Evaluation of different methodological approaches for monitoring water quality parameters in the coastal waters of Andalusia (Spain) using Landsat-TM data

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ABSTRACT

With the objective of quantifying different water quality parameters and mapping their spatial distribution, many experiences have been carried out using three water sampling campaigns simultaneous to the acquisition of Landsat TM images in two very different coastal areas of Andalusia. Focused on the method, problems relating to the sampling process, samples coordinate acquisition, regression methods, transformation of the original image channels and multitemporal analysis are taken into account here.

1. INTRODUCTION

The great environmental interest of the coastal area and littoral waters, together with their management and study difficulties (due to their high dynamism and the fact that the management of this space is responsibility of many national and regional organisations) led the Agencia de Medio Ambiente (A.M.A.) to start the "Monitoring programme of the quality and dynamics of the marine waters and coastal zone of Andalusia". Between the different study lines integrated in the framework of this programme, there is a subprogramme which is intended for the quantification and mapping of different water quality parameters in the coastal waters of Andalusia.

Since the early stages of remote sensing, these techniques have been used to estimate water quality parameters. Most of the research has been centred on the study of the relationship between water quality parameters and multispectral data supplied by satellite images, for which there is a great variety of sampling strategies, digital image processing techniques (geometric and atmospheric correction methods, ratios and other band transformations...) and procedures to find the relationship between the images and the water quality parameters (linear, logarithmic, simple or multiple regression...). This is the reason why, in order to start a programme to monitor the coastal water quality as a function of time, it is necessary to carry out some experiments and experience different methods in different areas so that the optimal method can be found.

2. OBJECTIVES

Considering this, three water sampling campaigns simultaneous to the acquisition of Landsat TM images were undertaken in two very different areas of the Andalusian coast: Tinto-Odiel estuary in Huelva and Algeciras Bay in Cádiz (**Fig. 1**). These areas were chosen to ensure that the final method would really be applicable to and operational for the whole coast of the region.

The objective was to analyse the possibilities and limitations of these techniques for their application in the Anda-

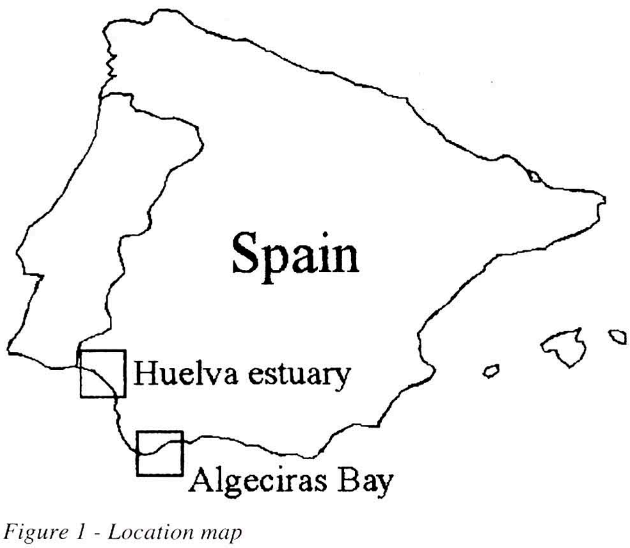


Figure 1 - Location map

lusian coastal water, and to establish the methodological basis for their development and operational application:

- Sampling procedures for the *in situ* water quality data.
- Image preprocessing and processing.
- Procedures to establish the relationship between the images and the water quality *in situ* data.
- Statistical and empirical assessment of the accuracy allowed by these techniques to estimate the different water quality parameters, using just the images without simultaneous *in situ* data.

3. MATERIAL

The selected areas (Tinto-Odiel estuary and Algeciras Bay), offering very different characteristics (the first one is located in the Atlantic coast and has a medium/high tidal range, while Algeciras Bay faces the Mediterranean Sea, is a well sheltered area and shows a small tidal range), provide a good reference to evaluate this method throughout the Andalusian coast, which is quite varied (there are high and rocky areas with cliffs, low areas with beaches or salt marshes, different tidal ranges, etc). The three selected dates for the sampling campaigns **(Tab. I)** (coincident with the acquisition of an image of the area of interest by Landsat 5) may be described as "summer" situations: calm weather during the dry season in a series of drought years, with limited river flow. Moreover, the two images of Tinto-Odiel estuary were acquired with similar tidal conditions.

With regard to the water quality parameters, the water samples were analysed for all the parameters of environmental interest **(Tab. I)**. A large number of parameters was selected in order to test all the possibilities of this technique.

The sampling points were located either by placing them in the map through visual references (Tinto-Odiel estuary, 10-10-89) or by taking their coordinates with a differential Global Positioning System (Tinto-Odiel estuary, 15-06-93 and Algeciras Bay, 09-09-92) whose maximum possible error was only 6 metres.

