FACTORS INFLUENCING THE RETREAT OF THE COASTLINE

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ABSTRACT

One of the main problems of coastlines around the world is their erosion. There are many studies that have tried to link coastal erosion with different parameters such as: maritime climate, sediment transport, sea level rise etc. However, it is unclear to what extent these factors influence coastal erosion. For example, the Intergovernmental Panel on Climate Change (IPCC) has predicted an increase in sea level at a much faster rate than that experienced in the first part of this century, reaching 1 m of elevation in some areas. Another factor to consider is the lack of sediment supply, since currently the contribution of new sediments from rivers or ravines is interrupted by anthropic activities carried out in their basins (dams, channelling, etc.). The big storms, increasingly frequent due to climate change, also should be considered, since they produce an off-shore sediments transport, so that these cross the depth of closure, causing nonreturn of the sediment to the beach. Also, the sediment undergoes a process of wear due to various reasons such as the dissolution of the carbonate fraction and/or breakage and separation of the components of the particles. All these elements, to a greater or lesser extent, lead to the retreat of the coastline. Therefore, the aim of this study is to analyse the different factors causing the retreat of the coastline, in order to determine the degree of involvement of each of them and, therefore, be able to pose different proposals to reduce the consequences of coastal erosion.
Keywords: coastline retreat, erosion, sand.

1 INTRODUCTION

One of the most important global problems is coastal erosion, affecting about 70% of sand beaches [1]. However, knowing whether a coastal system is in the process of erosion or not is not easy. For this purpose, it is necessary to know each of the parameters that affects each zone [2], and distinguish between anthropogenic factors and natural processes.

One of the most important elements caused by anthropogenic factors is climate change. According to Hughes [3] and Steffen [4], the world is on the verge of a 'new climate change' which will cause a rise in sea level. Carbon dioxide (CO_2) emission produce by man [5], which has increased since the beginning of the Industrial Revolution, is one of the many anthropogenic factors that can influence coastal erosion, since the ocean absorbs the CO_2 and reduces ocean pH, and with it, the degree of saturation of the seawater with respect to carbonate minerals [6]. This causes the reduction of the calcification of the organisms and an increase in carbonates dissolution [7].

In the same way, successive constructions carried out by man on the coast, such as harbours and breakwaters, have led to a series of imbalances in the environment [8–10], producing changes in incident waves, intense erosion, and even decline in the quality of coastal waters [11]. This last fact may result in damage to certain plant species [12].

On the other hand, in order to prevent flooding in the lower areas of the rivers (banks, etc.) construction of water channells, dams, reservoirs, etc. have been carried out in rivers, whose main consequence has been the decline in the amount of sediments carried by the rivers to the coast as well as an increase in the depth of the continental platform [13].

In terms of natural factors that may influence coastal erosion, the morphology and composition of the sediment as well as the marine climate [8, 9, 14–16] can be highlighted. Thus,

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López *et al.* [17] point out that sediment erosion is one of the natural erosion processes. This occurs by the dissolution of carbonates, the breakage of the particles as a result of the clash between them, and the separation of the mineral and the carbonated part of the particles. These three processes result in a decrease in size, causing a gradual shift within the continental platform. As can be noted, sediment morphology is essential, so a change in the natural sediment during nourishment causes the modification of beaches' sedimentology, thereby resulting in beach disequilibrium [16, 18].

Anthropogenic and natural factors have caused significant changes in the coastline. So, to determine the future evolution of these changes it is necessary to understand their origin. The complexity of the processes that occur within a coastal morphological system and the variety of involved factors (both natural and of human origin) makes that their study requires a local as well as global analysis of each of these factors for taking the decision on the course of action.

2 FACTORS AFFECTING COASTAL EROSION

The study of the position of the coast [19] provides information on the historical trend of that beach. But it is important knowledge of littoral drift generated not only by the incident waves or winds in the dune fields, but also by the sediment sea transport. Thus, it can be seen that the sediments located on the continental shelf are transported to the abyssal plains, through submarine canyons [20–24] producing an increase in the depth on the continental shelf, which can lead to setbacks in the coastline. This can be caused by human actions such as the construction of dams, weirs, canalization, etc. to prevent erosion of watersheds, which cut sediment transport to the sea [13].

Among the materials that make up the beaches, there are gravel and sand; thus, beaches can be classified into five groups depending on the content of sand and its distribution on the cross-shore profile [25]. It has also been observed that the coastline of gravel beaches are practically stable over time [26], while the sand beaches suffer severe erosion problems [27]. Therefore, the latter must be studied further.

