INDICATORS OF A GIS-BASED AERIAL IMAGES ANALYSIS OF THE PORTUGUESE NORTHWEST COASTAL DYNAMICS

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Abstract

The Portuguese northwest coast has been changing, morphologically and hydromorphologically. After a period of great sediment accumulation in central area of Portugal, a period of erosion occurs in the present. The Portuguese northwest coast is one of the most energetic ones and presents severe problems in almost its extension.

The main objective of this work, is to locally typify, classify and physically analyse the evolution of the coastal dynamic, in a medium and long term, as well as the hydromorphologies due to the wave action, based on the analysis of four aerial surveys (1995, 1996, 2001 and 2002), GIS tools and techniques.

In this paper some preliminary results of the morphological forms identified will be presented as well as some related considerations.

1. Introduction

On the Northwest Portuguese coastal zone the related sea action regime is one of the most energetic ones and dynamic forces acting in this area are therefore, its main modeller agent. The littoral drift act mainly in the North-South direction although some singular events from Southeast can be found due to wave refraction and diffraction.

The coastal stretch considered in this study was Cortegaça-Furadouro, located 25 km southwards Porto (figure 1). It is a flat area with an orientation NNE-SSW, formed by sandy beaches and sandy dunes with small elevations. This stretch was selected, due to its very highly dynamic characteristics that change the coastal forms constantly.

This coastal zone has significant erosion problems, which can be clearly noted but with small humans consequences, since that the shoreline regression only implies the loss of forested areas. The erosion problems are due to natural causes and anthropic reasons.

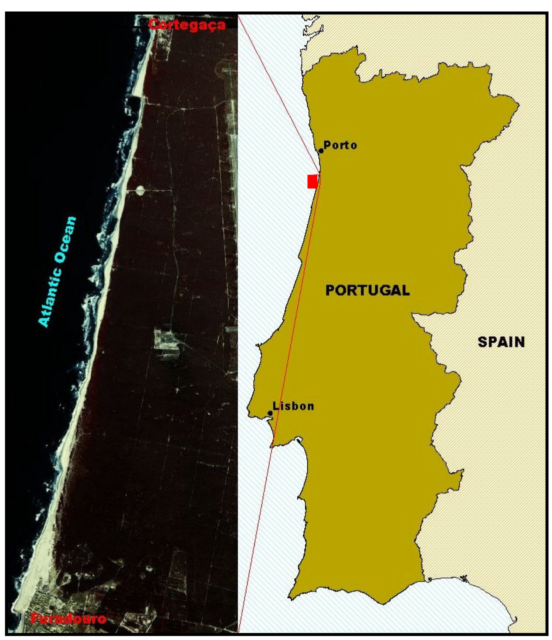


Figure 1 – Location of the study area.

The main storms that reach the Northwest coast of Portugal come from the North Atlantic, particularly between October and March (Veloso-Gomes *et al.*, 2003). The mean wave climate is characterized by waves from Northwest that can merge with waves generated by local winds (IHRH, 1993). Medium significant wave heights vary from 2 to 3 m, with periods ranging from 8 to 12 s and storm significant wave heights exceed 8 m, with periods reaching 16 to 18 s. Local wave conditions are different from the offshore ones due to the effect of the bathymetry and local phenomena, especially refraction, diffraction and shoaling. The most important directions are NW with 43.8 % of occurrence, WNW with 28.0% and NNW with 21.2% (figure 2) (Veloso-Gomes *et al.*, 2003).

The tide regime on the Northwest Portuguese coast is semidiurnal type, with tidal cycles of approximately 12h 25m and propagating from South to North, with a tide range up to 4.0 m.

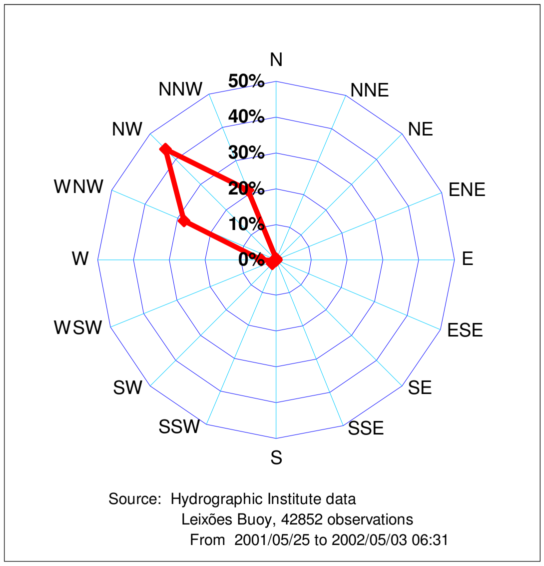


Figure 2 - Wave direction frequencies reaching the Portuguese West coast.

