

Coastal Erosion at Maria Farinha Beach, Pernambuco, Brazil: Possible Causes and Alternatives for Shoreline Protection

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ABSTRACT

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The aim of this study is to understand the main processes that are involved in the erosion of Maria Farinha Beach, in Recife, Brazil, a beach of great ecological and socioeconomic importance. Currently, the southern part of the beach is exposed to more frequent periods of erosion, especially during spring tides, while in the northern part accretion can be observed. The possible causes of erosion can be related to: (i) changes in longshore drift rates, resulting in a negative sediment budget; (ii) the impact of the incoming waves, that concentrate energy in a small sector, and/or (iii) urban development on top of the beach system. In order to minimize erosion problems, the following alternatives are suggested: (i) the construction of a submerged breakwater; (ii) the use of a sand bypassing system and (iii) the relocation of existing buildings. It is concluded that the erosion problem at Maria Farinha is complex and difficult to solve, since it has multiple causes.

ADDITIONAL INDEX WORDS: *Beach management, wave modeling, coastal processes.*

INTRODUCTION

The erosion of beaches in the metropolitan area of Recife is a widespread and long standing problem. In Pernambuco state, between Cape Santo Agostinho and Itamaracá Island, there are numerous records of erosion, described as moderate to severe (Manso, 1995). According to Neves and Muehe (1995), the impact of sea level rise in this area may be severe due to its location: a low-lying area between the Timbó and Capibaribe river mouths. Neves and Muehe (1995) also claim that there is a long history of shoreline erosion, particularly at Olinda, associated with the interruption of the longshore sand transport due to the construction of hard engineering structures.

Over recent years, the magnitude of coastal erosion on the beaches of the central Pernambuco has increased, while the earliest record of erosion in Pernambuco dates back to 1914 when damage, caused by the jetty at the Olinda Isthmus, was reported (FINEP/UFPE, 2009). Since then, erosion has been observed along several sections of coastline, especially in urban areas, including the beaches of Paulista, where hard engineering structures were installed in order to control or mitigate erosion effects. In an effort to diminish erosion problems, the municipalities decided to protect the shoreline through the construction of different types of hard structures along the coast, generally without a proper understanding of the local coastal dynamics. The beach environment has been greatly modified by the presence of these structures, which have impaired the natural beauty of the coast. These interventions were costly and results

were not always satisfactory; often transferring the erosion to adjacent beaches (FINEP/UFPE, 2009). According to analysis performed in the Integrated Environmental Monitoring project (FINEP/UFPE, 2009), which covered 48 km of the coastline, in Jaboatão dos Guararapes, Recife, Olinda and Paulista, erosion countermeasures were taken along a 24 km section (50% of the total considered length). Almost all of these interventions were carried out to protect public and/or private properties, ignoring the consequences to the beaches, by the placing of structures that reduce the incoming wave energy and modify the longshore sand transport.

In this context, the present study analyses the processes which govern the erosion of Maria Farinha beach, Paulista, in the north of the Recife metropolitan area. Currently, the southern part of this beach is prone to episodic erosion, while accretion is recorded in the northern part. As with many other beaches in this area, Maria Farinha beach is of a great value socioeconomically, being used intensively for touristic and recreational purposes, as well as ecologically, since it is a feeding area for migratory birds.

Background

The Maria Farinha Beach is located in the northern part of the Recife metropolitan area, in the municipality of Paulista, Pernambuco State, northeastern Brazil (Figure 1). This sandy spit stretches out between the Atlantic Ocean and the Timbó River.

The coastal plain is less than 10 km wide, with an average height above sea level of 4 m. It is formed by quaternary sediment deposits roughly aligned in a NNE-SSW direction. The long alignments of beachrocks are the most striking feature of this coastline (Neves and Muehe, 1995).

