THE IMPACT OF SEA LEVEL RISE ON THE TOURISM FACILITIES IN THE ANDALUSIAN COAST, SPAIN

PABLO FRAILE JURADO, PILAR DÍAZ CUEVAS AND ARSENIO VILLAR LAMA

University of Seville, Spain

Despite being often located in coastal areas, the factors to allocate tourism facilities have not commonly included the risk of sea level rise (SLR). The spatial exposure to sea level rise of these facilities is analyzed in this work in the Andalusian coast. This analysis took into account the location of the tourism facilities and the identification and spatial interpolation of local sea level rise trends registered by tide gauges located in the Andalusian coast. Present day (1990) and projected (2100) high tides have been spatialized over a DEM of Andalusia, with a horizontal spatial resolution of 10 m and a vertical accuracy of 0.68 m RMSE (root mean square error). The simulations of present and future high tides considering the impacts sea level rise are based on a bathtub model, which accounts for the effect of vertical barriers. The results reveal that a significant percentage of the hotels located nearby the shoreline might be flooded by future high tides during the next century. The risk of flooding is not only evident for spring high tides but also for average high tides. Moreover, a risk of future flooding has been identified for the roads that lead to certain hotels located away of the area of future potential damages caused by sea level rise. These findings demonstrate the necessity of making urban planning that deal with the future sea level rise.

1. Introduction

The studies of vulnerability and risks advised by all the documents and reports at international level (Intergovernmental Panel on Climate Change), National (National Plan for Adaptation to Climatic Change) and Regional (Andalusian Strategy for Climatic Change) frequently suffer data at suitable scales. This is a problem for spatialize the impacts linked to Climatic Change in general, and the potential sea level rise, in particular.

Sea level rise (SLR) is one of the main consequences of climate change leading to four main physical impacts: the increase of the processes of inundation by tides, floodings, erosion and intrusion of salt water (IPCC, 2007). Indeed, key national and international authorities (e.g. IPCC, 2007; European Environmental Agency, 2010) have encouraged the development of study projects to address this problem at both regional and local scales, particularly in view of ever-increasing urban pressure and the urgency of effective coastal management in, for example, highly populated deltaic settings and touristic hotspots (e.g. Sánchez-Arcilla *et al.,* 2008; Flocks *et al.,* 2009; Miner *et al.,* 2009; Hansen, 2010).

A common technique for assessing SLR impacts is the use of digital elevation models (DEMs) to identify potential flooding areas for various future SLR scenarios (e.g. Titus and Richman, 2001; Mazria and Kershner, 2007; Dasgupta et al., 2007; Rowley et al., 2007; Thieler, 2009; Zhang, 2011). The use of this methodology in Andalusia has shown a high increase of the flooded areas in all the region (Fraile, 2011; Fraile and Ojeda, 2012).

On the other hand, the tourism weight in the economy of Andalusia is higher than in other regions in Spain (11% of GDP), and tourism activities are especially intense in coastal areas. Thus, any adverse natural event on tourism facilities might mean high economical looses in the region. However, despite this fundamental importance, there are not detailed spatial data for this activity in order to implement accurate assessments, and the municipality is the maximum disaggregation entity for regulated tourist places.

The aim of this work is to identify the potentially damaged tourism facilities and golf courses in the Andalusian Coast due to SLR in the year 2100. To resolve this it is envisaged to use the analytical capabilities of GIS for the regionalisation of sea level rise and the use of geocoding software for the spacialization of tourism facilities in the Andalusian Coast.

