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Chapter

Land Uses Allocation: The Execution of an Artificial Beach and Its Complementary Infrastructures – Madeira Island – Machico, Portugal

Sérgio Lousada, Luís Loures and Rui Alexandre Castanho

Abstract

The present study aims to propose the creation of an artificial beach in the municipality of Machico and its complementary infrastructures, located on the south-eastern coast of the Madeira Island (Portugal). Machico's beach sand consists of a mixture of black volcanic sand and round basalt stones. Usually, it has clear waters and a quiet sea. This beach also has a mooring infrastructure, thus allowing access to the sea. In order to achieve this study's main goals, it was initially carried out an extensive review and bibliographic research. Subsequently, a sand beach and its shelter groins were simulated and designed to hypothetically promote the retention of the sand and mitigate the tidal effects. In addition to model the beach dynamics, an extensive characterization of the extreme maritime regime was performed. The model was developed based on topographic and hydrographic site surveys and the data using Wave Watch III model at 32.0°N, 17.0°W—obtained from SONEL web page, which gathers new data every 6 hours. Besides, the study also contemplated the analysis of the sea inundation quota for a return period of 100 and 500 years and its development along with the Master Plan of the City of Machico. Furthermore, some final remarks and conclusions will be shown; besides, some future projects should be developed to expand the knowledge of this thematic field.

Keywords: artificial beach, beach dynamics, coastal protection, extreme scalar wave height, GIS, maritime climate, maritime flood level, return period, sediment transport, waves

1. Introduction

Currently, there is enormous progress pressure in the coastal zone worldwide, which has resulted in the planning or construction of a large number of coastal developments. This situation requires more than protecting the existing coasts against natural risks, such as coastal erosion and coastal flooding. Typically, there is a need to rehabilitate many coastal areas under pressure from land development in the past and coastal erosion and degradation. However, in some regions, the high demand is not satisfied only with the rehabilitation of existing beaches [1].

In RAM (Autonomous Region of Madeira), the large concentration of hotels along the south coast, resulted in the reduction of free access spaces for the population to the sea, a situation that was compensated by the construction of several bathing complexes, cases of Ponta Gorda, Poças do Governador, Doca do Cavacas, Barreirinha, Ponta Delgada, among others [2].

From the rolled pebbles to the black sand, to the artificial and the various bathing complexes with natural pools, it is possible to find beaches for all tastes in Madeira; in fact, this created a competition with Porto Santo, until recently the only island in the archipelago with its nine-kilometer-long fine yellow sand beach [2].

In Madeira, initially, the beaches were all of rolled pebbles, with only one of black sand, the 'Prainha' in Caniçal (**Figure 1**), at the eastern end of the island, which is difficult to access, and some private and public bathing complexes in Funchal [2].

But about a decade ago the scenario started to change and one of the innovations was the import of sand from North Africa to build the artificial beach in Calheta (**Figure 2**) [2].

Calheta was the first beach in Madeira to import sand, having been inaugurated in 2004 and with two slope breakwaters as a form of protection. Praia da Calheta is a beach located in the parish of Calheta, on the island of Madeira, in Portugal, with a length of 100 meters. It is often sought after by canoeists and windsurfers [3]. This project was so successful that it was copied in the municipality of Machico, in the extreme east [2]. Located on the right bank of the mouth of Ribeira de Machico, Praia da Banda d'Além (**Figure 3**) is a beach that allows an immediate dive for those in the center of Machico [4].

With about 70 meters in length, the beach has locker rooms, changing rooms, showers, bathrooms, parking, and guarded during the bathing season [4]. This yellow sand beach is one of the few references of its kind on Madeira Island. It is

Figure 1.
"Prainha", Machico (source: https://www.madeiraallyear.com).

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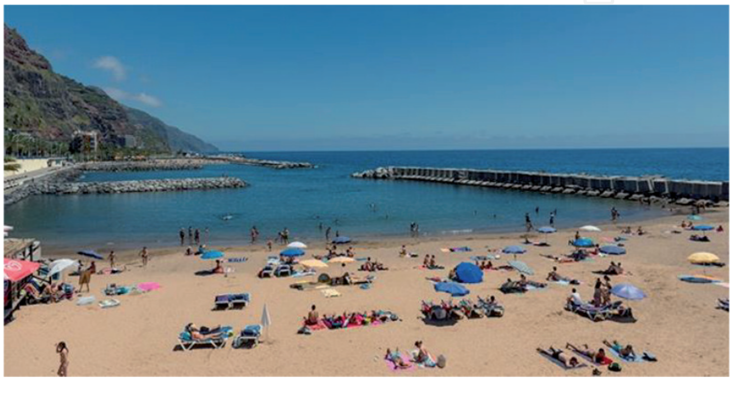

Figure 2.
Calheta artificial beach (source: https://www.madeiraallyear.com).