According to the tide range the shoreline can be classified as high-mesotidal (2-3.5 m)/low-macrotidal (3.5-5 m), according to the classification of Hayes (1979), (Coastal Engineering Manual, 2002).

It's expected, with this work, to improve the identification and typification, in meso-macrotidal beaches, of hydromorphologic patterns of breaking waves, sea bottom, and relation with local wave and tide regime, as well as, to improve the identification of coastal morphology patterns related with wave direction, sea bottom forms, wave heights and periods and beach profile. This will lead to a better understanding of the erosion phenomena.

However, it is important to stress that the interaction between waves and the dynamic solid frontiers, natural or artificial, is quite complex. This is due to the existence of dynamic actions, of non-linear interactions, of different time scales, and of high difficulty to obtain historical georefenciated data. The coastal morphodynamics is changing, over small time scales (days, weeks) to several hundred of years.

2. Coastal Zones Morphodynamic Classifications

Physical conditions vary along time and space, changing the beach profiles and the coastline configuration (Coastal Engineering Manual, 2002) leading to the inexistence of an "equilibrium state". The physical conditions variations are disturbed by the anthropic interference, that influences profoundly the coastal environmental, changing the natural movement and supply of sediments. Coastal works are constantly build and rebuild, dredging activities for navigation and civil construction proposes took place and changes at river basins occur. For these reasons, the "equilibrium" is much more instable.

It is important to study and understand how the sandy coasts respond to the changing of wave climate, tides, amount of sediments and other hydrodynamic factors. These areas are very important for the economy and for the shoreline protection from the sea action.

The interactions from which the hydroforms results (submerged dune, ripples, microripples, breaking bars, depressions, sand bars, micro bays, sand spits, erosion, overwashes,…) involving phenomena of shoaling, diffraction, refraction, breaking, run-up, run-down, tides and sediment movements, with higher or lower dominance determine the morphological evolution of the sea bottom, intertidal zone, beaches, dunes and sand spits.

According to the Coastal Engineering Manual (CEM), 2002, most of beach morphology and processes studies have concentrated on microtidal (<1 m) or low-mesotidal coasts (1-2 m). Based on field experiments in Australia, Wright and Short (1984) have presented a model of shoreface morphology as a function of wave parameters and sediment grain size. This model is applicable for coastal tide range between 0 and 2 m and wave breaker height (H_b) is greater than 0.5 m. They determined that the morphodynamic state of sandy beaches could be classified on the basis of assemblages of depositional forms and the signatures of associated hydrodynamic processes. Two extreme morphodynamic states were identified, fully dissipative and highly reflective, as well as four intermediate states with evidence of reflective and dissipative characteristics. Related with this, different morphological beach states have different modes of fluid motion. Wright and Short (1984) grouped the fluid motion into four categories:

- Oscillatory flows;
- Oscillatory or quasi-oscillatory flows;
- Net circulations;
- Non-wave-generated currents.

As refer in CEM, 2002, Wright and Short, 1984, concluded that the beach state is clearly a function of the breaker height, the wave period and sediment size. Over time, shoreline and profile variations are associated to the environmental and temporal conditions. These authors found that a dimensionless parameter (Ω) could be used to describe the beach state:

$$\Omega = \frac{H_b}{\bar{w}_s T} \qquad (1)$$

where H_b represents the wave breaker height, $\bar{w}_s$ the mean sediment fall velocity and T is the wave period. The value of Ω equal to 1 defines the reflective / intermediate threshold with a highly reflective stage. If $1 < \Omega < 6$ the beaches are intermediate type namely:

- Longshore bar-trough state;
- Rhythmic bar and beach state;
- Transverse-bar and rip state;
- Ridge and runnel/low tide terrace state

For Ω • 6 it marks the threshold between intermediate and dissipative conditions with a highly dissipative stage.