The water samples were taken as close as possible to the satellite pass time. During the processing stage those samples taken with a time difference longer than 45 minutes from this time were rejected. However, 90% of the water samples were taken within a 30 minutes time interval from the image acquisition.

4. METHODS

From an empirical point of view, the problem of quantifying water quality parameters from satellite images comes down to looking for the relation between two or more variables (simple or multiple regression), the dependent variable being a water quality parameter and the independent variable(s) the image values in the sampling points (either in the original channels or in any transformations of them). We will now describe the main stages followed in this study:

a) Image preprocessing. It has been proved that the image original values (DN) are not always the best to correlate with the water quality parameters, but some transformations of these digital values. Some of the transformations

Table I - Data used in the study

AREA	N° OF SAMPLES	IMAGE AND DATE	TIDAL CONDITIONS	PARAMETERS
TINTO-ODIEL ESTUARY	27	TM 202-34 10/10/89	Height: 2'69m Coef.: 0'69 Time to low tide: 6h 23m	conductivity, Temperature, Suspended solids, Cu, Fe, Ni, Zn Mn
TINTO-ODIEL ESTUARY	22	TM 202-34 15/6/93	Height: 2'57m Coef.: 0'57 Time from low tide: 5h 56m	pH, Turbidity, Suspended solids, organic matter, chlorophyll a, b and c, Secchi disk depth, Temperature, As, Fe, Zn, Mn cd.
ALGECIRAS BAY	33	TM 201-35 9/9/92	Height: 0'78m coef: 0'76 Time from low tide: 3h 52m	pH, Turbidity, Salinity, Suspended solids, Secchi disk depth, Temperature, chloride, Dissolved Oxigen, Organic matter, Oil, chlorophyll a, b and c

that have achieved good results in other experiences have been used here:

- Band ratios: TM 1/3, TM 2/3 (Zucchari et al, 1993) and TM 4/3 (Chesire et al, 1985).
- Principal components analysis (Jensen et al, 1986): six principal components resulting from the transformation of TM channels 1, 2, 3, 4, 5 and 7.
- Radiance calculated from TM calibration values (gain and offset).
- X and Y chromacity indices (Lindell et al, 1985) calculated from radiance values in TM channels 1,2 and 3 and 2,3 and 4.

b) Image normalisation. To manage the multitemporal analysis, it is essential to reduce the differences between the values of the different images caused by the effect of the changing atmospheric conditions and sun angles on the spectral response of the water.

As the objective is to establish a simple method in order to develop an operative programme, the normalisation procedures tested are very simple:

- Dark pixel correction method (Ritchie and cooper, 1987).
- Normalization by areas of constant reflectance (L6pez and Caselles, 1987).
- The third normalization procedure relies on the assumption that chromacity indices reduce the atmospheric effect affecting equally the involved channels Lindell et al, 1985).
- Finally, the images were transformed into actual reflectance values by using the 55 code (Tanré, 1990), in order to make them comparable.

c) Image values extraction. To obtain the images values for the sampling points, the mean of a three by three pixel array centred on the sampling point was calculated. The mean value was used as advised by Ritchie and Cooper (1987) to increase the signal to noise ratio and to reduce the possibility of error in the location of the sampling point.

In the regression analyses not all the sampling points were used. For example, in the Algeciras Bay experience, many of the samples were taken in areas of such clear water that the bottom was visible from the surface and contributed to the signal received by the satellite, so they had to be rejected, and finally only fourteen of the thirty three sampling points were used in the analysis. In the Tinto-Odiel estuary twenty two points were selected for the 1989 image and seventeen for the 1993 one.

d) Derivation of the predictive equations. As there is not general agreement about the actual shape of the relationship between water quality parameters and water spectral response, both linear and logarithmic models have been tested in the regression analysis. The multiple regression has been attempted with the "stepwise" method that automatically includes those independent variables that increase the multiple correlation coefficient, as a function of their partial correlation coefficient with the dependent variable (the water quality parameter) _

In order to establish the relationship between water quality parameters and image data, two methodological approaches have been followed:

1. Monotemporal: regression analysis between water quality data and image data for each date separately. It will allow to derive formulae to compute each of the water quality parameters starting from the image original channels or some transformations of them. Of course, the equations obtained by this method could only be applied to each date separately. This approach is useful to map the water quality parameters, spreading the point data obtained from the samples to the whole surface.
2. Multitemporal. The objective of this second approach was to calculate an equation that could be used to map the spatial distribution of water quality parameters without depending on simultaneous *in situ* data, so that it could be used to generate water quality maps for any date.