Figure 3.
Banda d'Além beach, Machico (source: https://www.madeiraallyear.com).

Figure 4.
Machico Bay (source: Authors).

framed in the emblematic Machico bay (**Figure 4**) inserted in a pleasant environment, making it, therefore, one of the favorite places regionally [4].

The introduction of sand from North Africa on the beaches of Madeira in recent years changed the appearance of the island but also extended the tourist offer for those seeking sun and sea [2].

The proposal presented is intended to create an artificial beach in the municipality of Machico and the necessary infrastructures, continuing the success of Praia da Banda d'Além, expanding the offer, and contributing to the economic and social development of the municipality and, consequently, RAM.

In addition to model the beach dynamics, an extensive characterization of the extreme maritime regime was performed in order to portray the analysis between the "MFL" maritime flood level, designates the sea level reached in exceptional situations and its iteration with the PDMM – essential instrument for spatial planning in the municipality of Machico. This part of the work has been previously developed, for example, in Colombia, where methodologies were proposed to estimate the long-term Maritime Flood Level (MFL) on a regional scale on the Caribbean coast and on the Pacific coast where a study was carried out in which a study was carried out. In fact, measures of vulnerability and adaptation to flooding in coastal and insular areas of Colombia were analyzed, depending on the characteristics of the population and its infrastructure [5].

2. Workflow: the used methods

In this study, a quantitative methodology is adopted, which is characterized by the use of quantification, data collection process, and treatment of these data through statistical techniques. It is often applied to sciences in descriptive studies that seek to discover and classify the relationship between variables, ideal for the physical–mathematical study.

Firstly, an essentially theoretical collection of information to be used in this study is carried out. So, it was established which support software is needed and which physical parameters contribute with greater significance in executing a project of this magnitude.

Based on the selected drawing and spreadsheet software and making use of the collected, organized, and treated data, a project consisting of a descriptive memory, a set of construction plans, a construction contract documents/special technical conditions, the respective health and safety budget and plan, were prepared and developed.

After elaborating on the project, observations and analyses are carried out on the set of written and drawn pieces and their importance during the design, execution, and exploration phases.

At the end of the study, the conclusions and intrinsic recommendations are presented, being this work based on the following organization chart (**Figure 5**).

Figure 5.
Organigram (source: Authors).

3. Case study

The Madeira Archipelago, an integral part of Portuguese territory, is located in the Atlantic Ocean 978 km southwest of Lisbon. Of volcanic origin, it is formed by the islands of Madeira (736 km^2), Porto Santo (43 km^2), Desertas (14 km^2) and Selvagens (4 km^2). Only the first two islands are inhabited, making up the other natural reserves [6, 7].

The island of Madeira has a very rugged orography (**Figure 6**), with the highest points being Pico Ruivo (1,862 m) and Pico do Areeiro (1,818 m). The relief, as well as the exposure to the prevailing winds, means that there are several microclimates on the island, which, together with the exotic nature of the vegetation, constitutes an important factor of attraction for tourism, the main activity in the region [6, 7].

There are no major thermal variations throughout the year, keeping the climate mild with average temperatures around 22°C (maximum) and 16°C (minimum) [6, 7].

The sea water temperature, due to the influence of the hot Gulf current, remains at 22°C in the summer, gradually cooling until reaching 17°C at the end of winter [6, 7].

