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Morphological Changes Induced by Coastal Protection on the Coast of Maputo City, Mozambique

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Abstract: Coastal change has merited attention because of heated arguments in the literature on this subject at national, regional, southern African, and international levels. The city of Maputo, the capital of Mozambique, which had been undergoing intense coastal erosion actions, was the target of large-scale intervention aimed at halting the advance of the sea and the consequent destruction of infrastructure. Coastal protection consisted of soft forms, artificial feeding, and heavy, longitudinal and transversal structures. This study was carried out along the protected line, about 3 km long, and aims to understand the morphological transformations in the Maputo city shoreline that occurred after the coastal protection. For that, the following technical methods were used: observation, a topographic survey of the beach cross-sections, and the shoreline evolution before and after coastal protection using 2008 and 2010 Google Earth satellite imagery prior to protection 2015, project completion year and 2018 monitoring year. The findings of the study revealed that the causes of coastal erosion persist, like constant removal by deflation of the borrowed sediment. Besides, vertical structures (groynes) intensify erosion in the downdrift while adherent structures interrupt the return of sediment deposited on the sidewalk and the road. The beach that experienced a positive sedimentary balance with artificial feeding has been losing more sediment than it gets. The transversal profiles show the beach shore has depressions that are submerged in the presence of high tides, bringing the sea closer to the adherent structure. Despite the sped up erosion observed, embryonic dunes were detected in some parts of the beach, signs of the establishment of dynamic equilibrium, becoming sites of sand accumulation and sediment source to the beach, through the exchange between the dune and the beach. With these results, a pilot station for artificial dune construction is being designed for beach stability.

Key words: Coastal erosion, coastal protection, morphological transformation change.

1. Introduction

Mozambique is in Southeast Africa. This location of the country is helpful from an economic point of view since it favours the construction of railway complexes, such as Nacala, Beira, and Maputo in the main bays.

The transit of goods between the countries of the hinterland and other continents and regions, through the Mozambican ports, contributes to the collection of revenue and improvement of the trade balance.

The coast of Mozambican coast, rich in marine and terrestrial biodiversity, is a privileged place to develop fishing and tourism activities. Fishing contributes to improve the diet of the population and the export of fishing products and is therefore an important source of income. Likewise, tourism, in frank development, is one of the Government's bets for revenue collection, employment generation, and improvement of the population's living conditions.

The advantages described above make the coastal area attractive and therefore of greater population concentration. However, it is morphologically sensitive. The coastal morphology changes constantly by the wind action, waves, tides and ocean currents. Most oceanic coastal areas are relatively new, existing in their current state as an environment of change [3]. According to the author, such changes result from the dynamic balance between the energy of waves, tides, currents, material supply, and slope of the coastal terrain.

The coastal strip of Mozambique is mostly made up of Quaternary formations. The storms and tropical

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cyclones of the Indian Ocean intensify the action of the waves and their abrasive power. This situation could become worse along with the current climate changes. In recent years, the dynamics of the coastline (advances and retreats) has been induced by the joint action of humans and climate change. The importance and magnitude of this problem have made the oceans a specific aim of sustainable development proclaimed by the United Nations, of which Mozambique is a signatory.

Coastal erosion is a problem in densely populated areas like Maputo city, the capital of Mozambique. In this situation, protection was the measure adopted to ensure the security of assets, save human lives, and improve the living conditions of the population.

2. General Aim

To understand the morphological transformations on the coastal edge of Maputo City after the coastal protection works.

3. Specific Objectives

- Describing the area of study before and after coastal protection;
- Characterizing the coastal protection works applied on site;
- Explaining the morphological change of Costa do Sol beach;
- Showing the impacts of coastal protection;
- Proposing sustainable forms of coastal management.

4. Methods and Techniques

The study was conducted at Costa do Sol beach, in an extension of about 3 km. The methodological basis was a literature review. Through geo-reference of satellite images from 2008, 2010, 2015, and 2018, coastlines were drawn using ArcGis 10.3, to assess their dynamics before and after coastal protection. The direct observation allowed the forms of coastal protection, landscape, and morphological changes of the area to be recorded. The topographic survey of the transversal profiles of the beach, carried out on 21 December 2018 using the Garmin 64× GPS, allowed its graphic representation, and the comparison consisted in identifying the similarities and explaining the differences between the updrift and the downdrift of the second groyne in the South-North direction.

