

# Coastal Zone Vulnerability and Risk Evaluation: A Tool for Decision-Making (An Example in the Caparica Littoral - Portugal)

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## ABSTRACT

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The Caparica-Espichel Coastal Arch, in the Portuguese western coast (Setúbal Peninsula and Lisbon Metropolitan Area), has a diversity of biophysical systems and different forms of human use that translate into distinct evolution dynamics, vulnerability and environmental risks. The area under study remains a remarkably representative example of the conflicts and problems arising from the anthropic pressure over a coastal area rich in natural values, framed by a lack of efficient planning and land management. This paper presents a conceptual model for the definition and characterization of environmental risk and vulnerability in the coastal areas under anthropogenic pressure, aiming mainly at supporting the development of strategies and measures for coastal environmental management. The methods for evaluation of vulnerability and risk, in what concerns marine and continental erosion, were developed with the use of the Geographic Information Systems, field work and the monitoring of the impact of extreme phenomena, such as the storms that occurred in the 96/97 and 02/03 winter seasons. This work deals with notions such as biophysical vulnerability, hazard and risk in coastal areas.

**ADDITIONAL INDEX WORDS:** *Hazard, evaluation, monitoring and environmental management methods.*

## INTRODUCTION

The coastal zones are the country's most densely populated areas, including the Metropolitan Areas of Lisbon and Oporto. Between Braga and Setubal, the majority of the cities have a population density higher than 100 inh/km<sup>2</sup>. The problems of the Portuguese coastal zones arise essentially from the consequences of the dynamics of the coastal system, as well as the type of use and management.

The Caparica -Espichel Coastal Arch (Figure 1), in the western coast of the Setúbal Peninsula, refers to the vast coastal arch reaching from Costa da Caparica up to the Espichel Cape. The evolution and occupation of this area is intimately connected to the territorial processes on the Lisbon Metropolitan Area (LMA), of which it is an integrated component.

The development model of the LMA is an excellent example of coastal area under pressure, this basically being the economic, political and population concentration in the coastal areas of the country. With an extensive coastal line with 540 km (Atlantic coast, Tagus estuary, Sado estuary and Albufeira lagoon) the LMA has revealed itself as a dynamic factor of the national economy with more than 60% of the total employment in the mainland in the secondary and tertiary sectors.

Nevertheless, the consequent concentration of the population, with more than 2,5 million inab. by 1991, and the exponential growth of the urban areas is by itself a complex territorial phenomenon. The result has been obvious, translating into serious environmental problems, with direct implications on lessening of the citizen's quality of life, with special relevance given to the occupation and loss of areas with geomorphologic, fauna, flora or landscape interest, due to their direct and indirect impact.

The coastal "territory" is, by definition, the area where marine and continental influences merge and it should include an area over and underwater, thus being a zone where transversal exchanges should be kept in order not to risk losing the integrity of the coastal biophysical systems through an overburden of their resilience limits (FERREIRA and LARANJEIRA, 2000).

From this, one deduces that in the littoral territory a dynamic equilibrium exists, arising from the interaction of a multitude of

