability of coastal storms in the North Atlantic Basin. Mar Geo 210:7–15

Kelly J (2000) Mapping coastal hazards along a rocky coast with eroding bluffs and beaches. In: Proceedings of the 3rd symposium on the Iberian Atlantic Margin Faro

Kirshen P, Watson C, Douglas E, Gontz A, Lee J, Tian Y (2007) Coastal flooding in the Northeastern United States due to climate change. Mitig Adapt Strat Gl 13:437–451

Klein YL, Osleeb JP, Viola MR (2004) Tourism-generated earnings in the coastal zone: a regional analysis. J Coastal Res 20:1080–1088

Komar PD, Allan JC (2008) Increasing hurricane-generated wave heights along the U.S. East Coast and their climate controls. J Coastal Res 24 (2): 479–488

Li K, Li GS (2011) Vulnerability assessment of storm surges in the coastal area of Guangdong Province. Nat Hazards Earth Syst Sci 11:2003–2011

LOICZ (1995) Coastal zone resources assessment guidelines. LOICZ, Manila

Maio CV, Gontz AM, Tenenbaum DE, Berkland EP (2012) Coastal hazard vulnerability assessment of sensitive historical sites on Rainsford Island, Boston Harbor, Massachusetts. J Coast Res 28(1A):20–33

McLaughlin S, Cooper JAG (2010) A multi-scale coastal vulnerability index: a tool for coastal managers? Environ Haz 9(3):233–248

McLaughlin S, McKenna J, Cooper JAG (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497

Nicholls RJ, De la Vega-Leinert A (2000) Synthesis of sea-level rise impacts and adaptation costs for Europe. In: De la Vega-Leinert A, Nicholls RJ, Tol RSJ (eds) European vulnerability and adaptation to the impacts of accelerated sea level rise. Flood Hazard Research Centre, Enfield

Penning-Rowsell E (2014) A realistic assessment of fluvial and coastal flood risk in England and Wales. Trans Inst Br Geogr 40(1):44–61

Phillips M, Crisp S (2010) Sea level trends and NAO influences: The Bristol Chanel/Seven Estuary. Glob Planet Change 73:211–218

Raji O, Niazi S, Snoussi M, Dezileau L, Khouakhi A (2013) Vulnerability assessment of a lagoon to sea level rise and storm events: Nador lagoon (NE Morocco). J Coast Res 65:802–807

Rangel N (2013) Efectos de temporales maritimos en sistemas litorales de la provincial de Cádiz. Ph.D. thesis, Cadiz University, Cadiz

Shaw J, Taylor RB, Forbes DL, Ruz MH, Solomon S (1998) Sensitivity of the coasts of Canada to sea-level rise. Bull Geol Surv Can 505:1–79

Small C, Nicholls RJ (2003) A global analysis of human settlement in coastal zones. J Coast Res 19:584–599

Soomere T (2008) Extremes and decadal variations of the northern Baltic seawave conditions. In: Pelinovsky E, Kharif C (eds) Extreme ocean waves. Springer, Berlin

Williams AT, Alveirinho-Dias J, Garcia Novo F, Garcia-Mora MR, Curr RH, Pereira A (2001) Integrated coastal dune management: checklists. Cont Shelf Res 21:1937–1960

Williams AT, Davies P, Ergin A, Balas C (1998) Coastal recession and the reliability of planned responses: Colhuw beach, The Glamorgan heritage coast, Wales, UK. J Coast Res 26:72–79

World Resources Institute (2010) Decision making in a changing climate. United Nations Development Programme World Bank and World Resources Institute, Washington

Chapter 2
Review of the Existing Risk Assessment Methods

Abstract This chapter deals with examination of existing risk assessment methods related to this topic carried out on a global basis; evidently, such a list is not exhaustive.

In past decades, the increase of human occupation and interests along coastal areas (Crowell et al. 2010) as well as in the knowledge of coastal processes and associated hazards (Komar 1998; Méndez-Lázaro et al. 2014), favored elaboration for several coastal sectors around the world, of vulnerability maps obtained through the use of Geographical Information Systems (GIS), computer-assisted multivariate analysis and numerical models (LOICZ 1995).

In Europe, and specifically Northern Ireland (UK), McLaughlin et al. (2002) developed a GIS based coastal vulnerability index at local, regional and national scales. In Germany, Burzel et al. (2010) elaborated integrated flood risk analysis for extreme storm surges for an estuarine area and an exposed island. De Pippo et al. (2008) and Anfuso and Martinez (2009) respectively analysed vulnerability of coastal sectors located in Campania and Sicily (Italy). Özyurt et al. (2008), Özyurt and Ergin (2009, 2010) and Ergin (2011) proposed an assessment method to determine the associated vulnerability to Sea level Rise for different coastal areas in Turkey.

With respect to Spain, Sánchez-Arcilla et al. (1998) evaluated the Ebro delta vulnerability over different time scales and Di Paola et al. (2011) investigated coastal vulnerability of the Canary Islands. Mendoza and Jiménez (2006, 2009) and Bosom and Jiménez (2011) analysed coastal vulnerability of the Catalonian coast to storm events. Malvárez and Domínguez (2000), Domínguez et al. (2005), Del Rio and Gracia (2009) and Santos et al. (2013) assessed vulnerability for different coastal sectors of Andalusia; meanwhile maps concerning the entire regional territory have been elaborated by Ojeda-Zújar et al. (2009). In Portugal, vulnerability maps have been elaborated by Coelho et al. (2009), Ceia et al. (2010) and Carrasco et al. (2012), among others.

In Morocco, Snoussi et al. (2008), Anfuso and Nachite (2011) and Raji et al. (2013) investigated coastal vulnerability to Sea Level Rise and storm events.

N. Rangel-Buitrago and G. Anfuso, *Risk Assessment of Storms in Coastal Zones: Case Studies from Cartagena (Colombia) and Cadiz (Spain)*,
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In China, Li and Li (2011) analysed the vulnerability assessment of storm surges in the coastal area of Guangdong Province.

In the USA, “Coastal Zone Hazard Maps” have been prepared for coastlines affected by hurricane Hugo (Bush et al. 1996) and the “National Flood Insurance Program” has been created by the government (Kelly 2000) under the supervision of the Federal Emergency Management Agency (Crowell et al. 2007a, b). Key engineering components of this program have been the Flood Insurance Studies, which were prepared in order to determine the elevation of the 1 % annual chance flood, which is a flood height that has a 1 % chance of being equaled or exceeded during any given year, sometimes referred as the “100 y flood” too. In this sense, several zones with different hazard levels have been determined along coastal USA zones using coastal storm surge analysis by using tsunami, hurricane, or coastal storm surge models such as the FEMA Standard Storm Surge Model (Surge), the Advanced Circulation Model (ADCIRC), or the Danish Hydraulic Institute Mike 21 hydrodynamic models and tide gauge analyses from long-term NOAA or United States Army Corps of Engineers tide gauge records (Crowell et al. 2010).

In Central and South America, Lizárraga et al. (2001) presented a vulnerability matrix combining beach width at Rosario (Mexico) with the probability of damage to landward structures and Szlafsztein and Sterr (2007) carried out a GIS—based vulnerability assessment of coastal natural hazards in the state of Pará, Brazil. Whereas Rangel and Anfuso (2009) and Rangel and Posada (2013) determined coastal vulnerability to erosion along several sectors of the Caribbean coast of Colombia.

Most of the above mentioned works were based on the use of indexes for combining different types of variables into a single measure: this is one of the most common methods of assessing coastal sensitivity, e.g. among others Cooper and McLaughlin (1998) and McLaughlin et al. (2002).

Few preliminary studies, Lizárraga et al. (2001), Domínguez et al. (2005), Anfuso and Martinez (2009) and Rangel and Anfuso (2009) used and combined among them a limited, easy to calculate number of parameters, essentially beach width, coastal erosion/accretion rates and land use typologies. Rates of coastal erosion/accretion, if available, constitute reliable data on the spatial distribution of erosive processes and associated hazard and can advantageously substitute numerous secondary parameters at some place difficult to calculate and/or overlapping among them (Williams et al. 2001).

In recent studies, the Coastal Vulnerability Index (CVI) and its adaptations are the most used techniques (Klein and Nicholls 1999). The CVI approach combines the coastal system susceptibility to change with its ability to adapt to changing environmental conditions and yields a relative measure of the system natural vulnerability to the effect of hazards as chronic and storm related coastal erosion processes, climate change associated processes, etc. The application of this methodology, under a GIS environment or multivariate analysis, is based on the modelling of a certain number of variables related to the specific hazard analysed and their interactions over the coastline. As a result, the main output is generally a set of colour-coded sensitive maps, thus allowing the most sensitive areas to be easily identified (Gornitz 1990; LOICZ 1995; Bush et al. 1996; Cooper and McLaughlin 1998; Kelly 2000; Ojeda-Zújar et al. 2009; Raji et al. 2013).

Several indexes have been used in different fields of study. They constituted a useful tool to simplify datasets categorizing them in order to establish relations that make their analysis easier (McLaughlin 2001). In the last two decades, development of coastal indexes has received much attention as they have been used for studying a range of process such coastal erosion (Forbes et al. 2003; Del Rio and Gracia 2009; Anfuso et al. 2010) or sea level rise (Gornitz and Kanciruk 1989; Gornitz et al. 1994; Thieler and Hammer-Klose 2000; Snoussi et al. 2008; Dwarakish et al. 2009; Özyurt and Ergin 2009).

Simple indexes assessed the physical vulnerability of the coast. Most of them have been derived from the initial work by Gornitz (1990), which proposed an index that was widely applied in the United States and adapted to be used in other parts of the world. In this sense, Gornitz (1990), in a study concerning the East coast vulnerability to SLR, considered seven variables, e.g. relief, rocky type, landform, vertical movements, shoreline displacement, tidal range and wave height. In a following study devoted to evaluate U.S.A. vulnerability to storms, hurricanes and SLR, Gornitz et al. (1993) introduced variables related to wave energy, tropical storms, hurricanes occurrence probability, etc.

In order to study characteristics and vulnerability of different coastal sectors of Italy, Dal Cin and Simeoni (1994) proposed the use of 15 variables including wave energy, longshore transport, evolution rates, width of the foreshore, sediment size, beach and nearshore slope, presence of defensive structures and ports, etc. To assess beach stability, Simeoni et al. (2000) proposed the application of the System theory based on the use of 14 physical parameters including cliff characteristics, presence of dunes, tidal range, etc. In a study carried out in Australia, Abuodha and Woodroffe (2006) considered 7 variables, e.g. dune height, barrier types, beach types, relative sea level change, erosion/accretion rates, mean tidal range and wave height. Özyurt and Ergin (2009) carried out a study on vulnerability of selected coastal areas of Turkey to SLR taking into account five main types of variables (coastal erosion, flooding due to storm surge, inundation and salt water intrusion to ground waters resources and to river/estuaries) which included a total amount of 22 sub-variables. Similar variables were also used by Özyurt and Ergin (2010).

Combined indexes were more complex and also examined aspects such as economic and social vulnerability (McLaughlin et al. 2002; Boruff et al. 2005; Szlafsztein and Sterr 2007). Gornitz et al. (1993) and Cooper and McLaughlin (1998) highlighted the importance of including demographic and other socioeconomic parameters in the classification procedure and as the omission of them limits the evaluation of vulnerable areas. According to McLaughlin et al. (2002), the absence of socioeconomic parameters in most of used indexes is due to the lack of suitable data and to the difficulties in ranking them on an interval or rational scale.

In their study, previous authors selected the socioeconomic parameters according to the availability of up-to-date data and to their useable format and relevance to coastal areas. Specifically, McLaughlin et al. (2002) considered the following socioeconomic variables: population, cultural heritage, roads, railways, land use and conservation status. Despite the economic value of some of them (e.g. roads, railways and land use) which are easy to calculate, in general, investigated variables are difficult to evaluate because they present great spatial and temporal distribution (e.g. population) or their intrinsic characteristics (e.g. cultural heritage and conservation status). According to McLaughlin et al. (2002), archaeological and historical monuments are also important in social and cultural terms and not only in economic terms; due to the difficulties in ranking them, previous authors decided to rank all sites with archaeological remains in the highest category. The incorporation of conservation issues raised very important difficulties too because the uncertainty in the criteria to follow and to the fact that such features are formed by natural wave forcing processes. In this sense, their maintenance cannot be carried out by protecting them by natural processes which have to continue to operate to keep them “alive”.

Szlafsztein and Sterr (2007) in a study regarding the coastal vulnerability linked to natural hazards in northern Brazil, introduced socioeconomic parameters as the total population and total population affected by floods, density of population, nonlocal population, poverty and municipal prosperity. Similar studies were carried out in China by Li and Li (2011) and took into account: Social economic index (e.g. population, roads, industrial and agricultural value and residential land), Land use index (farming, aquaculture and arable land), Eco-environmental index (beaches and wetlands, mangroves and rivers), Coastal construction index (coastal engineering, highways and buildings), Disaster-bearing capability index (seawalls, labour population and financial revenue).

Other studies took into account only land cover types or population density, e.g. De Pippo et al. (2008), Coelho et al. (2009), Del Rio and Gracia (2009) and Santos et al. (2013). De Pippo et al. (2008) investigated vulnerability in Northern Campania Region (Italy) taking into account the percentage of anthropogenic covered surface; Coelho et al. (2009) mapped coastal vulnerability to wave actions along a costal sector of Portugal by applying a methodology based on the use of 9 variables, one including socioeconomic activities, e.g. ground cover, which ranged from forest to industrial and Del Rio and Gracia (2009) and Santos et al. (2013) considered both land cover and population density in Cadiz area (SW Spain). Last, Burzel et al. (2010) classified damages into tangible and intangible ones depending on whether or not the losses can be directly assessed in monetary values. Tangible losses comprise damages of buildings and infrastructure, agricultural and industrial losses, as well as costs associated with evacuation, rescue operations and reconstruction. Intangible losses may be categorized into two groups: social and environmental losses and include loss of life and health impacts, cultural losses and damages to the environment.

References

Abuodha P, Woodroffe CD (2006) Assessing vulnerability of coasts to climate change: a review of approaches and their application to the Australian coast. In: Woodroffe CD, Bruce E, Puotinen M, Furness RA (eds) GIS for the Coastal Zone: a selection of papers from CoastGIS 2006. Australian National Centre for Ocean Resources and Security University of Wollongong, Wollongong

Anfuso G, Martinez JA (2009) Assessment of coastal vulnerability through the use of GIS tools in South Sicily (Italy). Environ Manage 43:533–545

Anfuso G, Nachite D (2011) Climate change and the Mediterranean Southern Coasts. In: Jones A, Phillips MC (eds) Disappearing destinations: climate change and future challenges for coastal tourism. CAB International, Wallingford

Anfuso G, Martinez JA, Nachite D (2010) Coastal vulnerability in the Mediterranean sector between Fnideq and M′diq (north of Morroco). Compt rend Acad bulg Sci 63(4):561–570

Boruff BJ, Emrich C, Cutter SL (2005) Erosion hazard vulnerability of US coastal counties. J Coast Res 21:932–942

Bosom E, Jiménez JA (2011) Probabilistic coastal vulnerability assessment to storms at regional scale—application to Catalan beaches (NW Mediterranean). Nat Hazard Earth Sys 11:475–484

Burzel A, Dassanayake D, Naulin M, Kortenhaus A, Oumeraci H, Wahl T, Mudersbach C, Jensen J, Gönnert G, Sossidi K, Ujeyl G, Pasche E (2010) Integrated flood risk analysis for extreme storm surges (XTREMRISK). COPRI, Shangai

Bush DM, Pilkey OH, Neal WJ (1996) Living by the rules of the sea. Duke University Press, Durham

Carrasco AR, Ferreira Ó, Matias A, Pacheco A, Freire P (2012) Short-term sediment transport at a backbarrier beach. J Coast Res 27(6):1076–1084

Ceia F, Patricio J, Marquez J, Alveirinho-Dias J (2010) Coastal vulnerability in barrier islands: The high risk areas of the Ria Formosa (Portugal) system. Ocean Coast Manage 53:478–486

Coelho CR, Silva F, Veloso-Gomes F, Taveira-Pinto F (2009) A vulnerability analysis approach for the Portuguese west coast. In: Popov V, Brebbia CA (eds) Risk analysis V: simulation and hazard mitigation. Institute of Technology, Wessex

Cooper JAG, McLaughlin S (1998) Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. J Coast Res 14:512–524

Crowell M, Scott E, Kevin C, McAfee S (2007a) How many people live in coastal areas? J Coast Res 23(5):3–5

Crowell M, Hirsch E, Hayes T (2007b) Improving FEMA's coastal risk assessment through the National Flood Insurance Program: an historical overview. Mar Technol Soc 41(1):5–14

Crowell M, Coulton K, Johnson C, Westcott J, Bellomo D, Edelman S, Hirsch E (2010) An estimate of the U.S. population living in 100-year coastal flood hazard areas. J Coast Res 26 (2):201–211

