

# GIS and Remote Sensing techniques integration aimed to the evaluation of the Esino catchment impact on coastal water quality.

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## ABSTRACT

The main aim of this work, carried out in the framework of the PRISMA2 national research program (Research and Experimentation Program for the Adriatic Sea)<sup>1</sup> was the definition of an appropriate working methodology which allowed to estimate the impact of the Esino drainage-basin (central Italy), and of the anthropic activities lying on it, on the coastal water quality of the Adriatic sea.

This aim was pursued by integrating techniques and instruments of analyses, such as GIS and remote sensing, which are often and often employed in natural resources managing and planning.

They allowed to generate a database easily updating, relative to a very large area which is strongly differentiated in its natural and anthropic features. The database contains raw data, provided by local public organisations managing the territory, information derived from elaboration of the previous data and remote sensed frames (acquired by the hyperspectral sensor MIVIS) purposely acquired to the aim of the study.

It was after all generated an "open" system, continually updating with environmental information before long available; moreover, were explored the potentialities of the MIVIS sensor (102 band, from the visible to the thermic IR) in the study of marine coastal water quality.

**Keywords:** coastal impact, water quality, erosion, MIVIS.

## 1. INTRODUCTION

Nowadays, more and more attention is being given to quantifying fluxes of particles, biogeochemically important elements and representative contaminants from land-sources to the coastal zone and to coupling models of riverine, estuarine, plume, shelf and shelf edge processes, such that the flux of materials may be simulated as a continuum from the catchments to the edge of the continental shelf. In particular, a strong attention is being paid to estimating fluxes during high river flows, when a substantial proportion of the total flux of sediments and contaminants occurs.

To this aim, it is fundamental a network of flow and water monitoring stations along the river courses, to provide data on water discharges and on fluxes of sediment, nutrient, metals and organic microcontaminants; this network must be coupled with sampling stations in marine waters providing data which define the stress entity concerning the coastal environment.

One of the major deficiency of coastal zone data is that they are rarely synoptic; while this may be of poor importance within offshore studies, processes in the coastal zones are often so dynamic that understanding is limited by the timeframe in which measurements of the master variables are made. This kind of problem can be solved making use of remote sensing techniques, which provide synoptic data of high spectral and spatial resolution allowing to interpret some important hydrodynamic processes. These data traverse the entire coastal zone from the nearshore through the littoral and onshore, such that the coastal zone can be studied as an entity, rather than as a boundary. They can be acquired coincident with the collection of cruise or ground data, allowing to estimate water parameters (e. g. transparency, suspended sediment, chlorophyll, temperature, dissolved organic carbon, oil spills) and to expand synoptically punctual information.

An essential condition, so that the flux of materials can be modelled as a continuum between riverine and estuarine waters, is the compatibility and the integration of measurements acquired on the land and in coastal waters.

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At present this is allowed by Geographic Information Systems (GIS) which represent the best way to collect, storage, manipulate and display geographic data (remote sensing data included). They allow the total integration of marine, river and remotely sensed data and the maintenance of the resulting databases. The use and the integration of GIS and Remote Sensing techniques is therefore a tool for coastal management and for the visualisation of natural and anthropogenic phenomena in coastal zones<sup>2</sup>.

## 2. STUDY AREA

The Esino river subtends a very large catchment, about 1253 Km<sup>2</sup> of extension, which entirely lies in Marche territory (central Italy). The river rises on Mount Cafaggio (1116 mt.), in the provinces of Macerata, and flows into the Adriatic sea a few kilometres north of Ancona, developing nearly 75 kilometres in length (figure 1).

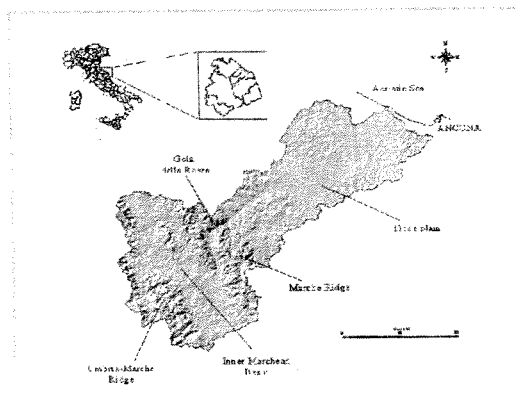


Figure 1: the Esino catchment.

