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Causes of the different behaviour of the shoreline on beaches with similar characteristics. Study case of the San Juan and Guardamar del Segura beaches, Spain

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HIGHLIGHTS

- The erosion rates are different in beaches with similar characteristics.
- Study of the shoreline evolution using aerial images since 1956
- Before nourishment the beach lost 50% of its surface area in the period 1956–1990.
- The greatest erosion occurs at beaches where sediment particles are more fractured.

GRAPHICAL ABSTRACT

TWO BEACHES	WHY THE DIFFERENT BEHAVIOUR OF THE SHORELINE?	SEDIMENT ANALYSIS
SIMILAR:		• **Wear**
• **Orientation**:		• SJ_1: 5 cycles vs. G: 3 cycles
• SJ_1:94.5°N vs. G:96.1°N	• **1956-1990**	• **Mineralogy**
• **Waves energy**	• SJ_o:-114,801 m^2	• % Quartz
• Mean Flow: SJ_1:94.9° *vs.* G:94.2°	• G:-79,416 m^2	SJ_o:26.4 *vs.* SJ_1:62.5 *vs.* G:30
• $H_{s,12}$: SJ_1:2.56 m *vs.* G:2.52 m	• **1992-2017**	• **Morphology**
• D_{50}:	• SJ_1:-12,646 m^2	• SJ_1: rounded and clusters
• SJ_1:0.220 mm vs. G:0.249 mm	• G:-88,232 m^2	• G: angular, fissures and follation

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ABSTRACT

Storms can alter the beach shape, relocating large volumes of sediments and generating drastic changes in the coastline. In the last 60 years, beaches shoreline behaviour has been different even though the energy of the waves was similar. Therefore, it is necessary to understand the factors that affect the sandy coasts for better future management. In this research, two beaches, with different erosion rate, located in the southeast of Spain (separated by only 40 km of distance) have been studied. The beaches: i) have similar orientations, ii) are open to waves with similar sand lengths of 9.8 km and 6.6 km, and iii) have similar median sediment size (D_{50}).

For its study, shoreline evolution has been analysed from 1956 to 2017. From the results obtained, it can be seen that: i) Between 1992 and 2017, San Juan just lost 3% of its surface, while in the previous period (1956–1990) it was 50%, and ii) Guardamar surface lost in 1992–2017 was 18%, and in the previous period it was 14%. For the analysis of the agents involved in both beaches, cross-shore profiles (volume), marine climate, biocenosis and sedimentology studies were carried out. The results showed that the energy on both beaches was very similar. The biocenosis had not changed and, however, the morphology of Guardamar seabed had increased to 1 m deep in some places, which had caused part of the beach berm erosion. Furthermore, important differences were found from the sedimentological study, concluding that the content of calcites and the degree of homogeneity of the particles are the real factors that caused these two beaches to behave differently against erosion.

1. Introduction

Throughout the world, coastal areas are highly productive. However, they are threatened by erosion, anthropogenic activities, *etc.*

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(EEA_EropeanEnvironmentalAgency, 2006), since there are areas in which the population tends to concentrate, as they are favourable for the development for human activities, which increases the potential for anthropogenic and natural damage (Ballesteros et al., 2018). A consequence of this human activity is the increasing construction of channels, or the rivers regulation, which have altered the natural dynamics of the coasts as a result of sediment retention or the lack of erosion of river basins, which have generated erosion problems around the world (Anthony et al., 2014; De Leo et al., 2017; Syvitski et al., 2009; Syvitski and Saito, 2007). Coastal erosion is therefore becoming a problem of increasing intensity (Marchand, 2010).

The increasing use of the coastal zone makes it necessary to understand coastal processes and the evolution of the shoreline. Only in Europe, it is estimated that around 20,000 km of coastline, accounting for 20% of its entire length, has coastal erosion problems (EC_EuropeanCommission, 2004). These areas are particularly vulnerable to both human-induced change and the effects of global warming (Nováčková and Tol, 2018). In this context, it is essential to have a thorough knowledge of the factors and processes involved in the coastal geomorphological system (Kumar et al., 2006), as well as to investigate strategies for mitigating and/or adapting to global erosion problems (Anthony, 2015; Syvitski et al., 2005), and the future consequences of sea level rise (Payo et al., 2016; Spencer et al., 2016).

The factors that influence the functioning of a beach are of different nature: on the one hand, there are the parameters that depend on the anthropogenic action that exists in the area, (Aragonés et al., 2015; Aragonés et al., 2016a; Pagán et al., 2016) and on the other hand, natural factors such as morphology, mineralogical composition of sediments or the maritime climate (López et al., 2016a; López et al., 2016b; Marcomini and López, 1997; Roberts et al., 1998).