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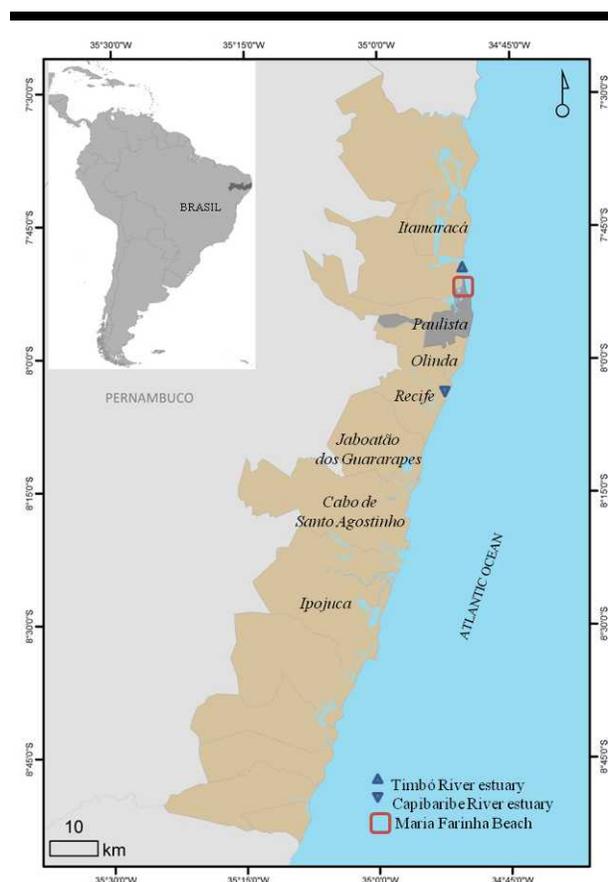


Figure 1. Location of study area. The inset shows Pernambuco state, within Brazil. The red square in the figure corresponds to the model grid.

The main ecosystems are sandy beaches, mangroves, beachrocks and coral reefs. As for the watercourses, the most important are the Timbó and the Paratibe Rivers, 13 km apart. The region has a tropical Atlantic climate with an annual average temperature of 27 °C and annual rainfall of around 2000 mm, unequally distributed between dry and rainy periods. The wind regime is governed by the general atmospheric pressure distribution pattern of the South Atlantic Ocean, with a predominance of SE trade winds.

The foreshore and the inner part of the continental shelf have an extremely complex bathymetry (Figure 2), with the presence of reef structures at various depths, paleo channels and other features. This complex morphology has a significant impact on the hydrodynamic processes (FINEP/UFPE, 2009).

The tides registered in the region are all semi-diurnal, being classified as mesotidal in terms of their amplitude, with a mean height of 1.67 m (FINEP/UFPE, 2009), which corresponds to the lowest high neap tide. The maximum tidal level reaches about 2.8 m at spring tide. The incoming waves, according to SMCBrazil reanalysis wave data (Oliveira, 2013), propagate from the ESE. The significant wave height is about 1.34 m, while the peak period is 7.4 s. The largest and smallest waves

occur in September and January, respectively (FINEP/UFPE, 2009). The main longshore transport is from South to North (FINEP/UFPE, 2009).

Regarding infrastructure, houses that are mainly used during the summer are concentrated directly on the beach, with medium to high density along most parts of the spit (FINEP/UFPE, 2009).