The catchment was chosen as study area by virtue of:

- . its high territorial valency: inside of it, in fact, lie the two appennine ridges (Umbria-Marche Ridge and Marche Ridge), the Inner Marchean Basin, a large hilly area and a wide flood plain reaching the Adriatic coast;
- . its high anthropication and industrialisation degree: inside the basin live more than 180.000 inhabitants residing in 30 communes (ISTAT, 1995) and lie industrial activities at high environmental risk (paper mills, metal and mechanical industries, tanneries, sugar refineries, one of the most important Italian oil-refinery), as well as a flourishing agricultural and zootechnics activity;
- . its extent compatible with a prevalently methodological study;
- . its impact on the coastal environment strongly emphasized by recent studies on the Esino river<sup>3-5</sup>.

## 3. MATERIALS

The typologies of data used are generically classifiable in three categories:

### . Digital data:

- . contour lines, at scale 1:10.000;
- . land-use cartography, at scale 1:10.000;
- . two frames acquired, in March and June '97, by the hyperspectral sensor MIVIS, with a ground resolution of 10 meters;

### . Analogic data:

- . data relative to 91 chemical-physical-biological water parameters, acquired near 17 sample points uniformly stationed along the Esino river. These data were collected during four different sampling campaigns, carried out in October '95 and in February, May and July '96;
- . thermo-pluviometrical data;
- . varied cartography;

. Field data, acquired simultaneously with the second MIVIS flight in the part of sea facing the Esino outlet, near 21 sampling stations (figure 2):

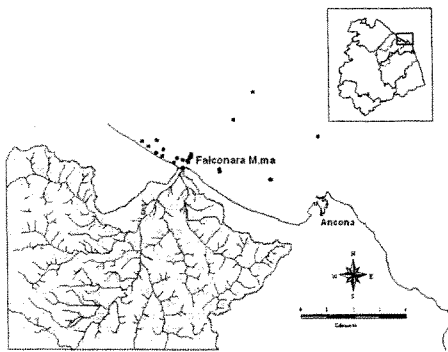


Figure 2: the 21 sampling stations.

- . air temperature;
- . water temperature;
- . water depth;
- . water spectral reflectances, measured by the portable, high resolved spectroradiometer FieldSpec<sup>TM</sup>FR (1 nm);
- . suspended solid concentration;

#### 4. METHODOLOGY

The impact caused by a river catchment on coastal water quality depends on what is produced inside the drainage-basin and carried to the sea by the hydrographic network; the elements able to alter the coastal water quality and to disturb the equilibrium of the coastal ecosystems can have natural or anthropic origin and can be generically classified as follows:

- . chemical compounds (prevalently of industrial or agricultural origin);
- . organic matter (mainly rising from urban refluents, from zootechny and more seldom from industrial discharged);
- . solid matter (rising from natural erosion processes);

A close cause-effect relation, therefore, links the anthropic activities lying on a drainage-basin, its main natural features and the impact caused on the marine environment.

Therefore, the best way to estimate the impact of a drainage-basin on the coastal environment consists in integrating analyses of data pertinent to the catchment, to forecast its impact on coastal waters, and analyses of data relative to the coastal water quality, to verify the importance of the impact.

In spite of some gaps, the quantity and the quality of the available data warranted to follow this kind of procedure; therefore, the research activity was directed to:

- . The forecast of the impact caused by the Esino catchment:

- . by generating a database, whose query allowed the identification of the most "stressed" fluvial segments and, by analysing in particular the Esino river water quality near the outlet, the forecast of the impact on the coastal environment;
- . by computing the intensity of the erosive processes inside the drainage-basin, and the quantity of sediments flowed into the sea, through the application of an erosion model, applicable to a catchment scale. This model estimates the erosion processes merely by means of quantitative geomorphic parameters describing the geometry of the hydrographic network<sup>6-8</sup>.

- . The verification of the importance of the impact:

- . by utilising the MIVIS frames to generate quantitative maps describing the solid load distribution in the part of sea facing the Esino outlet;
- . by carrying out, on the same frames, a chromaticity analysis<sup>9-11</sup> to deduce qualitative, multi-temporal information relative to transparency, suspended solid and chlorophyll concentration in the coastal waters;

To confer on the study the required homogeneity, rationality and completeness, all the available data were organised in one database, basic element of a geographic information system which gives, with regard to the dealt topics, a synthetic picture of the

environmental quality. To elaborate and analyse a so huge and complex amount of information it has been used the geographic information system ARC/INFO<sup>TM</sup>.

## 5. DATA PROCESSING

The first step of this stage consisted in generating a Digital Elevation Model (DEM) with a resolution of 30 metres, from contour lines at scale 1:10.000 with an equidistance of 25 metres over the mountain areas and of 10 metres in correspondence of the flood plain. The interpolation was carried out making use of the algorithm TOPOGRID, specifically conceived to generate hydrologically correct DEMs (figure 3).