5. Characteristics of the Coastal Area

The coast of Mozambique stretches for about 2,700 km, from the mouth of Rovuma River, in the North, to Ponta de Ouro, in the South. Along this extension, three morphological regions can be distinguished. The North is high and rocky; the Centre is characterized by deltas and estuaries; and the South is low and sandy with beaches and coastal dunes [2, 4, 7, 13, 14, 18-20].

Thus, we can find the following characteristics in each of the three regions:

- The North region, also called *Região de Baías* (Bay Region), about 800 km long, extends between the mouth of Rovuma River and the Island of Mozambique. It comprises of sedimentary rocks (calcarenites, limestone, and sand stones), coral reefs and therefore it is relatively stable. In this stretch, the greatest depths can be found at a short distance from the coast.
- The Centre, also known as *Região de Rios* (River Region), is about 900 km long, between the Mozambique Island and the Bazaruto Archipelago, with many of the great rivers running into the sea and flowing into the delta and estuary. The tides are as high as 7 m and are subject to cyclones every 6/16 years [7, 17]. Erosion processes are physically powerful and are a major problem in Beira city and lead to land and infrastructure loss. There are places where the coast recedes 1 m/year, such as Chinde, in the Zambeze River Delta [20]. In this region, the document adds, erosion is enhanced by the destruction of mangroves and probably by the decrease in the natural flow of sediments brought by the Zambezi River and caused by the Cahora Bassa dam.

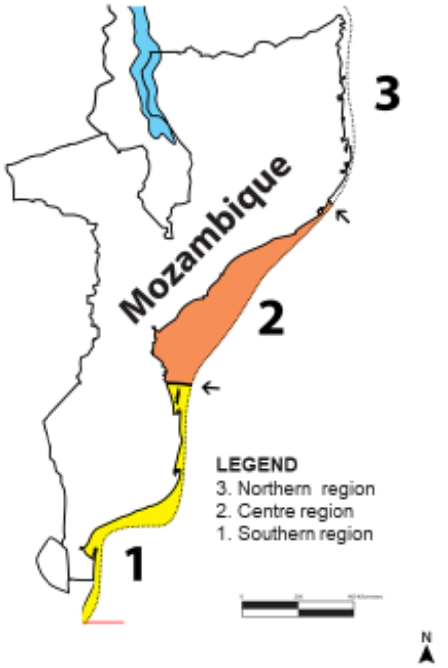

Fig. 1 Morpho-coastal regions.
Source: http://www.zonascosteiras.gov.mz/IMG/pdf/mangais_pt_ecologia.pdf.

• The South region is also known as *Região de Lagoas* (Lagoon Region). It extends for about 850 km, from Bazaruto to Ponta do Ouro. The coast is low and sandy and becomes muddy near the rivers. The coastal lagoons, elongated and parallel to the coastline, flank the two dune systems: the inland dunes of Pleistocene age, in an advanced state of diagenesis, and the coastal dunes of Holocene age [6, 18-20] (Fig. 1).

6. Characteristics of the Study Area

The area under study is on the south coast and is low, sandy, and dune.

Administratively, most of Maputo Marginal is at Polana Caniço D Neighbourhood, in Ka Maxaquene Urban District, in Maputo city, in Maputo bay. To the North, it flows into the Incomati River; to the South, the common estuary of Umbeluzi, Tembe, Maputo, and Matola Rivers and to the East, a group of islands of the Indian Ocean, the largest being Inhaca (Fig. 2).

