Ocean & Coastal Management 95 (2014) 264–281

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Multi-hazards coastal vulnerability assessment of Goa, India, using geospatial techniques

Pravin D. Kunte [a,*], Nitesh Jauhari [b], Utkarsh Mehrotra [b], Mahender Kotha [c], Andrew S. Hursthouse [d], Alexandre S. Gagnon [d]

[a] National Institute of Oceanography, Council of Scientific and Industrial Research (CSIR), Dona Paula, Goa 403 004, India
[b] University of Petroleum and Energy Studies, Bidholi, Dehradun, Uttrakhand 248001, India
[c] Department of Earth Science, Goa University, Goa 403004, India
[d] Centre for Environmental Research, University of the West of Scotland, Paisley, Renfrewshire PA1 2BE, Scotland, United Kingdom

ARTICLE INFO

Article history:
Available online 20 May 2014

ABSTRACT

The state of Goa in West India has a 105 km long coastline with beaches and cultural heritage sites of significant importance to tourism. The increasing incidence of tropical cyclones in the Arabian Sea in recent decades and the devastating impacts of the December 2004 tsunami in India stressed the importance of assessing the vulnerability of coastal areas to flooding and inundation, notably in view of climate change induced sea-level rising (SLR). This study aims to develop a Coastal Vulnerability Index (CVI) for the state of Goa and to use this index to examine the vulnerability of the different administrative units of the state, known as *talukas*. This is accomplished by using seven physical and geologic risk variables characterising the vulnerability of the coast, including historical shoreline change, rate of relative sea-level change, coastal regional elevation, coastal slope, mean tidal range, significant wave height, and geomorphology using conventional and remotely sensed data, in addition to two socio-economic parameters: population and tourist density data. Using a composite CVI based on those relative risk variables, each of the seven coastal *talukas* was categorised according to its vulnerability. The resulting vulnerability map depicts the *talukas* that are the most and least vulnerable to erosion, flooding and inundation of coastal lands, and that the inclusion of socio-economic parameters influences the overall assessment of vulnerability. This study provides information aimed at increasing awareness amongst decision-makers to deal with disaster mitigation and coastal zone management, and is a first step towards prioritising areas for climate change adaptation in view of the projected SLR and increased storminess.

1. Introduction

History shows a long and intrinsic relationship between coastal areas and human settlements (UNEP, 2005). In India, about 25 percent of the population lives within 50 km of the coast (Krishna, 2005). The coastal regions of India are under serious threat from tropical cyclones and tsunamis (Chaudhuri et al., 2013), whose destruction and loss of human life is mainly attributed to flooding as a result of a storm surge (Sindhu and Unnikrishnan, 2012). In the North Indian Ocean, tropical cyclones form over both the Arabian Sea and the Bay of Bengal (Chaudhuri et al., 2013). West India is impacted by tropical cyclones originating from the southeast Arabian Sea where one or two tropical cyclones form every year (Evan and Camargo, 2011). The west coast of India is also impacted by cyclones originating over the Bay of Bengal. However, these storms weaken after making landfall and travelling across the Indian subcontinent. Two recent tropical cyclones that formed in the Arabian Sea are Gonu and Phyan. Gonu, which developed in June 2007, and made landfall in Oman, is the strongest tropical cyclone on record in the Arabian Sea (Fritz et al., 2010). Phyan formed on November 4, 2009, and caused intensified waves and a moderate storm surge along west coast of India (Joseph et al., 2011).

Tsunamis refer to a vertical displacement of a water column as a result of an earthquake, volcanic eruption, or submarine mudslide (Krishna, 2005). Tsunamis are rare in the Indian Ocean in comparison to the Pacific Ocean. Nonetheless, past records show that parts of the Indian coastline have been inundated as a result of tsunamis (Patel et al., 2013). For instance, in 1945, a giant tsunami

* Corresponding author. Tel.: +91 9423060305; fax: +91 832 2450608.
E-mail addresses: kunte@nio.org, dr_pdkunte@yahoo.com (P.D. Kunte).

http://dx.doi.org/10.1016/j.ocecoaman.2014.04.024
0964-5691/

generated in the Arabian Sea affected the Makran coast in Pakistan with waves traced back to Mumbai and the coast of Goa (Jordan, 2008). However, except for the occurrence of these disastrous events, there is no detailed documentation either on the impact or magnitude of the disasters.

Although the frequency of tropical cyclones and the associated storm surge and coastal flooding is lower in the Arabian Sea than the Bay of Bengal (Dube et al., 1997), the recent occurrence of cyclones of the magnitude of Gonu and Phyan reminded residents and policy officers of the vulnerability of the coastal regions of western India to such hazards. In addition, the tsunami of December 2004 and its devastating impacts on the coastal zone reminded the country of its lack of preparedness to natural hazards (Krishna, 2005), and stressed the importance of performing scientific studies on its vulnerability to such coastal hazards, particularly in view of climate change induced sea−level rising (SLR) and an increasing coastal population, as well as the demand for reliable information from community residents, developers, and government decision-makers (Kumar and Kunte, 2012). One way to address this stakeholders' need is to classify coastal lands according to their sensitivity to erosion, flooding, and inundation. In the past, the major constraint in undertaking vulnerability assessments has been a lack of data (Sterr et al., 2003). However, recent advances in spatial data gathering and processing techniques, including satellite remote sensing and Geographic Information Systems (GIS), have helped to overcome this barrier.