Dal Cin R, Simeoni U (1994) A model for determining the classification, vulnerability and risk in the southern coastal zone of the Marche (Italy). J Coast Res 10:18–29

De Pippo T, Donadio C, Pennetta M, Petrosino C, Terlizzi F, Valente A (2008) Coastal hazard assessment and mapping in Northern Campania, Italy. Geomorphology 97:451–466

Del Rio L, Gracia FJ (2009) Erosion risk assessment of active coastal cliffs in temperate environments. Geomorphology 112:82–95

Di Paola G, Iglesias J, Rodriguez G, Benassai G, Aucelli P, Pappone G (2011) Estimating coastal vulnerability in a meso-tidal beach by means of quantitative and semi-quantitative methodologies. J Coast Res SI 61:303–308

Domínguez L, Anfuso G, Gracia FJ (2005) Vulnerability assessment of a retreating coast in SW Spain. Environ Geol 47:1037–1044

Dwarakish GS, Vinay SA, Natesan U, Asano T (2009) Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state, west coast of India. Ocean Coast Manage 52:467–478

Ergin A (2011) UNDP 2nd National communication to the UN framework convention on climate change; Impact, vulnerability and adaptation; Coastal Areas

Forbes DL, Taylor RB, Solomon SM, Craymer M, Manson GK, Dyke AS, Hodgson DA (2003) Crustal motion, climate change and coastal morphodynamics in the western Canadian Arctic. Geological Survey of Canada, Dartmouth

Gornitz VM (1990) Vulnerability of the east coast, USA to future sea level rise. J Coast Res 9:201–237

Gornitz V, Kanciruk P (1989) Assessment of global coastal hazards from sea-level rise. ASCE, Charleston

Gornitz V, Daniels RC, White TW, Birdwell KR (1993) The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. Oak Ridge National Laboratory, Oak Ridge

Gornitz VM, Daniels RC, White TW, Birdwell KR (1994) The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. J Coast Res 12:327–338

Kelly J (2000) Mapping coastal hazards along a rocky coast with eroding bluffs and beaches. In: Proceedings of the 3rd symposium on the Iberian Atlantic Margin, Faro

Klein R, Nicholls R (1999) Assessment of coastal vulnerability to climate change. Ambio 28 (2):182–187

Komar PD (1998) Beach processes and sedimentation. Prentice Hall, New Jersey

Li K, Li GS (2011) Vulnerability assessment of storm surges in the coastal area of Guangdong Province. Nat Hazards Earth Syst Sci 11:2003–2011

Lizárraga A, Christian M, Appendini A, Fischer D (2001) Planning for beach erosion: a case study, Rosarito Beach, Mexico. J Coastal Res 17(3):636–644

LOICZ (1995) Coastal zone resources assessment guidelines. LOICZ, Manila

Malvárez G, Domínguez R (2000) Origins, management and measurement of stress on the coast of Southern Spain. Ocean Coast Manage 28:215–234

McLaughlin S (2001) Assessment and development of a coastal vulnerability index for Northern Ireland employing GIS techniques. Ph.D. thesis, Coleraine, Ulster

McLaughlin S, McKenna J, Cooper JAG (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497

Méndez-Lázaro P, Peña-Orellana M, Padilla-Elías N, Rivera-Gutiérrez R (2014) The impact of natural hazards on population vulnerability and public health systems in tropical areas. J Geol Geosci 3:114–120

Mendoza ET, Jiménez JA (2006) Storm-induced beach erosion potential on the Catalonian Coast. J Coast Res 48:81–88

Mendoza ET, Jiménez JA (2009) Regional geomorphic vulnerability analysis to storms for Catalan beaches. P I Civil Eng-Mar 162(3):127–135

Ojeda-Zujar J, Alvarez JI, Martin D, Fraile P (2009) El uso de las TIG para el cálculo del indice de vulnerabilidad costera (CVI) ante una potencial subida del nivel del mar en la costa andaluza (España). Geofocus 9:83–100

Özyurt G, Ergin A (2009) Application of sea level rise vulnerability assessment model to selected coastal areas of Turkey. J Coast Res 51:248–251

Özyurt G, Ergin A (2010) Improving coastal vulnerability assessments to sea-level rise: a new indicator-based methodology for decision makers. J Coast Res 26(2):265–273

Özyurt G, Ergin A, Esen M (2008) Indicator based coastal vulnerability assessment model to sea level rise. In: Proceedings of the 7th international conference on coastal and port engineering in developing countries (COPEDEC) Paper E-06. Dubai, UAE

Raji O, Niazi S, Snoussi M, Dezileau L, Khouakhi A (2013) Vulnerability assessment of a lagoon to sea level rise and storm events: Nador lagoon (NE Morocco). J Coast Res 65:802–807

Rangel N, Anfuso G (2009) Medium-term evolution and vulnerability of a littoral sector of the Colombia Caribbean Sea. Compt Rend Acad Bulg 62(9):1131–1140

Rangel N, Posada B (2013) Determinación de la vulnerabilidad y el riesgo costero mediante la aplicación de herramientas SIG y métodos multicriterio en la línea de costa. Caribe Colombiano. Intropica 8(1):31–44

Sánchez-Arcilla A, Jiménez JA, Valdemoro HI (1998) The Ebro delta: morphodynamics and vulnerability. J Coast Res 14(3):754–772

Santos M, Del Río L, Benavente J (2013) GIS-based approach to the assessment of coastal vulnerability to storms. Case study in the Bay of Cádiz (Andalusia, Spain). J Coast Res 65:826–831

Simeoni U, Tessari U, Zamariolo A, Gabbianelli G, Grande C, Gonella M, Polo P, Atzeni P, Anconetani P, Pellizzari M (2000) Studio dell'Ancona e delle Vene di Bellocchio e del litorale tra Porto Garibaldi e Porto Corsini: proposta di sistemazione ambientale. Ferrara University Press, Ferrara

Snoussi M, Ouchani T, Niazi S (2008) Vulnerability assessment of the Moroccan coastal zone to the impacts of sea-level rise: the case of the Eastern Mediterranean Coast. Estuar Coast Shelf Sci 77:206–213

Szlafsztein F, Sterr A (2007) A GIS—based vulnerability assessment of coastal natural hazards, state of Pará, Brazil. J Coast Res 11(1):53–66

Thieler ER, Hammer-Klose ES (2000) National assessment of coastal vulnerability to sea-level rise: preliminary results for the US Pacific Coast. United States Geological Survey (USGS), Woods Hole

Williams AT, Alveirinho-Dias J, Garcia Novo F, Garcia-Mora MR, Curr RH, Pereira A (2001) Integrated coastal dune management: checklists. Cont Shelf Res 21:1937–1960

Chapter 3
Study Areas

Abstract The methodological approach for the determination of coastal risk index associated with storm impact has been tested and validated in Cartagena (Caribbean coast of Colombia) and Cadiz (SW Spain) areas. This chapter introduces the most important characteristics of both areas.

Cartagena is an important tourist city with a large seaport, located at the central Caribbean coast of Colombia (Fig. 3.1). Interaction among tectonic, climatic and oceanographic processes in this area has resulted in actual coastal settings, characterized by different geomorphologic units: (i) dissipative beaches and barrier islands composed of sand sediments of terrigenous and carbonate origin; (ii) marine terraces and cliff sectors, formed by Tertiary sandstones; (iii) coastal plains associated with fluvial-marine sedimentary processes, and (iv) coastal lagoons with mangrove swamps (Fig. 3.2). Tidal range is 30 cm (micro tidal environment) and lapse-time between successive high tides varies from 10 to 14 h. The average significant wave height is 1.5 m, while the average peak period is 6.5 s. Most of the year (November to July), the wave climate is dominated by the presence of swell waves approaching from the NE; rest of time, waves from NW, WSW and even SW occur. According to INVEMAR (2006) and Restrepo et al. (2012), seasonal variation in wave approaching direction is reflected by a decrease in significant wave height, with the lowest values (≤1.5 m) recorded between August and October, and most energetic conditions (>2 m) observed from November to July.

The net longshore sand drift has a dominant south-westward component, minor reversals to the northeast occurring during the rain periods (April to June and September to November) when southerly winds become dominant in some sectors. Erosive events are also related to the impact of hurricanes and cold fronts (Ortiz 2012; Ortiz et al. 2013). Hurricanes, usually originate in the Caribbean area from June to November and may affect the Colombia coast with strong winds, heavy rains and storm waves. In 1988 Hurricane Joan caused widespread flooding and over 200 deaths after moving into Central America, producing great damages in Cartagena region too (Lawrence Miles and Gross 1989). Cold fronts, occurring

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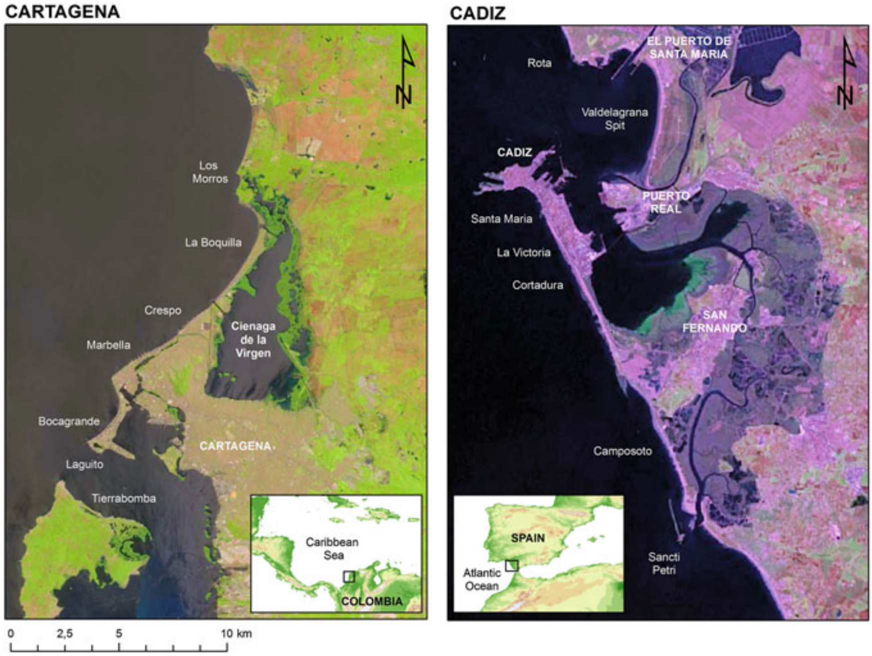

Fig. 3.1 Location of Cartagena (Colombia) and Cadiz (Spain) areas

during January, February and March, cause strong swell waves which impact may be increased by trade winds blowing from ENE. They usually hit the coast for about 48 h and have an average occurrence of six events per year (Ortiz et al. 2013).

Coastal occupation shows important tourist activities linked to both cultural resources and beach attractiveness. Good weather conditions make tourist activities very appealing during the entire year, making Cartagena the most popular destination along the Caribbean littoral of Colombia—147,280 of national and international arrivals were recorded in 2013.

As a result, Cartagena area has recently experienced a great increase of both popular and (especially) ‘high level’ tourism developments essentially consisting of 5 star chains hotels and golf courses. At present, huge pressure is applied by important building construction holdings to urbanize zones close to natural protected areas, to construct hotels and summer houses devoted to local and especially foreign tourists (Rangel et al. 2013). This tourism explosion has led to a rising demand for coastal related recreational activities, as well as for increased diving and snorkeling in protected areas, which already clashes with the existing coastal erosion problems associated with storms and hurricanes. In response to the ongoing coastline retreat (Restrepo et al. 2012), numerous hard protection structures of various types have been emplaced (Stancheva et al. 2011) with an associated deterioration of the coastal area (Rangel et al. 2013).

Fig. 3.2 Major geomorphologic characteristics observed along Cartagena area (Colombia). Groins along Bocagrande Beach (**a**), cliff erosion at Tierrabomba island (**b**), beach and cliff at Los Morros (**c**), rip-rap revetment at Crespo (**d**), tourist area at Castillogrande (**e**) and beach escarpment along Los Morros (**f**)

The Cadiz coastline is northwest-southeast oriented and characterized by a diversity of coastal landforms and environments including beaches, dunes, salt marshes, sand spits, cliffs and rocky shore platforms (Fig. 3.3). It presents semidiurnal and mesotidal range, with mean values of neap and spring tides of 1.0 and 3.5 m, respectively. The study area is affected by western and eastern winds; the western blow from WNW to WSW directions with a mean annual velocity of 16 km h^{-1} and a frequency of 13 %. They are related to the Atlantic low pressure systems that can continue for several days and affect large portions of the Iberian Peninsula. Winds blowing from E to SE directions are originally formed in the Mediterranean Sea and greatly increase in velocity due to channeling through the Gibraltar Strait. They show an annual frequency of 20 % and a mean velocity of 28 km h^{-1}. Due to coastline orientation, western winds give rise to both sea and swell waves, while easterly winds have no significant fetch and give rise to sea waves. The main longshore drift flows south-eastward and an opposite one is sometime observed but acquires certain importance only at specific sectors.

Fig. 3.3 Major geomorphologic characteristics observed along Cadiz area (Spain). Urban beaches of Valdelagrana spit (**a**), Santa Maria (**b**) and Cortadura (**c**). Natural beaches with dunes at Valdelagrana (**d**, **e**) and Camposoto (**f**)

Coastal towns and villages, summer houses, condominiums and recreational buildings, abound in the Cadiz area, in which economic activities are essentially related to summer tourism based on the presence of extensive sandy beaches. Such beaches, in past decades, have undergone erosion with locally recorded values greater than 1 m yr^{-1}, essentially associated with the impact of storm events (Muñoz and Enríquez 1998; Reyes et al. 1999; Benavente et al. 2002; Anfuso et al. 2007; Rangel and Anfuso 2011a, b, 2013). In order to balance coastal retreat trends and, especially to make beaches more attractive by enlarging the dry beach width, c. 13 million m^3 of sediments, with a cost of US$37 million, were injected in the 1990s (Muñoz et al. 2001). The volume added from 2000 to 2011 for maintenance purposes was only 2.3 million m^3 but the cost escalated from €3.6 to €5.8 million per year due to construction costs increases (Muñoz-Pérez and Gómez-Pina 2010).

References

Anfuso G, Domínguez L, Gracia FJ (2007) Short and medium-term evolution of a coastal sector in Cadiz, SW Spain. Catena 70(2):229–242

Benavente J, Del Río L, Anfuso G, Gracia FJ, Reyes JL (2002) Utility of morphodynamic characterization in the prediction of beach damage by storms. J Coastal Res SI 36:56–64

INVEMAR (2006) Climatologie de la vitesse et la direction des vents pour la mer territoriale sous juridiction colombienne 8° a 19° N—69° a 84° W. Atlas ERS 1 et 2 et Quickscat, Colombie. CNRS—UMRS 8591. Laboratoire de Géographie Physique—Programa Geociencias, Instituto de Investigaciones Marinas y Costeras, Santa Marta

Lawrence Miles B, Gross JM (1989) Atlantic hurricane season of 1988. Mon Weather Rev 117 (10):2248–2259

Muñoz JJ, Enríquez J (1998) Dinámica litoral de una unidad fisiográfica completa: Sanlúcar - Rota. Rev Obras Pub 3375:34–44

Muñoz-Pérez JJ, Gómez-Pina G (2010) Comentario sobre Avila Serrano et al "Variaciones sedimentarias y transporte litoral en playa de La Victoria, Cádiz, España". Cienc Mar 36 (1):99–104

Muñoz JJ, López de San Román B, Gutiérrez-Mas JM, Moreno L, Cuena GJ (2001) Cost of beach maintenance in the Gulf of Cadiz (SW Spain). Coast Eng 42:143–153

Ortiz JC (2012) Exposure of the Colombian Caribbean coast, including San Andrés Island, to tropical storms and hurricanes, 1900–2010. Nat Haz 61:815–827

Ortiz JC, Otero LJ, Restrepo JC, Ruiz J, Cadena M (2013) Cold fronts in the Colombian Caribbean Sea and their relationship to extreme wave events. Nat Haz 13:2797–2804

Rangel N, Anfuso G (2011a) An application of Dolan and Davis (1992) classification to coastal storms in SW Spanish littoral. J Coast Res 64:1891–1895

Rangel N, Anfuso G (2011b) Coastal storm characterization and morphological impacts on sandy coasts. Earth Surf Proc Land 36(15):1997–2010

Rangel N, Anfuso G (2013) Winter wave climate, storms and regional cycles: the SW Spanish Atlantic coast. Int J Climato 33:2142–2156

Rangel N, Anfuso G, Correa I, Ergin A, Williams AT (2013) Assessing and managing scenery of the Caribbean Coast of Colombia. Tourism Manage 35:41–58

Restrepo J, Otero L, Casas AC, Henao A, Gutiérrez J (2012) Shoreline changes between 1954 and 2007 in the marine protected area of the Rosario Island Archipelago (Caribbean of Colombia). Ocean Coast Manage 69:133–142

Reyes JL, Martins JT, Benavente J, Ferreira O, Gracia FJ, Alveirinho-Dias JM, López-Aguayo F (1999) Gulf of Cádiz beaches: a comparative response to storm events. Bol Inst Esp Oce 15(1–4):221–228

Stancheva M, Rangel N, Anfuso G, Palazov A, Stanchev H, Correa I (2011) Expanding level of coastal armouring: case studies from different countries. J Coast Res 64:1815–1819

Chapter 4
Used Methodology

Abstract This chapter details the methodology used to develop risk assessment to storms, divided into a general description of each index used, the role of the imagery used in the assessment and their database components.