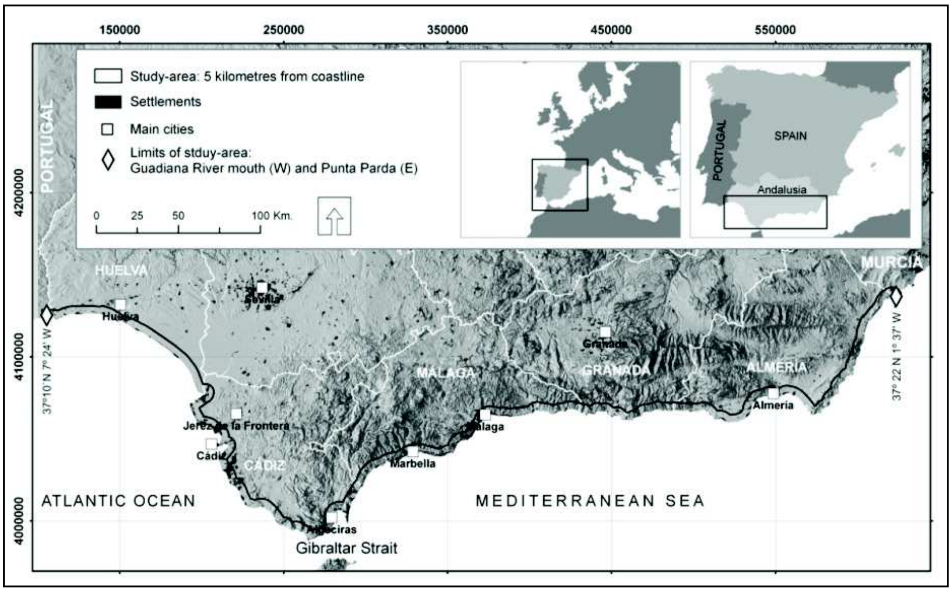
2. Study-Area: The Coast of Andalusia

The study area was the Coast of Andalusia (Spain). This area is limited by Portugal at West and the region of Murcia at East. It extends along 917 km, a 17.5% of the total Spanish coastline. Beaches, cornerstone of coastal tourism and central object of this work, represent a large percentage of its littoral, a 67.4% (Díaz *et al.,* 2012).

This area is very diverse and unique within Europe because occupies a transition zone between mid-latitudes and inter-tropical zones, and between the Atlantic Ocean and Mediterranean Sea.. There are two very different sectors in this coast: the Atlantic coast, mesotidal (3 m), very open and flat, and the Mediterranean coast, narrow, with high steps and with microtidal ranges.

High trends of sea level rise have been recorded in the tide gauges located along the andalusian coast. The tide gauges of Cádiz and Málaga have recorded SLR trends of 4.0 mm / year, values which are 2.3 higher than the global value for the period 1961-2011. On the other hand, the tide gauges located in the Gibraltar Strait (Tarifa and Algeciras) have shown very low SLR trends, with rates no higher than 1.0 mm / year, which is significantly lower than the global trend. Those differences might be related not only to different characteristics of the sea surface, but also to an important tectonic influence, which accelerate or moderate the global component of SLR (Fraile, 2011). Even there are other tide gauges with higher sea level rise trends (Huelva, Bonanza), the length of their time series is not enough to be used in this study, since they began to measure sea level in the decade of 1990.

Figure 1: The Coast of Andalusia



This coast is subject to a complex coastal dynamic that together with other phenomena, such as its neotectonic macrostructure and past sea level changes, have enabled the formation and development of diverse coastal environments such as beaches, barrier islands, saltmarshes, embayments, and rocky and sandy cliffs during the Holocene (Ojeda, 2003). The evolution, dynamics and landscape forms of this coast have been well documented (Ojeda, 1988; Zazo *et al.*, 1994; Goy *et al.*, 1996; Dabrio *et al.*, 2000; Ojeda, 2003; Zazo *et al.*, 2008; 2012).

3. Methods

The applied methodology involved three steps: i) calculating present and future SLR linked to climate change, ii) spatialization of tourism facilities at detailed scale and ii) finally spatialization of SLR values and identification of affected tourism facilities.

The use of the analytical capabilities of the Geographical Information System (GIS) is essential for the feasibility of this methodology.

3.1 Gauging and spatialization of future sea level rise

Future sea level rise surface were obtained from published previous works (Fraile, 2011), in which average an maximum high tides in the present and in a 2100 SLR scenario were compared. Essentially, this method consists of a surface analysis by the comparison of the heights of a flooding surface (defined by the height of inundation), and the elevations of a DEM, resulting in the identification of the areas lying below a predicted future inundation level.

The definition of the height of the future inundation is a task that requires the analysis of 4 different variables:

i)The future global SLR, obtained by a global SLR model. For the purpose of this analysis, the SLR model made by the Environmental Protection Agency of the USA in 1998 (Titus and Narayan, 1998) was used, since it allows a very simple definition in terms of probability and relationships with the other 3 variables used.

