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Research article

Implications of adopting a biodiversity-based vulnerability index versus a shoreline environmental sensitivity index on management and policy planning along coastal areas

G. Harik [a], I. Alameddine [a], R. Maroun [a], G. Rachid [a], D. Bruschi [b], D. Astiaso Garcia [b], M. El-Fadel [a,*]

[a] Department of Civil & Environmental Engineering, American University of Beirut, Lebanon
[b] Department of Astronautics, Electrical & Energetics Engineering, Sapienza University of Rome, Italy

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A B S T R A C T

In this study, a multi-criteria index was developed to assess anthropogenic stressors along the Mediterranean coastline. The index aimed at geo-locating pollution hotspots for informed decision making related to coastal zone management. The index was integrated in a Geographical Information System based geodatabase implemented at several pilot areas along the Northern (Italy and France), Eastern (Lebanon), and Southern (Tunisia) Mediterranean coastlines. The generated stressor maps were coupled with a biodiversity richness index and an environmental sensitivity index to produce vulnerability maps that can form the basis for prioritizing management and mitigation interventions towards the identification of pollution hotspots and the promotion of sustainable coastal zone management. The results identified significant differences between the two assessment methods, which can bias prioritization in decision making and policy planning depending on stakeholders' interests. The discrepancies emphasize the need for transparency and understanding of the underlying foundations behind vulnerability indices and mapping development.

1. Introduction

Coastal zones are sensitive ecosystems, highly vulnerable to both natural and anthropogenic hazards. While sea level rise, tsunamis and floods are well recognized as the main natural hazards for coastal areas, anthropogenic coastal developments cause pollution, overexploitation, and fragmentation (Angelidis and Kamizoulis, 2005; Finkl and Makowski, 2013). Various methods, tools, and approaches have been developed in an effort to assess, manage, and evaluate coastal vulnerability, hazards, and risks (Appelquist and Balstrøm, 2015; EU, 2003; Komendantova et al., 2014). To date, the Coastal Vulnerability Index (CVI) remains the most commonly used index/indicator for areas with poor data (Pendleton et al., 2005; Ramieri et al., 2011; Thieler and Hammar-Klose, 2000a, b). Recent work has focused on developing coastal hazard assessment tools that go beyond the largely physical-based CVI. The integration of socioeconomic factors alongside physical and environmental features has been shown to present a more holistic characterization of coastal vulnerabilities (Boruff et al., 2005; Ceia et al., 2010; Thatcher et al., 2013; Wamsley et al., 2015). Yet, the adoption of such an approach is still limited (Boruff et al., 2005), largely due to data constraints. Moreover, recent vulnerability characterization efforts have made use of data derived from Geographic Information Systems (GIS), remote sensing, and dynamic computer models (Butt and Li, 2015; Hassaan, 2013; Musaoglu et al., 2015; Pendleton et al., 2005; Szlafsztein and Sterr, 2007; Taubenböck et al., 2008; Thumerer et al., 2000); however the use of such models has also been limited by the lack of spatial data and/or the need for specialized expertise (Mcleod et al., 2010; Ramieri et al., 2011).

While hazard assessment- in the sense of identifying and evaluating the potential degree of harm for each type of hazard (EU, 2003)- is not new, the main focus has often been constrained to natural hazards or to specific types of anthropogenic activities i.e. oil spills or industrial pollution (Bakkensen et al., 2016; Castanedo et al., 2009). Cost Action 620 under the European Water Framework Directive can be singled out for its comprehensive methodology

* Corresponding author.
E-mail address: mfadel@aub.edu.lb (M. El-Fadel).

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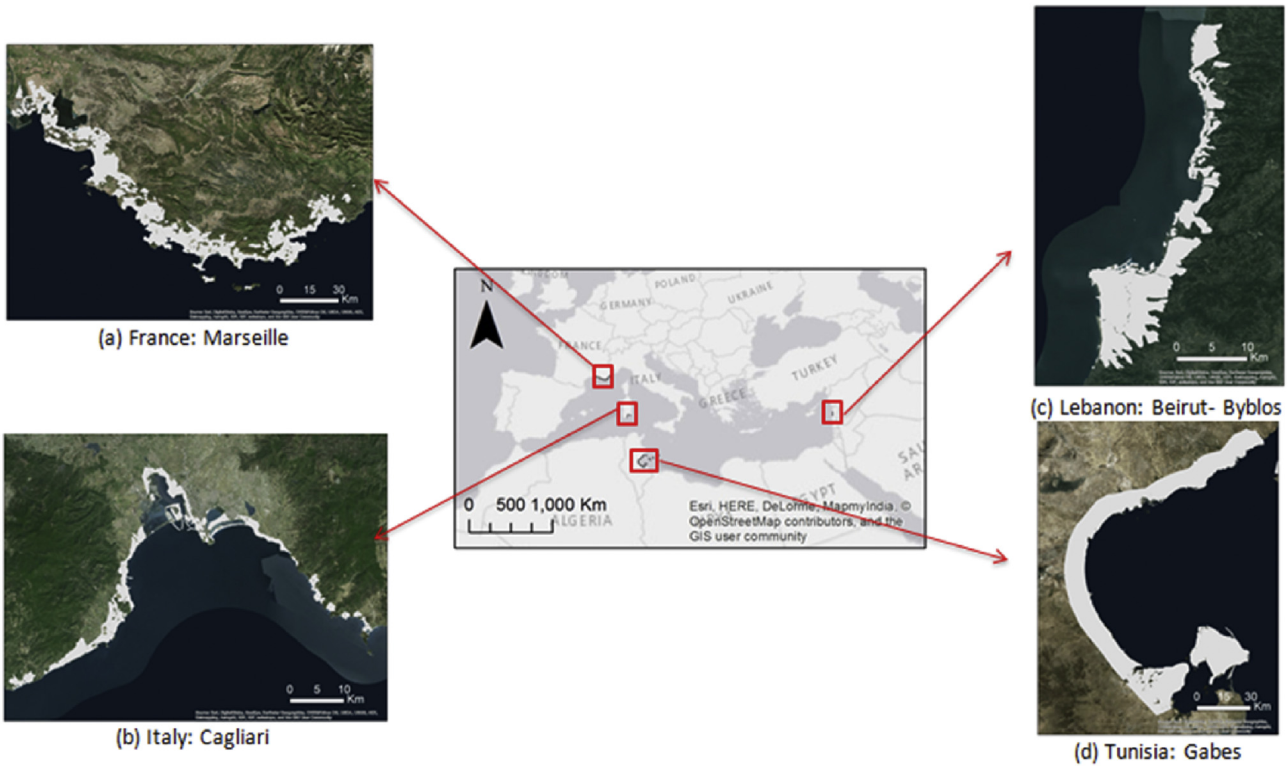

