Quantification of the Total Suspended Matter (TSM) in the Sea Breaking Zone

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Abstract

The coastal zone is a dynamic area where processes with different origins and scales interact. Satellite data have been used for monitoring the coastal zone to extract, in a global and systematic way, relevant information for coastal processes. Remote sensing techniques can be used to monitor water quality parameters like suspended sediments.

The objective of the work presented here was to establish a relationship between the Total Suspend Matter (TSM) and the seawater reflectance for the sea breaking zone in NW of Portugal.

Three experimental methods to determine the relationship between the TSM concentration and the above seawater reflectance were used. Spectral reflectance was measured with a spectroradiometer and water samples were collected simultaneously. A section of the northwest coast of Portugal, centred in Aveiro, was chosen as the test area.

Empirical relationships were established for reflectance values from the sensors SPOT/HRVIR, TERRA/ASTER and Landsat/TM at visible and near infrared bands and TSM concentration.

A Geographic Information System (GIS) has been developed in order to integrate all the relevant information about the study area

1. INTRODUCTION

Remote sensing is the process of inferring surface parameters from measurements of the upwelling electromagnetic radiation from a surface (Schmugge et al., 2002).

Remote sensing techniques can be used to estimate suspend sediments concentrations and thus help to understand the transportation and distribution of sediments driven by mechanisms such as tides and waves, river discharges, etc.

Substances in surface water can significantly change the characteristics of surface water. Remote sensing techniques depend on the ability to measure these changes in the spectral signature backscattered from water and relate these measured changes by empirical or analytical models to a water quality parameter, as suspend sediments (Ritchie at al., 2003).

Solar radiation reflected from sea water surfaces varied with the amount of suspends sediments and wavelength. In general, reflected solar radiation between wavelengths 500-700 nm increases as the concentration of suspend sediments increases.

The determination of suspend sediments from water reflectance is based on the relationship between the scattering and absorption properties of water. Most of the scattering is caused by suspended sediments. Sediment type affects the relationship between reflectance and suspended sediments concentration. The absorptive in-water components such chlorophyll A and Colored Dissolved Organic Matter (CDOM) have been shown to lower the reflectance. However, these effects are generally in wavelength bellow 500 nm (Myint and Walker, 2002).

Various studies have been carried out combining *in situ* measurements and satellite data in order to relate spectral properties and water quality parameters. Ritchie et al. (1974) developed an empirical approach to estimate the amount of suspended solids sediments. The general forms of these empirical relations are:

$$Y = AX + B \quad \text{or} \quad Y = AX^{B} \qquad (1), (2)$$

where Y is the remote sensing measurement (i.e., reflectance) and X is the water quality parameter (i.e., suspend sediments). A and B are empirically derived coefficients.

Islam et al. (2001) used a linear relationship between reflectance and suspend sediments concentration (SSC), which has been developed for Ganges and Bralimaputra rivers (India). The general form of this model is:\

$$Y = AX - C \qquad (3)$$

where X is SSC (mg/l), Y is spectral reflectance (in percent). A and C are the regression coefficients.

Forget and Ouillon (1998) established a relationship (R_k) between satellite equivalent reflectance and TSM concentration from Rhone River (France), using SPOT HRV and Landsat TM data.

A linear, polynomial, log-linear and log-log relationships were applied. The log-linear relationship gives the best correlation. This form is:

$$R_k = a_k \log_{10} TSM + b_k \qquad (4)$$

where a_k and b_k are empirically factors.

Doraxan et al. (2002) developed a experimental method to determining the water composition in Gironde Estuary (France), using SPOT data. They used *in situ* measurements of water refectance and collected water samples. They established empirical relationships between remote sensing reflectance in SPOT HRV bands and TSM.

A number of aerial photographic surveys have been carried out, covering the continental coast of Portugal. It is possible, just with visual inspection, to discriminate areas with different sediment concentrations, as shown in figure 1.

Figure 1: Aerial photography of the Portuguese Coast

The aerial surveys have not been done as frequently as required for coastal monitoring. There should be great advantages in replace aerial surveys for satellite data. A single satellite images covers a much larger area than a aerial photography and more frequently. An initial inspection of a satellite image from ASTER (Figure 2) showed that the same patterns identified on the airphotos could be observed on this image.