Firstly, an experience was carried out to get to know to what extent the equations derived from one date and place could be applied to a different date for the same place, after both images had been normalized. The formulae derived from one of the images were applied to the other image and the results were compared to the actual values measured on this second date. The results are thus empirically tested and it is possible to know the precision levels that each regression or normalization method allows. This is not strictly a multitemporal approach, as the equation is derived only from one date, but it is multitemporal in the sense that it allows the mapping of water quality parameters without coincident *in situ* water quality data.

The actual multitemporal approach is based in the calculation of an unique equation using the data from the two dates involved. It assumes that, being the two images normalized, it is possible to calculate a unique formula,as if both images had been acquired under the same atmospheric and sun angle conditions (Baranowska, 1993). This method is a priori expected to produce better results because more data have been used to derive the equation.

The first procedure was tested because if the results were considered good enough it would not be necessary to complicate any more the process, and the actual multitemporal approach could be considered useless.

For the multitemporal analysis only the two images of the Tinto-Odiel estuary were used. This has only been carried out for the suspended solids, because there were data for both dates.

e) Water quality parameters distribution maps. Once the predictive formulae have been derived, the best one (the one with the highest correlation coefficient and the least standard error of the estimate) is selected and applied to the image, which is converted into a map showing the spatial distribution of the parameter in question. To do that, the image transformed values are sliced and colour coded, with an interval width of double the standard error of the estimate **(Fig. 2)**.

5. RESULTS

Beforehand, and according to the specialised bibliography, only three of the analysed water quality parameters were expected to show a good relation with remote sensing measurements: turbidity (either expressed in Secchi Disk Depth units or U.T., because it is actually a measure of water colour), suspended solids and a chlorophyll (because both of them are expected to have a colouring effect in water). However, the regression analysis was applied to all the parameters and strangely the results do not agree completely with this expectations and some parameters that should not influence water spectral response (such as heavy metals) have shown very good correlation with the multispectral data.

The results from the monotemporal ânalysis are shown in **Table 2**.

With regard to Tinto-Odiel estuary and concerning the date A (10/10/89), the parameter that showed the best correlation with the image values was suspended solids, as expected. But zinc and manganese also reached values close to or even higher than 0.90 in the multiple regression analysis, which was not in the least expected. In the same way, high values were also obtained for the second principal component.

With respect to the date B (15/06/93), most parameters achieved a significant correlation coefficient with the multispectral data. Some values stand out, such as turbidity (whose correlation with multispectral data is fairly good, even with raw DN as shown in **Fig. 3**) and Secchi disk depth (physical parameters) and *a*, *b* and *c* chlorophyll (biological parameters) but also manganese, mercury and cadmium among the heavy metals. All of them showed correlation coefficients close to or higher than 0.90.