These authors concluded that a large temporal variation of Ω is accompanied by large changes in state, but when this variations take place in the domains of $\Omega < 1$ or $\Omega > 6$, there are no correspond changes in state. Intermediate beaches, where Ω is $1 < \Omega < 6$, are spatially and temporally the most dynamic ones. They can undergo rapid changes as wave height fluctuates, causing reversals in onshore/offshore and alongshore sediment transport.

As referred this classification is for microtidal or low-mesotidal coastal tide range. Until now, according with CEM, 2002, many details concerning the processes that shape high-meso- and macrotidal beaches (tide range > 2 m) are still unknown.

On a review realized for macrotidal beaches, Short (1991), summarized several points regarding their morphology:

- They are widespread globally, occurring in both sea and swell environments.
- Incident waves dominate the intertidal zone.
- Low-frequency (infragravity) standing waves may be present and may be responsible for multiple bars.

• The intertidal zone can be segregated into a coarser, steeper, wave-dominated high tide zone, an intermediate zone of finer sediment and decreasing gradient, and a low-gradient, low-tide zone. The highest zone is dominated by breaking waves, the lower two by shoaling waves.

• The cellular rip circulation and rhythmic topography that are so characteristic of microtidal beaches have not been reported for beaches with tide range greater than 3 m.

Based on gradient, topography, and relative sea-swell energy, Short (1991) divided macrotidal beaches into three groups:

• High wave, planar, uniform slope.

• Moderate wave, multi-bar.

• Low wave beach and tidal flat.

3. Coastal Dynamics Indicators of a GIS-based Aerial Images Analysis

3.1 Introduction

As referred, the Portuguese Northwest coast is very dynamic, with shoreline shape and profiles changing constantly.

Based on the classification of Wright and Short (1984), research is being underway to classify, identify and typify, in meso-macrotidal beaches, the hydromorphologic patterns of breaking waves, the hydroforms, the sea bottom, and the relation with local wave and tide regime, as well as, to improve the identification of coastal morphology patterns related with wave climate, sea bottom forms, and beach profile.

To reach these main goals GIS tools and coastal images will be need. In a first step aerial photography will be used and latter on satellite images. With this combination, GIS and images, it will be possible to digitalise coastal forms, analyse the local currents presented as well as sea bottom characteristics.

Remotely sensed data and images have been widely applied over the years to coastal environments with different degrees of success, largely dependent upon the application. Aerial photography, appear as a great source of information, as result of the high resolution and spatial detail, and a very important support for studies on small areas. In opposite the satellite images, until recently, offer a poor resolution, but offered a great spectral and temporal resolution and area coverage (Green, D. and King, S. 2002).

3.2 Data Acquisition and Analysis

The data used in this study is diverse with, different states (digital and hardcopy) and with different Datum.

Four aerial surveys were used, from different years (1995, 1996, 2001 and 2002), and one photogrametric survey (1996), based on a aerial survey of the same year. Only the first survey was in a digital format and ortorectified. The second and third ones were only available in a hardcopy format. The images of these surveys for this coastal area were scanned. The last survey was available in digital format but not ortorectified. It is important to refer that this last survey it is not a truly vertical aerial photography survey.

The GIS software used was the ArcInfo Workstation 7.2.1 and the ArcView 3.1.

After the scanning process (1996 and 2001) the georefencing process with the help of ArcInfo 7.2.1 was done. The scanning of aerial photographs could introduce sources of error affecting the subsequent use of the imagery. The georeferencing process was made based on common points of survey of 1995 (ortoreferenced) and on the photogrametric survey of 1996. The medium residual error was around 1 m.

Afterwards the coastline shape was digitised, according to the run-up line presented in the images. In such line it’s important to consider the wave patterns, the tide level and the sediment movement. The patterns of longshore currents, as well as morphological forms, were analysed and the waves movement around them was identified. In images of 1996 and 2001 it was digitised also the possible limit of the sediment dispersion. A final analysis was made (geometric one) and consisted on measurement of presented morphogical forms, and tries to relate them with the tide level and wave characteristics, as well as the relation between the length and the width.

3.3 Preliminary Results

The photography's analysis (figure 3) shows that the line shape of this area is very dynamic, presenting the same patterns in three surveys, 1995, 1996 and 2002. However, the sizes of the morphological forms are different in all images.