Images of different sensors have been tested to choose the most adequate for the discrimination of different breaking patterns.

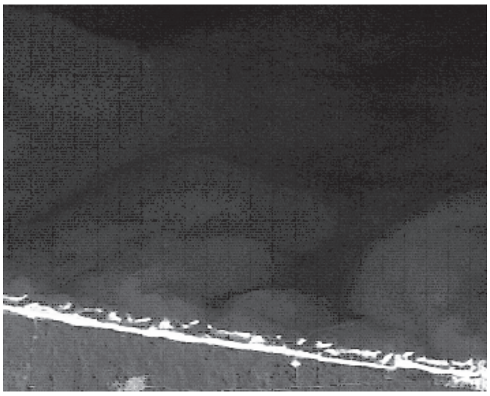

Figure 2: ASTER image of the Portuguese Coast

The objective of this work is to evaluate the potential of multi-spectral satellite images to quantify satisfactory the Total Suspended Matter (TSM) in the sea breaking zone. Data from Landsat TM, ASTER and SPOT HRVIR were tested.

2. STUDY AREA

A part of the Northwest coast of Portugal, around Aveiro, was chosen as a test area. This area is limited to the North by the Douro River mouth and to the South by Mira Lagoon (Figure 3). The total extension of this area is about 80 km with an orientation NNE-SSE.

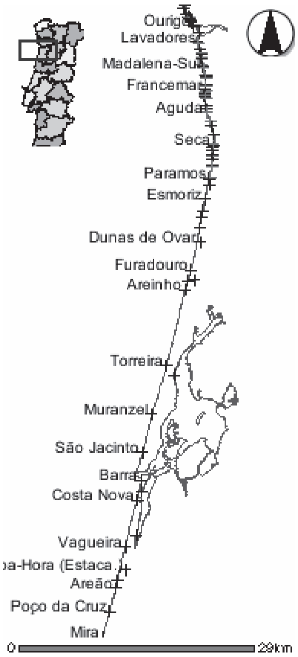

Figure 3: Study area

The littoral drift current act principally in the North-South direction. The wave climate has medium significance with wave heights from 2 to 3 m, with periods ranging from 8 to 12 s. Tides are of semidiurnal type, reaching a range of 2 to 4 m for spring tides. Meteorological tides are not significant.

The causes of the present situation of generalised coastal erosion, in this particularly area, have been identified as a coastal response to the weakening of the river basin sediment sources and river sediment transport, the mean sea level rise, the human occupation of waterfront and dune destruction (Veloso-Gomes et al., 2002). The hydroelectric plants reduce drastically the volume of solids transported to the the sea. The reduction of sediment transport is also associated to the extraction and dredging of sand rivers and to the river flow evolution along the year (Figure 4).

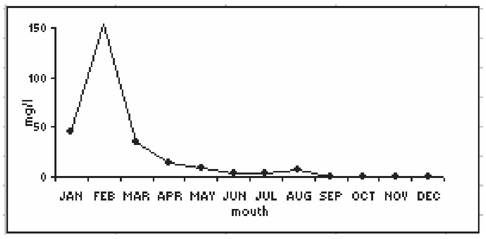

Figure 4: Total of solid sediments in Crestuma-Lever (Douro River) in 2001

3. EXPERIMENTAL METHODOLOGY

Different methods (maritime platforms, aerial platforms and simulation on the beach) were used to determinate a relationship between the TSM and the spectral response of the seawater.

3.1 Spectroradiometer

A spectroradiometer was used to determinate the seawater reflectance, in all the techniques. The spectroradiometer used was a FieldSpec FR, which operates between the 350 nm and the 2500 nm and has 10 nm of spectral resolution. The data collection is made through a fiber optic cable input with 1.2 meters in length and a 25° full angle cone field-of-view. The data quality depends critically on the precision, at the calibration stage.

3.2 Filtering process

The quantification of the TSM (mg/l) of the samples collected was made through a filtering process. The process follows the following steps: weigh and catalogue the filters; divide the water samples and filter; evaporation of the water contained in each filter; drying the filters; weigh again the filters. The quantification of TSM was made deducting the weigh of the final filter to the weigh of the initial filter. A cellulose nitrate filter was used, with a diameter pore of 0.45 μm.