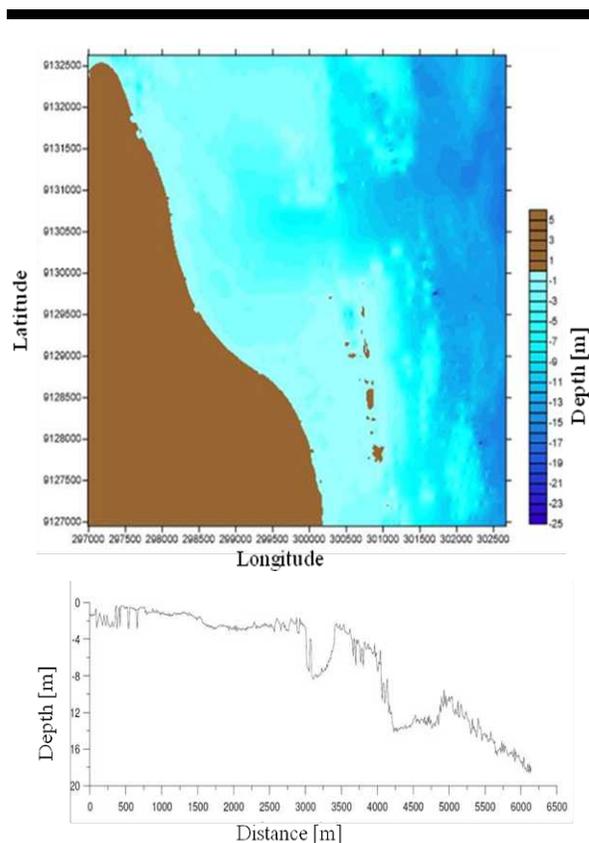


Figure 2. Bathymetry of the Maria Farinha Beach inner shelf, top figure. The bottom figure shows a cross-shore section of the beach, with channels and reefs visible (FINEP/UFPE, 2009).

Erosion processes affect the southern part of the spit, mainly during the higher spring tides, causing damage to properties and loss of scenic beauty (Figure 3).

METHODS

In order to understand the erosion processes, previous data were analyzed, including shoreline displacement rates, occupation rates, beach profiles and the presence of coastal defense structures based on FINEP/UFPE (2009) data. Analysis of incoming waves was performed by means of the wave propagation model WAPO (Silva *et al.*, 2005). The WAPO model was chosen because it is capable of reproducing wave phenomena such as: refraction, diffraction, shoaling, reflection and energy dissipation induced by both bottom friction and breaking.

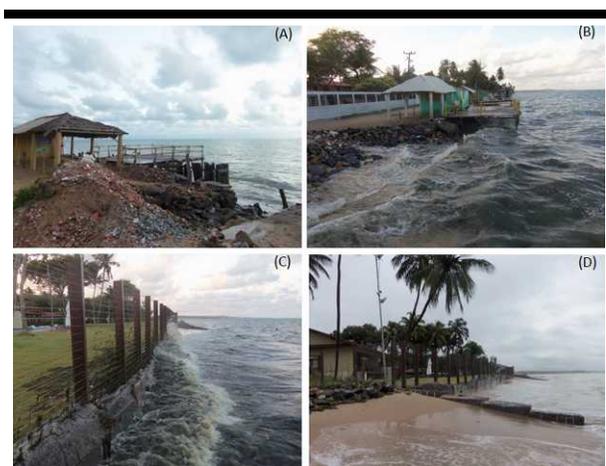


Figure 3. Examples of damage caused by erosion at Maria Farinha (A) damage to the bars on the beach during a spring tide (2.6 m) (06/04/2012), (B) and (C) water reaching the houses and fences (07/04/2012) (2.6 m), and (D) suppression of the backshore during a high tide 11/03/2012 (Photos: Rafael Amorim).

Different scenarios of tide level were modeled: mean tidal level (1.67 m) and maximum spring tide (2.8 m); with wave parameters (significant wave height $H_s=1.35$ m; peak wave period $T_p=7.4$ s and propagation direction in ESE) defined according to the SMCBrazil reanalysis data (Table 1/Oliveira, 2013). These wave parameters were chosen because they represent more than 90% of the incoming waves in the area. As a result, possible causes of the erosion and alternatives for solving this in the area were put forward.