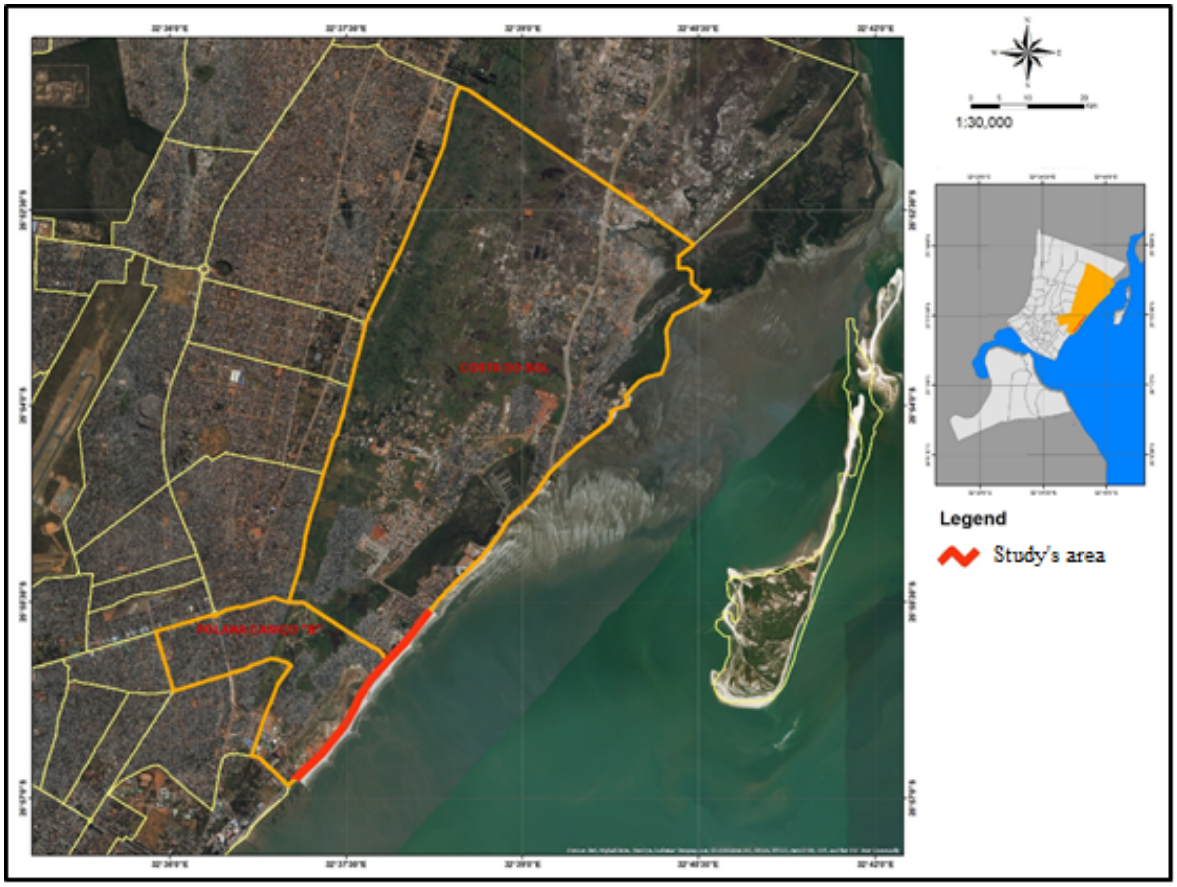

Fig. 2 Geographic location of Maputo marginal—Costa do Sol beach.

The scenic attractions of Costa do Sol beach concentrate new thriving infrastructure along Marginal Avenue, attracted by the rehabilitation and apparent stability of the beach. Among these, it is worth mentioning *Radisson* and *Glória* Hotels, Polana Hotel Casino, Baía*Mall* (Bay Mall), and the North American Embassy, still under construction. Other buildings include restaurants, residential buildings, and others that have gained new impetus, like Costa do Sol restaurant and Marés supermarket.

It is important to note that the development of tourism in Maputo bay began in 1960, with the extensive influence of the South African and the Rhodesian. After national independence, it gained new momentum in 2000 when the the Ministry of Tourism was created [15]. Hotels of international level replaced some old touristic infrastructures like the campsite, as was mentioned before.