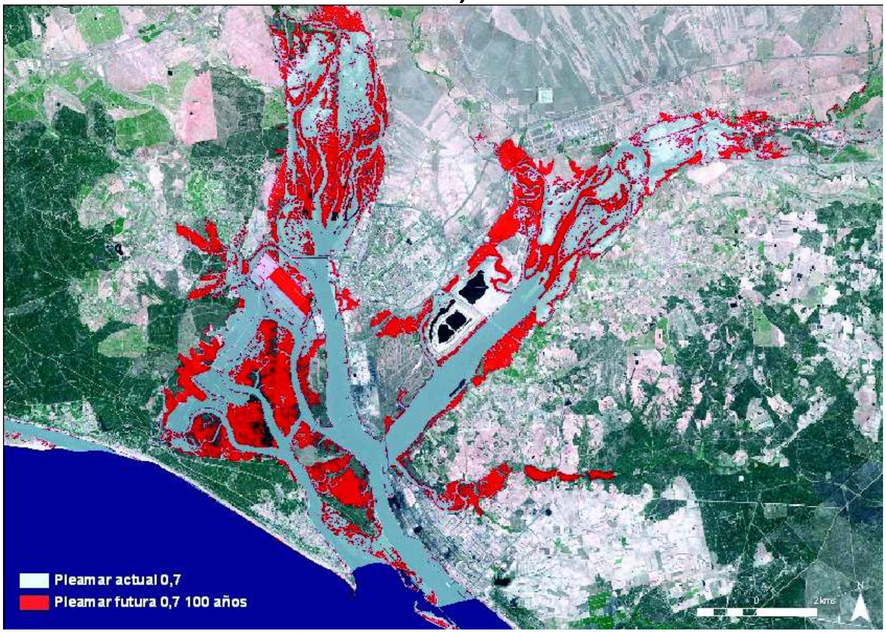
ii)The local SLR, measured from the data provided by the Permanent Service for Mean Sea Level (PSMSL), that allows to consider the expected effects of acceleration in SLR (Titus and Narayan, 1998; Fraile, 2011).

The local height of the spring tides, obtained from the two national sea and harbour authorities (Instituto Español de Oceanografía and Puertos del Estado).

The vertical difference observed between the local mean sea level registered in the tide gauge and the national levelling datum, which even does not use to be too high, it has values ranging from 0 to 41 cm in the andalusian coast.

The future inundation surfaces were obtained from the spatial interpolation of the four previous variables. Then, a comparison of the heights of each cell of a DEM and the total sum of the four variables was performed, identifying the cells that might be inundated in the future according to the model of EPA (Figure2). A present situation scenario was developed too, by analyzing only the last two variables (iii and iv), removing the future effect of SLR.

Figure 2: Present (in blue) and future (2100) average high tide (in red)



Source: Fraile (2011).

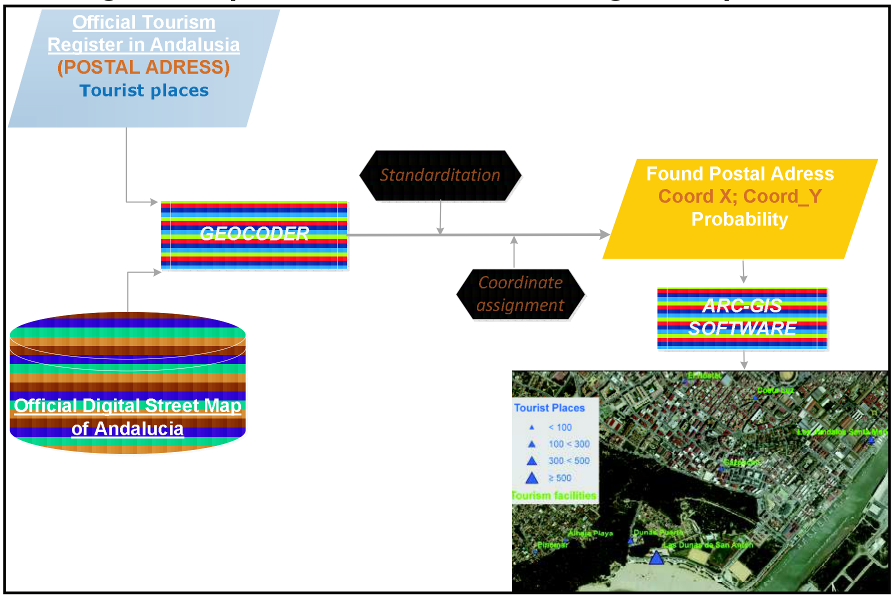
3.2 Spatialization of regulated tourism data

Spatialized tourism data in the coast of Andalusia at detailed scale were obtained using "Geocoder", a spatialization tool implemented in GIS by Junta de Andalusia (Zabala et al., 2010).

The application works mainly in two steps: i) standardization of postal addresses of each tourism facility provides from The Official Registry of Tourism of Andalusia and ii) assignment of the facilities coordinates through a comparison of their addresses to existing addresses in the Official Digital Streets Map in Andalusia (Moreno, 2011).

The application returns for each record a probability value between 0 and 1, meaning 1 "exact locations" and 0 "not found addresses". Intermediate values were applied based on the similarity between the two sources. When Geocoder returns 0 locations were manually assigned (using secondary sources of information like Google Maps, Google Street View or field work). Finally, assigned coordinates were mapped using ARC-GIS tools (Figure 3). Once all the locations were obtained, each record was filled with thematic data relative to Total Tourist Places assigned to every facility.