4.1 General Description and Calculation of the Assessment Indexes

In this work, the method proposed for the assessment of coast risk to storms, expressed by the Coastline Risk to Storms Index, has been based on the combination of three components or sub-indices within a GIS environment (Fig. 4.1):

(i) the Forcing variables contributing to storm-induced erosion (Table 4.1);
(ii) the Susceptibility sub-index (Tables 4.2 and 4.3) which described the coast resilience and susceptibility to erosion according to its specific morphological characteristics, within two main coast types (sandy and rocky),
(iii) The Vulnerability sub-index, which concerned with vulnerable targets, took into account socioeconomic, ecological and heritage aspects (Tables 4.4, 4.5 and 4.6).

Much of the used variables for the determination of used sub-indices have been chosen according to previous studies focused on chronic coastal erosion or sea level rise related hazards (Gornitz 1991; Gornitz et al. 1997; Cooper and McLaughlin 1998; McLaughlin et al. 2002; Coelho et al. 2009; McLaughlin and Cooper 2010; Özyurt and Ergin 2009, 2010; among others) and/or storm impacts (Burzel et al. 2010; Ceia et al. 2010; Carrasco et al. 2012; Di Paola et al. 2011; Li and Li 2011; Maio et al. 2012; Raji et al. 2013).

The selection of variables used in each sub-index has been made according to two principles. First, a number of representative variables have been selected for each sub-index but this number was kept low enough to avoid redundancy problems (Williams and Davies 2001) and, second, the chosen variables responded to

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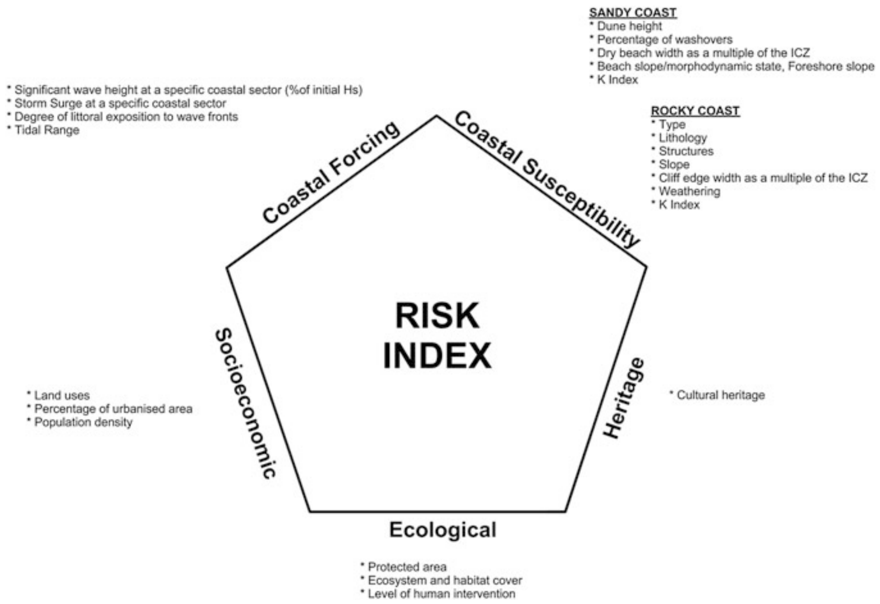

Fig. 4.1 Scheme of the variables used for the assessment of coast risk to storms

Table 4.1 Forcing variables contributing to storm-induced erosion

Costal forcing					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Significant wave height at a specific coastal sector (% of initial H_S)	Less than 20 %	20–40 %	40–60 %	60–80 %	80–100 %
Storm surge at a specific coastal sector	Less than 20 %	20–40 %	40–60 %	60–80 %	80–100 %
Degree of littoral exposition to wave fronts (García Mora et al. 2001)	10°–45° Oblique	x	0°–10° Sub-parallel	x	0° Parallel
Tidal range (McLaughlin and Cooper 2010)	Macrotidal	x	Mesotidal	x	Microtidal

the requirement expressed by Villa and McLeod (2002), i.e. they must be available and easy to obtain at any given area without requiring exhaustive survey work. Subsequently, the proposed methodology is very practical and easy to apply in any coastal area with similar datasets.

Table 4.2 Sandy coast susceptibility index

Sandy coast susceptibility					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Dune height (Gracia et al. 1999)	≥ 6	≥ 3	≥ 2	≥ 1	<1
Percentage of washovers (García Mora et al. 2001)	0 %	≤5 %	≤25 %	≤50 %	≥50 %
Dry beach width as a multiple of the ICZ (Anfuso et al. 2013)	5 times ICZ	4 times ICZ	3 times ICZ	2 times ICZ	Equal to ICZ
Beach slope/morphodynamic state, foreshore slope (Anfuso 2002)	Dissipative ($\tan \beta \leq 0.02$)	x	Intermediate ($0.02 < \tan \beta < 0.08$)	x	Reflective ($\tan \beta \geq 0.08$)
K Index (Aybulatov and Artyukhin 1993)	Extreme ($K > 1$)	Maximum ($K = 0.51 \div 1$)	Average ($K = 0.11 \div 0.5$)	Minimum ($K = 0.0001 \div 0.1$)	No structures ($K = 0$)

Table 4.3 Rocky coast susceptibility index

Rocky coast susceptibility					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Type (Sunamura 1992)	Cliff with horizontal shore platform	x	Cliff with sloping shore platform	x	Plunging cliff
Lithology (Sunamura 1992)	Granitic rocks, resistant metamorphic	limestone	Flysch, shale, tertiary sedimentary rocks	Quaternary deposits	Volcanic ejecta
Structures (Bieniawski 1989)	Virtual absence of discontinuities, cracks, joints, faults	x	Some evidence of discontinuities, cracks, faults	x	High density of discontinuities, cracks, faults
Slope (Anfuso et al. 2013)	<30°	31° ÷ 40°	41° ÷ 50°	51° ÷ 60°	>60°
Cliff edge width as a multiple of the ICZ (Anfuso et al. 2013)	5 times ICZ	4 times ICZ	3 times ICZ	2 times ICZ	Equal to ICZ
Weathering (Bieniawski 1989)	Unweathered	Slightly unweathered	Moderately weathered	Highly weathered	Decomposed
K Index (Aybulatov and Artyukhin 1993)	Extreme ($K > 1$)	Maximum ($K = 0.51 \div 1$)	Average ($K = 0.11 \div 0.5$)	Minimum ($K = 0.0001 \div 0.1$)	No structures ($K = 0$)

Table 4.4 Socioeconomic variables associated with the vulnerability sub-index

Socio-economic vulnerability index					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Land uses (CORINE project)	Bushes and scrubs	Pastures (dense grass cover) Pastures (grass + crop) Pastures (grass + threes)	Swamp area Salt marsh Coastal lagoon Wet area Gallery forest	Agricultural pond Cropland Complex cultivation area	Recreational structures Airports Industrial-commercial area Urban area Mining area
Percentage of urbanized area (Li and Li 2011)	Lower than 20 %	20 ÷ 40 %	40 ÷ 60 %	60 ÷ 80 %	Larger than 80 %
Population density (Li and Li 2011)	Lower than 10 inhabitants per square kilometre	11 ÷ 75	76 ÷ 300	301 ÷ 999	Greater than 1,000 inhabitants per square kilometre

Table 4.5 Ecological variables associated with the vulnerability sub-index

Ecological vulnerability index					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Protected area (IUCN 2008)	Strict nature reserve	x	Natural monument	x	Habitat/specie management area
Ecosystem and habitat cover (Li and Li 2011; McLaughlin and Cooper 2010)	Unvegetated area	x	Bushes, stubble, grassland, bare rocks	x	Strategic ecosystems: salt marsh, marine seaweed, coral reef, lagoons
Level of human intervention (Özyurt and Ergin 2009; Li and Li 2011)	Very low (lower than 20 %)	Low (40 ÷ 20 %)	Medium (60 ÷ 40 %)	High (80 ÷ 60 %)	Very high (more than 80 % of the area)

According to afore mentioned principles, 4 climatic factors have been chosen as variables for coastal forcing index estimation (Table 4.1). In order to have objective values of significant wave height and storm surge distribution along investigated coasts obtained by means of wave propagation, values corresponding to such parameters were expressed as percentage of their initial propagated values. The choice of those variables has been made according to the investigations on storm-induced erosion (e.g., among others, Stockdon et al. 2006; Pye and Blott 2008; Almeida et al. 2011; Esteves et al. 2011; Rangel and Anfuso 2013).

Table 4.6 Heritage variables associated with the vulnerability sub-index

Cultural heritage vulnerability index					
Parameter	Null/very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Cultural heritage (McLaughlin and Cooper 2010)	Absent	Local interest	Regional interest	National interest	International interest UNESCO world heritage site

Similarly, the susceptibility sub-index to erosion has been estimated as a function of the intrinsic coastal characteristics and 5 and 7 variables have been respectively chosen for sandy and rocky coastlines (Tables 4.2 and 4.3). The definition of those variables has been made according to the results obtained by numerous authors who studied the influence of different factors on sandy and rocky coasts stability (e.g. Garcia Mora et al. 2001; Gracia et al. 1999; Sunamura 1992; Trenhaile 2002, among others).

Analysis of targets potentially at risk took into account a series of vulnerability related variables in the socioeconomic, ecological and heritage contexts (Tables 4.4, 4.5 and 4.6). A total of 7 variables (3 socioeconomic, 3 ecological and 1 heritage) have been selected to obtain the vulnerability sub-index (Tables 4.4, 4.5 and 4.6).

According to Gornitz (1991), Gornitz et al. (1997), Hammer-Klose and Thieler (2001), used variables have been classified on a 1–5 scale; 1 indicated a low contribution to specific key variable for the studied sector, while 5 indicated a high contribution. Classes have been set on a numerical base and an ordinal scale approach was adopted in case of a semi-quantitative variable difficult to quantify (Cooper and McLaughlin 1998).

Hence, different variables have been calculated for a coastal area segmented in a number of sectors whose dimensions were defined according to data availability and coastal uniformity. In this sense, the methodology used can be applied at different spatial scales; in the presented study cases (Cadiz and Cartagena areas) investigated coastal areas presented a length of 30 km that were further divided into sectors of 500 × 500 m.

Dealing with the used variables, they were combined under a GIS environment into the Forcing, Susceptibility, Hazard and Vulnerability indexes (socioeconomic, ecological and heritage contexts). The scores of each variable have been summed with the scope of obtaining an absolute value for each sub-index according to the follow equations:

$$\boldsymbol{Coastal\ Forcing\ Index} = \frac{\sum Cf\ an - nCf}{nCf * 4} * 100 \qquad (4.1)$$

$$\boldsymbol{Susceptibility\ Index} = \frac{\sum S\ an - nS}{nS * 4} * 100 \qquad (4.2)$$

$$\boldsymbol{Hazard} = \frac{(Coastal\ Forcing\ Index * nCf) + (Susceptibility\ Index * nSb)}{nCf + nS} \tag{4.3}$$

$$\boldsymbol{Vulnerability} = \frac{\sum V\ an - nv}{nV * 4} * 100 \tag{4.4}$$

Being ***an*** each one of the variables used in each index (Coastal Forcing: Cf, Susceptibility: S and Vulnerability: V) and n the number of variables in each index.

In order to obtain a more realistic index in each context, the Relative Index of Risk (RI) has been calculated and expressed as a value of the theoretical hazard and vulnerability. Such value was normalized according to the index technique suggested by McLaughlin et al. (2002):

$$\boldsymbol{Risk} = \frac{[Hazard * (nCf + nS)] * [Vulnerability * (nV * 4)]}{(nCf + nS) + (nV * 4)} \tag{4.5}$$

The total risk to Storms Index was a single numerical value obtained by means of a weighted average of all the risk calculated (Social, Ecological and Heritage) according to the number of variables included in each of them—in order to not overestimate individual weight. Once the final indexes have been calculated, they were categorized by means of the natural breaks function analysis (Jenks and Caspall 1971) into five classes of risk ranging from very low (1) to very high (5).

Concerning the vulnerability sub-indexes, they have been constituted by complex variables, which included socioeconomic, ecological and heritage aspects. They were divided up in two types of data: (i) quantitative data, which included percentages of specific areas and/or associated densities (i.e. percentage of urbanized area, population density) and (ii) qualitative data, which included common specific variables previously established and classified (i.e. land uses, ecosystem and habitat cover).

4.2 The Role of Aerial Images and GIS into Risk Assessment to Storms

In this work, aerial photogrammetric flights, orthophotographs, and satellite images have been used to produce a high resolution base for the analysis and mapping of investigated variables. Specifically, the orthophoto of the Cadiz area, dated 2012 and provided by the Regional Administration (Junta de Andalucia), and the Orthophoto IGAC (dated 2012 and provided by Instituto Geografico Agustin Codazzi) were used as reference images for respectively Cadiz and Cartagena areas.

Mentioned orthophotos were processed under a GIS environment and a georeferenced mosaic image has been obtained. In a following step, it was been imported into the ESRI ArcGIS 10 software to map the different selected variables for the evaluation of hazard, vulnerability and risk associated to extreme storm events.

Table 4.7 Satellite images and aerial photogrammetric flights used in this work

Satellite images and aerial flights					
Cadiz			Cartagena		
Source	Year	Resolution/scale	Source	Year	Resolution/scale
Regional administration (Junta de Andalucia)	2012	0.5 m resolution	Instituto Geográfico Agustín Codazzi IGAC	2012	1 m resolution
ICA—Cartography Institute Andalusia	2005	0.5 m resolution	Landsat	2005	30 m resolution
ICA—Cartography Institute Andalusia	2001	0.5 m resolution	Landsat	1994	30 m resolution
ICA—Cartography Institute Andalusia	1991	1:40,000	Landsat	1990	30 m resolution
CECAF—AIR	1983	1:30,000	Instituto Geográfico Agustín Codazzi IGAC	1983	30 m resolution

Likewise, satellite images and aerial photogrammetric flights were used to reconstruct linear coastline evolution along Cartagena and Cadiz areas for the last 15 years (Table 4.7), e.g. medium to long-term period (Crowell and Buckley 1993).

Following the methods described by Leatherman (1983), Jiménez et al. (1997) and Pajak and Leatherman (2002), aerial photos have been scanned, geo-referenced, and computer rectified to eliminate scale and distortion problems (Chuvieco 2000; Lillesand and Kiefer 1987; Moore 2000). Ground Control Points (GCPs) for photo registration have been obtained from the geo-referenced 2012 satellite images and all information has been presented in Projected Coordinate System UTM Zone 18 (Cartagena) and UTM 29 (Cadiz). Taking into account the smooth topography of both studied areas, a polynomial transformation has been applied in registration process (Chuvieco 2000). The number of GCPs used varied from one photograph to another (from 9 to 15 units) and their position was located in unequivocal places (Thieler and Danforth 1994).

The error due to document distortion (Moore 2000) was resolved and controlled in the geo-referenced documents by visual observation, achieved by comparing the registered photographs with the base map and deriving the root mean square error (RMSE). Once all available images were overlapped, shorelines were identified and digitized into a geodatabase on the georectified images and orthophotographs, in order to compare and evaluate the displacements among shorelines of different years.

A key issue in the study of coastal erosion is the selection of an adequate feature that can serve as a shoreline indicator, e.g. it must properly reflect real shoreline position and evolution (Moore 2000; Boak and Turner 2005). Given that Cartagena is a microtidal environment, shoreline position was defined as the instantaneous water line position at the moment of the photo (Pajak and Leatherman 2002; Boak and Turner 2005). For the Cadiz area, which is a mesotidal environment, the dune foot was used as shoreline indicator.

The ArcGis 10 extension Digital Shoreline Analysis System (DSAS), v. 4.2 USGS Woods Hole—Massachusetts (Thieler et al. 2005), was used to quantify shoreline evolution, determine the dry beach/cliff edge width, and to validate the proposed Index. The DSAS uses, as an input, a series of shoreline positions referenced to an arbitrary baseline. In this work, the DSAS allowed the calculation of shoreline change rates at transects perpendicular to the baseline which was generated at a 500 m interval. The methodology allowed also calculating and classifying other investigated variables along each one of the 500 m long beach sectors in which coastlines were divided.