7. Dynamics of Costa do Sol Beach

The coastal zone of Mozambique is quite fragile from a morphological point of view because of its location in the interface zone between the lithosphere, the biosphere, and the atmosphere. The erosion of Maputo City marginal is originated, however, it is aggravated by anthropic interference in the coastal processes, as reported by the researches carried out by Refs. [9, 11, 13].

Ref. [13], for example, maintains that the most serious cause of coastal erosion in southern Mozambique is the flatness of the longitudinal profiles in the low stream and the flow deficit with which the sediments reach the mouth; more controlled by the marine regime than by the river regime. The author adds that only during extensive floods is there an outflow of sediment to the continental shelf.

In Costa do Sol, in particular, erosion is intensified by anthropic action and the potential solutions are preventing beach users from destroying the dunes; placing metallic or wooden pedestrian accesses and protecting dune vegetation [9].

Another factor to consider in coastal erosion is the dredging of the access channel to the port of Maputo. However, it still needs more research [11].

As mentioned above, coastal erosion in Mozambique and specifically in Costa do Sol beach is a real problem, as it threatens the buildings erected and their occupants and there is, therefore, a need to protect them.

8. Protection of Costa do Sol

The city's expansion and, above all, the density of infrastructure has increased the value of the land, hence the need to protect the buildings. It was in this context that the project to construct the Maputo Ring Road included protecting the coast, which was already showing worrying signs of erosion.

To protect goods and people on many beaches on Earth, man reacts by resorting to various options: not acting, retreating and relocating, artificially feeding the beach, or building stabilization structures [5, 22].

The first two options would not apply in Costa do Sol because it is the most valuable area in Mozambique. Letting erosion progress or resettling those affected would have difficult economic and social impacts on manage.

To protect the asset along the coast and to renew the beach value, the last two options were applied: artificial feeding and building longitudinal and transversal structures [16].

Artificial feeding is used to create or maintain the recreational state of the beach or to increase the capacity of the beach to protect properties from wave attack or storm flooding [10].

Transversal structures such as breakwaters, jetties, and groynes, which are intended to reduce the speed of waves and currents, interrupt the movement of the longitudinal current, reducing or eliminating the natural distribution of sediments along the beach. Longitudinal or adherent structures protect the asset from the erosive action of the sea but interrupt the exchange of sediments between the beach and the dune [10].

Three years after the project was completed, morphological transformations could be observed that, if not monitored, could aggravate erosion in the marginal.

9. Protection vs. Dynamics of Costa do Sol Beach

It was mentioned before that artificial feeding, longitudinal and transversal structures were applied in the study area, each one presenting its potentialities and fragilities.

(1) Artificial feeding consists of placing large amounts of sand or gravel in the coastal area to protect the coastline (Hall, 1952, Stumble, 1990 Seymour, 1995, quoted by Ref. [10]).

The source of sediments can be found on land, including sand from other beaches that have a positive balance. In recent times, however, the primary source of sediments is seabed deposits, dredged from ports, or extracted from the seabed [10].

Ref. [8] points out that sediments used in beach feeding should have the same grain-size as natural beach sediments. However, the author stresses, in practical terms, that the choice of material for artificial feeding depends on availability and cost.

In the case under study, the artificial feeding source was the adjacent seabed and was probably chosen based on its availability and above all by cost.

It was found that artificial feeding increased the width of the beach and the number of sediments moved by the wind by deflation (Fig. 3).

As seen in Fig. 2, the sidewalk, a privileged place for the morning walk of city dwellers, and the Marginal Avenue, the fastest way from the outskirts and Marracuene district to the centre of Maputo city, are sites of accumulation of beach sand. It results in a traffic jam, especially during rush hours, forcing pedestrians to enter the road to bypass the dunes, risking being run over.

This situation is aggravated because the Marginal Avenue was built on the front dunes, the natural purpose of which is to protect the continent from the onslaughts of the sea.

The absence of obstacles like dunes and ground vegetation, that covered them, and casuarinas, that played the role of windbreak, has exposed the beach to the erosive action of the wind. It is also possible that the grain size of the sediments used in artificial feeding differs from that of the original sediments.