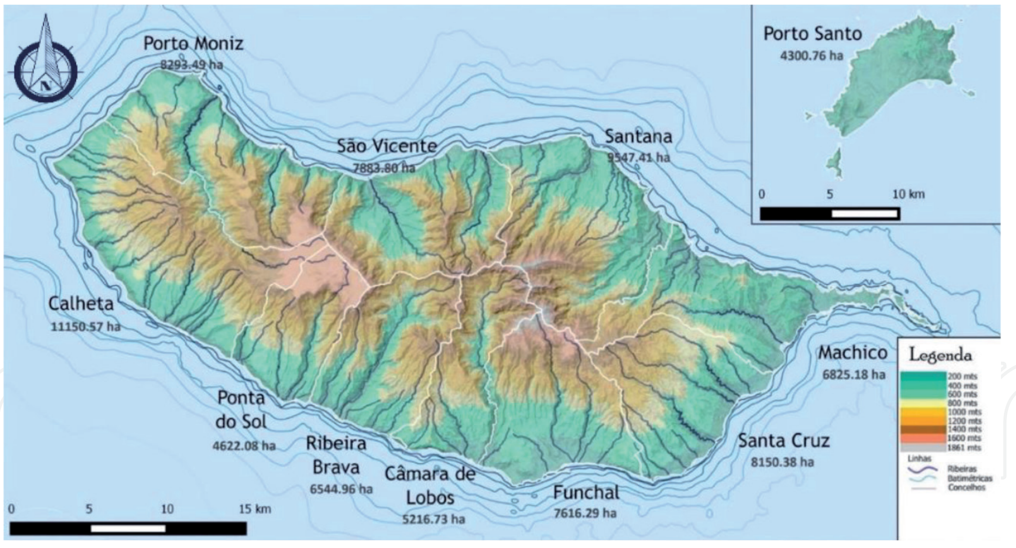

Figure 6.
Geomorphology of Madeira Island and Porto Santo), main and bathymetric streams with the limits and official areas of the municipalities (Author: L. C. Antunes).

Figure 7.
Proposal for a new beach and associated infrastructures (source: Authors).

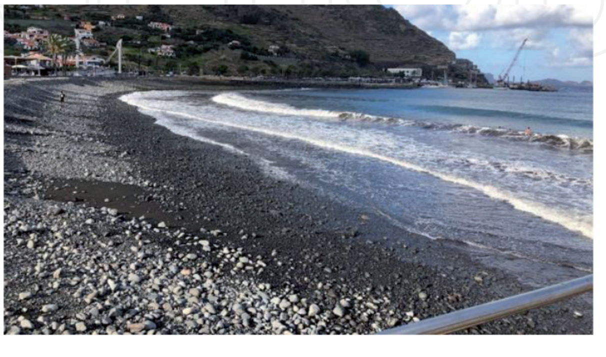

Figure 8.
Place to intervene (source: Authors).

The case study is located on the south-eastern coast, in the municipality of Machico (Madeira Island) with the following geographic coordinates: Latitude: 32°42′58.15″N, Longitude: 16°45′51.90″W (**Figures** 7 and **8**).

Figure 9.
Beach detail (source: Authors).

Machico beach (South) is a beach with a mixture of black sand and basalt stones (**Figure 9**). It has clear waters and a calm sea with a mooring (pontoon) structure that allows access to the sea or coast. The coast has several catering services and similar others.

The aim is to simulate the creation of a sand beach on the coast of Machico (South), simultaneously with the dimensioning of shelter groynes to promote sand retention and mitigate the undulation on the site (hypothetical project). One possibility for creating this beach is to use the dredged sand in the port of Funchal. For this, it is necessary to make a comparison between the profile of Garau and the real profile of the beach, measured in situ.

Additionally, there is a structural rehabilitation and expansion of the mooring structure (pontoon). Finally, the MFL is also calculated for a return period of 100 and 500 years. In order to model and design this analysis, a characterization of the extreme maritime regime is needed [8, 9].

As starting data, the local topographic and hydrographic surveys is provided, as well as the wave data (Wave Watch III model at 32.0°N17.0°W, obtained at www.sonel.org. – the historical series is wider (1952 to 2012), with data every 6 hours), as presented in **Figure 10**.