There are numerous definitions of vulnerability. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as a function of exposure, sensitivity, and adaptive (or coping) capacity (Das, 2012). Exposure in this case refers to frequency and magnitude of a climatic event, for example, a drought, while sensitivity represents the degree to which the system under analysis is impacted by that exposure. The third element, adaptive capacity, represents the ability of the system to adapt to or recover from that exposure (Hahn et al., 2009). According to the natural hazards' perspective, risk is the probability of an hazardous event to occur (Boruff et al., 2005), e.g. cyclone, tsunami, while vulnerability can be defined as the degree to which a person, community or a system is likely to experience harm due to exposure to that event (Kumar and Kunte, 2012). Vulnerability comprises a set of conditions and processes resulting from environmental and socioeconomic factors that increase the susceptibility of a community to the impact of hazards, and can also encompass the notion of coping capacity of the community to respond to disasters (Mahendra et al., 2011). Vulnerability assessments are performed to estimate the degree of loss or damage that could result from a hazardous event of a given severity, including damage to infrastructure, interruption of economic activities, and impacts on livelihoods (Kumar and Kunte, 2012).

A common way to assess vulnerability is by using indicators, which are usually combined together in a composite index. An example of a composite index is the Human Development Index, which incorporates various national indicators, notably, life expectancy, health, education, and standard of living, to provide an overall picture of well-being for a particular country (Hahn et al., 2009). Indicators and indices are useful to provide a simple representation of a complex issue and to make comparisons across time and between regions (Heltberg and Bonch-Osmolovskiy, 2010). Coastal environments are exposed to multiple threats, and for this reason, assessing vulnerability in such environments has led to the construction of composite indices, with a common index known as the Coastal Vulnerability Index (CVI). Integrated indices such as the CVI enable information from various sources to be combined together. They represent a complex issue in a simple way and are therefore a useful prioritisation tool for policy officers (Addo, 2013).

Thieler and Hammer-Klose (1999, 2000a, b) used such a CVI based on the work of Gornitz et al. (1994) and Shaw et al. (1998) to assess the vulnerability of the Atlantic, Pacific and Gulf of Mexico coasts of the United States to SLR (Boruff et al., 2005). Their index incorporated six physical variables, i.e., historical shoreline erosion or accretion, rate of relative sea-level change, coastal slope, mean tidal range, mean wave height, and geomorphology, with the end product highlighting the coastal areas where the impacts of SLR are expected to be the most severe. A CVI was also developed by Pendleton et al. (2005) to assess the vulnerability of the coast of the Golden Gate National Recreation area in Northern California to SLR by ranking the same variables as Thieler and Hammer-Klose (1999, 2000a, b). The variables selected for the construction of both the index of Thieler and Hammer-Klose (1999, 2000a, b) and Pendleton et al. (2005) accounted for the exposure and sensitivity of the coastal zone to SLR, but without considering the capacity of the affected communities to adapt to the projected changes.

The CVI methodology initially developed for the continental United States was subsequently applied to coastal locations in Alaska (Gorokhovich et al., 2014), Argentina (Diez et al., 2007), Brazil (Szlafsztein and Sterr, 2007), the Canary Islands (Di Paola et al., 2011), China (Yin et al., 2012), Ghana (Addo, 2013), Greece (Doukakis, 2005a, b; Gaki-Papanastassiou et al., 2010; Karymbalis et al., 2012), the Philippines (Clavano, 2012), South Africa (Hughes and Brundrit, 1992; Palmer et al., 2011), Thailand (Duriyapong and Nakhapakorn, 2011), and Turkey (Ozyurt and Ergin, 2009, 2010). The majority of those studies used the same geologic and physical variables as Thieler and Hammer-Klose (1999, 2000a, b), or a number of them depending on data availability, while a few also incorporated mean elevation and geology, two risk variables used in the original CVI studies by Gornitz (1991, 1994). In most studies, coastal vulnerability to SLR was determined on the basis of geologic and physical parameters only. However, vulnerability is also influenced by social, economic, and built-environment characteristics (Boruff et al., 2005).

Many studies that developed a physically-based CVI acknowledged the need to include demographic and economic variables to produce a more useful index (Clavano, 2012; Diez et al., 2007; Dominguez et al., 2005; Gornitz et al., 1994). For instance, Clavano (2012) suggested the inclusion of population density and coping capacity. Even though most of the socioeconomic variables influencing coastal vulnerability are known conceptually very few empirical studies incorporating human factors have been conducted (Boruff et al., 2005; Gorokhovich et al., 2014). Previous studies that included socioeconomic indicators in their vulnerability index include Boruff et al. (2005), Reyes and Blanco (2012), Szlafsztein and Sterr (2007), and Duriyapong and Nakhapakorn (2011). In these four studies a Socioeconomic Vulnerability Index (SVI) was linked to a physically-based CVI to assess the vulnerability of the coast of the 48 contiguous US states, a study site in the Philippines, the state of Pará in Brazil, and the Samut Sakhon coast of Thailand, respectively.

The SVI of Boruff et al. (2005) was based on Cutter et al. (2003) and incorporated 39 socioeconomic and demographic variables derived from the United States census; for example, median age of population, percent of elderly population, birth rate, ethnicity, per capita income, median rent or value of properties, percentage of population renting, housing unit density, and density of commercial development. Similarly, Reyes and Blanco (2012) computed their SVI using population and demographic data (i.e., age and gender), employment, and household size, but obtained it from questionnaires distributed to households in the study area. The index of Szlafsztein and Sterr (2007) also aimed to represent the