It should be noted that the removal of sand from the beach and its deposition on the road was a concern presented by the chairperson of the Board of Directors of the State-owned company Empresade

Fig. 3 Sand deposited by the wind on Marginal Avenue.
Source: Image captured by the authors on 17 December 2018.

Fig. 4 Embryonic dunes.
Source: Picture taken by the authors on 20 December 2018.

Desenvolvimento de Maputo-Sul, EP in charge of managing the Maputo Ring Road during the lecture delivered at the Pedagogical University in 2016.

The accumulation of beach sediments on the sidewalk and along the road disturbs the normal movement of pedestrians and vehicles, a situation that is aggravated on rainy days when water accumulates on the road because of clogging of rainwater runoff channels.

Despite the situation described above, there was evidence of embryonic dunes in some stretches of the coast. This is a sign of balance in the coastal system between the first and second groyne, in the South-North direction of the area under study, as illustrated by the image in Fig. 4.

The embryonic dunes, if not disturbed by trampling, may develop and reduce the impact of the wind on the beach sand and become a source of sediments to the beach system.

(2) The longitudinal or adherent structure was built to protect the Maputo ring road. During the sea breezes or during the storms that hit Maputo bay, the beach sand transposes the longitudinal structure but its return, during the land breeze, reduces drastically or is simply interrupted. Here, the beach, which once had a positive sediment balance with artificial feeding, has a negative sediment balance, and loses more sediments than it gains [21].

(3) The transversal structures or groynes, in seven, aim to reduce the impact of waves and to stabilize the beach. However, they interrupt the sediment transport made by the drift or coastal current, depositing sediments in the updrift and eroding in the downdrift.

The longitudinal and transversal structures transform the morphology, reduce permeability, and can intensify beach erosion.

10. Morphology of the Study Area

As previously mentioned, the coastal area is quite dynamic, as evidenced by the 2008 and 2010 coastlines, before the intervention, 2015 coastline, at the project completion year, and 2018 coastline in Figs. 5 and 6 below.

The coastline layout, in 2008, shows a retreat. In 2010, the coastline continued to retreat and in some points, which were already critical, the situation worsened even more. This is the situation that led to coastal protection.

Fig. 5 Dynamics of Costa do Sol line (2008-2018).
Source: WGS 1984 36 South Zone.

Fig. 6 Dynamics of Costa do Sol line (2008-2018).
Source: WGS 1984 36 South Zone.

In 2015, the coastline advanced towards the sea by artificial feeding. However, the line layout, in 2018, was quite worrying given the investment made and the time-lapse of only three years. The slimming of the beach in the entire study area is clear. The situation is exacerbated in the downdrift, in the left margin of each of the groynes, which takes us to agree with Ref. [7] when the author states that the longitudinal current moves in a South-North direction in almost the entire Mozambican coast.

Besides the longitudinal variation, a topographic survey of the transversal profile of the beach at the second groyne, just apposite *Baía* Mall, was conducted (Fig. 7).