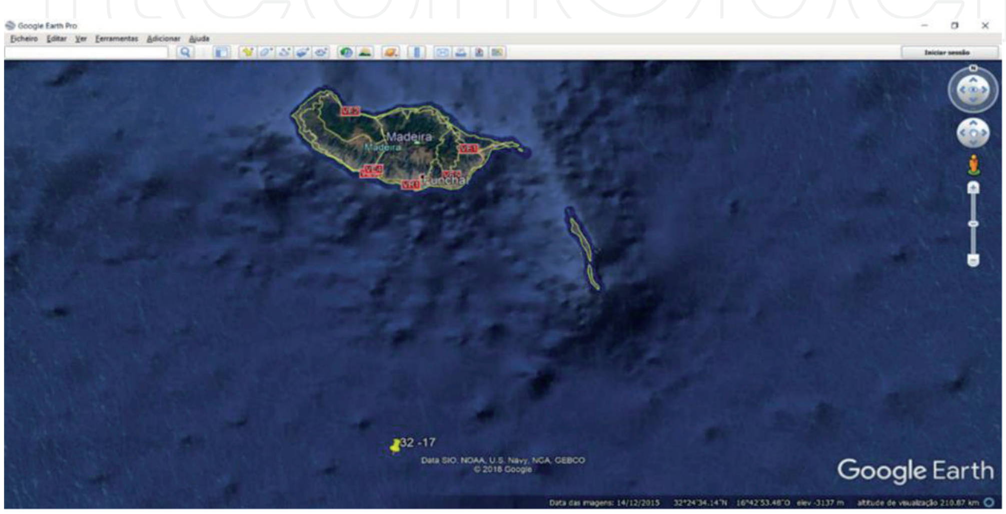

Figure 10.
Location of the buoy in relation to the coast (source: Author).

4. The processes to assess the maritime climate

Prerequisites:

- Choose a point on the coast where it is assumed that the Maritime Work will be projected, for which the Maritime Climate in Deep Waters will be calculated;
- Choose the type of Maritime Work to be projected, in order to calculate the Lifetime (L) and the Risk (R) that represents the calculation time.

The seven steps indicated in **Figure 11** were followed to obtain the Maritime Climate in Deep Waters at the chosen coast point.

The chosen coast point is located in the municipality of Machico – Machico Beach (South) with coordinates 32°42′59.23″N; 16°45′52.02″W. **Figure 12** shows the area where the project will be developed (hypothetical maritime work), in this case, an artificial beach, on which the study will be carried out.

The information used in the development of the maritime climate was SONEL database (database GOW – IH Cantabria de Santander – www.sonel.org), "Waves" tab. The point on the coast is approximately 82.5 km from the selected buoy located in the south-west of the island of Madeira (32°00′00.00″N; –17°00′00.00″W).

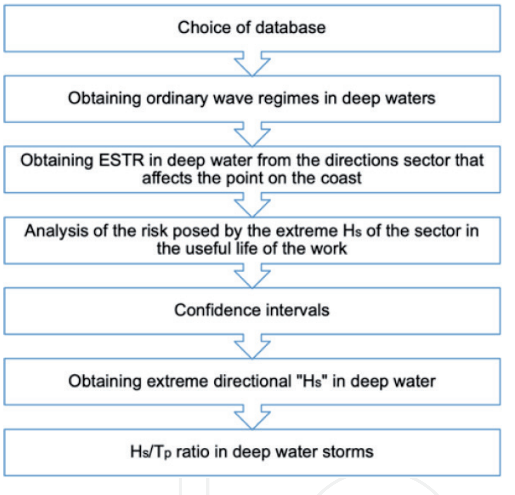

Figure 11.
Calculation methodology (source: Authors).

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Figure 12.
Proposal for a new beach and associated infrastructures (source: Authors).

Figure 13.
Range of directions that affect the point on the coast chosen (source: Authors).