4.3 Database Components of the Assessment Indexes

4.3.1 Coastal Forcing Index

The Coastal Forcing Index was defined as the level of potential stress a coastline could experience from a storm event (Table 4.1).

The first variable included in the coastal forcing index was wave height, widely used in vulnerability studies and usually expressed as a numeric value divided into different classes (i.e. Gornitz 1991; Gornitz et al. 1997; Coelho et al. 2009; McLaughlin and Cooper 2010; Raji et al. 2013). Since the goal of this study was to develop a general methodological approach, and wave height presents a great variability from one coastal area to another, it was not recommended to use an absolute common value, but it was proposed to determine the significant wave height value corresponding to storm conditions for any investigated area. The first step in this way was the determination of a threshold value that should reflect the water wave height at which erosion affects the considered coastal area. After some tests with diverse percentiles, it was found that Hs_{92} was the best percentile to define extreme wave height variability (Dolan and Davis 1992; Dorsch et al. 2008; Rangel and Anfuso 2013) and it represented rare events constituting only 8 % of records over the considered period, following Mortiz and Mortiz (2006).

Cadiz Forcing assessment has been based on the analysis of wave data obtained from the scalar buoy n° 1316 (36.50°N; 6.33°W), a waverider—datawell instrument which is located at a water deep of 21 m, in front of Cadiz city. Cartagena wave data have been obtained from the reanalysis of wind data available in the North American Regional Reanalysis database (fttp://ftp.cdc.noaa.gov/Datasets/NARR/monolevel, accessed April 2014) for a prediction point located in front of Cartagena (10.7°N; −75.6°W).

In a second step, the obtained value has been propagated by means of conventional wave propagation software (i.e. SWAN, SMC, among others) and different wave height values were obtained at each specific sector of a coastal area. SWAN and SMC software allow to obtain realistic estimates of random, short-crested wind-generated waves in such conditions for a given bottom topography, wind field, water level and current field. Both softwares are third-generation stand-alone (phase-averaged) wave models for simulation of waves in waters of deep, intermediate and finite depth. They are also suitable for use as a wave hindcast model. Such wave height distribution at each specific sector was expressed as percentage of the initial wave height value.

Concerning storm characteristics, they can be expressed in different ways, as an example, McLaughlin and Cooper (2010) considered the difference between storm and modal waves and storm frequency at each investigated sector. In the present work storm impact has been expressed by the calculation of storm surge elevation in each segment. Storm surge is a dome of increased sea level height due to air pressure reduction, wind and wave actions in association with the approach of a storm (Sallenger 2000; Stockton et al. 2006). This variable is a key value widely used which is the combination of swash ($\Delta\xi$), set-up (τs), run-up (R_2) and astronomical tide (TL) according with the formula:

$$\textbf{\textit{Storm Surge}} = \Delta\xi + \tau s + R_2 + TL \tag{4.6}$$

Swash ($\Delta\xi$), is generally defined as the time-varying location of the intersection between the ocean and the beach due a barometric decline and is defined by the formula:

$$\Delta\xi = (\Delta Pa)/(\rho\, g) \tag{4.7}$$

where $\Delta\xi$ is the sea level increase, ΔPa is the barometric pressure variation, ρ the sea water density and g the gravity acceleration.

Setup corresponds with the super-elevation of the mean water level, driven by the cross shore gradient in radiation stress that results from wave breaking (Longuet-Higgins and Stewart 1963, 1964). Bowen et al. (1983) wrote a simplified expression for setup by assuming normally incident shallow-water waves whose height within the surf zone was limited to a constant fraction of the local water dept. The resulting expression was:

$$\boldsymbol{\tau s} = \rho a\ CD\ W^2 \tag{4.8}$$

where W is the wind velocity, ρa the air density and CD is a constant value dependent of wind velocity (Bowden 1983).

Lastly, Runup (R_2) was defined here as the set of discrete water level maxima elevation, measured on the foreshore, with respect to still water level, which would occur in the absence of waves (Stockton et al. 2006). These authors defined the follow formulation for Run up:

$$R_2 = 1.1\left[0.35\beta_f(H_0L_0)^{1/2} + \frac{\left(H_0L_0\left(0.563\beta_f^2 + 0.004\right)\right)^{1/2}}{2}\right] \tag{4.9}$$

where H_0 is the wave height, L_0 is wave length and B_f is the beach slope. In the same way, for ultra-dissipative conditions, the same authors defined the run up as follows:

$$\boldsymbol{R}_2 = 0.0043(H_0L_0)^{1/2} \quad \text{for } \xi < 0.4 \tag{4.10}$$

As for wave height, no absolute value of storm surge has been given but class limits were expressed as percentages of the maximum value obtained in an area in order to have more representative and objective idea of its distribution.

The degree of littoral exposition to the dominant wave approaching direction influenced its sensitivity to storms impacts. This parameter has been taken into account by different authors and corresponded with the existing angle between the coastline (McLaughlin and Cooper 2010) and the storm wave fronts, usually measured by means of qualitative observations. According to Komar (1998) shore-parallel storm wave fronts involve higher hazard levels than shore-oblique wave fronts. In the present work, this parameter has been determined by considering the wave attack angle of most important storms which was categorized in a quantitatively way according to intervals proposed by García Mora et al. (2001).

Tidal range has been linked to both permanent and episodic inundation hazards (Gornitz et al. 1994). It was considered as a constant variable in local studies. In this case, a microtidal littoral has been considered more susceptible to storm related erosion than a macrotidal one according to McLaughlin and Cooper (2010).

4.3.2 Susceptibility Index—Coastal Characteristics

The Susceptibility index corresponds with the level of exposure and it can be further defined by the physical characteristics of the coastline. In this sense, this index included those factors that control littoral susceptibility to storms as a function of the type of coast (Tables 4.2 and 4.3).

On sandy coasts, dune systems are one of the most important coastal features. They are essential in coastal stability and protection, as they often constitute the final defence line against high water levels and waves during severe storms (Williams et al. 2001; Gracia et al. 2009). Likewise, dune ridge continuity is often interrupted by washover deposits that can greatly affect natural environments and human activities/infrastructures and constitute hot spots sensible to coastal erosion; in fact, if the dunes are eroded or fragmented, storm-protection function of the beach is lost (Kraus et al. 2002). Specifically, dune height and percentage of washovers in dune fronts indicate the health of dune systems and their capacity in protecting backing areas. They have been considered and categorized in numerous regional and local studies by means of qualitative and semiqualitative observations or absolute values (Goldsmith 1985; Abuodha and Woodroffe 2006; Coelho et al. 2009; Ceia et al. 2010; Santos et al. 2013). In this study, dune height and spatial density of washovers have been categorized by means of absolute values according to the classes proposed respectively by Gracia et al. (1999) and García Mora et al. (2001).

Beach slope and morphodynamic state have been referred to foreshore slope and beach morphodynamic state according to the Wright and Short (1984) classification. Both parameters are very important since they identify the relative susceptibility to inundation because of flooding associated with storm surges (Thieler and Hammer-Klose 2000) and the potential velocity of shoreline erosion during a storm (Pendleton et al. 2005). Beaches with gentle slopes (e.g. dissipative beaches), present fine sediments, low permeability and usually small morphological changes. Opposing, steeper-sloping beaches (e.g. reflective beaches), are composed by coarser sediments with greater permeability and usually major morphological changes. The latter are considered as highly susceptible areas, as in general the higher the slope, the greater is the eroded sediment volume (Abuodha and Woodroffe 2006). Such variables were considered in regional and local studies by means of absolute values (Özyurt and Ergin 2009, 2010; Santos et al. 2013) or in regional studies by qualitative observations (Abuodha and Woodroffe 2006).

Concerning cliffed coasts, the first proposed variable corresponded with the cliff type. This variable has been defined according to Sunamura (1992) which described three major types of cliffed coast on the basis of the profile form. Probably such an approach was an oversimplification but is easy to use and applicable everywhere because provides a useful framework for determining rocky coast susceptibility. Specifically, according to this approach, a horizontal shore platform is less susceptible to erosion than a plunging cliff coast.

According to Benumof and Griggs (1999) who investigated sea cliff erosion in USA, other important aspects in cliff resistance and, hence, stability, are the intrinsic variables controlling physical properties. Cliff lithology (Sunamura 1992) and cliff structures (Bieniawski 1989) represent important parameters controlling cliff stability—susceptibility. The lithology parameter describes the possible types of rocks that can be founded, and it ranges from low to high sensible lithologies to erosion processes (Sunamura 1983; Gornitz et al. 1994). Structures include a great diversity of attributes such as strata, fractures, etc. and they are at places the most important features in determining cliff evolution (Sunamura 1983) because they reduce the overall strength of the cliff, especially in low-energy environments (Greenwood and Orford 2008). The rank proposed in this work included the general types of structures that can easily be identified on cliffed zones and were commonly recognized as instability—erosion indicators, e.g. discontinuities, cracks, joints and faults.

A significant factor concerning the nature of rocky coasts is the cliff slope, which is considered to be directly linked to cliff susceptibility—stability (Bush et al. 1999; De Pippo et al. 2008; Del Rio and Gracia 2009). A strong relationship exists among cliff lithology, structures and slope, but the complex nature of this relationship allows the use of cliff slope as an independent variable without implying a redundancy (Del Rio and Gracia 2009; Anfuso et al. 2013).

Weathering include any kind of natural physical–chemical and geomorphologic processes that significantly reduce cliff resistance, like rock/soil piping, karstic dissolution, etc. (Anfuso et al. 2013).

Two parameters have been used for both sandy and cliffed coasts Susceptibility Index: dry beach/cliff edge width (as a multiple of the Imminent Collapse Zone ICZ, Crowell et al. 1999) and the armouring of the coast, expressed by means of the K Index (Aybulatov and Artyukhin 1993).

The dry beach/cliff edge width parameter represents a buffer zone to storm impact and hence it must be taken into consideration in coastal sensitivity determination. In regional and local studies, such variable was usually expressed by means of absolute values of coastal erosion rates (Gornitz et al. 1994; Del Rio and Gracia 2009; Raji et al. 2013). Since beach/cliff edge width can range a lot from coast to coast, it has been expressed as a function of the extension of the ICZ, which is the area subject to imminent erosion extended landward from the coastline for a distance equal to 10 feet (3 m) plus five times the average, annual erosion rate for the site calculated for medium- (10–60 years) or long-term time spans (<60 years, in the sense of Crowell and Buckley 1993). Such data can be available from previous studies and are usually obtained by means of aerial photographs (Smith and Zarillo 1990).

Mapping coastal armouring, e.g. the level and type of coastline protection structures and ports/harbours, is an important issue due to many reasons. It is a key factor in the assessment of tourist sustainability, coastal scenery evaluation, as well as for the identification of areas recording bathers' safety problems (Ergin et al. 2004; Hartmann 2006). Results from inventorying coastal structures and evaluating their impacts on the coast could help to highlight the state of the coastline and to form the primary base useful in any coastal decision-making process. For evaluating the level of armouring, e.g. the impact of structures, the so called coefficient of technogenous impact, K has been used as an indicator (Aybulatov and Artyukhin 1993). This coefficient represents the relation between the total length (l) of all man-made structures (i.e. jetties, groins, breakwaters, etc.) at certain coastal section and the length (L) of the investigated sector. According to this methodology, different categories of technogenous impact have been obtained ranging from minimal at $K = 0.0001–0.1$; averaged when $K = 0.11–0.5$; maximal at $K = 0.51–1.0$ and extreme if $K > 1.0$.

4.3.3 Vulnerability Index—Vulnerable Targets

The vulnerability index corresponds with a value that denotes the ability of a coastline to cope with and recover from a coastal storm event, as defined by its socioeconomic, ecological and heritage resilience (Tables 4.4, 4.5 and 4.6).

4.3.3.1 Socioeconomic Context

The socioeconomic context reaches a relevant importance because the concept of vulnerability is closely connected with humans and society (Li and Li 2011). In the present work the socioeconomic context of the vulnerability index has been constituted by a series of variables representing social, economic and human activities that, because their exposure or intrinsic vulnerability, may be impacted by storms (McLaughlin et al. 2002; Boruff et al. 2005—Table 4.4).

The first parameter used in the socioeconomic context was the land use. This parameter can be defined as "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (FAO/UNEP 1999). Land use is a key factor in determining storm erosion impact since it controls to a great extent the economic value of an area (Del Rio et al. 2012) and it has been considered in regional and local studies as a significant variable in determining coastal vulnerability, e.g. Ceia et al. (2010), Li and Li (2011) and Santos et al. (2013). In the present work, land use categories have been considered according to the results of the European project "Coordination of Information on the Environment" (CORINE, http://www.eea.europa.eu/publications/COR0-landcover, accessed June 2014) and they broadly coincided with the ones proposed by McLaughlin et al. (2002) and McLaughlin and Cooper (2010); vulnerability ranged from low (bushes and scrubs areas) to high sensitivity values (urban and industrial infrastructure areas).

The percentage of urbanized area can be considered as a more specific descriptor than land use type, as it comprises diverse types of features that are of development and significant economic value (Del Río et al. 2012). In the present work, the percentage of urbanised area has been expressed according to the density of human infrastructures and it broadly corresponded with the "engineered frontage" used by Özyurt and Ergin (2009, 2010), the "coastal construction index" by Li and Li (2011) and "settlements", "roads" and "railway" sub-indexes considered by McLaughlin and Cooper (2010).

The population density of a specific area is a major issue when analyzing any type of sensitivity and, although its use is not common in published indices (McLaughlin et al. 2002), most coastal classifications acknowledge the need of considering this parameter (Cooper and McLaughlin 1998). Further, population density was very useful to appropriately describe human coastal occupation especially to discriminate between developed and undeveloped countries. Such parameter has been used in regional (Li and Li 2011) and local (Santos et al. 2013) studies. Authors such Crossett et al. (2004) and Crowell et al. (2007) took into account the population density as a direct "erosion-inducing" variable because the presence of large numbers of people near the coastline may produce in general damaging impacts on it. A higher population density involves more exposure and hence a higher impact of coastal hazards therefore, in densely populated areas, prevailed a trend of protecting properties from coastal erosion, turning this variable into economic terms; meanwhile, low population density areas many times have no resources for protection.

4.3.3.2 Ecological Context

Most of existing vulnerability studies take into account only the human and social aspects but, when storms strike coastal areas, their environment and ecosystems can be seriously damaged, with associated loss of valuable natural and conservation status aspects. The ecologic context of the vulnerability index has been evaluated by means of three variables representing ecological characteristics that may be impacted and altered by storms, according to their susceptibility and degree of exposure (Table 4.5).

The parameter "protected area" covers locations that receive special protection because of their recognised natural and/or ecological values. The International Union for Conservation of Nature (IUCN) classified protected areas according to their management objectives. The categories were recognised by international bodies such as the United Nations and by many national governments. Strict nature reserve areas showed a large complete set of native species in such ecological significant densities that—after the impact of natural events—were capable of returning to normal original conditions in a natural way or by time -limited interventions. Aversely, a protected area with sustainable use of natural resources was more susceptible to storm erosion due to their degree of anthropogenic intervention.

The associated value of ecosystem and habitat cover is represented by the existing variations between unvegetated areas and strategic ecosystems, since the existence of an ecosystem service designation (i.e. strategic ecosystem), increases the impact of erosion related to storms affecting these natural zones (McLaughlin et al. 2002). The justification is that, on a specific coastal area, a strategic ecosystem has an intrinsic value that might be threatened by storm related erosion even if it does not show human related activities.

The level of human intervention is an ecological parameter indicative of the "natural state" of a specific coastal area and attempts to define the ecological vulnerability as a function of the level of human occupation and transformation of the original environment. A higher level of human interventions entails a higher storm erosion impact because the human activities tend to degrade and fragment the natural environment increasing in this sense its vulnerability.

4.3.3.3 Heritage Context

Storms have been recently affecting many natural and cultural World Heritage properties and, for this reason, this became an issue of investigation for many scientists in the past years. Specifically, the World Heritage Committee requested to the World Heritage Centre of UNESCO, in collaboration with the Advisory Bodies (IUCN, ICOMOS and ICCROM) and interested States Parties, to take into account the heritage in any kind of sensitivity assessment. In this work, the cultural heritage context has been taken into account following to the UNESCO cultural heritage classification that ranged each location according to its interest, from local to international (Table 4.6).

