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# Mapping and analyzing socio-environmental vulnerability to coastal hazards induced by climate change: An application to coastal Mediterranean cities in France☆

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ABSTRACT

The densely populated cities of continental Mediterranean France, which are prone to erosion, are facing a potentially multi-hazard threat, due to a rise in sea-level that is expected to increase by between 0.07 and 0.12 m during the 21st century. The aim of this study is the superimposition of two widely used empirical indexes – the Coastal Sensitivity Index and the Social Vulnerability Index. In this research, the CSI is based on the following 6 parameters: geomorphology, coastal slope, sea-level rise, shoreline changes, mean tidal range and significant wave height, while the SVI used is constructed from 9 parameters: population < 14 years old, population over 75 years old, women, single parent families, families with more than two children, tenants, average density (inhabitants/km$^2$), unemployed population, population with no education and foreigners. The research was initially conducted on the French Mediterranean coast, where environmental inequality was observed, and led to the selection of 3 areas of interest for a further investigation in finer scale (municipality/*département*/coastal district scale). It was noted that in certain cases the socio-environmental vulnerability of a municipality (as a whole) differed from the one presented in its coastal district. Thus, the socio-environmental vulnerability of a place is related to the study's scale, and the interest lies in the recognition of the most vulnerable coastal districts of cities, in conjunction with coastal sensitivity, in order to prioritize the efforts for coastal management.

## 1. Introduction

During the last century, coastal Mediterranean urbanization increased dramatically, with an urbanization rate of nearly 65%, which is estimated to increase to 79% by the year 2030 (Brauch, 2003; Plan Bleu, 2015; UN, 2000), mostly due to the high concentration of natural and socio-economic values located on coasts (Mitchell, 1999; Sachs, Mellinger, & Gallup, 2001; UNCHS, 2001). An estimated 40.8% of the European population live in near-coastal zones, while the population of the Mediterranean coastal regions increased from 95 million in 1979 to 143 million in 2000 (Plan Bleu, 2015). In France, 50% of the population is living within 50 km of the sea (Eurostat, 2012). An anticipated sea-level rise, as a result of increasing global temperature, is expected to accelerate coastal dynamics (EM-DAT, 2012; IPCC, 2013; NOAA, 2016): the predictions of future global sea-level from several climate models range between 0.25 and 0.98 m by the year 2100 (Cazenave & Nerem, 2004; IPCC, 2013), while for the Mediterranean Sea a rate between 0.07 and 0.12 m on average will possibly be noted during the 21st century (Gualdi et al., 2013). Among the significant negative effects of future sea-level rise are coastal erosion, frequent and intensified cyclonic activity and associated storm surge flooding, that may affect the coastal zones. Faced with this threat, Mediterranean municipalities, identified as "hot-spots" (IPCC, 2013; Plan Bleu, 2015) are obliged to investigate alternative solutions for sustainable urban planning and development (EM-DAT, 2012; Mavromatidis, Mavromatidi, & Lequay, 2014), in order to improve their capacity to adapt to this new climate change reality (Houghton et al., 2001). The first step of this investigation lies in understanding and incorporating the notion of vulnerability as a powerful analytical tool (Adger, 2006; Plan Bleu, 2015).

As Levefre (1991) notes, "space is a social product or a complex social construction", which influences spatial practices (Mavromatidis, 2012). The social, political and economic power relations based on which we create our building environment (material processes), affect our relative

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vulnerability within an environment that is co-created by nature and society (Mavromatidis and Mavromatidi, 2012; Mavromatidis et al., 2014). Although most hazards are natural, disasters – expressed as the activation of a dormant hazard, − are not natural and therefore cannot exist without humans (O'Keefe, Westgate, & Wisner, 1976; Steinberg, 2000; Wisner, Blaikie, Cannon, & Davis, 2004). Thus, they must mainly be examined as the outcome of human actions – as the "actualization of social vulnerability" (Lewis, 1999).

According to Lélé (1991) the awareness that the ecological sustainability of the people-nature interplay can be affected by the combination of ecological and social conditions can contribute noticeably to the environment development debate. Any conflict in social and power relations is revealed through material practices as conflict within the environment, in the form of inequalities in risk exposure (Harvey, 1996; Oliver-Smith, 2004). Therefore, coastal vulnerability is about placing the people who may experience disaster or potential hazard at the heart of analysis and strategic planning of coastal cities, in order to prevent human, economical or environmental losses, caused by sea-level rise.

In terms of determining the concept of vulnerability, the development of official statistics since the 19th century has enabled the link between socio-economic insecurity and exposure to degraded living and working environments to become apparent (Fassin, 2009). The notion of "environmental inequalities" experienced its latest manifestation in the wake of the American Civil Rights movement (Taylor, 2000). The starting point was the link between environmental vulnerability (exposure to natural and anthropogenic risks, difficult access to environmental amenities) and social vulnerability (poverty, poor access to education and membership of ethno-racial minorities). Such empirical observations – also made in Europe – gave rise to theoretical considerations in terms of environmental justice (Fraser, 2005) and intersectionality (Yuval-Davis, 2015), as a "plurality of the logic of domination" (Fassin, 2015). Conversely, Ulrich Beck (1992) in "Risk Society" argues that the most vulnerable populations in terms of exposure to a hazard are not always the most disadvantaged socially and economically, questioning the systematic nature of the accumulated social and environmental vulnerability. In doing so, he highlights the restructuring of traditional social inequalities in the context of contemporary risks. Beyond the theoretical controversy, these two readings of vulnerability enable us to see the plurality of actual or potential situations.

