Ocean and Coastal Management 167 (2019) 20–31

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Coastal exposure assessment on Bonassola bay

L. Mucerino[a,*], M. Albarella[b], L. Carpi[a], G. Besio[c], A. Benedetti[d], N. Corradi[a], M. Firpo[a], M. Ferrari[a]

[a] DISTAV Dipartimento di Scienze della Terra dell'Ambiente e della Vita, Corso Europa, 21, 16132, Genova, Italy
[b] ASIT - Ca' Foscari University of Venice, Dorsoduro 3861, 30123, Venezia, Italy
[c] DICCA Dipartimento di Ingegneria Civile etc, Via Montallegro, 1, 16132, Genova, Italy
[d] CNR-ICMATE, via E. De Marini, 6, 16149, Genova, Italy

ARTICLE INFO

Keywords:
Coastal exposure
Runup
XBeach
Gravel beach
Storms

ABSTRACT

This paper illustrates a novel coastal exposure assessment approach. The approach is based on the employment of the model chain *WavewatchIII + XBeach*, which is first used to draw a map showing the extent of the populated areas that are likely to be interested by flooding, and subsequently to establish the exposure of the area to specific events. The model chain is calibrated by comparing the simulated runup values of a storm with those obtained by processing on-field images recorded by a camera system. The approach herein presented allows to take into account the local coastal geomorphology features and hydrodynamics of the area so as to obtain locally accurate results. The information collected is usable by local beach managers in coastal management planning.

The method is applied on Bonassola beach, which is a pocket beach located on the NW Mediterranean along the Eastern coast of Liguria, Italy. Weather and offshore waves data collected during the last 16 years were used. The application of this method has allowed to draw a map of the areas that are subject to flooding during storms and has correctly stated that three of the seven biggest storms in the last 16 years would eventually result into flooding of populated area. The study has also shown that the exposure of the study area to the storms is sensitive to the period and the direction of the waves.

1. Introduction

Coastal areas are subject to natural hazards that can result into significant economic and environmental damages, with storm induced inundation and erosion being very frequent worldwide (Pérez-Maqueo et al., 2007). In particular, Mediterranean coastal zones support a very high population density that leads to high social and bio-geophysical vulnerabilities as coastal infrastructures are exposed to direct waves (Bosom and Jiménez, 2011).

Quantification of the damaging effects of hazards is object of the risk analysis, however when dealing with coastal flooding, two different interpretations of the risk exist and two related and incompatible taxonomies: one is used in the IPCC and defines Coastal vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard, and risk as the product Hazard * Exposure * Vulnerability (Barros et al., 2014), while a more traditional taxonomy defines the Coastal vulnerability as the susceptibility of a coastal area to be affected by either inundation or erosion (Di Paola et al., 2014), and risk as the product Damage * Probability of occurrence. (Di Risio et al., 2017). In this work the IPCC definition is used.

In the scientific literature several approaches are reported to assess coastal hazard and risk, that differ in complexity, in the number of processes that they include, in the possibility of application at various scales, in the accuracy of the results and in the resources that they require (Satta et al., 2016).

Coastal exposure can be assessed at a local or regional scale. A local scale assessment implies working at a much more detailed scale than that used by local beach managers (Jiménez et al., 2007), and requires details of the beach and of the coastal populated area.

Various tools are suggested to assess coastal exposure: index-based methods, such as the Coastal Vulnerability Index (CVI) (Gornitz, 1990), (Gornitz, 1991), (Gornitz, 1993) and its derivatives, that are very effective for an evaluation of the exposure on regional and large scales and also for a rough evaluation at a local scale, GIS-based decision support systems, that support decision makers in a sustainable management of natural resources and in the definition of mitigation and adaptation measures (Mocenni et al., 2009), and methods based on dynamic computer models that allow to integrate the time dimension in the analysis and mapping of exposure and risks of coastal systems to

* Corresponding author.
E-mail address: luigi.mucerino@edu.unige.it (L. Mucerino).

https://doi.org/10.1016/j.ocecoaman.2018.09.015
Received 10 May 2018; Received in revised form 24 September 2018; Accepted 25 September 2018

climate change (Hinkel et al., 2010), (Mcleod et al., 2010), (Warrick et al., 2009), (Hsu et al., 2006). Index-based studies at a local scale mostly rely on the identification of mono-dimensional shoreline segments (Gornitz, 1990), (Torresan et al., 2012), so that the information about the spatial discontinuity of hazards and vulnerability conditions at a local scale may be obscured, and misleading policy-related decisions may result (Kienberger et al., 2009).

Although a vast literature detailing specific system response to perturbations exists, see e.g. (Bosom and Jiménez, 2011), (Özyurt and Ergin, 2010), (Cooper and Jay, 2002), there are only few comprehensive reviews that may assist coastal managers in the selection of an appropriate method for conducting a coastal exposure assessment (Mcleod et al., 2010), (Ramieri et al., 2011). Also, despite wave-induced water levels are a direct threat to people, infrastructure, and ecosystems, they are not routinely included in the analysis of coastal hazards, for instance, in the weather forecasting community. In fact, due to the large number of different processes involved in coastal zones, their relative importance, and the relative highly varying time dynamic characteristics, the development of an universal methodology to assess exposure on coastal areas is a difficult task.

Coastal exposure assessments at a local scale need details on beach flooding and morphodynamic processes during storms, which are dependent on the total water level at the shoreline (Sallenger, 2000), (Jiménez et al., 2012). Accurate prediction of the local wave runup height not only allows accurate exposure assessments and risk analyses but is also essential for the design of effective and non-intrusive coastal protection works (Briganti et al., 2005) and beach nourishment projects (Dean, 2001), as well as for the prediction of storm wave, surge, and tsunami effects (Korycansky and Lynett, 2007) and the planning of efficient coastal management schemes (Kroon et al., 2007) (Muñoz-Perez et al., 2001) (Xue, 2001).