Fig. 1. Pilot areas (White highlights designate boundaries of assessed zones).

that aims to quantify both anthropogenic and natural hazards. However, its applicability has so far been limited to studying vulnerabilities and risks associated with carbonate aquifers (EU, 2003).

Historically, the Mediterranean has witnessed intense human activities due to its strategic location between three continents. The coastline has thus been affected by high maritime traffic along with a wide range of anthropogenic stressors, including industrialization, urbanization, tourism, agriculture, fishing, and over-exploitation of resources. These stressors have led to pollution, loss of species and habitats, as well as the degradation and fragmentation of ecosystems. While such stressors are encountered all along the Mediterranean, their frequency, intensity and impacts

Table 1
Generated thematic layers characterizing potential anthropogenic pollution stressors (attributes in bold are those used for stress quantification).

Hazard	Attributes
Agriculture	Name, Type, **Intensity (Fallow/Organic/Light Conventional/Moderate Conventional/Heavy Conventional),** Area (in km^2), Fertilizer Use (Yes/No)
Urban areas	Name, **Urbanization intensity (Rural/Moderate/Heavy)**, Area (in km^2), Presence of sewage network (Yes/No), Waste Water Treatment Plant (WWTP) (Yes/No), WWTP Treatment technology (None/Primary/Secondary/Tertiary), Number of outfalls
Tourism establishments	Name, **Area (in km^2),** Connected to sewage network (Yes/No), Presence of a WWTP (Yes/No), WWTP treatment technology (None/Primary/Secondary/Tertiary), Numbers of outfalls, Volume of wastewater discharge (m^3/day), Presence of a Marina (Yes/No), Includes sea filling activities (Yes/No)
Ports and marinas	Name, **Type (Wharf/Marina in resort/Marina/Oil Terminal),** Size (Small/Medium/Large), **Area (in km^2),** Connected to sewage network (Yes/No), Presence of a WWTP (Yes/No), Vessels, Includes sea filling activities (Yes/No), Storage tanks (Yes/No), Activity level (arrivals/day)
Industries	Name, Type, **Size (Small/Medium/Large),** Area, Sewage network connection (Yes/No), Outfall Number, **Storage tanks (Yes/No)**, Inclusion of Port (Yes/No), Work Status (Active/Closed), Polluting Status (Yes/No)
Airport	Name, **Area (in km^2),** Storage tanks (Yes/No)
River mouth[a]	Name, flow, watershed area
Landfill	Name, Status (Closed Landfill/Active Landfill/Closed Open Dump/Active Open Dump), **Area (in km^2),** Leachate discharge (Yes/No), Presence of a WWTP (Yes/No)
Outfall	Name, Type (Domestic/Industrial/Agricultural), Discharge Rate (in m^3/day), Onshore outlet (Yes/No), Offshore outlet (Yes/No), Length in sea (in meters), Depth (in meters)
Waste water treatment plant	Name, **Treatment type (Primary/Secondary/Tertiary/Inactive),** Area (in km^2), **Volume treated (in m^3/day)**
Oil platforms	Name, Type (Drill barge/Drill ship/Jack up/Platform/Semisub), Status (Drilling/Production/Inspection), **Production rate (in m^3/day),** Accident (Yes/No), Age
Maritime traffic	Accident (Yes/No), Length of line (in Km), **Traffic volume (vessels/day)**
Oil and HNS tanks	Name, Type, **Volume (in m^3),** Frequency of filling (per month)

[a] River mouths may not be an evident source of coastal pollution. Yet in the Mediterranean, they are classified as such because according to UNDP-MAP (2012) and UNEP-MAP-RAC/SPA (2010), the four major rivers flowing into the Mediterranean (Ebro, Rhone, Po, and the Nile) along with tens of other smaller rivers are invariably point sources of pollution, as these rivers carry untreated domestic and industrial wastewaters and agricultural runoff from upstream areas to estuaries and into the sea. In this study, a panel of technical experts under the GREAT MED project was consulted about their understanding of river-based pollution. All members across the four countries opined that river mouths are a potential land based source of pollution. As such, the river mouth was considered an anthropogenic stressor.