According to sand definition, five types can be found depending on the size: i) very coarse sand (2–1 mm), ii) coarse sand (1–0.5 mm), iii) medium sand (0.5 to 0.25 mm), iv) fine sand (from 0.25 to 0.125 mm) and v) and very fine sand (0.125–0.063 mm). So, the first problem encountered in the making of artificial sand is repeating the process of settling that occurs in the rivers, until the texture of the coarser particulars are similar to that of the sand grains of the beach. Therefore, there are great differences (sizes and roundness) between the particles found on beaches (Fig. 1a) and those produced artificially (Fig. 1b), which causes discomfort to the beach user. This is why administrations tend to use sand dredged from the sea. However, such actions create problems in the biocenosis of the dredged areas, and in the disappearance of phytocoenoses and zoocenosis. Therefore, there is more and more criticism for dredging and regulations are stricter [28].

Figure 1: **(a)** Natural sand. **(b)** Artificial sand.

In addition, the uncontrolled process of nourishment of a beach can generate silting of some plant species (such as *Posidonia oceanica*) and, therefore, an imbalance in the profile and increase in erosion [29]. To reduce beach erosion, the use of breakwater in the coastal areas to prevent movement of sediments is common, both transversely and longitudinally, which generates a significant environmental impact within and outside the performance area [30, 31] (Fig. 2).

Sand is the second most used material in the world, which is why it is becoming scarce [32, 33]. Therefore, it is essential to have a knowledge of its composition and behaviour. The composition of most of the sandy sediment consists of a variable mixture of quartz and bioclastic carbonate. The first comes from the erosion of the watershed, the coastal drift, erosion of the cliffs and washing sediments of the continental platform, while the bioclastic carbonate component represents the contribution of the coastal environment; however, for the moment, the relative proportion of each contribution cannot be established [34]. In particular, in the Mediterranean Sea, *Posidonia oceanica* meadows contribute to a great extent to carbonated material of bioclastic origin, as demonstrated in the Sinis Peninsula, Sardinia [35]. The study of the components of the sand can give us an idea of why two beaches with the same energy and the same D_{50} have different coastline movements (Fig. 3).

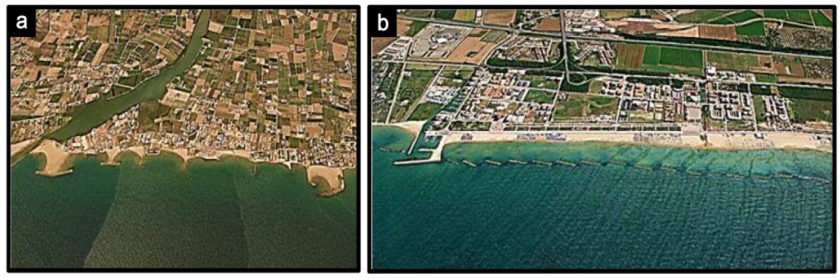

Figure 2: Breakwater and closed areas to avoid entering the waves in **(a)** Cullera (Spain) and **(b)** San Salvo (Italy).

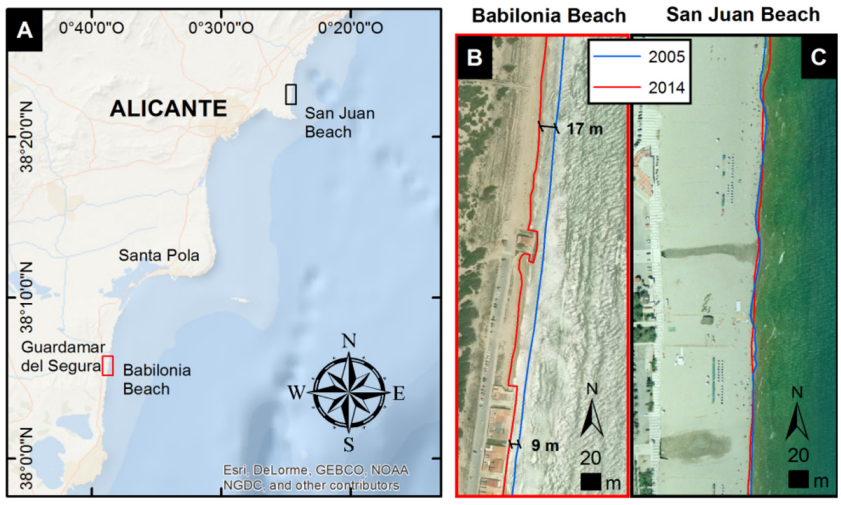

Figure 3: Comparison of beaches. **(b)** Babilonia beach (Guardamar) D_{50} = 0.24 mm origin Segura River and **(c)** San Juan beach (Alicante) D_{50} = 0.24 mm origin dredging. Both are open beaches and the waves are similar.

One of the physical characteristics of sediments that can provide us information is the grain size. The larger the particle the greater flow or energy needed to stay in suspension. Suspension is the more frequent sediment transport process. It is a selective process, thicker materials sediment first, and as energy decreases so will the finer particles. So, authors Demarest and Kraft [36] relate the movements of the shoreline with the movement of sediments offshore, since these relocate on the profile, while those outside of that limit will be very difficult to return to the beach [37–39].