References

Abuodha P, Woodroffe CD (2006) Assessing vulnerability of coasts to climate change: a review of approaches and their application to the Australian coast. In: Woodroffe CD, Bruce E, Puotinen M, Furness RA (eds) GIS for the Coastal Zone: a selection of Papers from CoastGIS 2006. Australian National Centre for Ocean Resources and Security University of Wollongong, Wollongong

Almeida LP, Ferreira Ó, Vousdouskas MI, Dodet G (2011) Historical variation and trends in storminess along the Portuguese South coast. Nat Hazards Earth Syst Sci 11:2407–2417

Anfuso G (2002) Morfología y dinámica sedimentaria del litoral gaditano entre Chipiona y Rota. Serv. Publicaciones Univ. Cádiz

Anfuso G, Gracia FJ, Battocletti G (2013) Determination of cliffed coastline sensitivity and associated risk for human structures: a methodological approach. J Coastal Res 29(6):1292–1296

Aybulatov NA, Artyukhin YV (1993) Geo-ecology of the World Ocean's Shelf and Coasts. Hydrometeo Publishing, Leningrad

Benumof BT, Griggs GB (1999) The dependence of seacliff erosion rates on cliff material properties and physical processes: San Diego County, California. Shore Beach 67:29–41

Bieniawski ZT (1989) Engineering rock mass classifications. Wiley, New York

Boak E, Turner I (2005) Shoreline definition and detection: a review. J Coast Res 21(4):688–703

Boruff BJ, Emrich C, Cutter SL (2005) Erosion hazard vulnerability of US coastal counties. J Coast Res 21:932–942

Bowden KF (1983) Physical oceanography of coastal waters. Ellis Horwood, Southampton

Burzel A, Dassanayake D, Naulin M, Kortenhaus A, Oumeraci H, Wahl T, Mudersbach C, Jensen J, Gönnert G, Sossidi K, Ujeyl G, Pasche E (2010) Integrated flood risk analysis for extreme storm surges (XTREMRISK). COPRI, Shangai

Bush DM, Neal WJ, Young RS, Pilkey OH (1999) Utilization of geoindicators for rapid assessment of coastal-hazard risk and mitigation. Ocean Coast Manage 42:647–670

Carrasco AR, Ferreira Ó, Matias A, Pacheco A, Freire P (2012) Short-term sediment transport at a backbarrier beach. J Coast Res 27(6):1076–1084

Ceia F, Patricio J, Marquez J, Alveirinho-Dias J (2010) Coastal vulnerability in barrier islands: the high risk areas of the Ria Formosa (Portugal) system. Ocean Coast Manage 53:478–486

Chuvieco E (2000) Fundamentos de Teledeteccíon Espacial. Rialp, Madrid

Coelho CR, Silva F, Veloso-Gomes F, Taveira-Pinto F (2009) A vulnerability analysis approach for the Portuguese west coast. In: Popov V, Brebbia CA (eds) Risk Analysis V: Simulation and Hazard Mitigation. Institute of Technology, Wessex

Cooper JAG, McLaughlin S (1998) Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. J Coast Res 14:512–524

Crossett KM, Culliton PC, Wiley TJ, Goodspeed TR (2004) Population trends along the Coastal United States: 1980–2008. Coastal trends report series, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring

Crowell M, Buckley MK (1993) Calculating erosion rates: using long-term data to increase data confidence. Coastal Zone'93. ASCE, New York

Crowell M, Leikin H, Buckley M (1999) Evaluation of coastal erosion hazards study: an overview. J Coast Res 28:2–9

Crowell M, Hirsch E, Hayes T (2007) Improving FEMA's coastal risk assessment through the National Flood Insurance Program: an historical overview. Mar Technol Soc 41(1):5–14

De Pippo T, Donadio C, Pennetta M, Petrosino C, Terlizzi F, Valente A (2008) Coastal hazard assessment and mapping in Northern Campania, Italy. Geomorphology 97:451–466

Del Rio L, Gracia FJ (2009) Erosion risk assessment of active coastal cliffs in temperate environments. Geomorphology 112:82–95

Del Río L, Plomaritis TA, Benavente J, Valladares M, Ribera P (2012) Establishing storm thresholds for the Spanish Gulf of Cádiz coast. Geomorphology 143:13–23

Di Paola G, Iglesias J, Rodriguez G, Benassai G, Aucelli P, Pappone G (2011) Estimating coastal vulnerability in a meso-tidal beach by means of quantitative and semi-quantitative methodologies. J Coast Res SI 61:303–308

Dolan R, Davis RE (1992) An intensity scale for Atlantic coast northeast storms. J Coast Res 8:352–364

Dorsch W, Newland T, Tassone D, Tymons S, Walker D (2008) A statistical approach to modeling the temporal patterns of ocean storms. J Coast Res 24(6):1430–1438

Ergin A, Karaesmen E, Micallef A, Williams AT (2004) A new methodology for evaluating coastal scenery: fuzzy logic systems. Area 36:367–386

Esteves LS, Williams JJ, Brown JM (2011) Looking for evidence of climate change impacts in the eastern Irish Sea. Nat Hazard Earth Sys 11:1641–1656

FAO/UNEP (1999) The future of our land: facing the challenge. Guidelines for integrated planning for sustainable management of land resources. FAO—AGLS, Rome

García Mora MR, Gallego JB, Williams AT, García Novo F (2001) A coastal dune vulnerability classification. A case study of the SW Iberian Peninsula. J Coast Res 17(4):802–811

Goldsmith V (1985) Coastal dunes. In: Davis RA (ed) Coastal sedimentary environments. Springer, Berlin

Gornitz V (1991) Global coastal hazards from future sea level rise. Palaeogeogr Palaeocl 89:379–398

Gornitz VM, Daniels RC, White TW, Birdwell KR (1994) The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. J Coast Res 12:327–338

Gornitz VM, Beaty TW, Daniels RC (1997) A coastal hazards data base for the U.S. West coast. Oak Ridge National Laboratory, Oak Ridge

Gracia FJ, Rodríguez-Vidal J, Benavente J, Cáceres L, López Aguayo F (1999) Tectónica cuaternaria en la Bahía de Cádiz. In: Pallí L, Roqué C (eds) Avances en el estudio del Cuaternario. Univ. de Girona, Girona

Gracia FJ, Sanjaume E, Hernández L, Hernández AI, Flor G, Gómez-Serrano MÁ (2009) Dunas marítimas y continentals, Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid

Greenwood RO, Orford JD (2008) Factors controlling the retreat of Drumlin coastal cliffs in a low energy marine environment—Strangford Lough, Northern Ireland. J Coast Res 23(2):285–297

Hammer-Klose ES, Thieler ER (2001) Coastal vulnerability to sea-level rise, a preliminary database for the U.S. Atlantic, Pacific, and Gulf of Mexico coasts. U.S. Geological Survey, Charleston

Hartmann D (2006) Drowning and beach safety management along the Mediterranean beaches of Israel: a long-term perspective. J Coastal Res 22:1505–1514

IUCN (2008) Red list—State of the World's species. IUCN, Gland

Jenks GF, Caspall FC (1971) Error on choropletic maps: definition, measurement, reduction. Assoc Am Geo 61(2):217–244

Jiménez JA, Sanchez-Arcilla A, Valdemoro HI, Gracia V, Nieto F (1997) Processes reshaping the Ebro delta. Mar Geo 144:59–79

Komar PD (1998) Beach processes and sedimentation. Prentice Hall, New Jersey

Kraus NC, Millitello A, Todoroff G (2002) Barrier breaching processes and barrier spit breach, Stone Lagoon, California. Shore Beach 70(4):21–28

Leatherman SP (1983) Shoreline mapping a comparison of techniques. Shore Beach 51:28–33

Li K, Li GS (2011) Vulnerability assessment of storm surges in the coastal area of Guangdong Province. Nat Hazards Earth Syst Sci 11:2003–2011

Lillesand TM, Kiefer RW (1987) Remote sensing and image interpretation. Wiley, Toronto

Longuet-Higgins MS, Stewart RW (1963) A note on wave set-up. J Mar Res 21:812–814

Longuet-Higgins MS, Stewart RW (1964) Radiation stresses in water waves; a physical discussion, with applications. Deep-Sea Res 11:529–562

Maio CV, Gontz AM, Tenenbaum DE, Berkland EP (2012) Coastal hazard vulnerability assessment of sensitive historical sites on Rainsford Island, Boston Harbor, Massachusetts. J Coastal Res 28(1A):20–33

McLaughlin S, Cooper JAG (2010) A multi-scale coastal vulnerability index: A tool for coastal managers? Environ Haz 9(3):233–248

McLaughlin S, McKenna J, Cooper JAG (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497

Moore L (2000) Shoreline mapping techniques. J Coast Res 16(1):111–124

Moritz H, Moritz H (2006) Evaluating extreme storm power and potential implications to coastal infrastructure damage. 9th International workshop on wave hindcasting and forecasting, Victoria

Özyurt G, Ergin A (2009) Application of sea level rise vulnerability assessment model to selected coastal areas of Turkey. J Coast Res 51:248–251

Özyurt G, Ergin A (2010) Improving coastal vulnerability assessments to sea-level rise: a new indicator-based methodology for decision makers. J Coast Res 26(2):265–273

Pajak MJ, Leatherman S (2002) The high water line as shoreline indicator. J Coast Res 18(2): 329–337

Pendleton EA, Thieler ER, Jeffress SW (2005) Coastal vulnerability assessment of golden gate national recreation area to sea-level rise. USGS, Galesville

Pye K, Blott SJ (2008) Decadal-scale variation in dune erosion and accretion rates: an investigation of the significance of changing storm tide frequency and magnitude on the Sefton coast, UK. Geomorphology 102:652–666

Raji O, Niazi S, Snoussi M, Dezileau L, Khouakhi A (2013) Vulnerability assessment of a lagoon to sea level rise and storm events: Nador lagoon (NE Morocco). J Coast Res 65:802–807

Rangel N, Anfuso G (2013) Winter wave climate, storms and regional cycles: the SW Spanish Atlantic coast. Int J Climato 33:2142–2156

Santos M, Del Río L, Benavente J (2013) GIS-based approach to the assessment of coastal vulnerability to storms. Case study in the Bay of Cádiz (Andalusia, Spain). J Coast Res 65:826–831

Smith G, Zarillo G (1990) Calculating long-term shoreline recession rates using aerial photographic and beach profiling techniques. J Coast Res 6(1):111–120

Stockdon HF, Holman RA, Howd PA, Sallenger AH (2006) Empirical parameterization of setup, swash, and runup. Coast Eng 53:573–588

Sunamura T (1983) Processes of sea cliff and platform erosion. In: Komar PD (ed) Handbook of coastal processes and erosion. CRC Press, Boca Raton, USA

Sunamura T (1992) Geomorphology of rocky coasts. Wiley, New York

Thieler ER, Danforth W (1994) Historical shoreline mapping: improving techniques and reducing positioning errors. J Coast Res 10(3):549–563

Thieler ER, Hammer-Klose ES (2000) National assessment of coastal vulnerability to sea-level rise: preliminary results for the US Pacific coast. United States Geological Survey (USGS), Woods Hole

Thieler ER, Himmelstoss EA, Zichichi JL, Miller TL (2005) Digital shoreline analysis system (DSAS) version 3.0—an ArcGIS extension for calculating shoreline change. US Geological Survey, Woods Hole

Trenhaile AS (2002) Rock coasts, with particular emphasis on shore platforms. Geomorphology 48:7–22

Villa F, McLeod H (2002) Environmental vulnerability indicators for environmental planning and decision-making: guidelines and applications. Environ Manage 29:335–348

Williams AT, Davies P (2001) Coastal dunes of Wales: vulnerability and protection. J Coast Cons 7:145–154

Williams AT, Alveirinho-Dias J, Garcia Novo F, Garcia-Mora MR, Curr RH, Pereira A (2001) Integrated coastal dune management: checklists. Cont Shelf Res 21:1937–1960

Wright LD, Short AD (1984) Morphodynamic variability of surf zones and beaches: a synthesis. Mar Geol 56:93–118

Chapter 5
Spatial Distribution of Assessment Indexes

Abstract This chapter presents the results regarding with the variables chosen for the Risk index assessment. The presentation consists of a set of maps that show the distribution of the different indexes obtained.

5.1 Coastal Forcing Index (CFI)

The Coastal Forcing Index (CFI) was presented in Fig. 5.1 and Table 5.1 and showed values ranging from low to very high.

At Cartagena area, the CFI essentially showed medium to high values respectively for the 38 and 21 % of the littoral. Such values were recorded at Crespo, Marbella and Bocagrande sectors (Fig. 3.1). The rest of the coast (41 %) presented low CFI values.

At Cadiz area, high (30 %) and very high (34 %) values prevailed. They were mainly observed between Sancti Petri and La Victoria (Fig. 3.1) and covered a total length of 15 km. Medium CFI values were recorded at 14 % of the littoral, while low and very low values characterised the 20 and 2 % of the study area.

Obtained data suggested the dominance of medium to very high Coastal Forcing Index values that were related to the conjunction of several factors determining the way in which wave energy is distributed along the coastline:

(i) The absence of obstacles in front of them;
(ii) The degree of littoral exposure to waves;
(iii) The local bathymetric characteristics.

Specifically, coastal orientation determines the level of exposure to the main approaching wave direction (point 3, Table 4.1) and hence the prevalence of longshore or shore normal transport important in beach and dune erosion (García Mora et al. 2001), meanwhile bathymetric conditions determine wave shoaling and dissipation, which determine points 1 and 2 in Table 4.1. The rectilinear orientation of the coastline and the homogeneous characteristics of the nearshore area allow the

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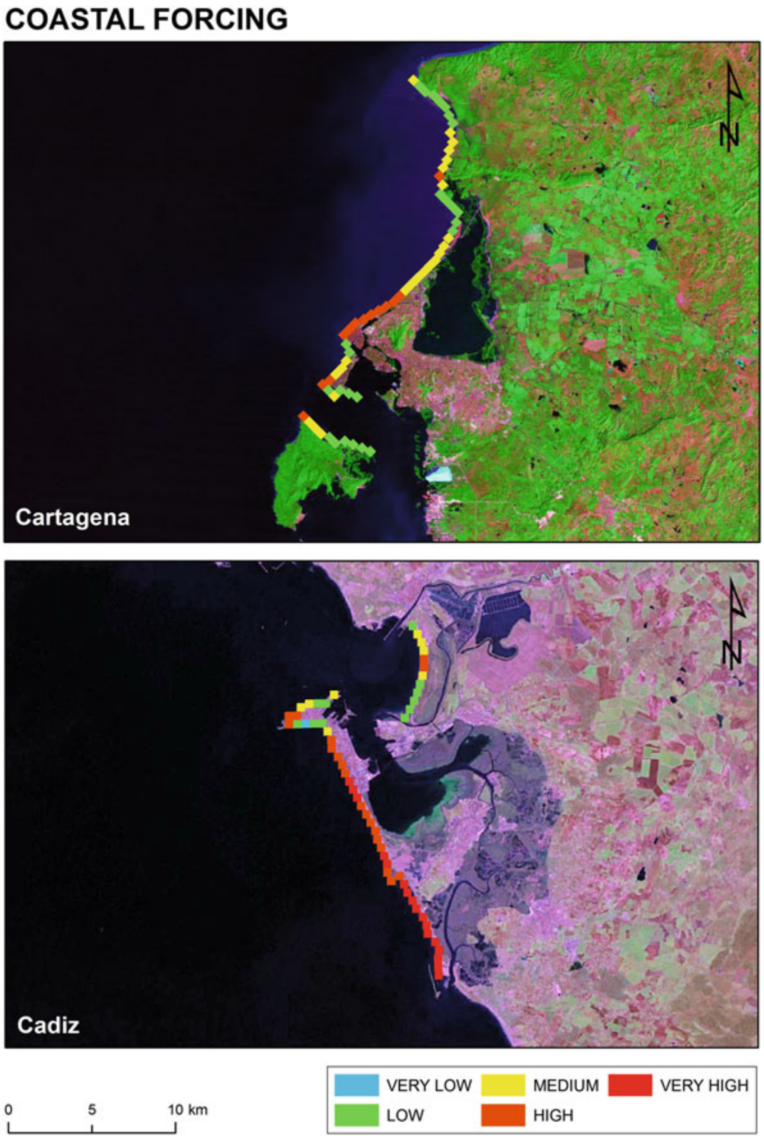

Fig. 5.1 Coastal forcing index calculated for Cartagena and Cadiz areas

arrival of high energy waves with associated, elevated storm surge values at both sites. Further, the higher values of CFI observed at Cadiz (with respect to Cartagena) are linked to the greater exposition of this coast; it is parallel to the incoming wave fronts which predominantly approach from the SW (Rangel and Anfuso 2013). At both sites, low CFI values were observed in sheltered areas, namely

Table 5.1 Distribution of coastal forcing index calculated for Cartagena and Cadiz areas

Coastal forcing		
Class	%	
	Cartagena	Cadiz
Very low	0.0	1.8
Low	41.0	19.6
Medium	37.7	14.3
High	21.3	33.9
Very high	0.0	30.4

Valdelagrana spit in Cadiz (Benavente et al. 2006; Anfuso et al. 2008) and at the different bays located at the northern part of Cartagena coast (Moreno et al. 2006; Rangel et al. 2011; Ortiz 2012).