Table 1. Wave reanalysis data provided by SMCBrazil software for Marinha Farinha beach (Oliveira et al., 2013)

Direction	Probability of Occurrence	H_s (m)	T_p (m)
E	2.11	1.01	7.72
ESE	92.14	1.35	7.44
SE	5.75	1.25	6.51

RESULTS

Analysis of medium-term coastal changes during the period 1974-2008 reveals that this stretch of coastline exhibits different patterns of shoreline evolution in the southern part (-0.19 m/year, ± 0.22) and at the point of the spit (+2.1 m/year, ± 0.81) (FINEP/UFPE, 2009) (Figure 4). Regarding the beach profiles, Pontal showed beach accretion with a positive sediment budget of about 10.07 m³/m, which is very different from that of the southern section, the critical area of erosion, which has a negative sediment budget of 48.33 m³/m (Figure 5b). These data confirm the tendency recognized in the medium-term, *i.e.* erosion in the south and accretion in the north.

The main direction of the longshore transport in the study area is from South to North. Recent interventions aimed to minimize the effects of the erosion have been undertaken on the Paulista Coast (Figure 6A): there are about 1,850 m of seawalls and revetments, 280 m of groins and jetties and 2,520 m of

breakwaters. These coastal defenses and many others placed by local governments have caused significant changes in the longshore sediment transport, affecting upstream drift rates (FINEP/UFPE, 2009) and reducing the sediment supply to Maria Farinha beach. Furthermore, a large sediment flow can be observed to the north of Maria Farinha beach, where there are numerous sand banks, sand waves, shoals and a small island near the growing spit (Figure 6B).

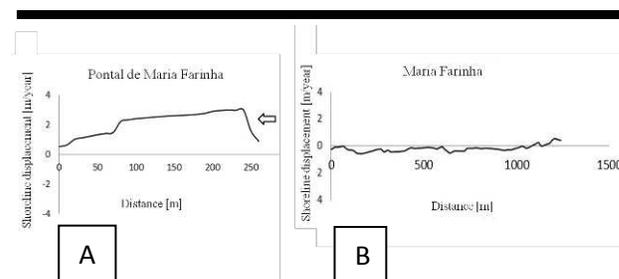


Figure 4. Analysis of shoreline displacement by FINEP/UFPE (2009) (A) medium-term accretional trend at Pontal, where the spit is located, (B) erosional trend in the southern part of Maria Farinha beach. The middle inset is a sketch of the analysed coastline strength.

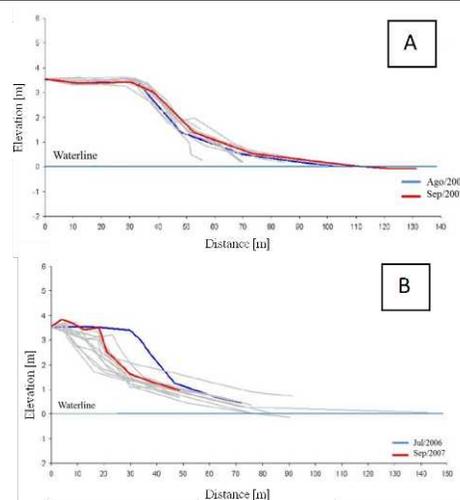


Figure 5. Beach profiles by FINEP/UFPE (2009) (A) stability at Pontal and (B) erosion in the southern part of the beach. Highlighted in blue are the profiles obtained at the beginning of the survey and in red those obtained at the end of the survey.

Nevertheless, not all the sediment eroded from Maria Farinha beach is deposited at Pontal, since the rates of erosion and deposition are different, suggesting that other sinking sources exist in the area.

The results of the wave modeling verify that the reefs, in the southernmost part of Maria Farinha beach, protect the coastline from incoming waves. In the area without reefs, there is no

sediment supply and the concentration of wave energy removes the sand, causing erosion (Figure 7).