Wear processes are other natural factors that are necessary to consider. The dissolution of the carbonate fraction and breakage and separation of the components of the particles are processes that generate a reduction on the particle size, and result in a decrease on the median sediment size [17]. Therefore, by decreasing the size of the particle, this moves offshore, and when it crosses the depth of closure it can no longer return to the beach, causing the retreat of the coastline [13].

Another aspect that has not yet been named is climate change [3, 4], which generates more extreme weather events, such as coastal storms of high intensity, significant changes in temperature and extreme precipitations [40]. All this will cause a great impact on the coastline and a rising sea level. In the latter aspect, the scientific community does not agree on how and when this increase will occur. For example, the IPCC [40] indicates that it is unlikely that the global average sea level would increase more than 1 m in this century. However, other studies indicate that if Greenland and Antarctica thawed, sea levels would rise between 65–70 m [41].

Moreover, the increase in greenhouse gases emissions (especially CO_2) can cause the planet to warm up to 7°C at the end of this century [42]. This increase in atmospheric CO_2 would be even faster if the ocean were not able to act relatively quickly as a sink for about half the excess of CO_2 that has occurred in recent decades [7, 43]. While this absorption has mitigated the increased concentrations of CO_2 in the atmosphere around 55% [43], it has caused oceans to present greater amounts of CO_2 [44–46]. One consequence is the pH decrease and the saturation with calcium carbonate mineral – a process known as 'ocean acidification' [47, 48]. The direct consequence of this acidification is the increase in the capacity of carbonate dissolution (fundamental part of the composition of the sand from the beaches), this fact has received relatively little attention compared to the ability of the organisms to calcify [49].

Both rising sea levels and pH increase are factors that will influence species such as *Posidonia oceanica* or *Cymodocea nodosa*. These species are usually located up to the bathymetric -40 in clean water conditions in the Mediterranean [50, 51]. Their presence reduces the wave energy and improves the stability of the seabed [50, 52].

Therefore, factors affecting shoreline retreat are numerous and different backgrounds, so their study and knowledge is essential for later use in coastal nourishment.

3 STRATEGIES TO REDUCE THE EFFECTS OF EROSION

Many people live on the coast and are affected by the consequences of erosion. Globally, more than 150 million people reside within 1 m of the level of high tide and 250 million people live within 5 m of the high tide line [53], so it is extremely important to have knowedge of each of the elements that cause coastal erosion. Therefore, on the one hand, it is important to understand perfectly the mechanism that produces this setback, and on the other, to arrive at ways to mitigate the effects of erosion.

A first study would be on the historical aspect of the evolution of the coastlines, to determine the amount of contributions that have stopped supplying (by rivers, ravines, etc.) and to analyse the morphological changes in the seabed.

Second, since the gravel beaches are morphologically stable whereas sandy beaches are in constant erosion, it is important to try to get the materials that make up the beach, on one hand, be as stable as possible, and on the other hand, to ensure that their cross-shore profile is comfortable and safe for the users of the beach. This type of obtained profile will be between a sand profile and a gravel profile, being able to better adapt to the changes that occur within the continental shelf with lower volumes required contribution.

Third, the environmental impact in defending shores is a very important aspect. Therefore, it should be limited (as noted above) to the construction of dikes and breakwaters, as well as nourishment with sand dredging. This largely determines the type of actions required to be carried out to protect the coastline. So, the industrialization of artificial sand is imperative. In order to select the sand to defend the coastline, you must know about its evolution, its transverse and longitudinal movement on the coast and also ensure that it has the highest possible durability.

The origins of these sands can be different. Sediments retained in the reservoirs and/or weir should be recovered, for two reasons: i) to prevent silting of the dam, which consequently reduces their capacity and stability, and ii) to reuse of sediments, considering the possible contaminants and the separation process of the different sizes of retained sediment. These sands can come from nearby quarries. Like sand from dams, should take into account three factors: i) remove fines that comprise the sample (< 0.063 mm), ii) controlled rounding of the fracture faces and iii) know the type of carbonate that makes up the sand. Therefore, whatever the solution that is adopted, it is important to know the erosive process that will endure in order to plan their maintenance over time.

4 CONCLUSION

Currently, we are in a context of global change, because of which it is essential to know the relationship between the dynamics of seawaters and erosion processes on the coasts. This study raises the need for a methodology (currently nonexistent) from which to predict the evolution of the coastline, knowing the involved factors. First and the most important is to quantify the processes that are occurring on a global scale, such as sea level rise and the CO_2 excess. Following this, the analysis must be performed locally, to determine the causes and to quantify lack of sediments, and the composition of the sand. Then, nourishment should plan and select the most suitable artificial sand, so that it allows providing stability and security to the beach, as well as easy maintenance. All this would be impossible to be carried out without the help of administrations and unanimity of the scientific community.

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