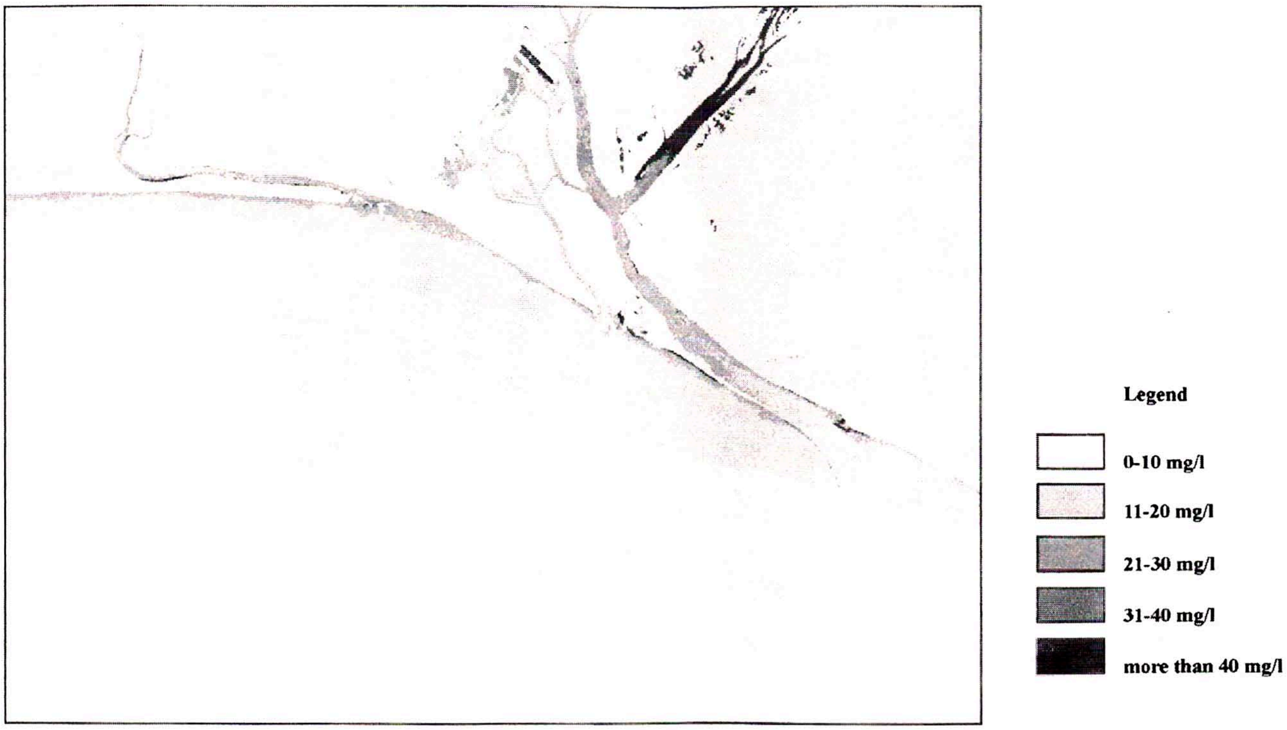


Figure 2 - Suspended solids spatial distribution in Tinto-Odiel estuary (15-06-93) as derived from the monotemporal approach

Table 2 - Monotemporal analysis. Single and multiple correlation coefficients between satellite images and samples for the main water quality parameters

Parameters	**Original channels simple correlation**						**mul.**	**Chromaticity Indices simple correlation**				**Principal Componentes Analysis simple correlation**					
(Dates)	**1**	**2**	**3**	**4**	**5**	**7**	**corr.**	**x123**	**y123**	**x234**	**y234**	**CP1**	**CP2**	**CP3**	**CP4**	**CP5**	**CP6**
							Physical parameters										
Turbidity																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'72	0'83	0'64	0'55	0'60	0'52	0'93	0'74	0'89	0'09	0'11	0'74	0'63	-0'56	0'13	-0'32	-0'83
C	0'11	0'22	0'15	-0'04	0'59	-	0'75	0'12	0'06	0'52	0'01	0'22	0'33	-0'34	0'45	0'44	-
Secchi disk depth																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	-0'50	-0'48	-0'36	-0'27	-0'34	-0'18	-0'89	-0'44	-0'62	-0'13	0'00	-0'47	-0'29	0'22	0'17	0'12	0'75
C	-0'28	-0'39	-0'36	-0'09	-0'40	-	-0'90	0'14	0'10	0'49	0'09	-0'43	-0'32	0'38	-0'13	-0'49	-
Suspended solids																	
A	0'67	0'75	0'81	0'86	0'64	0'46	0'94	0'78	0'57	0'72	0'63	0'70	0'90	0'60	-0'51	0'14	0'56
B	0'73	0'70	0'66	0'61	0'66	0'55	0'78	0'68	0'68	0'32	0'29	0'61	0'53	-0'49	0'07	-0'32	-0'78
C	-0'34	-0'19	-0'24	0'18	-0'18	-	-0'34	0'05	0'02	0'13	0'18	-0'38	-0'13	0'26	-0'04	0'03	-
							Biological parameters										
Chlorophyll a																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'59	0'64	0'53	0'43	0'46	0'44	0'92	0'64	0'80	0'00	0'11	0'61	0'52	-0'42	0'23	-0'18	-0'77
C	0'40	0'49	0'47	0'29	0'47	-	0'82	0'14	0'18	0'04	0'09	0'52	0'45	-0'55	0'07	0'45	-
Chlorophyll b																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'44	0'48	0'35	0'25	0'27	0'23	0'89	0'48	0'70	0'16	0'04	0'43	0'32	-0'19	0'05	0'07	-0'84
C	0'23	0'34	0'36	0'13	0'46	-	0'71	0'13	0'28	0'12	0'31	0'32	0'39	-0'50	0'15	0'44	-
Chlorophyll C																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'72	0'76	0'68	0'60	0'62	0'62	0'88	0'76	0'83	0'22	0'26	0'73	0'67	-0'59	0'39	-0'36	-0'69
C	0'18	0'32	0'35	0'16	0'57	-	0'66	0'15	0'27	0'09	0'25	0'31	0'47	-0'57	0'24	0'48	-
							Heavy metals										
Copper																	
A	0'41	0'59	0'59	0'56	0'37	0'21	0'79	0'67	0'60	0'41	0'47	0'45	0'66	-0'61	0'59	0'05	0'58
B	0'35	0'44	0'35	0'27	0'28	0'32	0'76	0'50	0'66	0'00	0'14	0'35	0'34	-0'23	0'19	0'05	-0'77
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc																	
A	0'49	0'69	0'70	0'65	0'47	0'29	0'89	0'79	0'68	0'49	0'59	0'51	0'75	-0'72	0'61	0'03	0'65
B	0'47	0'56	0'45	0'38	0'36	0'40	0'89	0'60	0'80	-0'05	0'08	0'47	0'43	-0'30	0'24	0'07	-0'86
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese																	
A	0'63	0'79	0'81	0'74	0'58	0'42	0'91	0'83	0'69	0'54	0'67	0'59	0'83	-0'78	0'52	-0'04	0'67
B	0'65	0'72	0'61	0'54	0'55	0'52	0'94	0'73	0'90	-0'20	0'13	0'65	0'58	-0'49	0'15	0'13	-0'84
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercury																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'88	0'89	0'81	0'78	0'80	0'71	0'96	0'85	0'92	-0'47	0'18	0'87	0'79	-0'75	0'09	-0'47	-0'60
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium																	
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	0'77	0'84	0'76	0'72	0'70	0'74	0'96	0'85	0'91	-0'44	0'27	0'78	0'75	-0'65	0'34	-0'28	-0'68
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