As it can be observed, the patterns of breaking are very similar in all surveys, being the wave direction mainly from the west quadrant. The wave breaking area indicate the existence of a submerged bar (figure 3). The movement of sediments, occurring on the direction North-South, can also be seen as well as the mega cusps positions. These positions are related with the wave direction, the tide stage, and the drift longshore currents. In the images of 1996 and 2001, it is possible to see also the enormous sediment dispersion area, resulting from the existent rip currents. The rip currents are also present in the other two images.

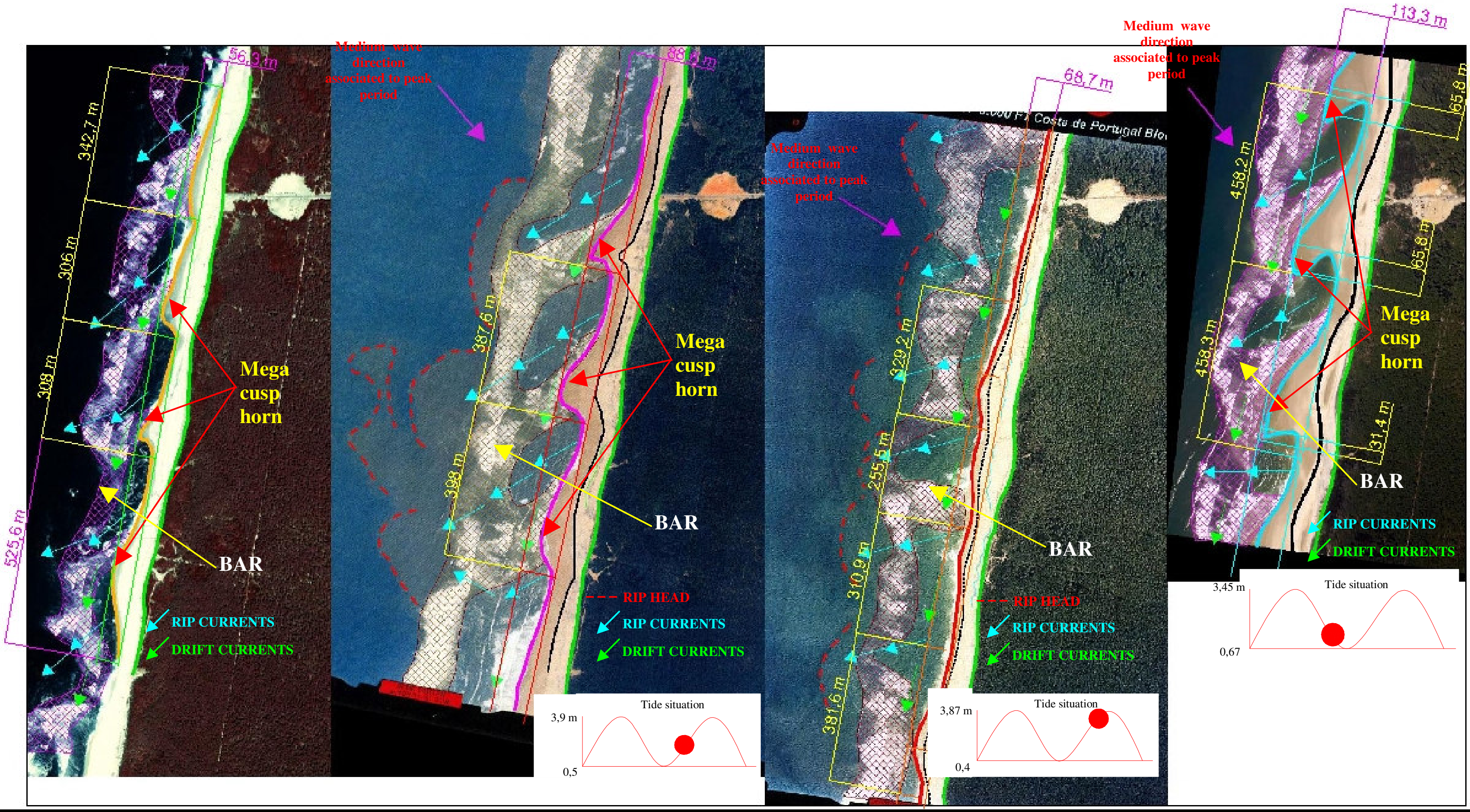
As it can be observed in figure 3, the hydroforms presented in the surveys of 1995, 1996 and 2002 are very similar. Such forms increased in dimension and could indicate that the dynamic process increases. However it could be the result of the tide stage. In the lower tide it is possible to see almost the total mega cusp area. In high tide the area that could be seen is very small.