3.3 Field Work

3.3.1 Maritime Platform

To simultaneously measure the reflectance and the concentration of suspended sediments, a campaign was carried out. Samples of water (about of 1 litre) were collected and the reflectance measured at same location (Figure 5). The position and depth of each location was also measured using a GPS receiver and an echo-sounding lead. The main problems with this method were the difficulty in to immobilizing the boat and the impossibility of collect data in the breaking zone.

Figure 5: Maritime Platform

3.3.2 Aerial Platform

A helicopter was used to collect water samples and to simultaneously measure the reflectance. The helicopter was stabilized about 2-3 meters of the sea surface and 30 samples of water were collected and measure the reflectance. The position of the helicopter was measured using a GPS. This method allows for measurements to be made over the sea breaking zone.

Figure 6: Aerial Platform

3.3.3 Simulations on the beach

To simulate different concentrations of suspended sediments four campaigns had been carried out in different beaches, to consider different types of sand (texture, colour and grain size). A container with 80 cm of height and 40 cm of diameter was used. To minimize the effect of reflection of the sides and the bottom of the container it was lined with a black and completely cloudy plastic. The reflectance was measured and water samples were taken simultaneously, for a range of sediment concentrations (Figure 7).

Figure 7: Simulations on the beach

4. SATELLITE IMAGES

Images of three sensors with adequate spectral, temporal and spatial resolution for the discrimination of zones with different concentrations of sediments were tested. Images from ASTER, SPOT HRVIR and Landsat TM were used (Table 1).

Table 1: Satellite images tested

Sensor	Date	Time	Tide height
Landsat TM	24/07/1997	10:45	1.09 m
SPOT HRVIR	14/10/1998	11:35	2.85 m
ASTER	24/10/2001	11:43	1.29 m

4.1 Characteristics of the satellite data used

Landsat TM 5 image data consists of seven spectral bands with a spatial resolution of 30 meters, except the thermal infrared band (band 6), that has a pixel of 120 meters.

Table 2: Thematic Mapper (TM) bands used

Band	Wavelength (manometers)	Resolution (meters)
TM1	450-520	30
TM2	520-600	30
TM3	630-690	30
TM4	760-900	30

SPOT 4 HRVIR has four spectral bands, as follows: visible band (B1): 0.50 to 0.59 µm; visible band (B2): 0.61 to 0.68 µm; near infrared band (B3): 0.78 to 0.89 µm and shortwave infrared (SWIR) band: 1.58 to 1.75 µm. The multispectral X mode corresponding to bands B1, B2, B3 and SWIR with a ground resolution of 20 m. The monospectral M mode corresponds to band B2 with a ground resolution of 10 m.

ASTER consists in 14 spectral bands (Table 3) of three different subsystems; the Visible and Near Infrared (VNIR) with 15 m of spatial resolution, the Shortwave Infrared (SWIR) with 30 m of spatial resolution and the Thermal Infrared (TIR) with 90 m of spatial resolution.

Table 3: ASTER VNIR bands

Band	Wavelength (nanometres)	Resolution (meters)
VNIR1	520-600	15
VNIR2	630-690	15
VNIR3	760-860	15

Since it is intended to cover gaps in the existing data of the study zone, the access to archived data is an important factor. In this sense, TM and SPOT HRVIR data have advantages because they are available since 1982 and 1986 while ASTER data is only available since 2000.

4.2 Image processing

All the satellite images were calibrated for radiance (Eq. 4) and reflectance (Eq. 5) values,

$$L(\lambda) = \alpha DN(\lambda) + \beta \qquad (4)$$

$$R(\lambda) = \frac{\pi L(\lambda) d^2}{E(\lambda)\cos\theta} \qquad (5)$$

where L is the spectral radiance (Wm^{-2} sr^{-1} µm^{-1}), DN is the digital number, α is the slope and β is the offset, R is the reflectance (unitless), d is the Earth-Sun distance in astronomical units, E is the mean solar exoatmospheric irradiances and θ is solar zenith angle in degrees.

The geometric correction was made using ground control points collected with GPS. All images were geometrically corrected with high accuracy (lower than a pixel).