A: Huelva 10/10/89; B: Huelva 15/06/93; C: Algeciras 09/09/92.

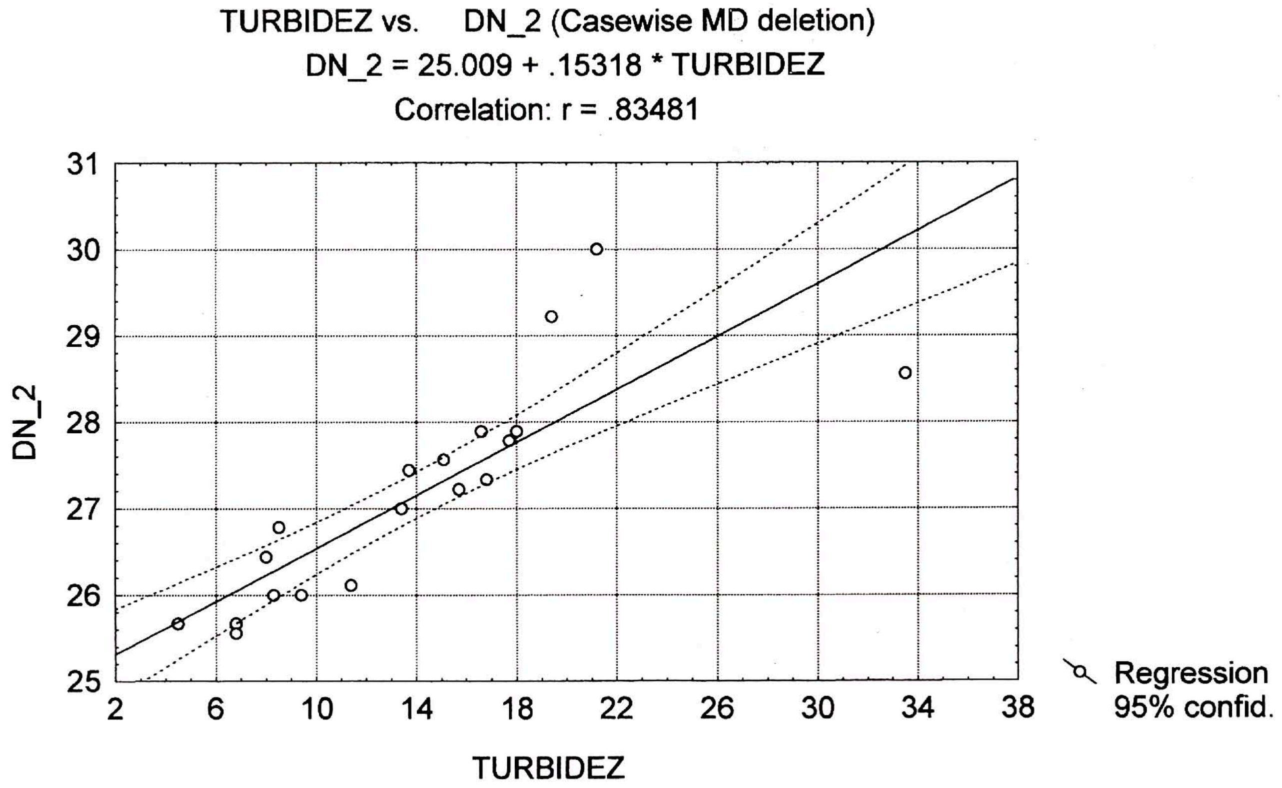


Figure 3 - Scatterplot of Turbidity versus DN in band 2, for the Tinto-Odiel estuary, 15/06/93

In the Algeciras Bay, date C (09/09/92), only two parameters achieved a significant correlation coefficient: Secchi disk depth and a chlorophyll. On the other hand, the low values obtained for the suspended solids contrast with Tinto-Odiel estuary results and with the initial expectations.