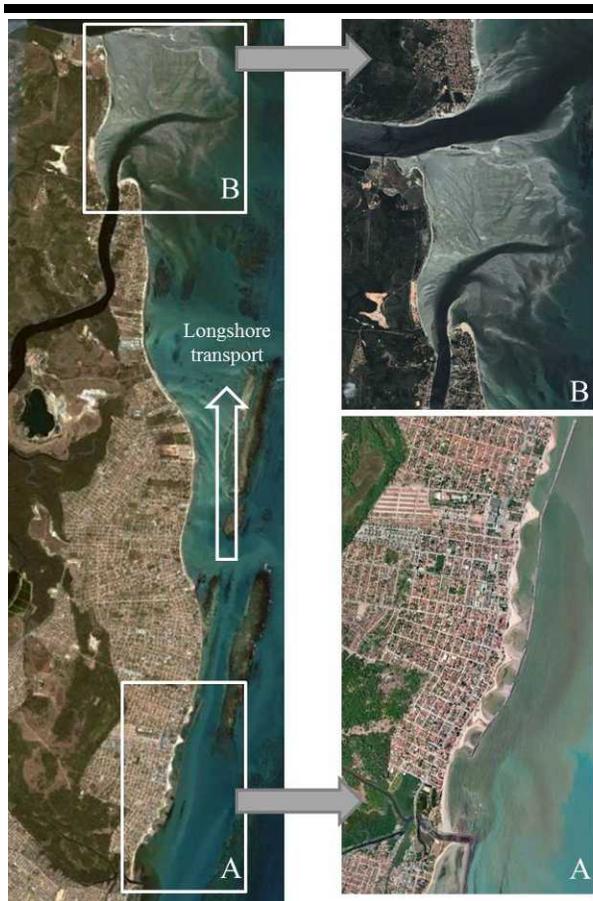


Figure 6. Littoral drift scheme along the Paulista coast (A) longshore drift interrupted by a sequence of breakwaters; the first formed a tombolo and (B) sandbanks, sand waves, shoals and an island formed in the north of the study area (FINEP/UFPE, 2009; Image source: GoogleEarth©).

The situation is particularly serious with maximum spring tides as shown in Figure 8. At the northernmost portion of the study area the Timbó River estuary acts as a hydraulic jetty, blocking the longshore drift and contributing to sediment accumulation.

According to the MAI project, (FINEP/UFPE 2009) part of the erosion problem in this area is directly related to the increasingly dense land usage near the coast, especially constructions built over the dunes and at the backshore. Analysis of the occupation between 1974 and 2008 shows a substantial increase in areas of medium and high density (Figure 9). Moreover, numerous buildings have been constructed at the backshore (FINEP/UFPE, 2009), reducing the space in which coastal processes occur under undisturbed conditions and affecting the beach system equilibrium.

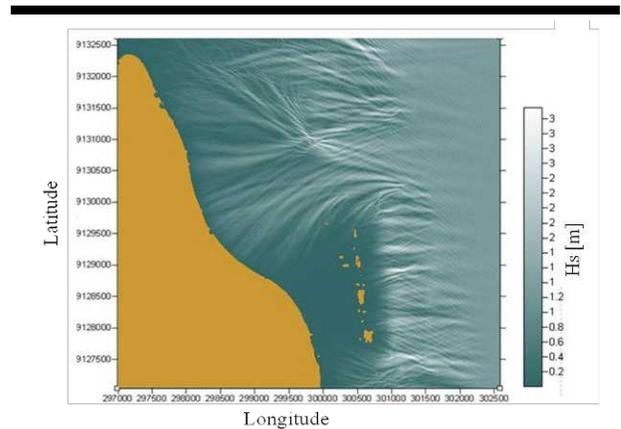


Figure 7. Wave propagation pattern for a tidal level of 1.67 m (mean tide for the area) and Hs of 1.35 m, Tp of 7.4 s and ESE wave direction.

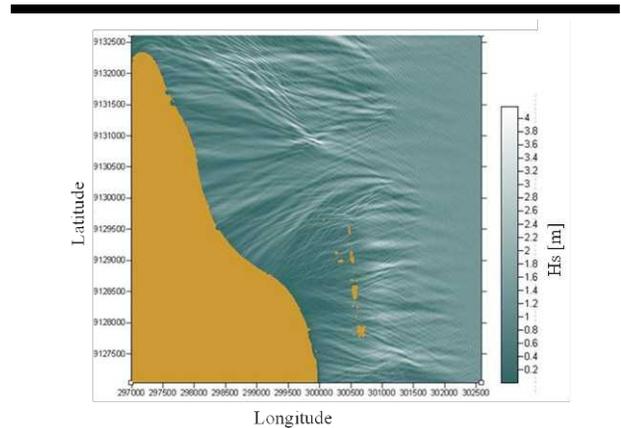


Figure 8. Wave propagation pattern for a tidal level of 2.8 m (maximum spring tide) and Hs of 1.35 m, Tp of 7.4 s and ESE wave direction.