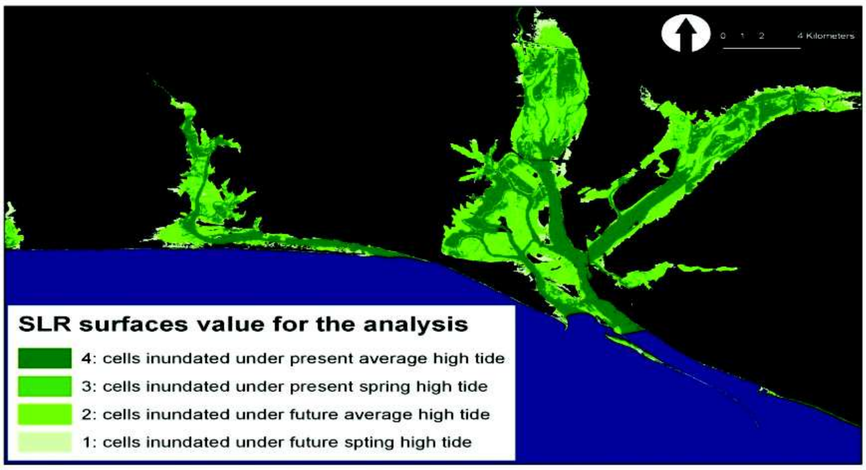
Figure 3: Spatialization method for regulated places



3.3 Spatial analysis

Hotels and golf courses that intersect to the surfaces of present high spring tide, future average tide and future high spring tide were identified. A relative index was built in order to identify the exposure of each element (Figure 4), assigning a maximum value of 4 to the hotels and golf courses that might be flooded even in the present conditions of mean sea level, and a value of 1 to those that only might be flooded under the extreme conditions of a high spring tide in the year 2100. 0 value was assigned to the hotels and golf courses with no risk of inundation.

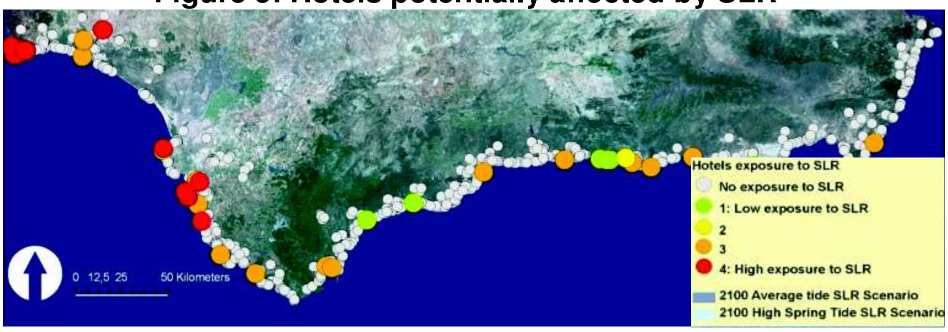
Figure 4: SLR surfaces value for the analysis



4. Results

The analysis made shows that 72 of the studied hotels might be affected by flooding during high spring tides before the year 2100 (Figure 5). This data is less than a 10% of the hotels located near the coast. 34 of the 72 (47.2%) potentially affected hotels are identified as flooded by any average high tide in the year 2100. 27 of the studied hotels are identified as a maximum exposure (37.5% of potentially affected hotels), because they might be affected by certain tides (especially if they happen during a combination of high tides and storms). 76% of the affected hotels are located in the Atlantic coast, although only a 30% of the total amounts of the studied hotels are located in this coast.

Figure 5: Hotels potentially affected by SLR



There are around 90 golf courses in the coast of Andalusia. 28 of them are located near sea and just 12 reach the coastline. Only 4 golf courses would be clearly affected. These facilities are settled on sandy formations, transformed tidal marshes and floodplains.

5. Discussion and Conclusions

SLR might affect a significant number of hotels located near the coast during the XXI century in Andalusia. Despite there are no complete analysis of natural hazards in this area, SLR could become into a one of the main future hazard for a small percentage of the hotels located near the coast.

The obtained results are similar to the obtained by other studies in the Mediterranean Sea (El-Raey et al., 1999) and significantly lower to other studies made in coast with higher tidal ranges and more affected by storm surges and other atmospheric adverse events (Jallow et al., 1996, Fish at al., 2005).

Most of the affected hotels are located in the Atlantic coast. This difference might be explained by the longer distance between hotels and coastline. This different location pattern are probably due to the identified source of danger: high spring tide in the Atlantic coast, that allow locate hotels closer to coastline, and extend of storm surges in Mediterranean coast, moving away hotels from the coast.

In the case of golf installations, the need for large areas along with the high price of land in the seafront motivates the implementation of these complexes not so much close of the sea. For this reason, the SLR may be considered a very specific risk and affects just a few installations, and the potentially affected gold courses might easily find measures to mitigate the impacts of SLR.

Acknowledgements

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