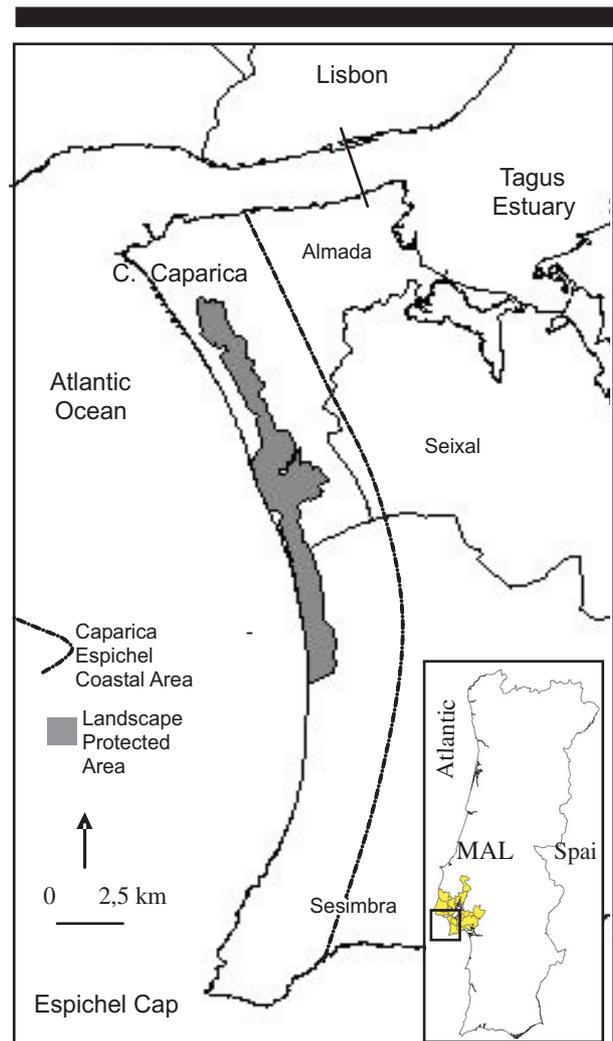


Figure 1 - Caparica - Espichel Coastal Arch.

biophysical and socio-economic variables, the knowledge of which (and data access) is quite unequal, because some of them are still unknown and others present themselves under different shapes, of sometimes hard compatibility (FERREIRA, 1999).

This work deals with notions such as biophysical vulnerability, which should be understood as the degree of susceptibility of the biophysical systems to an irreversible degradation, if its resilience capacity is overpassed (LARANJEIRA, 1997, RUST and ILLENBERGER, 1996). It is thus, assumed that the generalized and persistent evidence of degradation shown by a biophysical system are sure signs that it has become incapable of naturally self-regulation.

This notion of vulnerability, based on the biophysical systems' resilience capacity, completes in a significant way the territorial vulnerability, understood, by the definition of VARNES (1984), PANIZZA (1990) or FERREIRA (1997 and 1999), as the degree of susceptibility to the loss of a certain element or group of elements by the territory namely populations, goods and economical activities, when exposed to a natural or man-induced hazard, by introducing the biophysical component (FERREIRA and LARANJEIRA, 2000). Also, hazard is considered as the probability of occurrence of potentially destructive phenomena over a certain period of time and on a certain area (FERREIRA, 1999).

Under this notion, a certain risk of a biophysical nature, or biophysical risk, translates into a probability and is calculated by the hazard (natural or induced) multiplied by the degree of the territorial vulnerability, including the vulnerability of the biophysical systems.

The hazard determines the probability of the risk manifestation (on a certain scale), while the vulnerability is a conditioning of the risk degree. It should be stressed that the risk notion always implies material or human losses (quantifiable) on a certain area, over a defined time frame. Thus, an area with high vulnerability may not necessarily translate into an area of high risk.

## METHODS

The model depicted below (Figure 2) aims at summarizing the fundamental variables for vulnerability and biophysical risk evaluation on coastal areas. As expected, this evaluation requires the knowledge of the interaction of a high number of biophysical and socio-economical variables, to which one should add the management tools that allow the characterization of the biophysical and antropic littoral

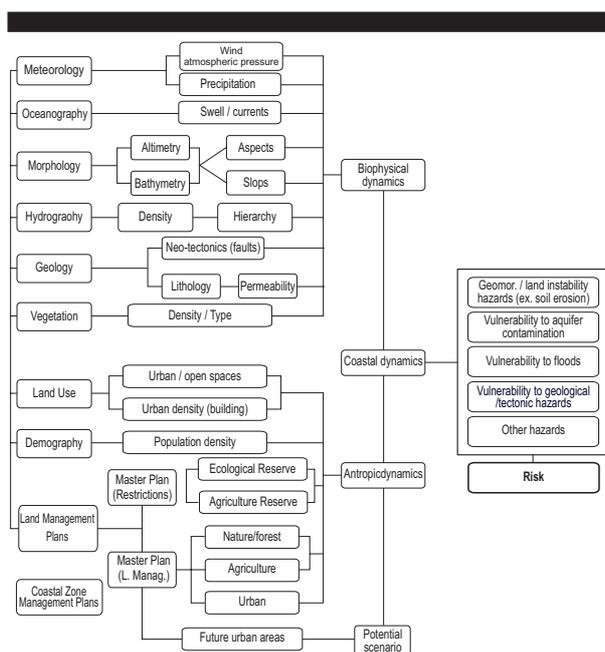


Figure 2. Conceptual model for vulnerability and risk evaluation (biophysical) of the Portuguese coastal areas (FERREIRA, 1999).

dynamics. The data matching between the littoral biophysical dynamics and the littoral antropic dynamics, allows the definition, in an integrated manner, of the littoral environment dynamics. This, enables the identification and description of the areas vulnerable to certain types of hazards as well as the evaluation of the associated risks, either existent or potential ones. The identification and characterization of areas with a high vulnerability and biophysical risk is thus, the fundamental basis for the definition of strategies and environmental management tools, properly applicable and applied to a specific littoral area.