5. EMPIRICAL MODELS BETWEEN TSM AND SATELLITE SENSOR REFLECTANCE

A relationship between seawater reflectance and the TSM for each band of the visible and the infrared to each sensor was established (Eq. 6).

$$R_{Eq.Sat.} = \frac{\int R_m(\lambda)\varphi(\lambda)d\lambda}{\int \varphi(\lambda)d\lambda} \qquad (6)$$

where $R_{Eq.Sat.}$ is the equivalent reflectance of the satellite, R_m is the reflectance measured by the spectroradiometer and φ is the sensor spectral response.

Linear, polynomial, logarithmic, power and exponential models were tested for all satellite images. The correlation and regression coefficients of each one were calculated.

5.1 Landsat TM

For all bands tested the linear and polynomial models presented a high correlation factor ($R^2 \geq 0.96$). The power model presented a little bit worst result ($0.94 \leq R^2 \geq 0.90$). The exponential and logarithmical models presented much worse results than all other models. The results are presented in the tables 5 and 6.

Table 4: Linear Model (R=A*TSM+B) for TM data

Regression Coefficients	TM1	TM2	TM3	TM4
A	0.019	0.026	0.027	0.018
B	0.137	0.088	-0.132	-0.639
R^2	0.96	0.97	0.97	0.96

Table 5: Power Model ($R=A*TSM^B$) for TM data

Regression Coefficients	TM1	TM2	TM3	TM4
A	0.075	0.039	0.020	0.0005
B	0.765	0.925	1.047	1.616
R^2	0.92	0.94	0.94	0.90

5.2 SPOT HRVIR

The results for all models are similar to those obtained with TM data, as it can be seen in tables 7 and 8:

Table 6: Linear Model (R=A*TSM+B) for SPOT data

Regression Coefficients	XS1	XS2	XS3
A	0.025	0.027	0.018
B	0.129	0.190	0.679
R^2	0.97	0.97	0.96

Table7: Power Model ($R=A*TSM^B$) for SPOT data

Regression Coefficients	XS1	XS2	XS3
A	0.043	0.016	0.0001
B	0.901	1.089	1.828
R^2	0.94	0.93	0.84

5.3 ASTER

The correlation coefficient for all models are similar those obtained with SPOT and TM data. The figure 8 shows the polynomial model established for ASTER VNIR1.

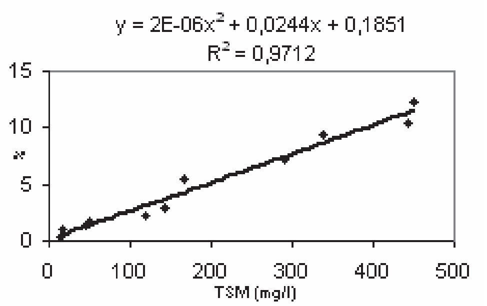

Figure 8: Polynomial model from ASTER VNRI1 data

5.4 Discussion of the results

The linear models established for all the images tested presents a correlation factor (R^2) higher than 0.95. The non-linear models present a lower but acceptable correlation factor. A great similarity is verified between the model coefficients and correlation factor, for identical bands of different sensors (Table 8).

Table 8: Regression coefficients and correlation factor for identical bands of the three sensors tested

Sensor/Band	Wavelength (manometers)	A	B	R^2
SPOT/XS1	500-590	0.025	0.128	0.97
ASTER/VNIR1	520-600	0.025	0.131	0.97
Landsat/TM2	520-600	0.026	0.088	0.97

6. CONCLUSIONS

This study shows that remote sensing are an effective tool to rapid and accurately determine the amount of TSM. However, the *in situ* measurements are essential to validate the process.

The reflectance of the satellite images tested has very high correlation with the TSM in the wavelength between 500 and 900. There is a peak in reflectance between 550 and 600 nm, and from the

900 nm the reflectance is practically null (Figure 9).

The measurement conditions affect the results. The influence of sea bottom and the open ocean in the reflectance measures and the distribution of the sediments in the water column need to be considered.

A Geographic Information System (GIS) is being implemented, with all available information for the study area, from existing cartography and geographic databases. Information about TSM obtained from boat and helicopter is also being included. Specific tools are being developed for the GIS in order to properly address the physical processes in the coastal zone as a function of time.