The presence of social vulnerability, coupled with the absence of coastal sensitivity, would correspond to a situation of "strict" social inequalities. Situations of socio-environmental vulnerability which are characterized by a combination of coastal sensitivity and social vulnerability tend to lead to environmental inequalities (Deldreve, 2015). Conversely, an absence of both coastal sensitivity and social vulnerability could in theory create a situation of environmental justice (Taylor, 2000). However, the absence of both coastal sensitivity and social vulnerability at a local scale may also hide socio-spatial segmentations on larger scales, which are especially frequent in coastal cities (Deboudt, 2010). Finally, when individuals are subjected to environmental vulnerabilities while escaping any social vulnerability, the situation could correspond to Beck's above-mentioned notion of the "Risk Society" – a situation of "strict" coastal sensitivity. However, the economic, social and cultural capital of these individuals permits them to be characterized by a specific action capability (Nussbaum, 2003), allowing them to feedback on their environmental vulnerability (to protect themselves, to move, to influence public policies, in particular).

Understanding "vulnerability paths" (Magnan & Duvat, 2015) – or in other words the processes whereby societies produce disasters – has increasingly become a topic of scientific research. Several approaches in the form of indexes have been proposed in order to predict the physical process of the coastal zone, under the influence of anticipated sea-level rise at national and regional level (Mavromatidi & Karymbalis, 2016; Karymbalis et al., 2012; Karymbalis, Chalkias, Ferentinou, Chalkias, & Magklara, 2014; Diez, Perillo, & Piccolo, 2007; Pendleton, Thieler, & Williams, 2004; Thieler & Hammar-Klose, 1999; Gortnitz, 1991). However, in most cases, coastal sensitivity to marine processes is approached only on the basis of topographic, geological, oceanographic and meteorological parameters, without taking into consideration the human population who may be directly or indirectly influenced (Adger, 1999; Alwang, Siegel, & Jorgensen, 2001). Many researchers who dealt with hazards in coastal cities highlighted the need to include demographic and economic variables in order to create a more useful composite index for the evaluation of vulnerability (Clavano, 2012; Diez et al., 2007; Gornitz, Daniels, White, & Birdwell, 1994; Lichter & Felsenstein, 2012). In this context, investigations have been made relating to the evaluation of risk in coastal zones by taking into account not only natural, but also socio-economic variables (Gorokhovich, Leiserowitz, & Dugan, 2014; Plan Bleu, 2015; Reyes & Blanco, 2012; Szlafsztein & Sterr, 2007), including risk perception analysis (Meur-Ferec, Deboudt, & Morel, 2008, Rulleau, Rey-Valette, Flanquart, Hellequin, & Meur-Férec, 2015).

This current research provides a conceptual link in improving our understanding of the connection between coastal sensitivity and social vulnerability, on the scale of Mediterranean France (region, county, municipality). For this reason, the calculation methodologies of two widely used empirical indexes - the CSI of Shaw, Taylor, Forbes, Ruz, and Solomon (1998) and the SVI of Flanagan, Gregory, Hallisey, Heitgerd, and Lewis (2011) - are applied. The aim of the study was to use free data in order to examine the coastal sensitivity and vulnerability of our study area, as a rapid, preliminary way to identify susceptible areas, in county and municipality-level. The conceptualization of the procedures that cause changes can be a good policy framework to determine the coastal vulnerability objectives of a social-ecological system. Since human actions and social structures are integral to nature (Adger, 2006), this comparison can be useful in providing recommendations for the efficient use of existing methods for mapping and analyzing the vulnerability of coastal Mediterranean cities to climate change and sea-level rise.

## 2. Materials and methods

### 2.1. Historical retrospection of the study area

The French Mediterranean coastline is 1703 km long and marked by contrasting historical heritage (Fig. 1). To the East, the *Côte d'Azur* (the Riviera), mostly rocky, with a sequence of small bays and headlands, was soon converted into an elitist seaside resort: the English aristocracy played a pioneering role in this region, way back in the 18th century (Bottaro, 2014). Despite the relative democratization of leisure, this region is still characterized to this day by the elitism of its seasonal and permanent vacationers. In the West, the *Languedoc-Roussillon* has long been an agricultural hinterland and its coastal lagoons have been occupied by traditional small fishing crafts. Its sandy coasts were deemed inhospitable, due to the presence of mosquitoes (vectors of fever), that exposed local populations to particularly high mortality rates (Sagnes, 2001). However, taking advantage of the modernization of the post-war policies, the *Languedoc-Roussillon* region was the subject of an ambitious development program. Drainages, mosquito control, impoundments and urbanization, initiated in 1960 by the Interministerial Mission Racine turned *Languedoc-Roussillon* into the symbol of mass tourism. Several cities operated as seaside resorts (*La Grande Motte*, *Le Grau du Roi*, *Cap d'Agde*, *Valras Plage*). Between *Languedoc-Roussillon* and the *Côte d'Azur* a composite mosaic of territories can be found. The *Rhône* Delta is home to several natural reserves and the Camargue Regional Park was designed in 1970 as a green buffer zone between the tourist urbanization of *Languedoc-Roussillon* and the petrochemical industry in the *Etang de Berre* (Picon, 2008). The *Etang de Berre*, the largest coastal lagoon in Europe, has indeed been invested by the petrochemical industry since the 1930s (Daumalin, 2013). Connected to the sea by the *Canal de Caronte*, *the Etang de Berre* is connected to the port of the city of Marseille and its extensions up to the *Fos* container terminal. Weakened by the economic crisis, these municipalities are struggling between the modernization of their port infrastructure and seaside reconversion. These coastal landscapes all remain strongly influenced by their industrial heritage (Bertran de Balanda, 2014).