The proposed methods for vulnerability and biophysical risk evaluation on littoral areas incorporate, as previously mentioned, an elevated number of components and variables. We will only address vulnerability and risk assessment related to erosion phenomenon. In fact, erosion, either marine or continental, is one of the main factors responsible for environmental deterioration and the consequent loss of biodiversity in the studied area. Since all the information proposed in the model was not available on a digital format we chose to characterize the variables, found fundamental for the assessment of the vulnerability to hydric (continental) and marine erosions, through two distinct methods (FERREIRA, 1999):

a) for the continental variables: multi-criteria assessment, considering the data to handle and the extension of the area, which allowed the ranking of information of different types and sources, based on an evaluation expressed in values and modifying factors, according to the intensity and the degree of importance of each of the variables;

b) due to the lack of data and detailed studies on the littoral dynamics of the studied area, for the marine variables, we chose the analysis of the morphogenic effects of a series of storm episodes, from December 1995 to January 1996. To better characterize the storm episodes and their consequences, we have studied the weather conditions and corresponding waves as well as the field record of the erosion effects registered in the area.

Starting with the classification and matching of the chosen variables, according to the criteria described by FERREIRA (1999), we have reached different levels of biophysical vulnerability. The calculation of different groups of risk has soil use as its basis, this last one understood in the sense of the existence, and distinction of, territorial segments that are socially referenciable. Thus, we have introduced in this analysis, through an indirect path, the socio-economical factors (the ones bearing territorial expression) that can stress or attenuate both human and material damages and losses.

Due to the high number of variables under consideration it has been necessary to use a Geographic Information System which, through a georeferenced database, has allowed a systematic and efficient matching of information as well as the elaboration of different settings. Below (Figure 3) an example can be found of the referred variables as well as the achieved results (FERREIRA, 1999).

## RESULTS AND ANALYSIS

The results from the application of the devised model clearly reflect, the used methods and its clear dependence from the considered variables and corresponding classifications. Putting the results into a spatial model, allows for a clearer view of the different patterns of the studied variables behaviour respective to erosion hazard and erosion risk. As shown in Figure 4, the hazard and risk to erosion are higher along the coastline and along the fossil cliff, displaying a strong subjection to the lithology, slopes and soil use.

From the study of the consecutives episodes of storm during the timeframe of December 1995 to January 1996, it has been concluded that the total area of the Caparica-Espichel Coastal Arch has been affected, in an identical form, by a tidal waving characterized by great heights as well as total energy (heights reaching sometimes as high as 9m). This has been due, during some periods, to the storm surge effect), causing the important

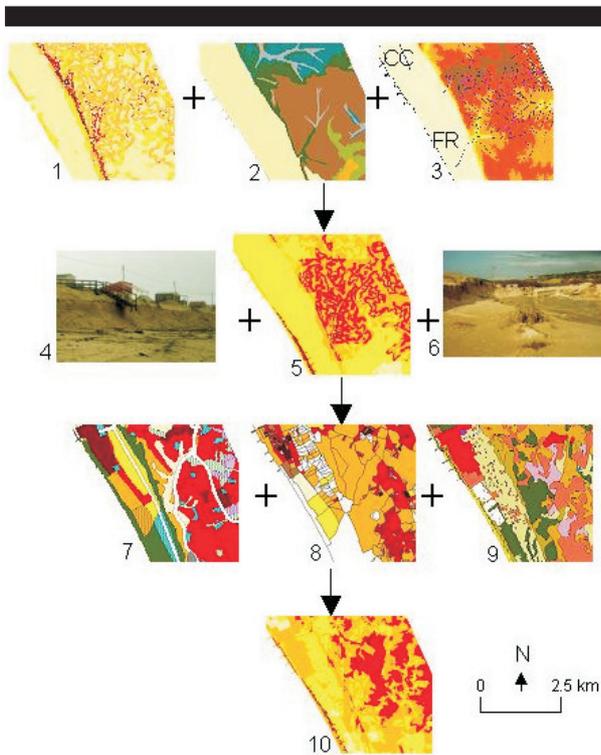


Figure 3. Some of the referred variables, 1 Slops; 2 Lithology; 3 Altimetry and hydrography; 4 Coastal erosion; 5 Vulnerability; 6 Fluvial and coastal erosion; 7 Master plan; 8 Population density; 9 Land use; 10 Risk (FERREIRA, 1999).

morphogenic action associated with these storm episodes (FERREIRA, 1999).