5.2 Susceptibility Index (SI)

The Susceptibility Index distribution along Cartagena and Cadiz areas was presented in Fig. 5.2 and Table 5.2.

The Cartagena area was mainly classified (62 %) inside the medium class of susceptibility. Results showed how this was the case of Bocagrande—La Boquilla sector, a series of dissipative urban beaches with medium to high erosion rates (Fig. 3.1; Rangel and Posada 2013) which score is improved because of the high degree of armouring (Rangel et al. 2011; Stancheva et al. 2011). High (28 %) and very high (5 %) SI values were recorded at Tierrabomba and the Northern part of Cartagena area (Fig. 3.1), where small cliffs of soft diapiric Tertiary materials, composed by faulted and weathered sandstones and clays, are directly exposed to wave action and experience important retreat rates (Correa and Alcántara 2005; Martinez et al. 2010; Rangel and Posada 2013). Low SI values do not exceed the 6 % of the area.

The Cadiz area recorded high values of SI along the 57 % of its extension. Such values are mainly observed along the central—southern sector of Valdelagrana spit and from Cortadura beach to Sancti Petri (Fig. 3.1), a dissipative to intermediate series of beaches with significative erosion rates, low values of dune height, high percentage of washovers and low human interventions (Del Rio and Gracia 2009; Rangel and Anfuso 2013). Lastly, low (29 %) and medium (14 %) values are distributed along the urban littoral of Cadiz area; such values are related to the presence of wide dry beaches, usually 3 times the ICZ width.

Few hard coastal protection structures are observed at Cadiz, the ones that occur are essentially seawalls and revetments. Conversely, at Cartagena, numerous groins and breakwaters have been built over the past 50 years (Rangel et al. 2011; Stancheva et al. 2011). One hundred groins, with a total length of about 4 km, are observed between the Bocagrande and Crespo sectors, which showed medium

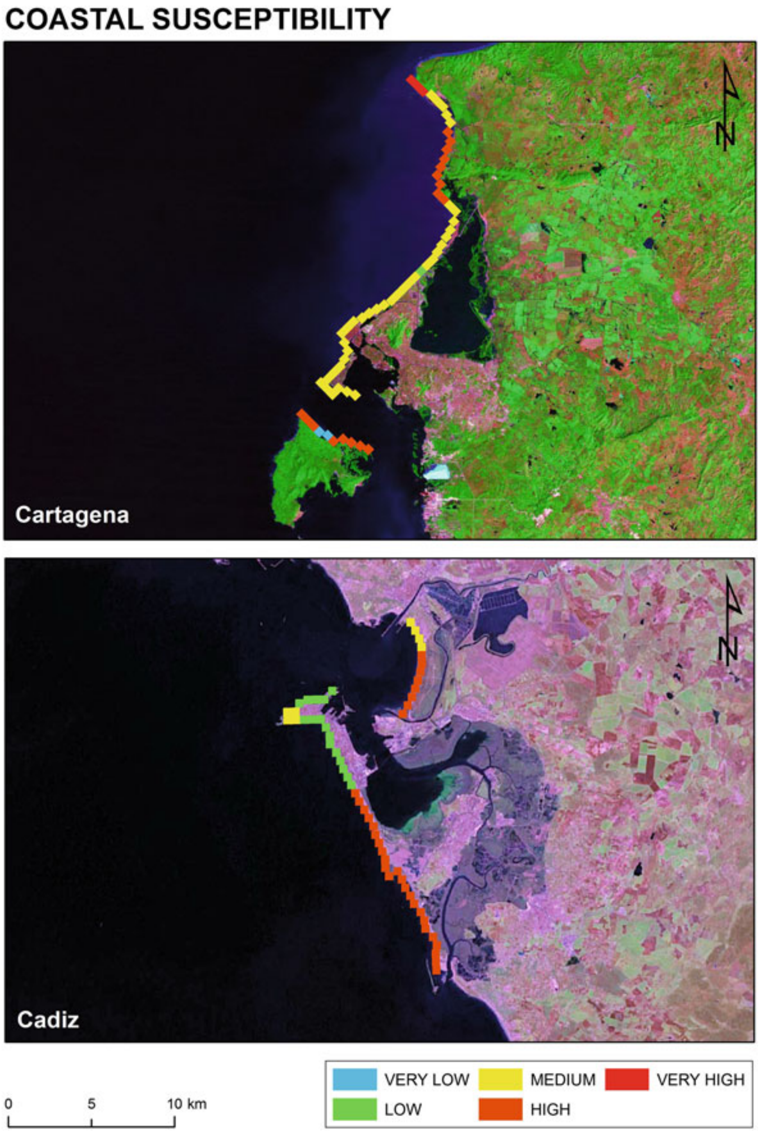

Fig. 5.2 Susceptibility index calculated for Cartagena and Cadiz areas

susceptibility values. These groins are impermeable and made of blocks of calcareous rocks obtained from Tertiary rocks extracted from nearby quarries, with an average cost of 20 €/m^3. Presently, the groins have locally stopped erosion creating a narrow, swash aligned coastline with a typical "zig-zag" shoreline trend.

Despite the level of armouring decreasing coastal risk, many adverse effects occur: loss or damage of the natural landforms; irreversible coastline modifications;

Table 5.2 Distribution of susceptibility index calculated for Cartagena and Cadiz areas

Coastal susceptibility		
Class	%	
	Cartagena	Cadiz
Very low	4.0	0.0
Low	1.6	28.6
Medium	62.3	14.3
High	27.9	57.1
Very high	4.2	0.0

interruption or reduction of sediment input from the eroding cliff to the adjacent beaches; aggravation of downdrift erosion; loss of valued sand material from the beach and shallow water-area during construction of the structures; negative visual impacts; lost access for swimmers to the water-area; dangerous bathing conditions and “coastal squeeze” (Pilkey and Dixon 1996; Doody 2004; Cooper and Pilkey 2012; Rangel et al. 2013).

Both investigated areas have intrinsic parameters for which coastal zone managers can do little or nothing to decrease susceptibility, so emphasis should be given to assessing ways of improvement and upgrading other ones. Concerning sand coasts, in order to counteract coastal retreat and decrease coastal susceptibility, dune ridges can be strengthened by implanting vegetation, nourish the dunes, emplace dune fences and reduce the extension and/or eliminate the washover fans. Nourishment works devoted to form wide dissipative beaches constitute a way of improving points 3 and 4 (Table 4.2). Such nourishment works and dune recovery initiatives are environmentally friendly and improve natural habitat and coastal scenic characteristics (Rangel et al. 2013).

5.3 Hazard Index (HI)

Hazard is the probability of occurrence of a potential damaging phenomenon (in this case, storm event) within a specific period of time and within a given area (Varnes 1984). The HI shows the potential of different sectors to experience significative damages associated with the effect of storm wave events (Fig. 5.3; Table 5.3) and it is the result of the crossing of Forcing and Susceptibility Indexes.

In the Cartagena area, the Hazard Index presented low to high values. Medium values were clearly dominant, accounting for the 60 % of the coastline—essentially the Crespo—Marbella sector (Fig. 3.1). High values accounted for 35 % of the coastline, occurring in Bocagrande, El Laguito and Tierrabomba sectors (Fig. 3.1). Low hazard values covered just over the 5 % of the coastline in areas essentially located north of Cartagena.

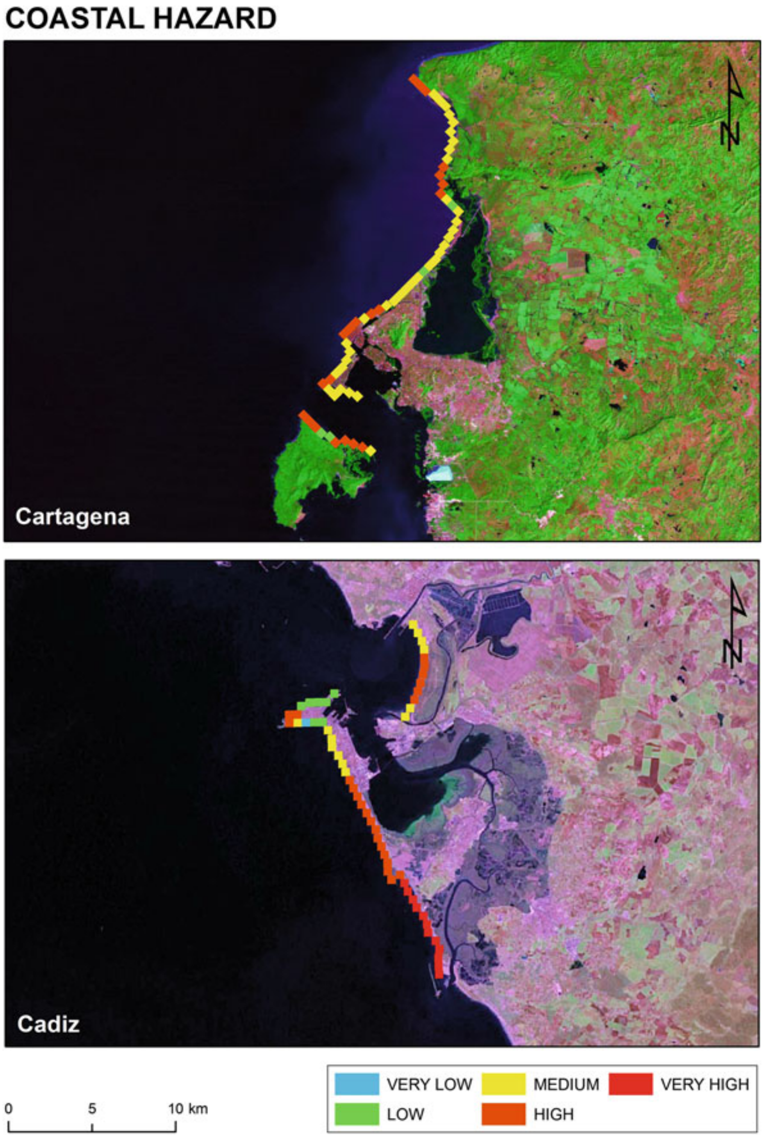

Fig. 5.3 Hazard index calculated for Cartagena and Cadiz areas

Along the Cadiz littoral, high and very high values of HI prevailed with a total amount of 62 % of the coastline; such values were linked to the high level of exposition of the littoral (e.g. high and very high values of the SI). Specifically, very high HI values, occurring between Camposoto—Sancti Petri sector, accounted for 21 % of the coast. High values (41 %) were observed at Cortadura sector and along the central—southern sector of Valdelagrana spit. Medium HI values

Table 5.3 Distribution of hazard index calculated for Cartagena and Cadiz areas

Coastal hazard		
Class	%	
	Cartagena	Cadiz
Very low	0	1.79
Low	6.56	12.5
Medium	59.02	23.21
High	34.42	41.07
Very high	0	21.43

were observed along 24 % of the coast and were recorded in the urban beaches of El Puerto de Santa Maria (northern sector of Valdelagrana spit) and La Victoria—Santa Maria sector (Fig. 3.1). Low values were distributed along the 15 % of the coast and included areas (i.e. the historic centre of Cadiz) protected by defence structures, essentially seawalls.

The areas with high and very high HI values presented important erosion rates in past decades. An elevated percentage of areas with high and very high values of HI, gave erosion rates that exceeded 1.5 m yr^{-1} (Fig. 5.4), as observed by Correa and Alcántara (2005) in Cartagena, and by Rangel and Anfuso (2013) in Cadiz area.

Fig. 5.4 Examples of coastal erosion along Cartagena and Cadiz areas. Cliff erosion at Tierrabomba (**a**), erosion and rip-rap revetment at Bocagrande (**b**) and Marbella (**c**) beaches, sequence of coastal erosion at Valdelagrana beach, 16-11-2009 (**d**), 06-01-2010 (**e**), 12-03-2010 (**f**), and 24-12-2010 (**g**)

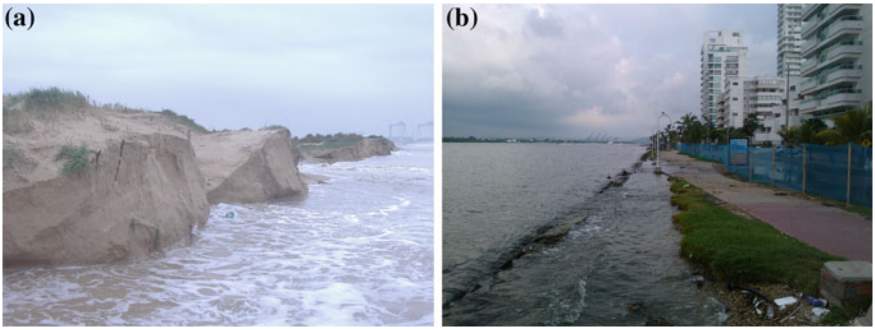

Fig. 5.5 Coastal flooding along Cartagena and Cadiz areas. Flooding at Valdelagrana beach **a** due to a storm event occurred December 2009, and **b** at Cartagena city because of spring tides

In this sense, such good correspondence confirms the validity of the applied methodology, e.g. the higher the Hazard Index the greater the recorded erosion, as observed in similar circumstances in Northern Ireland by McLaughlin et al. (2002).

Coastal flooding is the other process linked with very high and high values of HI. In both investigated areas most damaged sectors are affected by elevated values of run up recorded during extreme wave conditions (Fig. 5.5). Recent examples of this phenomenon were observed during December 2009 and January 2010 when the run up related to extreme wave conditions reached values of 0.50 m in Cartagena (Andrade et al. 2013) and 0.65 m in Cadiz (Rangel 2013).

5.4 Vulnerability Index (VI)

The Vulnerability Index (VI) allows evaluation of the potential impacts of extreme storm events in a socioeconomic, ecological and heritage frameworks. Significant variations can be found within each one of the investigated areas and among them. The different vulnerability indexes are presented in Fig. 5.6 and Table 5.4.

5.4.1 Socioeconomic Index (VsI)

In Cartagena, very high and high values of the Socioeconomic VsI were observed in 67 % of the area, associated with the most densely populated sectors which presented a high percentage of urbanised area (i.e. Tierrabomba, Bocagrande, Marbella and Crespo—Fig. 5.6 and Table 5.4). A similar behaviour was observed in Cadiz associated with the high concentration of population that is located between the historic centre of Cadiz and Cortadura sector, covering about 45 % of the total area (Fig. 5.6; Table 5.4). Very low and low values of VsI were found along low human

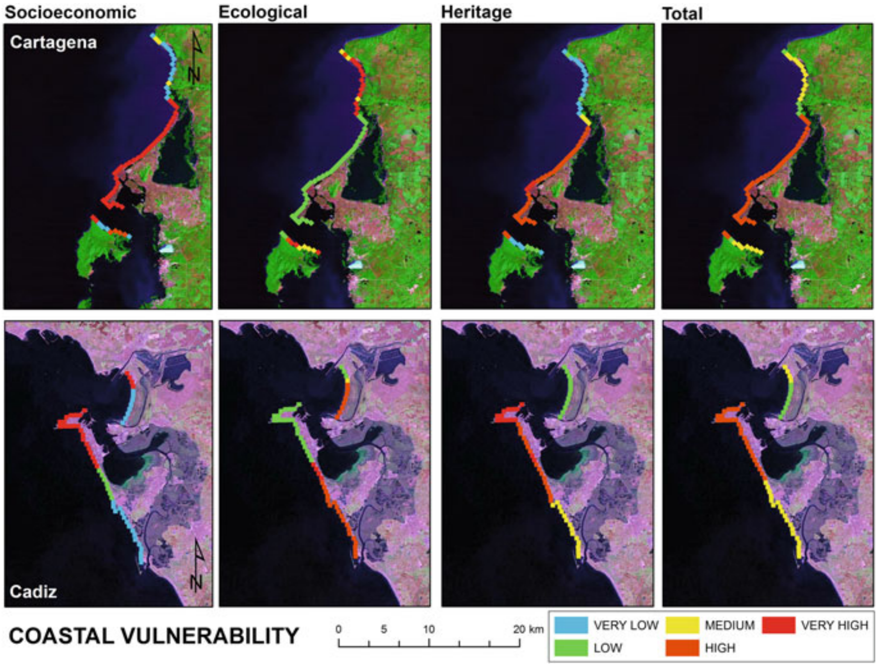

Fig. 5.6 Vulnerability indexes calculated for Cartagena and Cadiz areas

intervention areas such as the northern part of Cartagena and the southward of the Valdelagrana spit—Camposoto beach in Cadiz, reaching values of 28 and 51 % respectively. Medium values of this index (5 %) were observed just in specific areas in the north of Cartagena (Fig. 5.6; Table 5.4).