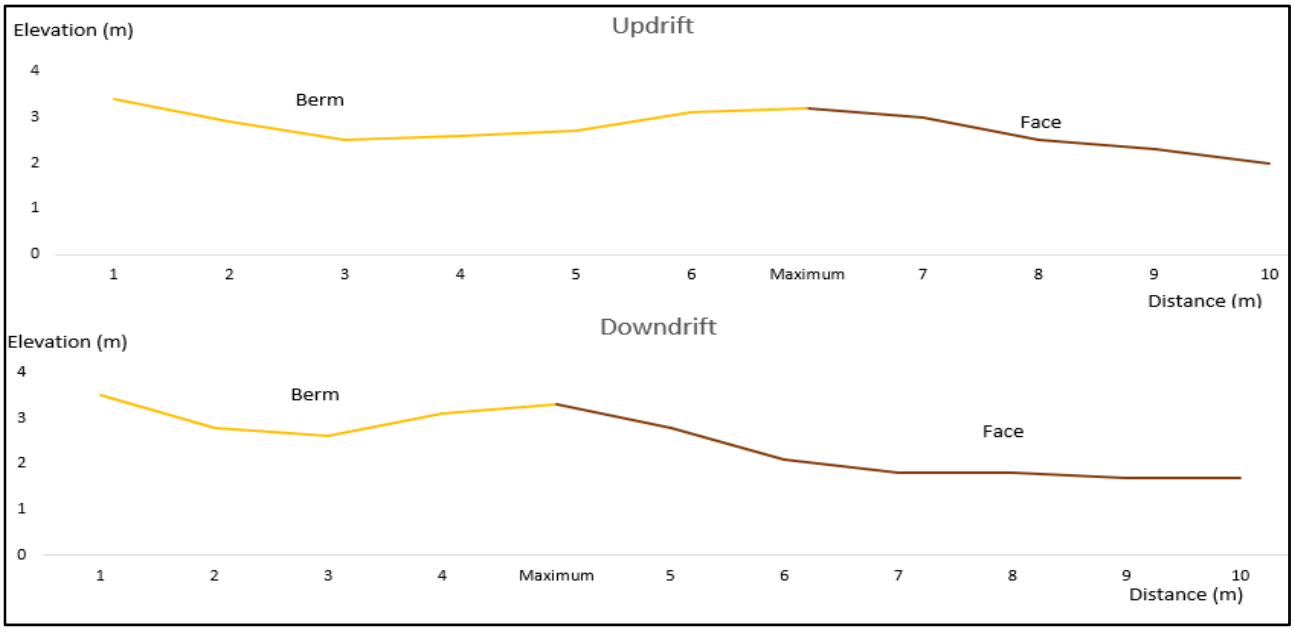

Fig. 7 Transversal beach profiles on updrift to downdrift of the second groyne.

The outcomes showed significant morphological differences on the beach face and berm. Fig. 5 shows the profiles of the beach at low tide on both sides of the groyne.

The Beach berm is the immersed part of the beach; It is the place where beach users sunbathe. The Beach face is the part affected by the swash and backwash [1, 10]. Fig. 7 shows morphological differences in the berm and beach face.

(1) The beach berm is more extensive in the updrift than it is in the groyne's downdrift.

(2) The beach face is less steep in the updrift than in the downdrift.

The existing differences are a result of the hydrodynamics, i.e., the action of waves and especially longitudinal currents.

- When constantly hitting the beach, waves carry sediments to the land during the swash and to the sea during the wave backwash. The slope of the beach face depends on the amount of water and sediments carried in both directions [10]. It will be less steep in sandy beaches, with less water loss by percolation, and steeper in gravel beaches [10].
- In the study area, the grain size of sediments is the same, if we take into account the same source fed it. However, there are significant differences in processes, which are reflected in the morphology.
- In the updrift, the amount of sediments carried during the flow is bigger and part of the sediments is swept and brought back to the sea. While in downdrift, the sediments taken to the beach during the wave flow are smaller but, during the reflux, the speed of the return wave is bigger, which increases its power of start and transport.
- The role of the coastal drift is to transport sediments along the coast [10, 12]. The authors clarify that in its movement, when the current encounters natural or anthropic obstacles, such as groynes, it deposits the sediments in the updrift and bypasses the obstacle with very few sediments.

The overlapping of the profiles (Fig. 8) shows that the beach berm is of accretion in the downdrift and removal in the updrift. The opposite happens with the beach face: There is accretion in the updrift and removal in the downdrift.

It should be noted that the greater extension of the berm in the updrift exposes it to the wind action. Erosion by deflation causes depressions, where water accumulates during high tides, a situation that may expose structure adherent to the wave action.