Among the different approaches to establish the best relation between *in situ* data and multispectral ones, the multiple regression method has always given the best results. Concerning the new channels, it highlights the sixth principal component and the Y chromacity index for the TM bands 1, 2 and 3, the latter one specially for the chlorophyll. The logarithmic regressions did not improve essentially the correlation coefficients with respect to the linear ones, not even for chlorophyll, although this kind of logarithmic regression has been reported to achieve good results in other areas (López y Caselles, 1989; Grunwald et al, 1988).

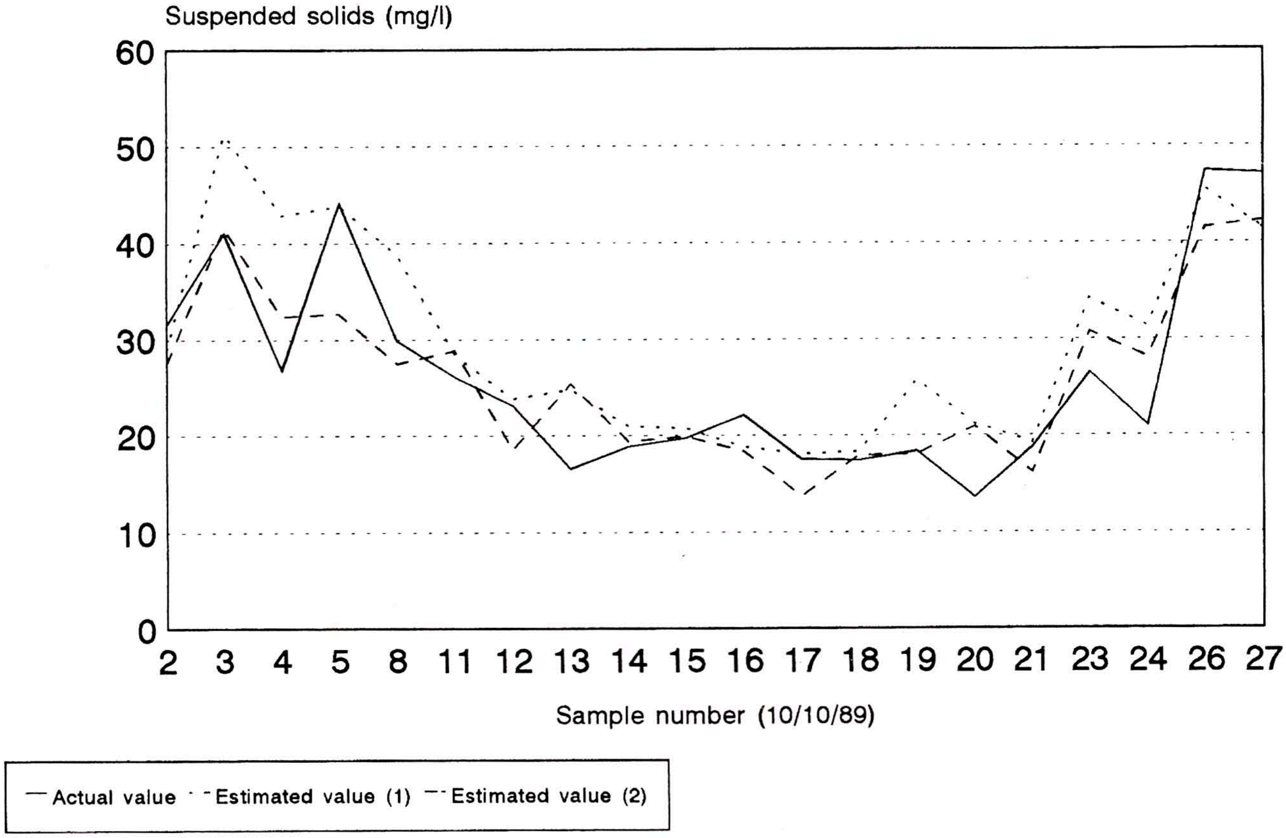
Regarding the multitemporal approach, the first attempt (application of the equation derived for the image dated 15/06/93 to the 10/10/89 one) shows the best results (that is, lower error in the quantification of suspended solids) when both images are normalised through the relative atmospheric correction method by using areas of constant reflectance. The equation which allows the more accurate estimation for the suspended solids is the one that includes band 2, as can be inferred from the analysis of the estimated results (**Fig. 4**) and its comparison with the actual values, showing an average error of 6.3 mg/I. Moreover, this estimation becomes more significant when compared with the best one obtained for this date (10/10/89) and band in the monotemporal analysis, with a 0.86 correlation coefficient and a 5.4 mg/I standard error.