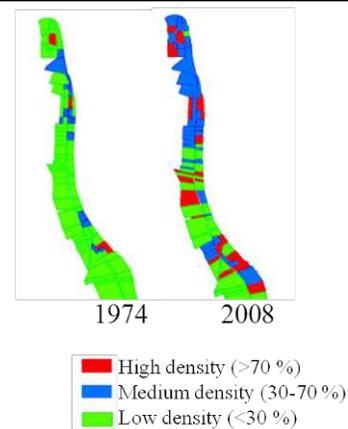


Figure 9. Evolution of the occupational density of the area along Maria Farinha beach (FINEP/UFPE, 2009).

DISCUSSION

On the basis of the analysis of available data (shoreline displacement and beach profiles, as well as previous studies – FINEP/UFPE, 2009) and comparing the results of numerical simulations predicting wave propagation patterns, three possible hypotheses as to causes of the erosion at Maria Farinha beach can be made: negative sediment balance; wave action; and urbanization.

Depending on the erosion mechanisms and causes, three alternatives are suggested in order to minimize the erosion at Maria Farinha beach. However, the adoption of any of these schemes would require more specific and detailed studies. The first alternative would act directly on the causes, giving a possible solution for the problem. The second and third options would act on the consequences of the problem, thus mitigating its effects:

(i) Construction of a submerged breakwater, which would act in a similar way to a natural reef, dissipating the energy of incoming waves (Figure 10). This type of structure would reduce cross-shore sand transport and sediment loss over the inner shelf and would slowly promote beach recovery.

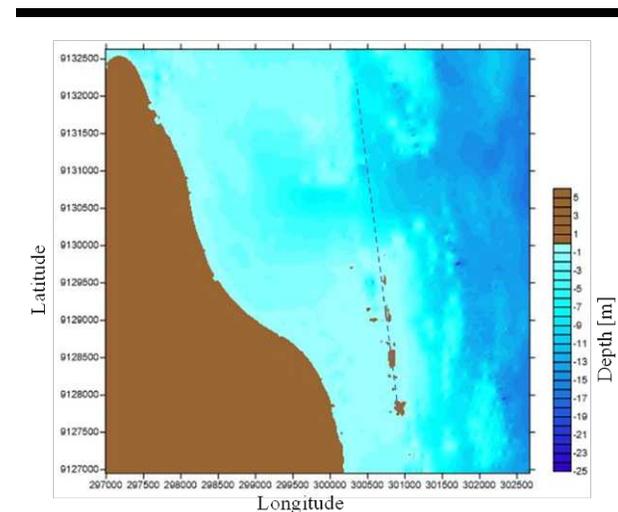


Figure 10. Location of the proposed submerged breakwater, which would dissipate the wave action at Maria Farinha beach.

(ii) Creation of a continuously operating sand bypassing system, which would transfer sediment from the banks and the sandy spit southward (Figure 11). Attention is needed to the environmental impact of this option because of the ecological importance of the area. Sand bypassing is operating in many places around the globe, *e.g.*, in Florida, USA (Finkl, 1993) and the Gold Coast, Australia (Dyson *et al.*, 2013). The bypassing system could be operated simply by pumping the sand back in to the system or even taking it from the spit by tractors and backhoes. Such a system would be a sustainable method of maintaining the improved beach (Dyson *et al.*, 2013).