From the Digital Elevation Model it was extracted the hydrographic network of the catchment; to this aim it has been used the "fluxes method", which is based on hydraulic principles and involves the computation, for each cell of the DEM, of two quantities: the flowdirection and the flowaccumulation (figure 4)<sup>12-13</sup>.

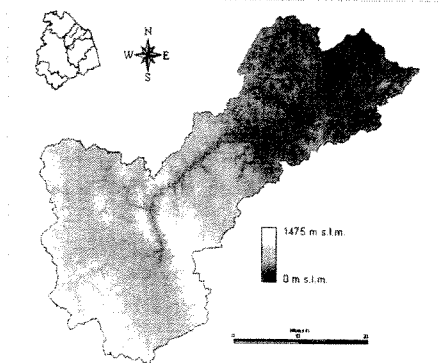


Figure 3: Digital Elevation Model.

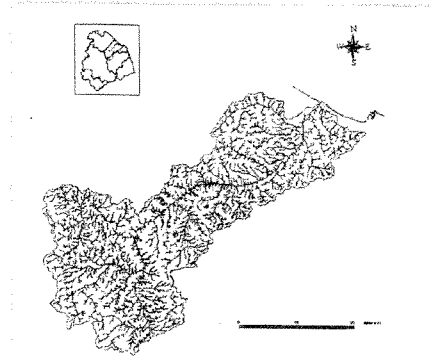


Figure 4: the hydrographic network.

Verified its reliability in correspondence of some sample sites, the hydrographic network was finally hierarchised (through the Strahler method<sup>14</sup>) in view of the subsequent extraction of the quantitative geomorphic parameters required to study the erosion processes.

All the data relative to the Esino water quality were then digitised and introduced in an appropriately organised database; the 17 sampling stations were localised on the hydrographic network and digitised on a punctual cover which was lastly related to the database just generated, to warrant the possibility of referring geographically the results of the database query.

The following step of this stage consisted in elaborating the frames acquired by the MIVIS sensor; the images, provided radiometrically and geometrically corrected, were atmospherically corrected making use of the 6S<sup>15</sup> code, which made them available for multi-temporal analyses.

Moreover, the data acquired during the survey carried out simultaneously with the second MIVIS flight were elaborated and made available for the analyses.

Finally, last step of the processing stage, the all data utilised were projected on the geographic projection system UTM 33.

## 6. RESULTS AND DISCUSSION

The analysis stage developed in three different steps.

Firstly, by querying the database, the data relative to the Esino river water quality were analysed: the most polluted fluvial segments were identified and the chemical-physical properties of the river in correspondence of the outlet considered, to forecast its impact on the coastal environment.

This analysis enhanced, along the whole river course, a diffuse pollution attributable to a wrong urban effluents discharge, causing a strong contribution of nutrient substances into the coastal waters.

Moreover, a classification was accomplished making use of a water quality index (WQI) specifically conceived for the management of surface water quality<sup>16-19</sup>.

Then, the application of an erosion model allowed to evaluate the quantity of sediments flowed into the sea per year from the catchment, and to compare the intensity of the erosive processes characterising the study area with those fitting other Italian river-basins to which the same model had been previously applied.

The model quantitatively estimates the erosion processes merely by means of quantitative geomorphic parameters describing the geometry of the hydrographic network:

- . Drainage density (D);
- . Bifurcation ratio (Rb);
- . Number of hierarchical anomaly (Ga)
- . Index of hierarchical anomaly ( $\Delta a$ );
- . Density of hierarchical anomaly (ga);

It considers, as an index of the erosive processes intensity, the parameter Tu (mean annual sediment yield, tons/sq.Km/yr) and suggests two equations:

$$\text{LogTu} = 1.82818\log D + 0.01769ga + 1.53034 \quad (\text{to be applied if } D > 6) \quad (1)$$

$$\text{LogTu} = 0.33479D + 0.15733\Delta a + 1.32888 \quad (\text{to be applied if } D < 6) \quad (2)$$

First step in the application of this model was the computation, from the hydrographic network previously extracted, of the Drainage density (D); the value obtained, 3.84, suggested to apply the equation (2) which involves the parameters Index of hierarchical anomaly ( $\Delta a$ ) and Bifurcation ratio (Rb), necessary for the computation of  $\Delta a$  (table 1).

Drainage density (D)	3.84
Bifurcation ratio (Rb)	4.6
Index of hierarchical anomaly ( $\Delta a$ )	0.24



Table 1: Geomorphic parameters used to retrieve the erosive processes intensity by means of the equation 2.