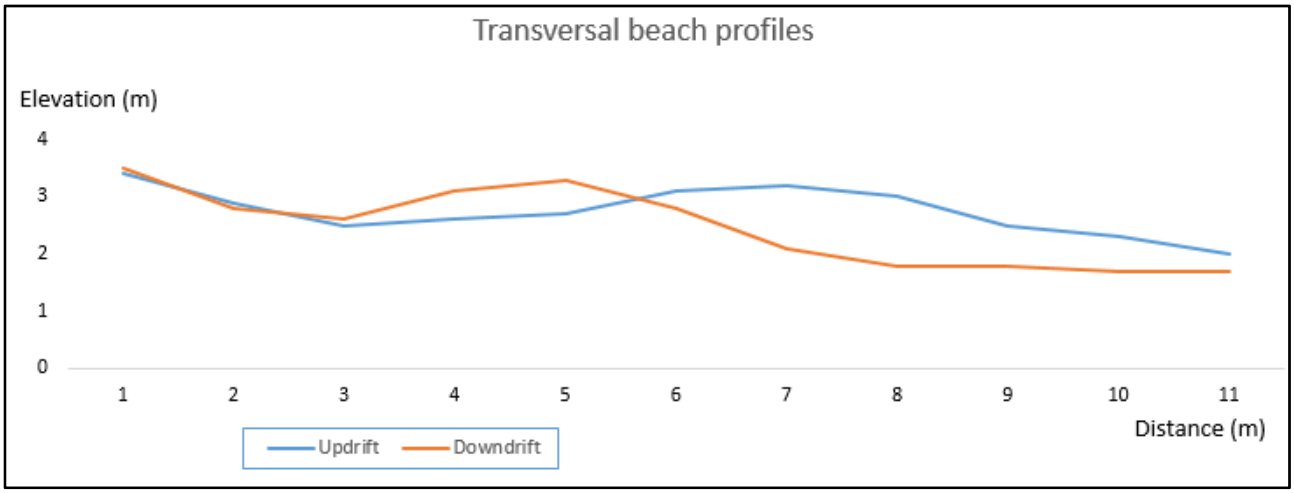

Fig. 8 Overlapping of the beach transversal profiles on the second groyne.

Table 1 Impact of coastal protection.

Sector	Positive impact	Negative impact
Economic	Increased density of housing infrastructure, hotels, and casinos that sustain tourism, that is considered an activity that drives the economic development of the country.	Need for constant monitoring and maintenance of the works because of the sped up advance of the sea, with high costs.
Social	Improved living conditions of city dwellers: Maputo Ring Road has made the traffic easy, reduced stress, revitalized laser activity, and physical maintenance.	Accumulation of sand on sidewalks and public roads hindered the normal movement of vehicles and pedestrians, especially during and after strong winds and/or storms.
Environmental	(1) Artificial beach feeding increased the width of the beach to protect the coast from the onslaught of sea waves and increase its beach value. (2) Vertical structures were designed to reduce the intensity of waves and currents.	(1) The destruction of dunes and other obstacles has sped up the removal of sediment by the wind. (2) The transformation of the natural landscape has reduced the scenic value of the beach, altered the natural distribution of sediments, and intensified erosion in some stretches.

11. Impact of Coastal Protection

The coastal area is quite dynamic, so that any human intervention, even with the best intentions, is likely to have negative impacts (Table 1).

Despite the negative economic impact of coastal protection, because of the need for monitoring, when considered holistically, this is the most economic, social, and environmentally feasible and sustainable measure because it is always for early correction of unforeseen foreseen and unforeseen situations.

12. Conclusion

Costa do Sol beach has always been preferred for leisure and tourism for its scenic value. However, from some point, it suffered sped up erosion that retracted the tourist and recreational activity and threatened to destroy socio-economic infrastructures built along the coast.

The coastal protection consisted of artificial feeding of the beach, longitudinal and transversal structures, which increased the bathing value and attracted more infrastructures (supermarket, hotels, and housing buildings) along Marginal Avenue, making it a privileged area of the capital of the country.

However, some interventions have proved unsafe. The permanent removal of sediments from the beach by deflation is reducing the width of the beach and forming depressions that are filled with water during high tides. The removal also occurs in the downdrift of the groynes, which can contribute, in a short stretch, to the advancement of the sea along the adherent structures.

Despite its high cost, monitoring must be carried out with the deep mastery of the morphodynamic processes of the coast to correct foreseen and unforeseen situations.

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