(iii) Relocation of the buildings located next to the beach. According to USACE (2002), relocation is an option for locations of low population density. It provides the necessary

space for coastal processes and leads to the slow recovery of a beach. In the case of Maria Farinha beach, great political effort and investment would be required to apply this solution, considering the number of buildings and businesses there and the diversity of beach usage as well as the varied political interests in the area.

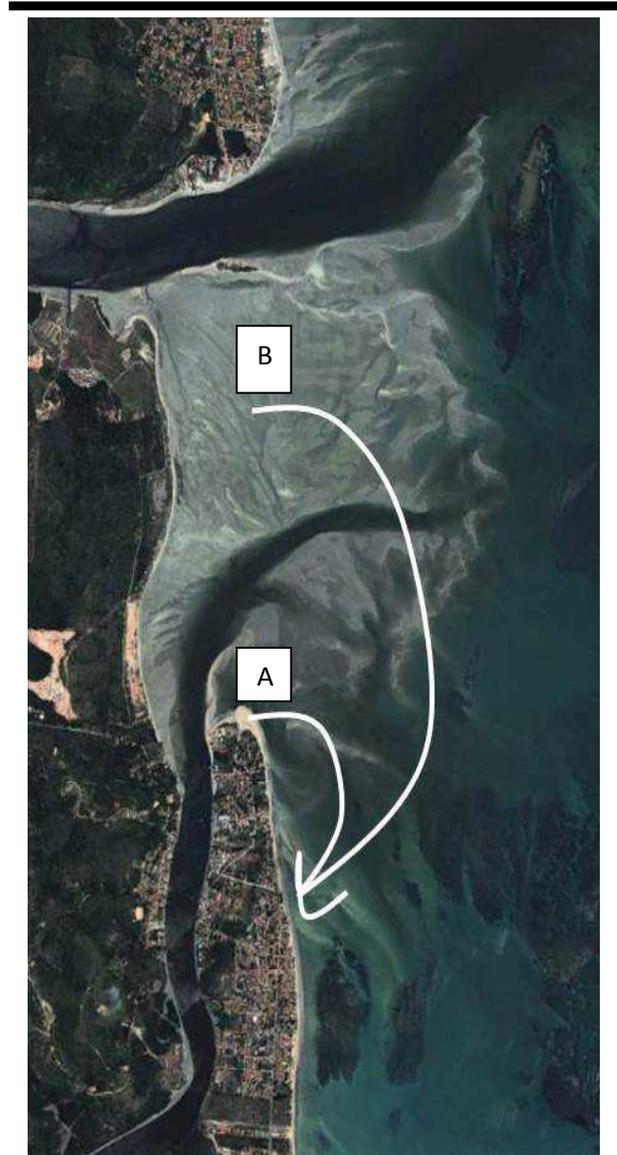


Figure 11. Proposed sand sources for sand bypassing—sandbanks (A) in the north, close to Pontal de Maria Farinha and (B) at Gavoia Beach.

CONCLUSIONS

The erosion problem at Maria Farinha beach is complex and difficult to solve, since the problem has multiple causes, including the construction of coastal defenses. As it affects several municipalities the problem is exacerbated. Wave

propagation simulations have shown that the combination of high spring tides and high waves, significantly impact the coast of Maria Farinha. The comparison between the numerical model results and the profile data (not shown in this document) indicates that under these conditions the beach profile where erosion is observed is more exposed to wave energy than the beach profiles showing accretion. Three possible solutions are suggested – the construction of a submerged breakwater, the deployment of a sand bypassing system and the relocation of buildings on the beach front. Due to the diverse beach usage, the implementation of a sand bypassing system is recommended. The option of doing nothing would cause continued erosion in the critical area taking into account the presence of urbanized areas, often irregular, all along the beach. The case of Maria Farinha beach indicates the necessity of better understanding coastal processes and thorough planning prior to coastal development. It is highlighted that, if preventive efforts had been made in the past, prior to development, such as establishing a buffer zone or a setback line, much of the erosion on Maria Farinha beach would have been avoided.

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