The distribution of the VsI suggests that variables such as land use and population density determine the degree of coastline impacts associated with extreme storm events. Such observations are in concordance with Del Rio and Gracia (2009) and McLaughlin et al. (2002). These authors suggested that the variability of land use type is the most effective variable in the discrimination of impact levels, in this case from a socioeconomic point of view. Later authors stated that the number of people living on a specific area is a major issue in the analysis of any type of risk. Further, population density constitutes a key factor in the calculation of the Socioeconomic VsI because of its relative nature that makes it obviously more widely applicable than absolute population features (Rygel et al. 2006; Del Rio and Gracia 2009). Likewise, the population density has a double implication in the VsI determination: (i) it is associated with the susceptibility because it is directly affected by storm waves and (ii) it can contribute to coastal erosion.

Table 5.4 Distribution of vulnerability index calculated for Cartagena and Cadiz areas

Coastal vulnerability								
Class	%							
	Cartagena				Cadiz			
	Socioeconomic	Ecological	Heritage	Total	Socioeconomic	Ecological	Heritage	Total
Very low	27.9	0.0	31.2	0.0	42.86	0	0	0
Low	0.0	60.7	8.2	8.2	12.5	42.86	21.43	14.29
Medium	4.9	12.0	4.9	31.1	0	1.79	25	41.07
High	6.6	3.3	50.8	60.7	0	48	28.57	44.64
Very high	60.7	24.1	4.9	0.0	44.64	7.14	25	0

5.4.2 Ecological Index (VeI)

The integration of ecological designations inside of any kind of vulnerability assessment represents a great challenge (McLaughlin et al. 2002). The main problems arise in deciding how to rank specific sites. 'Protection' of a conservation site can hardly include protection from the action of natural wave forcing processes which formed it.

In this study, the Ecological Vulnerability Index (VeI) was calculated considering the presence of protected areas, natural vegetation cover and the level of human intervention (Fig. 5.6; Table 5.4). The calculation of the VeI along Cartagena and Cadiz areas showed values inversely proportional to the calculated VsI.

Results showed very high and high values of the VeI, in the order of 28 and 55 % respectively for Cartagena and Cadiz areas (Fig. 5.6; Table 5.4). This difference was due to the fact that Cadiz area presented—compared to Cartagena—an elevated number of areas with a certain ecological significance and/or protection status. Examples of them (Fig. 3.1) were Valdelagrana spit and Camposoto—Sancti Petri sector which respectively belong to the "Marisma de los Toruños y Pinar de La Agaida" metropolitan Park and the "Bahia de Cadiz" Natural Park.

On the other hand, low values of VeI were observed in 61 % of the Cartagena area—because of the high degree of human intervention, and 45 % of the Cadiz area. Medium classes reached values of 12 and 2 % for Cartagena and Cadiz, respectively (Fig. 5.6; Table 5.4).

5.4.3 Heritage Index (VhI)

Archaeological and historical monuments are very important in economic and social terms because they form part of the cultural resource and are irreplaceable (McLaughlin et al. 2002). In a "perfect" scenario, archaeological and historical monuments should be analyzed stand-alone and in detailed way.

The international and national interest, linked to cultural and heritage reasons, lead to very high and high values of VhI for Cartagena (65 %) and Cadiz (53 %), as is shown in Fig. 5.6 and Table 5.4. Areas of interest were represented by the historic centers of both cities that face the sea and are protected by forts and walls. Of special interest was Tierrabomba sector in Cartagena (Fig. 3.1). It showed high values because is the native and residence area of an ethnic minority group with the legal status of "national interest".

The combination of all the Vulnerability indexes gave a general sense of the vulnerability of the study areas (Fig. 5.6; Table 5.4). The total vulnerability index for both areas ranged from low to high values. Specifically, in Cartagena, high values were clearly dominant, accounting for the 61 % of the coastline. Medium values accounted for the 31 % while low values were observed along the 8 %. Along Cadiz area, the distribution of medium and high values predominated with 45 and 41 % respectively, while low values were recorded along the 14 % of the coastline.

5.5 Risk Index (RI)

Any kind of Risk Assessment must include the two separate components that constitute the Risk, in this case the Hazard Index (HI) and the associated impact expressed by means of the Vulnerability Index (VI; Birkmann (2007). In this sense, both indexes (HI and VI) were combined into the Risk Index (RI) which is a numerical value obtained by means of a weighted average of both indexes according to the number of variables (Del Rio and Gracia 2009; Santos et al. 2013).

The value of the Risk Index (RI) can be defined as the combination of the probability of an event (extreme storm waves) and its negative consequences in a socioeconomic, ecological and heritage contexts. Socioeconomic, Ecological, Heritage and Total RI results are presented in Fig. 5.7 and Table 5.5.

From a socioeconomic point of view, the Risk assessment showed that most sensible zones were located along urbanized areas of Cartagena (Tierrabomba, Bocagrande, Crespo) and Cadiz (from Cortadura to La Victoria sector—Figs. 3.1 and 5.7; Table 5.5). Previously mentioned data showed a strong relation between wave energy, coastal erosion, associated vulnerability and the characteristics of human interventions.

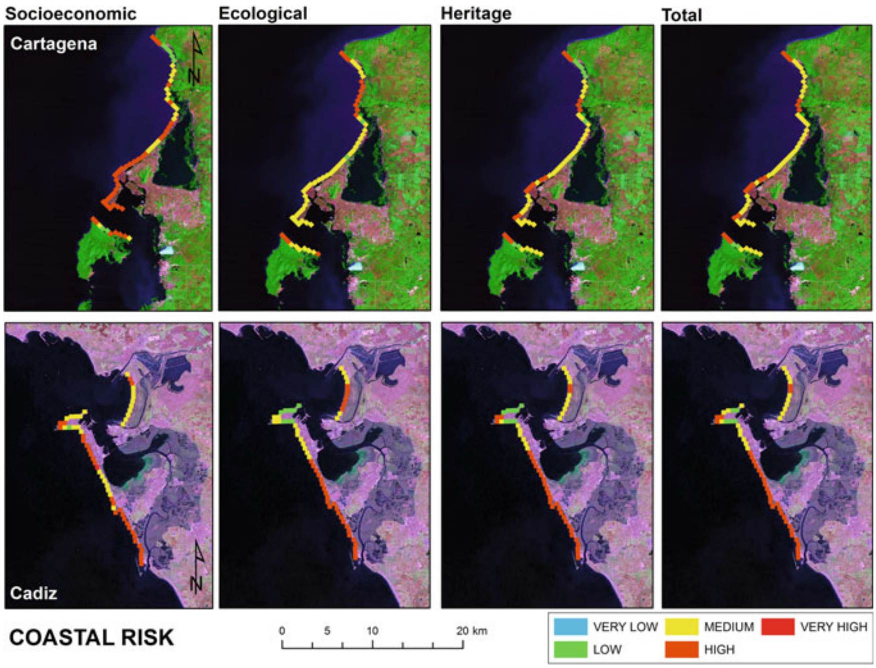

Fig. 5.7 Risk indexes calculated for Cartagena and Cadiz areas

Table 5.5 Distribution of risk index calculated for Cartagena and Cadiz areas

Coastal risk								
Class	%							
	Cartagena				Cadiz			
	Socioeconomic	Ecological	Heritage	Total	Socioeconomic	Ecological	Heritage	Total
Very low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low	11.5	3.3	13.1	3.3	1.8	14.3	14.3	8.9
Medium	27.9	72.1	60.7	70.5	46.4	32.1	30.4	35.7
High	60.7	24.6	26.2	26.2	50.0	53.6	55.4	55.4
Very high	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0

The Ecological Risk (Ecological RI) represented the probability of loss in areas with certain level of ecological importance (i.e. natural parks). Along Cartagena area, it was observed the dominance of medium values; meanwhile high values prevailed along Cadiz area (Fig. 5.7; Table 5.5).

The Heritage risk assessment (Heritage RI) showed how the areas of high risk coincided with the historic centre of Cartagena and Sancti Petri—Cortadura sector in Cadiz (Figs. 3.1 and 5.7; Table 5.5).

The combination of each one of the previously RI indexes brought to the determination of the general panorama of Risk along the investigated areas (Fig. 5.7; Table 5.5).

References

Andrade CA, Thomas YF, Nicolae Lerma A, Durand P, Anselme B (2013) Coastal flooding hazard related to swell events in Cartagena de Indias, Colombia. J Coastal Res 29(5):1126–1136

Anfuso G, Benavente J, Del Rio L, Gracia FJ (2008) An approximation to short term evolution and sediment transport pathways along the littoral of Cadiz Bay (SW Spain). Environ Geol 56:69–79

Benavente J, Del Río L, Gracia FJ, Martínez JA (2006) Coastal flooding hazard related to storms and coastal evolution in Valdelagrana spit (Cadiz Bay Natural Park, SW Spain). Cont Shelf Res 26:1061–1076

Birkmann J (2007) Risk and vulnerability indicators at different scales: applicability, usefulness and policy implications. Environ Haz 7:20–31

Cooper JAG, Pilkey O (2012) Pitfalls of shoreline stabilization. Springer, Berlin

Correa ID, Alcántara J (2005) Historical and recent shore erosion along the Colombian Caribbean coast. J Coast Res 49:52–57

Del Rio L, Gracia FJ (2009) Erosion risk assessment of active coastal cliffs in temperate environments. Geomorphology 112:82–95

Doody JP (2004) ‘Coastal squeeze’—an historical perspective. J Coast Conserv 10(1–2):129–138

García Mora MR, Gallego JB, Williams AT, García Novo F (2001) A coastal dune vulnerability classification. A case study of the SW Iberian Peninsula. J Coast Res 17 (4):802–811

Martínez J, Yokoyama Y, Gómez A, Delgado A, Matsuzaki H, Rendón E (2010) Late Holocene marine terraces of the Cartagena region, southern Caribbean: the product of neotectonism or a former high stand in sea-level? J South Am Earth Sci 29:214–224

McLaughlin S, McKenna J, Cooper JAG (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497

Moreno D, Agamez M, Castro E, Voulgaris G (2006) Beach morphology and coastal protection along headland bays in Cartagena, Colombia. J Coast Res 39:1658–1664

Ortiz JC (2012) Exposure of the Colombian Caribbean coast, including San Andrés Island, to tropical storms and hurricanes, 1900–2010. Nat Hazards 61:815–827

Pilkey O, Dixon K (1996) The corps and the shore. Island Press, Washington

Rangel N (2013) Efectos de temporalis maritimos en sistemas litorales de la provincial de Cádiz. Ph.D. thesis, Cadiz University, Cadiz

Rangel N, Anfuso G (2013) Winter wave climate, storms and regional cycles: the SW Spanish Atlantic coast. Int J Climato 33:2142–2156

Rangel N, Posada B (2013) Determinación de la vulnerabilidad y el riesgo costero mediante la aplicación de herramientas SIG y métodos multicriterio en la línea de costa. Caribe Colombiano Intropica 8(1):31–44

Rangel N, Stancheva M, Anfuso G (2011) Effects of coastal armouring in the Bolivar department (Caribbean Sea of Colombia). Prob Geogr 1–2:97–106

Rangel N, Anfuso G, Correa I, Ergin A, Williams AT (2013) Assessing and managing scenery of the Caribbean Coast of Colombia. Tourism Manage 35:41–58

Rygel L, O'Sullivan D, Yarnal B (2006) A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country. Mitig Adapt Strat Glob Change 11:741–764

Santos M, Del Río L, Benavente J (2013) GIS-based approach to the assessment of coastal vulnerability to storms. Case study in the Bay of Cádiz (Andalusia, Spain). J Coast Res 65:826–831

Stancheva M, Rangel N, Anfuso G, Palazov A, Stanchev H, Correa I (2011) Expanding level of coastal armouring: case studies from different countries. J Coast Res 64:1815–1819

Varnes DJ (1984) Landslide Hazard Zonation: a review of principles and practice. Commission on landslides of the IAEG, UNESCO

Chapter 6
Final Reflections

Abstract This chapter discusses the management, validation and methodological concerns related with the risk assessment to storms presented in this book and gives ideas about the implications of the use of this methodology as a tool for coastal planning and management.

6.1 Data Management

The use and implementation of different kinds of information into a GIS project, e.g. wave data propagation, geomorphologic units, etc., and the generation of new one by means of spatial analysis, allowed the creation of an initial data base containing the hazard, vulnerability and risk assessment for Cartagena and Cadiz areas.

The obtained information can be easily used in its entirety or partially, i.e. at different levels and scales, by local planning staff or other kind of end users according to their specific goals, for example environmental programs, tourism and coastal zone management plans, etc.

Further, according to Nunes et al. (2009), the use of GIS tools allow the collection of a great amount of different data and, one of its main advantages, is the possibility of constantly update the initial information with new sets of data. In this sense variables as significant wave height, land uses, percentage of urbanised areas, population density, among others, can be easily integrated, spatially analysed and updated into a GIS environment in order to provide an Integrated Coastal Zone Management plan (Fischer and Arredondo 1999; Anfuso and Gracia 2005).

The used method gives an "instantaneous picture" analysis of coastal risk to storm wave related hazard for a given area. In fact, great advantages of the proposed method are the fact that it is based on recent coastal evolution and erosion processes effects as well as its flexibility and adaptability to the specific features of each area to be investigated. In this sense it represents a basic and appropriate evaluation tool previous to the elaboration of any kind of coastal management plan.

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The application of the proposed methodology allowed to classify Cartagena and Cadiz as medium to high risk areas, with an absence of very high and very low risk zones. Such results can be broadly compared with previous studies carried out in the investigated sites by Rangel and Posada (2013) and Santos et al. (2013) for Cartagena and Cadiz areas respectively.

Rangel and Posada (2013) and Santos et al. (2013) investigations took into account a methodology close to the one proposed in the present study. Former authors considered two groups of parameters (physical and social) which categorization gave rise to three classes of vulnerability, meanwhile five groups of parameters were considered in the present study (forcing, susceptibility, socioeconomic, conservation and heritage), which allowed to classify the coast into five classes of vulnerability.

Considering that the Physical Vulnerability Index of Santos et al. (2013) and Rangel and Posada (2013) were broadly similar to the proposed Hazard Index, it is possible to highlight a good correspondence for both areas with the results presented in this study. In the same way, the Social Vulnerability Index presented by previous authors was very similar to the Socioeconomic Vulnerability Index calculated in this study; a good correspondence was observed for the classification of urban areas, which were ranked within the "very high" vulnerability class.

At regional scale, Ojeda-Zujar et al. (2009) classified the entire coastline of Andalusía; Cadiz zone was categorised as a "very high" vulnerability area. No regional or local classification exists for the Caribbean coast of Colombia, the Rangel and Posada (2013) work and the present one being the only existing assessments.

6.2 Index Validation

New methodological approaches to hazard, vulnerability and risk assessment should be tested and validated before being considered adequate for their purposes (Cooper and McLaughlin 1998).

Results obtained in this work have shown that 90 % of the Cartagena and Cadiz coastlines are subjected to medium to high erosion risk related to storm events, e.g. are potentially affected by shoreline retreat processes.

The methodology proposed by McLaughlin et al. (2002) was used in this work to test the obtained results by comparing coastal risk with the coastline evolution recorded during the 1983–2013 period. Erosion/accretion trends constituted a variable that has been taken into account in many regional and local studies (Gornitz et al. 1994; Abuodha and Woodroffe 2006; Coelho et al. 2009; McLaughlin and Cooper 2010) but in this case it has not taken into account because it is partially included within the calculation of points 3 and 9 of Tables 4.2 and 4.3 concerning the dry beach and the cliff edge width, which were expressed as a function of the Imminent Collapse Zone (and hence retreat rates).

In order to confirm this, the linear multiple regression method was used for each segment of the studied coastline to evaluate the existing correlation between the calculated Risk Index (RI) and coastline evolution (CE), by means of the following expression:

$$\mathrm{RI} = \mathrm{f}(\mathrm{CE}) \tag{6.1}$$

In order to corroborate the validation processes, coastal evolution was expressed by means of tree different methods: the Net Shoreline Movement (NSM), the End Point Rate (EPR) and the Linear Regression (LRR), Himmelstoss (2009).

Results of this validation are presented in Table 6.1 and show a tolerable goodness of fit of the multiple regression model according to the coefficient of multiple determinations R^2, with around 83 % of the variation in the RI being explained by the model.

If the value of the Risk Index is not in acceptable accordance with coastal evolution data, other important factors—not included in the index—are influencing coastline erosion (Del Rio and Gracia 2009). This was not the case for the present study, this way confirming the validity of used method and the absence of external, local factors that can affect coastal retreat.

6.2.1 Methodological Concerns

The present work deals with a topic of great importance. Natural disasters have huge negative impacts on human activities and structures as well as on social and political concerns of human life and on ecological and conservation aspects (McLaughlin et al. 2002; Li and Li 2011). Further, even if disasters are due to natural processes, the associated impacts are many times increased by human interventions/actuations such as an inexistent or inappropriate coastal planning (Komar and Allan 2008; Jones and Phillips 2011).