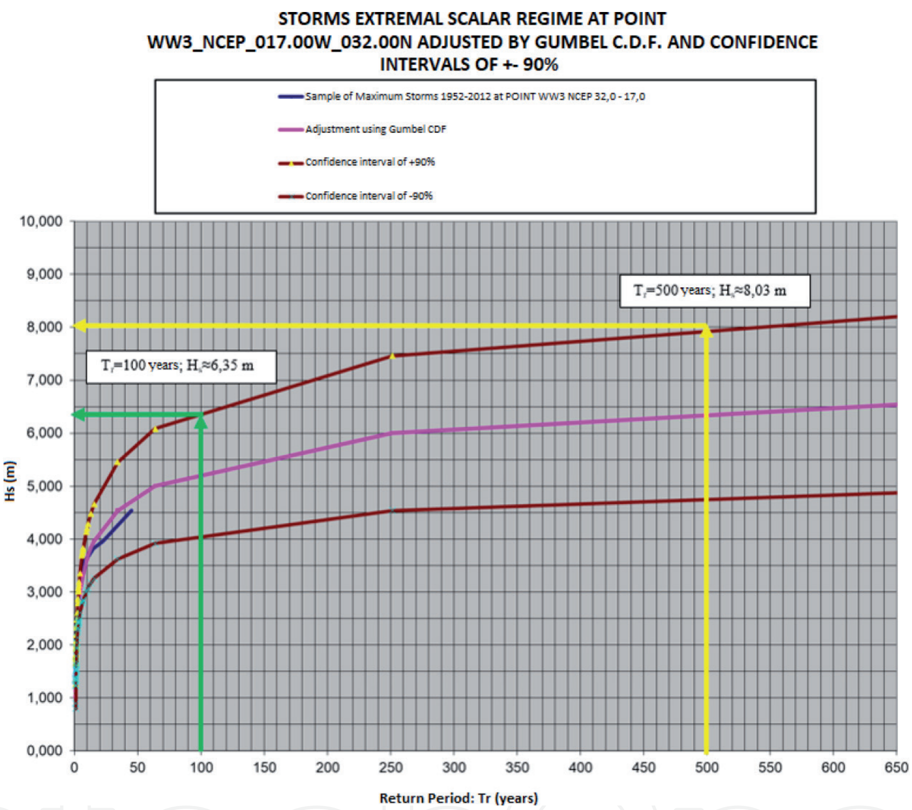

Figure 14.
Extreme scalar temporal regime adjusted by the C.D.F. Gumbel together with the confidence bands for the ± 90% percentile (source: Authors).

In this specific case, and for the point on the coast chosen, the directions to be considered include the sectors SSW-S-SSE-SE-ESE of wind rose, as shown in **Figure 13**.

In order to obtain the Extreme Scalar Temporal Regime (ESTR), it is first necessary to obtain the maximum annual directional significant wave height (hs, max) and the peak period (tp – seconds).

Figure 14 shows the graph on the Cartesian axes – Return Period Selection (Tr) vs. extreme scalar wave height (Hs) – for our 59-year-old sample (1952–2011) (chosen database, SONEL (www.sonel.org), "Waves" separator, namely the buoy located in the south-west of the island of Madeira (32°00′00.00″N; –17°00′00.00″W)), through the C.D.F. Gumbel together with the confidence bands for the ± 90% percentile.

After executing the previous task, we have the following:

- C.D.F. Gumbel (asymptote I) we have an extreme scalar Hs for the confidence band, percentile + 90% whose value is Hsee = 6.35 m, for Tr = 100 years;
- C.D.F. Gumbel (asymptote I) we have an extreme scalar Hs for the confidence band, percentile + 90% whose value is Hsee = 8.03 m, for Tr = 500 years.

Then focus on the calculation of the maritime flood level of the beach of Machico (South) – municipality of Machico, on the south coast of Madeira (Portugal). Along with that developed over the previous information, it is intended to obtain a comprehensive view of the local dynamics in order to schematize its performance.

The MFL, designates the sea level reached in exceptional situations. It depends on the following factors: characteristics of the swell or the incident storm (Hs, Tp), slope of the beach and the existence or not of coastal defenses.

It is possible to distinguish several levels of maritime floods depending on their origin: the simple maritime, the simple rainwater and the rain-sea combination.

A comparative analysis in two dimensions of the area and topographic levels covered by the MFL was carried out for the beach of Machico (South) – municipality of Machico (Portugal), as well as its iteration with the Machico Master Plan – basic instrument for spatial planning in the municipality of Machico. That said, with the use of Microsoft Excel and AutoCad software, it was possible to develop this analysis. Thus, the order described below allows us a better understanding of the above-mentioned:

- Hsedir for the range of directions that affect the work, which multiplied by the directionality coefficient, Cd, of the respective direction, gives the maximum value of Hsee = 3.42 m;
- C.D.F. Gumbel (asymptote I) we have an extreme scalar Hs for the confidence band, percentile + 90% whose value is Hsee = 6.35 m, for Tr = 100 years;
- C.D.F. Gumbel (asymptote I) we have an extreme scalar Hs for the confidence band, percentile + 90% whose value is Hsee = 8.03 m, for Tr = 500 years.

