Ocean and Coastal Management 158 (2018) 56–63

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Vulnerability assessment of the South-Lebanese coast: A GIS-based approach

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ARTICLE INFO

Keywords:
Coastal Vulnerability Index (CVI)
Sea level rise
GIS
Remote sensing
Mediterranean basin
Lebanon

ABSTRACT

The sea-level rise phenomenon affects several socio-economic and ecological aspects worldwide, particularly in terms of coastal erosion and saltwater intrusion. While the Mediterranean region is showing an increase vulnerability to the sea-level rise, in this study, we implement the Coastal Vulnerability Index (CVI), between 2005 and 2013, on the Southern Lebanese coast. The selection of this study area is related to its commonly known vulnerable sandy beaches. The CVI is derived from six physical and geological variables that are estimated using Geographical Information System and Remote Sensing techniques. Results show that this eastern Mediterranean coast has a moderate (66% of its total lengths) to high coastal vulnerability (30% of its total lengths) to the sea-level rise. As predicted, sandy beaches in our study area represent the most vulnerable regions. On the other hand, an absence of a Pearson correlation between the amount of the sea level rise and the sea surface temperature, is shown. It is probably related to the direct human interference that eclipsed the climate change as the main driving force in that period (i.e. 2005–2013). In this context, we propose an intervention strategy that focuses on offering 'soft' technics performed at the sandy beaches and in dune systems. Stakeholders are encouraged to implement this approach to combat the coastal vulnerability of these areas. And by applying the proposed method to other limited-resources/datasets countries, regional organizations and institutions could have vital information to reduce the impact of the SLR at a larger-scale.

1. Introduction

Historically, sea levels have been fluctuating between one hundred meters below to 6 m above the present level with changes in global temperatures (Donn et al., 1962; Oldale, 1985; Smith and Tirpak, 1988). However, during the last century, sea level has risen at a significantly larger rate than any previous several millennia (Church and White, 2006; Church et al., 2008). Thus, the Sea Level Rise (SLR) is considered closely related to the global warming and a key indicator of the world climate change (Bindoff and Willebrand, 2007). This phenomenon results from three primary contributing factors: (i) ocean thermal expansion; (ii) mountain glaciers and polar ice caps melt; and (iii) change in terrestrial storage (Dasgupta et al., 2009). SLR, which is often experienced through its effect on extreme levels (Church et al., 2008), causes severe ecologic and socio-economic impacts (Church and White, 2011). The most affected areas are the coastal zones presenting severe coastal erosion, flooding of wetlands and estuaries, saltwater intrusion, and threats to socio-economic activities and infrastructure (Kos'yan et al., 2012; Jonah et al., 2017).

The *Intergovernmental Panel on Climate Change (IPCC)* reports that the mean global elevation varies between 43 and 73 mm/year with an average of 58 mm/year (Stocker et al., 2013); the Mediterranean sea shows an increase of 2.44 ± 0.5 mm/year between 1993 and 2012 (Bonaduce et al., 2016). Yet, the change of sea level at regional- and global-scale might not be aligned with local levels on a particular coast. Thus, producing local-based studies is vital particularly when their findings have greater practical importance in terms of improving information for decision-makers (Smith and Tirpak, 1988).

In this context, the coastal vulnerability assessment becomes a fundamental research at national and regional level, especially when preparing for the possibility of such a rise. Vulnerability is defined simply as the consequences of natural phenomenon, of given intensity, on a subject (Lollino et al., 2014; Mhawej et al., 2016). However, three broad characterization of vulnerability related to SLR could be found in the literature (Dolan and Walker, 2006). The first views vulnerability in terms of exposure to hazardous events and their effects on people and structures (Dolan and Walker, 2006). The second perspective characterizes vulnerability as a mixture of socio-economic factors that influence the degree to which someone's life, livelihood, property, or assets are put at risk by the occurrence of a hazard event (Blaikie et al.,

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https://doi.org/10.1016/j.ocecoaman.2018.03.028
Received 14 November 2017; Received in revised form 8 March 2018; Accepted 14 March 2018