Numerical models are emerging as an effective approach in the evaluation of the storm surges induced water levels and impact on the coastline. Coastal hydrodynamic and morphodynamic models, such as *XBeach*, allow to simulate a broad range of nearshore beach processes, including wave breaking, surf and swash zone processes, dune erosion, overwashing and breaching (Roelvink et al., 2009). Coastal zone models, such as *SWAN* (Booij et al., 1999) and *MIKE21SW* (Mike, 2009) allow to simulate random, short-crested wind-generated waves in coastal regions and inland waters. Sea wave propagation models, like *WaveWatchIII* (Tolmanet al., 2009), (Komen et al., 1996) allow to model the generation and propagation of waves along oceans and large seas like the Mediterranean.

Model chains obtained by coupling these models allow to predict inshore water level and runup excursion at a local scale given offshore information about the meteorological conditions and wave height. Since such information can be easily gathered and to some extent predicted by modern equipment and technologies, in very recent years literature has oriented towards the employment of model chains. In (Stockdon et al., 2007) wave runup elevation and setup were calculated from modelled offshore wave conditions using *SWAN* and an empirical parameterizations (Stockdon et al., 2006) for the evaluation of coastal vulnerability and runup elevation. In (Casella et al., 2014) runup levels on Borghetto Santo Spirito Beach (Liguria, Italy) were computed by means of a model couple of *MIKE21SW* model and *Cshore* (Kobayashi, 2009), a phase averaged cross-shore model. In (McCall et al., 2010) *SWAN* was coupled with XBeach to evaluate beach response and overwash dynamic on Santa Rosa Island during Hurricane Ivan. In (Diaz et al., 2016) a model chain composed of *WaveWatchIII*, *SWAN* and *XBeach* was used to evaluate beach erosion processes induced by hurricanes impact in Varadero (Matanzas, Cuba).

Coastal risk assessment methodologies based on model chains have been proposed in the last years. In the Coastal Storm Modeling System (CoSMoS) project (Barnard et al., 2014) a framework over a large geographic area on US East Coast was setup and a model chain based on XBeach was used to evaluate Coastal hazard. In (Sano et al., 2011) an assessment of vulnerability to climate change in the Gold Coast of Australia was proposed, using XBeach to compute morphodynamic response to extreme storms under future sea level rise. In the context of the MICORE project, model chains based on XBeach have been proposed as a method for predicting coastal flooding in various regions, including Lido di classe and Lido di Dante (Italy) (Harley et al., 2011), Lido de Sete (France), Cadiz Urban beach (Spain), Praia deFaro (Portugal), Mariakerke beach (Belgium), Egmond beach (Netherland), Dee estuary (UK), Dziwnow split (Poland) and KamchiaÃ -Shkorpilovtsi (Bulgaria) (Bolle et al., 2011), (Ciavola et al., 2011). Most of the methodologies proposed are based on the employment of 1D models, that give accurate results only if the alongshore morphology of the beach is very regular. This is not a correct assumption for large part of the Ligurian coast, which is characterized by small beaches abruptly interrupted by cliffs. Also, most of the works of the MICORE project have focused their attention on the accuracy of the prediction of the physics of the event, rather than on the risk that it poses, therefore in these work there is not, for example, an exposure assessment or a proposal of a simple tool that is easy to understand for people usually involved in beach management.

In this paper we describe a methodology to evaluate a bi-dimensional coastal exposure map on a study area along Liguria coastline, using the model chain *WaveWatchIII + XBeach* to compute runup excursion on local scale. This work establishes a relationship between offshore climate (1999–2015) and coastal flooding, taking into account morphology, anthropization and hydrodynamic pattern. Offshore dataset has been provided by DICCA Meteocean hindcast (www.dicca.unige.it/meteocean/hindcast.html) spanning for the period (1979–2017) (Mentaschi et al., 2013), (Mentaschi et al., 2015). The model chain has been validated by comparing its results with camera systems observations and employing the time stack method (Zhang and Zhang, 2008), (Takewaka et al., 2000), (Kuo et al., 2009) to evaluate runup excursion on the images.

The most important outcome of this work consists of a coastal exposure map in which exposure levels are related to runup excursion induced by the most severe storms in 1999–2015. The map highlights flooded areas of investigated area using three different exposure levels: urban area, beach resorts zone and bathing zone.

2. Methods

The approach followed in this work is summarized in Fig. 1, and the steps are further detailed in the next Subsections.

2.1. Topographic-bathymetric surveys and grain-size analysis

Bonassola beach, see Fig. 2, is located on the western Mediterranean sea on the eastern coast of Regione Liguria, Italy. The beach is 410 meters long, oriented NNW-SSE and lies in a small bay geographically delimited by two promontories with its backshore constrained by a promenade. Due to this morphology, the beach is totally exposed to events from SW (Mastronuzzi et al., 2017). Also, due to the strong embayment, the area is subject to cross-shore sediment movements beyond depth closure and to beach rotation during swell event from SE (Komar, 1998), (Silvester and Ho, 1972), (Balduzzi et al., 2014).

A complete characterization of the morphology of the beach was obtained by performing bathymetric and beach topographic surveys, while for the broader area around Bonassola datasets of the LIDAR survey (2008) supplied by Regione Liguria were used, see Fig. 2. As shown in Fig. 1 the morphology of the study area was used both for implementing the numerical simulations and for calculating the exposure map.

The bathymetric data was collected using a multibeam echosounder and is characterized by an horizontal resolution of 0.25 m and a vertical resolution of 0.0125 m.

Beach topographic surveys took place from 16 to 29 November