The observed weather conditions have equally caused a strong storm on land (abundant rains) with severe littoral repercussions.

However, the field monitoring of the storm effects has shown the fact that, not only do the different littoral biophysical systems have different responses, as obviously expected, but also the same system can prompt a significantly different response when faced with the very same phenomenon.

Considering only the different beaches systems frontal dune (littoral plains) and cliffs, namely the fossil cliff, four major types of erosion mechanisms triggered by the studied storm episodes, can be found:

1. Marine erosion, which has strongly affected the dune ridge, creating cliff-like profiles along the dune front of the system reaching as high as 6 m, which caused severe beach erosion. In the beach-cliff system the wave strength has destabilized, through undercut, a large part of the alluvium which fossilizes the coastal front as well as the active cliff, causing vast erosion;

2. Marine erosion by oceanic overflow, recorded in all of the main paths through the dune ridge up to the beach, clearly showing the system's vulnerability, since all the discontinuities of the dune ridge of antropic origin are taken advantage of;

3. Hydric erosion (mass movement and soil erosion) responsible for gully phenomena in the cliff system, fossil or active;

4. Mixed erosion (with simultaneous marine and hydric origins).

Through the analysis of the morphogenics effects of the studied group of storm episodes it was then possible to know which of the littoral systems are more vulnerable to the marine erosion. Nevertheless, the fossil cliff has a high vulnerability to the erosion risks, namely the mass movement hazards, jeopardizing human lives and accounting for major losses.

The behaviour of the above mentioned systems, reveals that the vulnerability to marine erosion is strongly dependent on the lithology (loosen sands from the frontal dunes ridges and less

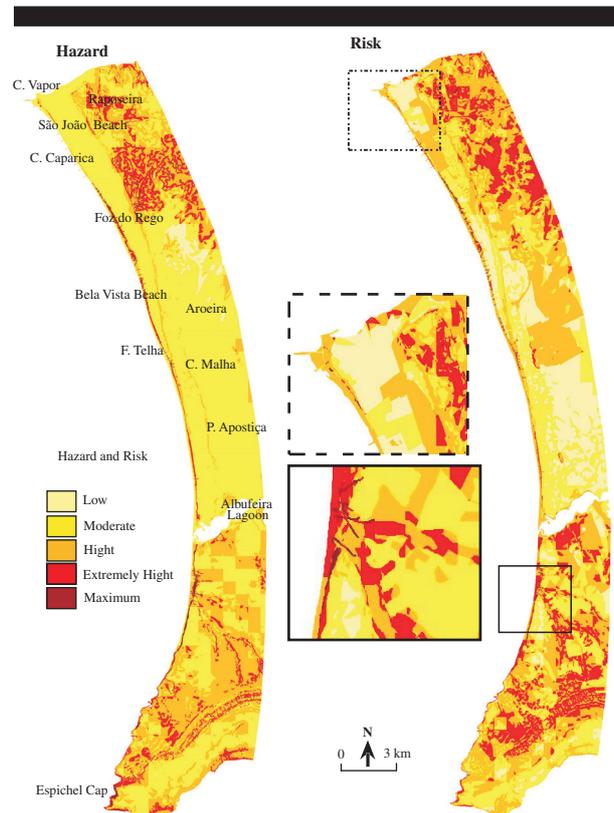


Figure 4. Hazard and risk on the Caparica-Espichel Arch (FERREIRA, 1999).

consolidated materials from the cliff), on the Arch location (as believed that in a western storm, the energy arising from the waves concentrates mainly inside the coves) as well as on the degradation due to its inadequate use (areas of discontinuity of the frontal dune arising from the opening of paths to the beach).