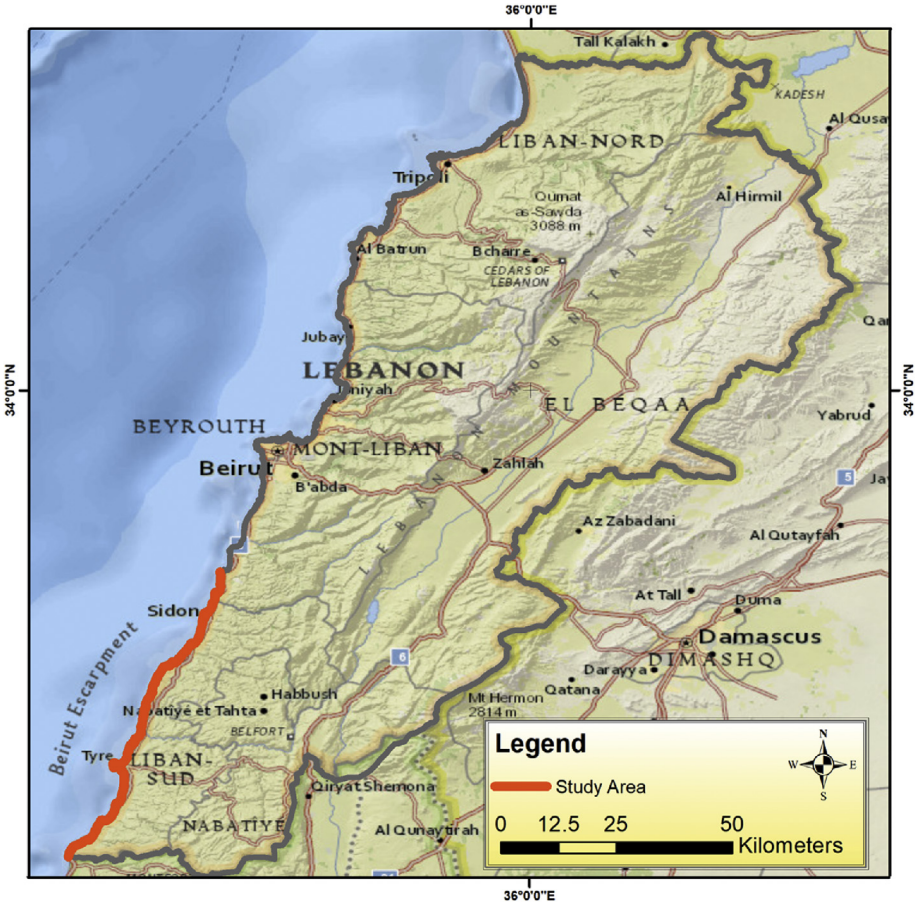

Fig. 1. Location of the Southern Lebanese zone (*Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp*).

Table 1
Lengths and percentages of the geomorphological structures of the Southern Lebanese coast.

Type	Length (km)	Percentage (%)
Artificial Beach	1212	12.9
Rocky Beach	13.5	14.4
Sandy Beach	32.54	34.9
Pebble Beach	9.82	10.6
Estuary	0.33	0.3
Low Cliff	20.3	21.8
Cliff	4.81	5.1
Total	**93.3**	**100**

2014; Dolan and Walker, 2006). The third combines the previous perspectives by integrating both the physical event and the limited capacity of communities to respond for such a rise (Wu et al., 2002; Dolan and Walker, 2006).

Several types of indices are being used to assess the coastal vulnerability to SLR (Smit and Wandel, 2006). They provide a prompt and consistent approach for characterizing the relative vulnerability of different coasts (Kay and Travers, 2008; Goodhue et al., 2012). These indices were systematically cited in the IPCC report in 1991 on *Common Methodology for vulnerability assessment* (Abuodha and Woodroffe, 2006). The most commonly used are *Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies (SURVAS)* (e.g. Nicholls and de la Vega-Leinert, 2000), *Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise (DINAS-Coast* and *DIVA)* (e.g. Hinkel and Klein, 2003), *Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM)* (e.g. Warrick et al., 2005), *Community Vulnerability Assessment Tool (CVAT)* (e.g. Flax et al., 2002), *Coastal Vulnerability Index (CVI)* and *Coastal Social Vulnerability Index (CSoVi)* (e.g. Boruff et al., 2005).

CVI, developed by Gornitz (1990), classifies the vulnerability to the sea level rise into five levels (i.e. Very Low, Low, Moderate, High and

Table 2
Thresholds used in the CVI calculation.

Level	Very Low	Low	Moderate	High	Very High
Variables	1	2	3	4	5
Geomorphology	Artificial Shoreline, Rocky Beach	Cliff	Low Cliff	Pebble Beach, Estuary	Sandy Beach
Coastal Slope (%)	> 45	30; 45	15; 30	8; 15	< 8
Relative rate of Sea Level Rise (mm/year)	According to the vulnerability linked to erosion and advancement				
Erosion/Advancement (m/year)	> +2	+1; +2	+1; −1	−1; −2	< -2
Average Tidal Height (m)	> 6	4; 6	2; 4	1; 2	< 1
Average Wave Height (m)	< 0.55	0.55; 0.85	0.85; 1.05	1.05; 1.25	> 1.25
CVI					