As it is possible to verify in figure 3, the values of the considered parameters, are not available for all surveys (1995). This fact is a limitation, and doesn't use all the potentialities images, once it is not possible to compare the shapes presented because there are no knowledge of the existent conditions.

In a geometric analysis, with the increase of morphological forms height its width seems to increase too, and it can be observed (figure 3) in the images of 1995, 1996 and 2002 surveys. When comparing the surveys of 1996 and 2002 it is possible to observe that the morphological forms are very well shaped, with the length and width very similar and proportional. The reason between length (L) and width (w) in both surveys is very similar. With small differences on sizes, for 1996 survey is equal to 4,4 and for 2002 survey 4. Looking carefully to the image of 2002 survey the dimension of the two first the mega cusps heads are very similar (in length and width) and the third is approximately half of this value.

Relatively to the survey of 1996, it is possible to observe, once again, that the sizes of the mega cusps are very similar.

In the survey of 1995, due to the fact that there are no values available, it is only possible to observe that the middle mega cups presented in the image have very similar shapes, and when compared with the 1996 and 2002 surveys, it could be verified that the hydrodynamic conditions were probably very similar.



Survey Date	July/August, 1995	September 29th, 12 35 hours, 1996	September 17th, 2001	August 13tr, 12 00 hours, 2002
Tide	Not Available	Low – 0.50 m (11 05 hours) High – 3.90 m (17 40 hours)	Low – 0.40 m (08 19 hours) High – 3.87 m (14 38 hours)	Low – 0.67 m (11 59 hours) High – 3.45 m (18 18 hours)
Wave Height	Not Available	2.0 m	0.6 m	1.3 m
Wave direction	Not Available	320º N	281º N	322º N

Figure 3 – Analysis of the aerial surveys and physical conditions.

In the survey of 2001 it is only possible to observe a small cusp that could be related with the tide level, being the mega cusp covered by the water. This fact could be related with the direction of waves that is almost normal to the coastline, reducing the strongness of the longshore drift currents.

These morphological forms when compared with the classification of Wright and Short (1984) for microtidal coast, present forms very similar in plan with the intermediate rhythmic bar and beach model.

4. Conclusions

The morphological forms analysis based in aerial images, with the help of GIS, is very helpful to observe phenomena that occur in the surf zone.

When comparing the images, was possible to observe that the mega cusps size increases, and that can be related on one hand by the tide level and by other hand with the wave climate characteristics. These factors influence the longshore currents that are responsible for the transport of an important amount of sediment through the coastline.

In all images it is possible to detect rip currents, especially in the surveys of 1996 and 2001 were it is possible to identify the heads of such currents. According to Short (1991), CEM (2002), this fact never was reported in coasts with tidal ranges higher than 3 m.

The hydroforms presented in this meso-macrotidal coast, seems very similar when compared with the classification presented by Wrigth and Short (1984).

Research is being carried on along other Portuguese Northwest coastal zones.

References

- Green, David R. & King, Stephen D. 2002. *Remote Sensing and Imagery for Coastal Environments*, URISA, United States, ISBN #: 0-916848-37-X.
- Instituto de Hidráulica e Recursos Hídricos, 1993. *Plano de Aproveitamento da Zona entre o Molhe Sul e a Ponte-Cais nº3*, Estudos de Agitação no Porto de Leixões, Vol. 1.
- Morang, A. & Parson, L., 2002. *Coastal Engineering Manual- Coastal Morphodynamics*, Chapter IV-3, US Army Corps of Engineers, Washington.
- Short, A. D. 1991. *Macro-meso Tidal Beach Morphodynamics – An Overview*, Journal of Coastal Research, Vol 7, No 2, pp 417-436.
- Veloso-Gomes, F., Taveira-Pinto, F., Neves, L. & Pais-Barbosa, J., 2003. Eurosion Project (ENV.B3/SER/2001/0030 (RIKZ –1146)). *A European initiative for sustainable coastal erosion management. Review of experiences of coastal erosion control and management*, Vol 2, Instituto de Hidráulica e Recursos Hídricos, Faculdade de Engenharia da Universidade do Porto, Porto.
- Wright, L. D. & Short, A. D. 1984. *Morphodynamic Variability of Surf Zones and Beaches: A Synthesis*, Marine Geology, Vol 56, pp 93- 118.