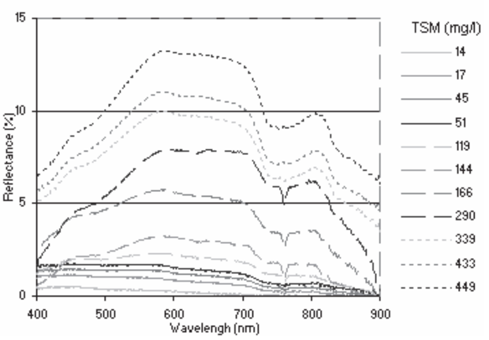

Figure 9: Relastionship between TSM and seawater reflectance

Work in currently being done in order to incorporate low spatial resolution satellite data from MERIS e MODIS in the GIS. These sensors provide nearly daily images, which could be a great advantage for monitoring purposes.

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EIA and SEA Tools for Shore Protection Interventions

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Abstract

In the last years, several European Programmes were performed and others are still running also in Sicily (EUROSION, INTERREG, etc.) to highlight, under different points of view, the need for softer techniques of coastal protection. Studies on Environmental Impact Assessment (EIA) of interventions and Strategic Environmental Assessment (SEA) of plans are still not enough disseminated.

With the aim to prevent and/or mitigate shoreline retreat on many beaches with hard and emerged coastal defence structures, several Administrations in Italy have published public tenders, containing guidelines for the definition of priority areas to be protected and/or the indication of the best technical practices.

In the island of Sicily, seventeen shore protection interventions were funded: some of them, besides fitting with environmental acceptable measures and a limited environmental impact (beach nourishment with nearshore berm creation), present also some innovative environmental solutions.

In this paper, basic tools for implementing SEA and EIA procedures on shore protection interventions/programmes will be proposed, to participate at the European need of standard guidelines for beach-fill projects with high environmental compatibility.

1. INTRODUCTION

1.1 Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA)

In the last years, Environmental Impact Assessment (EIA) procedures have been a key instrument of European Union environmental policy for assessing the effects of certain public and private projects. These have been reflected by the Directives 85/337/EEC, 97/11/ECC and 2003/35/EC, that help to identify, describe and assess the direct and indirect effects of private or public projects on factors including ‘‘landscape, material assets and cultural heritage”, aimed to the formulation of a judgment of compatibility and involving the public participation (Council of the European Communities, 1985; Council of the European Union, 1997).

In June 2001, another directive (2001/42/EC) was emanated by the European Parliament and the Council of the European Union, focused not more on single projects, but also on Strategic Environmental Assessment (SEA) of policies, plans and programs.

The Strategic Environmental Assessment (SEA) could become, after it will be adopted in all EU Member States a decisive and effective tool for sustainable development. It would be also required to assist the local Administrations in the formulation of future development strategies and policies and will contribute to more transparent planning by involving the public and by integrating environmental considerations, intervening on the alternatives of location and on the transversal actions of environmental interest.

The primary objective of SEA directive 2001/42/EC is the guarantee of a high level of environmental protection and promotion of sustainable development, assuring the correspondence of the Development Plans and the Operative Programs with the objectives of the sustainable development (European Parliament and the Council of the European Union, 2001).

SEA does not replace or reduce the need for EIA procedures, but it can help to streamline the incorporation of environmental concerns (including coastal problems) into the decision-making process, often giving to EIA procedures a more effective process.

Other aims and benefits of SEA are to strengthen EIA projects by identification of potential impacts and cumulative effects, justification and location of proposals and also reducing the time necessary to assess individual schemes (Partidario, 1996; 2000).

In Italy, at present, while several national and regional rules have receipt the EIA Directives, there are not any legislative dispositions, compulsory to introduce the SEA Directive inside the national legislative system.

Nevertheless, all Member States have to transpose the amended Directive by 21 July 2004 at the latest; after all, the Member States acknowledged the need to strive for a balanced recognition of environmental matters at early stages of decision making in order to achieve a significant preventive approach (Feldman et al., 2001).

Considering this well defined legislation, there is a lack of standard guidelines for interventions of coastal protection. Some general guidelines are