In the actual multitemporal analysis, the best correlation coefficients for suspended solids are obtained through the normalised relative atmospheric correction method from constant reflectance areas and multiple regression (r = 0.79; standard error = 5.7 mg/l), followed by band 4 with the same normalization method (r = 0.78; standard error = 5.93 mg/I). The worst results, as expected, are obtained from images without normalization. That is, any method of normalization greatly improves the results, as expected.

6. INTERPRETATION AND CONCLUSIONS

Based on the above results, some conclusions can be drawn, both for the monotemporal and multitemporal methods. First we will refer to the monotemporal approach:

a) The water quality parameters used in this study can be divided into three groups according to their possibility of being quantified by means of remote sensing techniques,



(1) Equation derived from the 15/06/93 campaign.
(2) Equation derived from the two campaigns, 15/06/93 and 10/10/89.

Figure 4 - Multitemporal analysis. comparison between measured in situ values and estimated values for the suspended solids in the Tinto-Odiel estuary

which in fact is related to their influence in the spectral response of water.

1. The first group includes those parameters that, as it was expected, show high correlation with the image data in most of the cases, irrespective of the approaches undertaken (single bands, ratios, principal components, simple and multiple regression, etc): turbidity, suspended solids and chlorophyll. These are the parameters that, in agreement with the existent bibliography, seem to be the most appropriate to be monitored using remote sensing techniques.
2. There is a second group of parameters, among those analysed, which showed very poor correlation in every single case (pH, conductivity, salinity, dissolved oxygen...). This behaviour was expected, because this parameters are not known to influence the spectral response of water, and therefore they cannot be quantified by means of remote sensing techniques.
3. Strangely, a third group of parameters was found, integrated mainly by heavy metals. These parameters achieved very good correlation coefficients with the multispectral data, although it is known that, at the concentrations found in the Tinto-Odiel estuary, they should not affect water colour and therefore, the water spectral response.

b) Turbidity is the most decisive parameter influencing the water spectral response. In the same way, it is the parameter achieving the best correlation coefficients in the 15/06/93 Huelva case, the only one where both chlorophyll and suspended solids offered good correlation coefficients too.

This higher correlation is understood because it is the only parameter whose measuring technique and units (spectrophotometer and nephelometric units) are similar to that used by remote sensing instruments. In that sense, it is recommended to measure this parameter during the sampling campaign using spectrophotometer instead of employing Secchi disk (as it is a more objective measure of turbidity and, specially, because it provide information about more subtle variations in turbidity).

In addition, turbidity is a very important parameter from the environmental point of view, because it is the result of the sum of other indicators (chlorophyll, suspended solids,

Table 3 - correlation coefficients between the main water quality parameters and turbidity and their ranges in the Algeciras 09/09/92 and Huelva 15/06/93 cases

Parameters (units)	Algeciras		Huelva	
	Range	r	Range	r
Suspended solids (mg/1)	32,00-55,00	-0,16	15,20-58,90	0,71
Secchi disk depth (m)	5,00-10,00	-0,81	0,50- 4,70	-0,77
chlorophyll a (ppb)	0,31- 9,55	0,69	0,00-32,10	0,89
chlorophyll b (PPb)	0,07- 2,23	0,46	0,00- 8,00	0,90
chlorophyll c (ppb)	0,44- 8,67	0,57	0,90-17,00	0,88
Turbidity (u.T.)	1,20- 4,30	-	4,50-33,50	-

etc) and it supplies information on light penetrability in the water. This integrating role of turbidity makes clear that the best correlation between other parameters and remotely sensed data were achieved when using visible bands, due to the fact that these are the best to discriminate colour changes in water.

c) concerning the erratic behaviour of suspended solids, some important considerations can be established. In Tab. 3 it is possible to observe how similar ranges of content of suspended solids in two of the experiments (Huelva 15/06/93 and Algeciras 09/09/92) resulted in totally different correlations with the multispectral data. The reason is that there is not always a direct relationship between the quantity of suspended solids measured in weight by volume of water and the spectral response measured by the sensor. The spectral response of suspended solids does not only depend on the weight; on the contrary, it is highly influenced by other factors, such as grain size or composition. As a consequence, for future campaigns measure of weight by grain size of suspended solids is suggested.