Natural hazards and disasters are a common occurrence in many developed and developing countries, and produce important economic losses. In the United States of America, during the past decade (2000–2009), flooding, severe storms and hurricanes have been responsible for economic loses estimated in more than $1.14 billion. In 2013, a total of 19 disasters affected around 552,000 peoples in Latin America and the Caribbean, and Philippines was strike by a huge typhoon which

Table 6.1 Results of the linear multiple regression analysis performed in order to validate the Risk Index

RI = f (NSM)		RI = f (EPR)		RI = f (LRR)	
Multiple R	0.73	Multiple R	0.83	Multiple R	0.78
Multiple R^2	0.70	Multiple R^2	0.77	Multiple R^2	0.75
Adjusted R^2	0.68	Adjusted R^2	0.74	Adjusted R^2	0.68

produced the displacement of 4.1 millions of people, 6,069 fatalities and the damage and destruction of 1.1 million houses (Méndez-Lázaro et al. 2014).

Previous data underline the importance and interest of further research on such topics in order to full understand natural process and valuate coastal risk to mentioned events, in this case storm events. Since the goal of this study was to develop a general methodological approach easily and objectively applicable at different areas, the evaluation of the Coast risk index to storms was based on an objective and quantitative methodology to remove uncertainty and subjectivity.

The methodological approach development in this work has been designed with the objective of being a scientifically complete planning tool, easy to use, that takes into consideration the higher amount of factors involved into the risk related to storms. It consists in a relatively simple series of indexes applicable to different coastal areas, becoming a general and not site-specific method.

One of the points to be taken into account in the application of the indices is the zoning, e.g. the method used to define coastal sectors (McLaughlin and Cooper 2010). For this work, in order to have an optimum zoning scheme, each one of the investigated variables was calculated along a constant and uniform coastal stretch of 500 × 500 m. This was easily accomplished for the Cartagena and Cadiz sites due to the previous general knowledge of the areas.

Many considered parameters and their division in the five-classes considered intervals, were not expressed by means of predefined absolute values, which can greatly range from one place to another, but using specific, calculated absolute values referred to (and representative of) used parameters at investigated places.

In most other cases, in order to qualitatively or quantitatively describe some specific parameter and to slow down subjectivity in defining its division into five classes, the parameter definition and variance were established according to existing previous studies carried out on considered specific subjects.

Of special attention in this kind of assessments is the scale of work due to the spatial resolution of the used zoning because obtained results will be strongly linked to the spatial scale. Given that hazard, vulnerability and risk assessments have to be evaluated for coastal management purposes, spatial resolution of the segmentation must be in agreement with the level at which it is projected to support stakeholders and management decision-making (i.e. local, regional and national). Cooper and McLaughlin (1998) defined that any kind of index should indicate the approximate range of areas or distances over which it is valid, since the scale of the index greatly influences the feasibility and convenience of inclusion of certain variables.

Within the Forcing Index (Table 4.1), the threshold value of significant wave height corresponding to storm conditions for an investigated area was not proposed in a subjective way (Abuodha and Woodroffe 2006; Di Paola et al. 2011; Santos et al. 2013; etc.) but was determined according to the methodology proposed by Moritz and Moritz (2006), as it is strictly dependent on the local wave climate. The Storm surge, which has a great importance in coastal erosion, was also obtained in a similar way by calculating it for each specific site and not proposing an absolute, predefined value (Di Paola et al. 2011; Bosom and Jiménez 2011).

Further, the degree of coastal exposition to wave fronts, usually described in a subjective and qualitative manner (high/low, etc.), was characterised according to specific studies on sand coast exposure carried out by García Mora et al. (2001) who defined such parameter according to the angle formed by approaching waves with the coastline. Waves that approach parallel to the coast give rise to a predominant cross-shore transport and associated high erosion of dry beach and dunes; waves which approaching angle is oblique, give rise to alongshore transport and less important beach and dune damage (García Mora et al. 2001; McLaughlin and Cooper 2010).

Concerning tidal range, different opinions exist. In studies carried out at a local scale, this variable is usually not taken into account because no spatial variations are observed. In regional studies, Gornitz (1990), Abuodha and Woodroffe (2006) and Coelho et al. (2009), considered microtidal areas less vulnerable to erosion/inundation processes and SLR. Other authors, e.g. Ozyurt et al. (2008), McLaughlin and Cooper (2010) and Di Paola et al. (2011), considered microtidal environments as more vulnerable areas because erosion processes take place in a narrow littoral zone, and this was the posture adopted in this study.

With respect to the Susceptibility Index for both sandy and rocky coasts (Tables 4.2 and 4.3), specific works of Gracia et al. (1999) and García Mora et al. (2001) were used to determine the heatless of dune ridges (Table 4.2). A well developed dune ridge constitutes a barrier to erosion/inundation processes (Abuodha and Woodroffe 2006) and a natural reservoir of sediments (Gracia et al. 1999). Conversely, washover fans interrupt the spatial continuity of the dune ridges and constitute preferential ways of inundation (García Mora et al. 2001).

Despite such parameters having great importance in the determination of coastal susceptibility to erosion/inundation processes, they were not (or were only partially) considered in many existing studies (McLaughlin et al. 2002; Li and Li 2011). The importance of dune ridge health in preventing inundation processes was also highlighted by Crowell et al. (2007, 2010). These authors determined on the presence of primary frontal dunes, areas subject to coastal flooding and "high-velocity waters" for the elaboration of risk maps for the Federal Emergency Management Agency of U.S.A.

Well known works of Bieniawski (1989) and Sunamura (1992) were used to characterise rocky coast features such as coastal type, lithology, structures, etc. (Table 4.3).

Similarly within the Susceptibility Index for sandy and rocky coasts, parameters such as the "Dry beach width" and "Cliff edge width" were defined in an objective way according to local retreat rates following the methodology of Anfuso et al. (2013) and not considering the absolute values (Abuodha and Woodroffe 2006; De Pippo et al. 2008; Di Paola et al. 2011; Raji et al. 2013; Santos et al. 2013) that can range a lot from one place to another and whose magnitude is, in any case, related to local retreat rates.

The level of armouring and associated classes was expressed according to the classic work of Aybulatov and Artyukhin (1993) but different interpretations exist concerning the effectiveness of hard protection structures. Following Pilkey and

Dixon (1996) and Anfuso and Nachite (2011), coastal defence structures quite often stabilise the coastal sector directly protected but give rise to erosion problems in downdrift areas according to the "domino" effect. Jones and Basco (1996) and Basco (1999, 2004) emphasised that there are many misconceptions behind the perception that seawalls increase erosion and destroy beaches. They argued that the scientific literature is full of misleading statements and after analysing long series of data, concluded that most negative effects attributed to seawalls have been proved to be wrong. Basco (1987) commented that, *volume erosion rates* are *not higher in front of seawalls but seasonal sand volume variability in front of walls is generally greater than at non-walled locations. Winter season waves drag more sand offshore but summer swell waves pile more sand up against walls in beach rebuilding.*

McLaughlin et al. (2002) considered coastal protection structures as indicators of erosion either actual or threatened. Even with coastal defences, continuing wave attack ultimately raises the economic costs of protecting the site to exceed the actual value of the land and therefore the site is abandoned and its value declines rapidly.

Ozyurt et al. (2008) and Di Paola et al. (2011) associated the presence of protection structures with a low level of vulnerability and this was the case of the present study. It was considered that at a time scale of a decade, coastal structures protect backing structures and/or human activities in a reliable and effective way and are generally stable and do not need maintenance works.

Concerning the Socioeconomic Vulnerability Index (Table 4.4), the inclusion of social and economic parameters in coastal vulnerability indices is a really important point but, unfortunately, it entails several difficulties (Gornitz 1990; McLaughlin et al. 2002) and is usually omitted from published indices, because of the difficulties in obtaining and ranking the data (Li and Li 2011). In this study, three parameters were taken into account; specifically, the "Land use" parameter was based on the results of the European research project on land uses "CORINE" (http://www.eea.europa.eu/publications/COR0-landcover, accessed June 2014). The "Population density" parameter was broadly based on the investigations of Li and Li (2011), Santos et al. (2013), etc. and limits were based according to the classes defined by The World Bank (http://data.worldbank.org/indicator/EN.POP.DNST, accessed June 2014), to have more objective values of general significance and not subjective ones of limited, local value. The "Percentage of urbanised area" was simply expressed into five successive classes according to Li and Li (2011).

The Conservation Vulnerability Index (Table 4.5) incorporated several parameters which were considered only in a limited number of study cases (Gornitz et al. 1994; McLaughlin et al. 2002; McLaughlin and Cooper 2010; Li and Li 2011; Santos et al. 2013). In order to give an objective importance to the different existing features of land protection and ecosystems, the subdivision of the "Protected areas" parameter was carried out according to the "International Union for the Conservation of Nature" (http://en.wikipedia.org/wiki/IUCN_protected_area_categories, accessed June 2014) and the "Ecosystem and habitat cover" parameter, was defined according to the classes established by McLaughlin and Cooper (2010) and Li and Li (2011).

The parameter “Level of human intervention” is related to those features which are indicative of development and significant ecological and economic value. Del Rio et al. (2009) considered that a higher level of development entails a higher erosion impact not only due to the increased exposure, but also because human activities tend to intensify vulnerability by negatively influencing coast stability.

The Cultural Heritage Index (Table 4.7) included only one parameter concerning cultural heritage, which categorization in classes is difficult (McLaughlin and Cooper 2010). In the case of archaeological remains, aspects such as their age or level of importance (local or international) can be taken into account, and the latter was the criteria used in this work.

Lastly, additional enhancements in development of the indices can be made, for example by including more variables in the assessment of hazard, vulnerability and risk related to storms. The selection and addition of different variables must avoid redundancy and ambiguity. Further, increasing in the number of variables requires the increasing of the complexity of the index, so in any case a balance should be found among applicability, scientific validity and facility of use (Williams et al. 2001; McLaughlin and Cooper 2010).

References

Abuodha P, Woodroffe CD (2006) Assessing vulnerability of coasts to climate change: a review of approaches and their application to the Australian coast. In: Woodroffe CD, Bruce E, Puotinen M, Furness RA (eds) GIS for the coastal zone: a selection of papers from CoastGIS 2006. Australian National Centre for Ocean Resources and Security University of Wollongong, Wollongong, Australia

Anfuso G, Gracia FJ (2005) Morphodynamic characteristics and short term evolution of a coastal sector in SW Spain: implications for coastal erosion management. J Coastal Res 21(6): 1139–1153

Anfuso G, Nachite D (2011) Climate change and the Mediterranean Southern Coasts. In: Jones A, Phillips MC (eds) Disappearing destinations: climate change and future challenges for coastal tourism. CAB International, Wallingford

Anfuso G, Gracia FJ, Battocletti G (2013) Determination of cliffed coastline sensitivity and associated risk for human structures: a methodological approach. J Coastal Res 29(6): 1292–1296

Aybulatov NA, Artyukhin YV (1993) Geo-ecology of the world Ocean’s shelf and coasts. Hydrometeo Publishing, Leningrad

Basco DR (1987) The Effects of Seawalls on Coastlines and Beaches (with specific application to Sandbridge Beach, Virginia). City of Virginia Beach, Virginia

Basco DR (1999) Misconceptions about seawall and beach interactions. In: Ozhan E (ed) Land-ocean interactions: managing coastal ecosystems. Proceedings of the Medcoast-EMECS joint conference, vol 3. Medcoast, Ankara

Basco DR (2004) Seawall impact on adjacent beaches: separating fact from fiction. J Coastal Res 39:24–28

Bieniawski ZT (1989) Engineering rock mass classifications. Wiley, New York

Bosom E, Jiménez JA (2011) Probabilistic coastal vulnerability assessment to storms at regional scale—application to Catalan beaches (NW Mediterranean). Nat Hazard Earth Syst 11:475–484

Coelho CR, Silva F, Veloso-Gomes F, Taveira-Pinto F (2009) A vulnerability analysis approach for the Portuguese west coast. In: Popov V, Brebbia CA (eds) Risk analysis V: simulation and hazard mitigation. Institute of Technology, Wessex

Cooper JAG, McLaughlin S (1998) Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. J Coast Res 14:512–524

Crowell M, Scott E, Kevin C, McAfee S (2007) How many people live in coastal areas? J Coast Res 23(5):3–5

Crowell M, Coulton K, Johnson C, Westcott J, Bellomo D, Edelman S, Hirsch E (2010) An estimate of the U.S. population living in 100-year coastal flood hazard areas. J Coast Res 26 (2):201–211

De Pippo T, Donadio C, Pennetta M, Petrosino C, Terlizzi F, Valente A (2008) Coastal hazard assessment and mapping in Northern Campania, Italy. Geomorphology 97:451–466

Del Rio L, Gracia FJ (2009) Erosion risk assessment of active coastal cliffs in temperate environments. Geomorphology 112:82–95

Di Paola G, Iglesias J, Rodriguez G, Benassai G, Aucelli P, Pappone G (2011) Estimating coastal vulnerability in a meso-tidal beach by means of quantitative and semi-quantitative methodologies. J Coast Res SI 61:303–308

Fischer DW, Arredondo MC (1999) Municipal coastal hazard planning: Los Angeles and Orange County city responses. J Coast Res 15(4):974–984

García Mora MR, Gallego JB, Williams AT, García Novo F (2001) A coastal dune vulnerability classification. A case study of the SW Iberian Peninsula. J Coast Res 17(4):802–811

Gracia FJ, Rodríguez-Vidal J, Benavente J, Cáceres L, López Aguayo F (1999) Tectónica cuaternaria en la Bahía de Cádiz. In: Pallí L, Roqué C (eds) Avances en el estudio del Cuaternario. Univ. de Girona, Girona

Gornitz VM (1990) Vulnerability of the east coast, USA to future sea level rise. J Coast Res 9:201–237

Gornitz VM, Daniels RC, White TW, Birdwell KR (1994) The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. J Coast Res 12:327–338

Himmelstoss EA (2009) DSAS 4.0 Installation instructions and user guide. In: Thieler, ER, Himmelstoss EA, Zichichi JL (eds) Digital shoreline analysis system (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change. U.S. Geological Survey, Charleston

Jones B, Basco DR (1996) Seawall effects on historically receding shorelines. American Society of Civil Engineers Florida, USA

Jones A, Phillips M (2011) Disappearing destinations. CABI, London

Komar PD, Allan JC (2008) Increasing hurricane-generated wave heights along the U.S. East Coast and their climate controls. J Coastal Res 24(2):479–488

Li K, Li GS (2011) Vulnerability assessment of storm surges in the coastal area of Guangdong Province. Nat Hazards Earth Syst Sci 11:2003–2011

McLaughlin S, Cooper JAG (2010) A multi-scale coastal vulnerability index: a tool for coastal managers? Environ Haz 9(3):233–248

McLaughlin S, McKenna J, Cooper JAG (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. J Coast Res 36:487–497

Méndez-Lázaro P, Peña-Orellana M, Padilla-Elías N, Rivera-Gutiérrez R (2014) The impact of natural hazards on population vulnerability and public health systems in tropical areas. J Geol Geosci 3:114–120

Moritz H, Moritz H (2006) Evaluating extreme storm power and potential implications to coastal infrastructure damage. In: 9th international workshop on wave hindcasting and forecasting, Victoria

Nunes MA, Ferreira Ó, Schaefer M, Clifton J, Baily B, Moura D, Loureiro C (2009) Hazard assessment in rock cliffs at Central Algarve (Portugal): a tool for coastal management. Ocean Coast Manage 52:506–515

Ojeda-Zujar J, Alvarez JI, Martin D, Fraile P (2009) El uso de las TIG para el cálculo del indice de vulnerabilidad costera (CVI) ante una potencial subida del nivel del mar en la costa andaluza (España). Geofocus 9:83–100

Ozyurt G, Ergin A, Esen M (2008) Indicator based coastal vulnerability assessment model to sea level rise. COPEDEC, Dubai

Pilkey O, Dixon K (1996) The corps and the shore. Island Press, Washington

Raji O, Niazi S, Snoussi M, Dezileau L, Khouakhi A (2013) Vulnerability assessment of a lagoon to sea level rise and storm events: Nador lagoon (NE Morocco). J Coast Res 65:802–807

Rangel N, Posada B (2013) Determinación de la vulnerabilidad y el riesgo costero mediante la aplicación de herramientas SIG y métodos multicriterio en la línea de costa. Caribe Colombiano Intropica 8(1):31–44

Santos M, Del Río L, Benavente J (2013) GIS-based approach to the assessment of coastal vulnerability to storms. Case study in the Bay of Cádiz (Andalusia, Spain). J Coast Res 65:826–831

Sunamura T (1992) Geomorphology of rocky coasts. Wiley, New York

Williams AT, Alveirinho-Dias J, Garcia Novo F, Garcia-Mora MR, Curr RH, Pereira A (2001) Integrated coastal dune management: checklists. Cont Shelf Res 21:1937–1960