As to the risk of erosion, calculated by the matching of the biophysical vulnerability and the soil uses, an higher extension of risk areas, considering the former identified vulnerable areas, has been found, because areas previously classified as with low vulnerability now clearly present an elevated risk of erosion (marine and continental), namely the urban areas.

## DISCUSSION AND CONCLUSIONS

This way, integrated in the LMA, the studied area is a significant example of the problems and conflicts arising from the antropic pressure over a littoral area, with rich natural assets, as well as the lack of an efficient territorial management and planning and the inexistence of an environmental management capable of allowing a sustainable development of the coast, with clear consequences for the economy of this region. The storm episodes which took place in the last Winters (December 2000 and January 2001, February 2003 and January 2004), responsible as they were, for a generalized erosion in all of the studied area, specially with unrecoverable damages in the north sector of the dune ridge and fossil cliff, have demonstrated once again the need to incorporate more studies on vulnerability and biophysical risk on the Coastal management Plans (central administration) as well as the Master Plans (local administration).

Despite its relative simplicity, the presented methods, have demonstrated a strong efficacy, in the identification of the problematic territorial units, because it allows a clear identification of the areas with a high hazard and risk. The areas thus identified by FERREIRA (1999), as the most vulnerable and more subject to a stronger erosion risk, are exactly those that have revealed themselves as more affected by erosion causing enormous financial damages and jeopardizing human lives. (Figure 5)

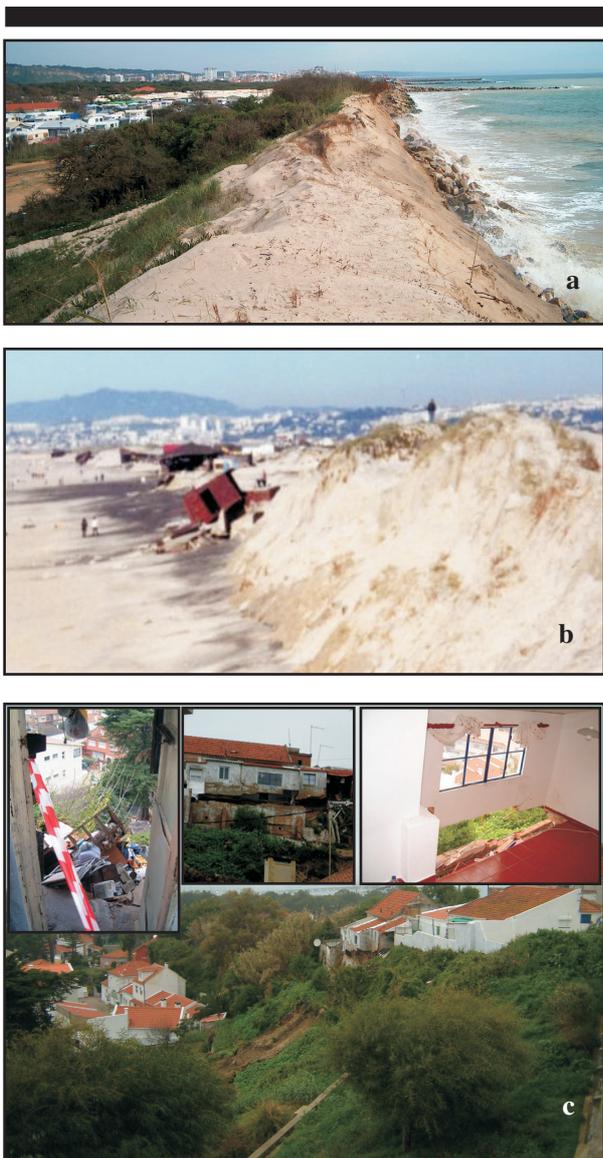


Figure 5. Dune ridge and fossil cliff several erosive episodes, after the use of the identification methods (see also Fig. 4). a) S. João Beach (Costa da Caparica), February 2003 destruction of the dune ridge, causing an increased risk to camping parks and other buildings. b) S. João Beach (Costa da Caparica), January 2001 dune ridge erosion and destruction of the beach facilities c) Raposeira (fossil cliff), January 2004 landslide with destruction of several houses.

Considering that this is an expedite method and easy to use, we find it to be a suitable, basic instrument for the definition of the areas that are more prompt to biophysical risk and the results from its proper use could allow for an improvement of the land management aiming at a new model of planning, efficient and sustainable (REES, 1990) of a sparse resource such as the coastal territory.

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