d) chlorophyll is the parameter showing the best correlations (except turbidity). Some conclusions can be drawn from the analysis of its behaviour in the different cases:

- the regression analysis established between suspended solids, chlorophyll and turbidity in the two dates **(Tab. 3)** shows that these parameters are highly correlated in the case of Huelva (15/06/93). On the contrary, in Algeciras 109/09/92) suspended solids do not have any effect on turbidity, this being caused mainly by the chlorophyll registered in that campaign.
- from what have been stated above, it is possible to consider turbidity as a consequence of the interrelationship between suspended solids and chlorophyll, as it is known to occur in coastal waters (case 2 waters) (Robinson, 1985). In that sense, the results obtained in the Algeciras Bay could be explained by the stable hydrometeorological conditions that preceded the sampling date (lack of rain and wave storm that could produce high suspended solids rates), which brought about the prevalent role of chlorophyll as turbidity producer. However, the usual situation in coastal environments, and particularly in estuaries, is the occurrence of a continuous mixture of both parameters on account of waves and tidal currents. In that sense, it seems necessary to study in depth the interference between suspended solids and chlorophyll in different situations (algal peak production, high concentrations of suspended solids during the rainy season, etc) in order to clarify their incidence on turbidity and therefore in the spectral response measured by the sensor, which will be done as a parallel working line, independent to a certain extent from the satellite data.

e) Among the heavy metals, there are some that did not show any correlation with remote sensing data as expected, such as Fe and As, for example. But, on the other hand, some of them (Zn, Mn, Hg and Cd) were found to achieve very good correlation with the multispectral data. In general, this strange behaviour could be explained for two different reasons:

1. The samples have been taken in an area where the heavy metal concentration is extremely high, enough to colour the water. This is not the case, as the heavy metals concentrations are not very high. Moreover, a metal such as Fe, perhaps the one with the highest colouring capability is not at all correlated with the multispectral data.
2. Heavy metals are directly and highly correlated with one or some of the water quality parameters known to influence the spectral response of water. For example, they may be important constituents of suspended solids, or be associated to a certain kind of organic matter. Then, their relation with the multispectral data is not direct, but through this water quality parameters that directly influence water colour. This is the case here, as high correlation have been found between this group of heavy metals and suspended solids ($r > 0.8$).

Being the relation between heavy metals and water colour indirect, it is not possible to quantify them from the multispectral data, nor to generalise the derived equations to other situations. But this does not mean that remote sensing is useless to map heavy metals. In fact, if this relation with water colouring parameters persists, remote sensing data would allow to indirectly identify and map the areas potentially affected by these elements, although it will not be possible to produce detailed quantitative cartography. Even this limited application is regarded as very important and useful from an environmental point of view, as we are dealing with potentially toxic elements.

As in the case of turbidity, more studies will be carried out in order to verify if this relation is persistent.

f) In relation to the multitemporal approach, it has been found that, as expected, the use of sets of data from different dates (even for the same place, as it is the case here) leads to a reduction of the accuracy of the estimations with respect to the monotemporal analysis. This is due mainly to the difficulties in eliminating completely the differences between both satellite images caused by unequal atmospheric and illumination conditions when they were acquired. This is the reason why the best results have been obtained when normalizing both images by the relative atmospheric correction method or their transformation into real reflectance values by using the 55 code. These methods result better because they take into account the two main sources of error: atmospheric dispersion and solar angle. This two methods provided similar results, but the fact that the application of the relative atmospheric correction method is much simpler and needs less data than the use of the 55 code, this method is recommended for future experiences. Although providing passable results, the dark pixel correction method must be carefully used because it only corrects the effects of the atmospheric dispersion.

With regard to the multitemporal method, some conclusions can be drawn:

- The application of the equation derived from a single date to another image, although producing less satisfactory results, has the advantage that its verification is totally empirical because the *in situ* data collected for the second image have not been used in the regression analysis **(Fig. 4)**.
- Better results are achieved using the actual multitemporal approach (derivation of predictive equations using data from the two dates), but these are not greatly improved in comparison to the previous method **(Fig. 4)**.

Although it seems that the actual multitemporal approach does not bring much improvement over the use of the equation derived from a single date for two images of different dates representing similar hydrodynamic conditions, it could be of great interest to obtain an unique predictive equation for multiple conditions and geographic areas because it results in a better normalization in the case of very heterogeneous situations. In this way its lower precision can be compensated for its operational advantages in the context of a programme aiming at covering the whole of the Andalusian coast.

Different hydrodynamic conditions and new geographical areas will have to be analyzed in future campaigns in order to test both multitemporal approaches, as this is only the first experience of a much wider working programme that will include more water quality parameters.

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