One of the natural factors is grain size, a fundamental property of sediment particles, which affects their dragging, transport and deposition. Therefore, grain size analysis provides important clues for sediment source, transport history and deposition conditions (Bui et al., 1989; Guillén and Hoekstra, 1996). It is also important to know the characteristics of the material used in beach nourishment, since every time a modification of the natural sediment is made, there are a change in the sedimentology of the beaches (Marcomini and López, 1997; Pagán et al., 2018). The successive constructions carried out on the coastline have altered coastal dynamics (Newton et al., 2012; Pagán et al., 2017), producing an irregular cross-shore distribution in the sediments size (Bayram et al., 2001). Many authors such as Demarest and Kraft (1987) relate the movements of the shoreline to the movement of sediments above the off-shore depth. On-shore, the sediment particles are relocated within the cross-shore profile, while those that exceed the depth of closure (DoC) will not return to the beach (Aragonés et al., 2017b; Hallermeier, 1978; Hallermeier, 1980). However, others authors such as López et al. (2016a) demonstrate that the movement of the shoreline is due (among others) to the sediments wear, which experience at least three different erosion phenomena. These phenomena are: i) collision of suspended particles, causing a process of wear and sediment reduction; ii) dissolution of the carbonate fraction of the sample; and iii) rupture and separation between the mineral fraction and the carbonate fraction that initially formed the sediment. These three phenomena, which act together, lead to an alteration in the composition of the sand, and a decrease in the particle size with its corresponding cross-shore movement seaward. Another factor to be taken into account is the fragile union that conforms the particles, which makes it rapidly diminish the particle size, and consequently a retreat of the shoreline is produced (Pagán et al., 2018).

The maritime climate is another aspect that influences the shoreline evolution. Depending on the amount of energy released when the waves break, there are alterations of greater or lesser magnitude on any coastal sector. However, the magnitude and speed of change for a given wave energy will depend on the type of material on which it is produced (Pardo and Sanjaume, 2001).

The various natural factors mentioned above cause the shoreline to be in continuous movement. Emery (1961) developed a beach profiling methodology to measure short-term shore position changes over a 13-month period. However, in order to study the long-term historical evolution of the shoreline, it is necessary to have access to numerous databases, basically maps and historical nautical charts, in most cases with very limited reliability, and aerial photographs (Fenster et al., 1993). The latter provide greater and more reliable results, but their application is restricted to the last decades, making aerial photography the most used document for the calculation of erosion and/or accretion rates (Baily and Nowell, 1996; Jiménez et al., 1997; Ojeda et al., 2013). The use of aerial photographs taken in different years allows a quantitative comparison of the evolution of the shoreline in different areas. This allows establishing numerical trends, to estimate sedimentary movements or to evaluate the consequences of human actions (Anders and Byrness, 1991). In recent years, this technique has been perfected using digitally restored orthorecapitalized frames, which considerably reduces possible errors caused by the displacement of stereoscopic images (Moore and Griggs, 2002; Ojeda et al., 2002).

The study of the evolution of the shoreline is useful to establish a record of shoreline fluctuations and understand how the beach evolves and responds to environmental conditions (Norcross et al., 2002). However, there may be anthropogenic factors that modify the cross-shore profile of the beach by modifying its volume and not its surface, which can lead to significant errors in controlling the evolution of the shoreline from surfaces obtained from orthophotos. For that reason, in this work, both surface variations and the volume lost on the beach are analysed, in order to find out why two beaches with similar orientations, the same size of sediment and energy, present different shoreline evolution.

2. Study area

The present work focuses on two beaches located in the southeast of Spain, on the Mediterranean coast (Fig. 1). These beaches are: i) the beach of San Juan-Muchavista located about 7 km northwest of the city of Alicante. It is a sandy beach that exceeds 100 m wide in several points, and whose total length is 6.6 km. It is located between Cabo de las Huertas (Alicante) to the south and Cabo Azul (Campello) to the north, maintaining a north-south orientation.

San Juan beach has a total length of 6582 m and an average width of 80 m, reaching a maximum of 130 m. Its total area is 53.3 ha. It is an open beach with grey sand, and its median sediment size is 0.24 mm (average of 10 samples taken in 2014 by the University of Alicante). A massive regeneration was carried out on this beach between 1990 and 1991 with 4.284.324 m^3 of sand from Sierra Helada.

ii) The other study beaches are Viveros, Babilonia Centro, La Roqueta, Moncayo, El Campo and Les Ortigues, all located in the municipality of Guardamar del Segura, in the southeast of the province of Alicante. It borders at its northern end with the mouth of the Segura River, and limits to the south with the Canal de la Mata. This beach has a length of 9.9 km and an average width of 59 m, reaching a maximum of 121 m. Its total area is 23.4 ha. It is an open beach with golden sand, and its median sediment size is 0.271 mm (21 samples analysed by the University of Alicante). The actions carried out on this beach can be seen in Table 1.

In the area studied, tides have little relevance, with oscillations due to atmospheric pressure being even more important than tides themselves, with the value of astronomical tides being around 0.3 m, whereas meteorological tides can reach values of up to 0.45 m (http://www.puertos.es, and (Ecolevante, 2006)).

3. Methodology

For the study of the behaviour of the beaches, the following process was followed: i) study of the shoreline evolution; ii) analysis of the cross-shore profile (volume); iii) study of the maritime climate; iv)