Regarding to the Machico Master Plan and its resolution, we will be sent to:

- Article 29 – Identification of spaces – Depending on the existing or proposed dominant use, the following classes and subclasses of spaces are considered, identified in the planning plan:

  a. Natural spaces – Natural spaces for recreational use (beaches);

- Article 31 – Identification of the operational planning and management units (UOPG) – Without prejudice to the elaboration of municipal plans of a lower hierarchy for the entire area of urban land production in the municipality, the UOPG identified in this Plan and which are considered a priority intervention are the following:

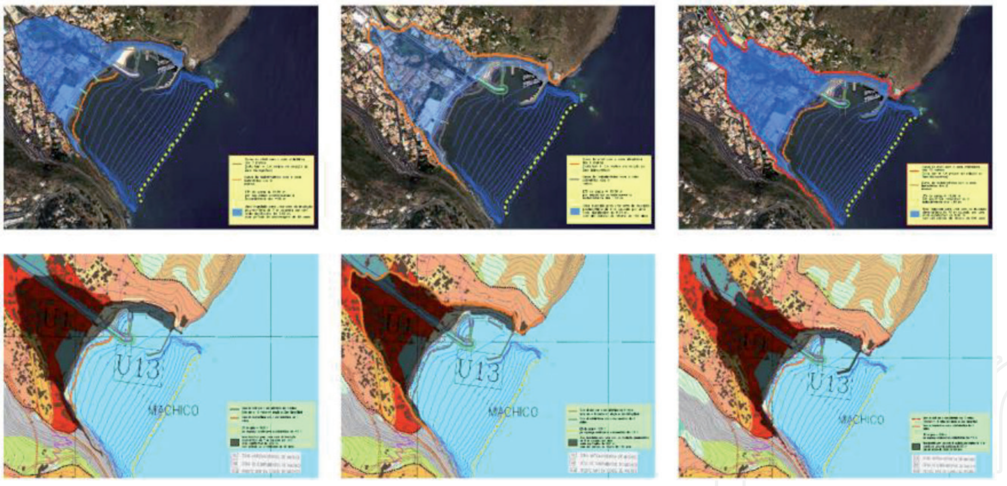

Figure 15.
Comparison of "MFL" maritime flood level – Hs (Real, Tr = 100 and Tr = 500) (source: Authors).

a. U1 – Machico old/historic area;

b. U2 – Machico equipment area;

c. U13 – Machico sea front.

After analyzing the Machico Master Plan, and in view of the increase in the value of Hsee, the uses of soil and their categorization were identified, with an increase of these in relation to the value of Hsee, as shown in **Figure 15**.

5. Closing section

The main focus of this study is the "Execution of an Artificial Beach and Respective Complementary Infrastructures (Madeira Island – Machico)."

From the bibliographic analysis, knowledge is acquired at the level of the execution methodologies related to the different alternatives to develop a complete artificial beach project.

So, considering the broad scope of the theme of this study and the slowness associated with it, it was possible to achieve the purposes previously stated in a satisfactory manner, complementing the knowledge acquired throughout academic life with scientific information and experimental analysis (use of different software).

In the development of this study, a comparative analysis between the "MFL" maritime flood level was carried out for the beach of Machico (South) – municipality of Machico (Portugal); as well as its iteration with the PDMM – essential instrument for spatial planning in the municipality of Machico, is processed, demonstrating that the creation of a project for a maritime work (artificial beach), is adequately connected with the territorial and urban planning, as well as the land uses described in the Machico Master Plan.

Two levels of risk of simple maritime flooding are distinguished:

1. The generated by the simultaneous performance of:

    a. Meteorological + astronomical + extreme weather tide – Whether the SEA storm (generated by cyclones or storms) or the SWELL (generated by rainstorms) causing maritime flooding, or by impact;

b. Astronomical + meteorological tide + wide waves – In this case, the greatest risk of flooding occurs when the astronomical and meteorological tides occur simultaneously.

2. The Flood is generated by extreme events at sea: tectonic, volcanic or impact tsunamis. These result from any combination of tides and are of such magnitude that it is not economically viable to design any infrastructure that minimizes damage.

3. The process for calculating the MFL is slow and laborious. However, it shows that an increase in the value of Hsee corresponds to the largest affected area on land, so greater area relative to different uses of soil will be affected.

Contextually, we believe this research would be essential to develop and improve some aspects if it is intended to continue to develop a similar study, namely:

a. The main aspect of being mentioned is the continuation and optimization of the monitoring carried out along the coast in RAM, in order to obtain a more accurate characterization of it, at different levels, undulation, geology, bathymetry, topography, etc.;

b. Optimize the spreadsheets developed throughout this study;

c. Modeling and interaction between wave heights and port structures, in order to minimize errors made over these years (recent past);

d. Analysis of the influence of the tide level in the flow in artificial water channels, direct relationship with the risk of floods downstream, and its interconnection with the analysis of the coastal dynamics (accounting of the effective solid transport).

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