The value of Tu obtained, 377 tons/sq.Km, according with S. Ciccacci et al.<sup>6</sup> who applied the same model with regard to 14 Italian sample catchments, is in good agreement with the lithological characteristics of the area showing a rather high intensity of the erosive processes.

Due to the good results obtained by applying the model to the whole catchment, it was resolved to produce an erosive index map, describing the variations of the erosive processes intensity in the study area.

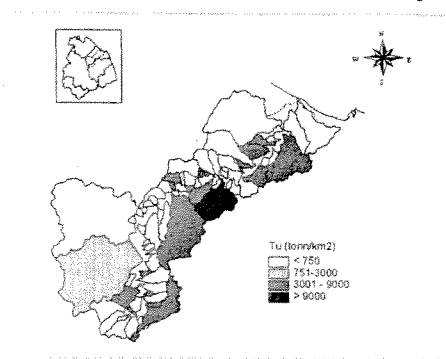


Figure 5: the Erosion Index Map.

To this aim, all the sub-catchments with an order higher than the first and an extension higher than one square Kilometre were identified and, for each one of them, the value of Drainage density (D) computed. As most of these values were  $> 6$ , the equation (1) was applied, which involves the Drainage density (D) and the Density of hierarchical anomaly (ga). This way, the Tu values for each sub-basin were computed and the erosion index map at last generated (figure 5).

The map is in good agreement with the lithological characteristics of the area; it presents, in fact, the greatest Tu values over the hilly sites which are constituted by pelithic, highly erodible, lythotipes whose high slopes represent an important instability factor.

The lowest values are on the contrary located over the appennines ridges, constituted of calcareous rocks, highly resistant to erosion.

Finally, the verification of the importance of the Esino river impact on coastal water quality was accomplished by analysing the remote sensing data; the frames acquired by the MIVIS sensor were employed to define, in the part of sea facing the Esino outlet

and in two different temporal moments, the water characteristics with regard to transparency, suspended sediment and chlorophyll concentration.

Simultaneously with the second MIVIS flight were collected the total suspended sediment concentrations [SS], in correspondence of 6 sampling points facing the river outlet. The purpose was to identify, on the georeferenced image, the points where those concentrations had been measured and to define the correlation between the [SS] values and the surface reflectance values measured by the MIVIS sensor to generate a map describing the solid load distribution in the tract of sea of interest. Due to some errors occurred during the acquisition stage (i. e. sunglittering), a large part of the MIVIS frame was not employable and in that part lied, unfortunately, four of the six sampling stations: the correlation between [SS] and surface reflectance values wasn't, therefore, directly definable.

Hence, it was necessary to follow a different procedure which finally allowed to define an "indirect" correlation between remote sensed data and [SS] values. It was possible because, in addition to the determinations relative to the suspended sediments concentrations, during the survey had been acquired spectral signatures near 21 sampling points, 12 of which lied in the part of MIVIS frame employable for the analysis.

Therefore, the problem was resolved as follows:

. by defining the spectral ranges (corresponding to the MIVIS bands) which gave the best correlation between [SS] values and the water reflectance values measured by the FieldSpec<sup>TM</sup>FR spectroradiometer (350-2500):

$$[SS] \longleftrightarrow \text{FieldSpec}$$

. by defining, with regard to the best correlated spectral ranges, the relation between the FieldSpec reflectance values and the surface reflectance values measured by the MIVIS sensor:

$$\text{FieldSpec} \longleftrightarrow \text{MIVIS}$$

. by deducing, from the results obtained in the previous steps, the expression describing the relation between [SS] and surface reflectance values:

$$[SS] \longleftrightarrow \text{MIVIS}$$

. by using the last expression to generate a solid load concentration map.

The best correlation between FieldSpec measures and suspended solid concentrations came out from a combination of the average reflectance values measured in the spectral ranges  $\Delta\lambda_1 = 433-453$  and  $\Delta\lambda_2 = 513-533$  lying in the blue and red region of the visible spectrum, and corresponding to the MIVIS bands 2 and 5, respectively (Tab. 2):

$$[SS] = \{ 5.9838 * \{ [\rho(\Delta\lambda_1) + \rho(\Delta\lambda_2)] / \rho(\Delta\lambda_1) \} \} - 11.869 \quad (3)$$

Successively, the points where the radiometric measures have been acquired were located on the frame and the relations between FieldSpec reflectance and MIVIS reflectance values in band 2 and 5 were defined by a statistical regression analysis:

$$\rho(\Delta\lambda_1) = [3.23 * \rho_{\text{MIVIS}}(\text{band2}) - 0.21] \quad (4)$$

$$\rho(\Delta\lambda_2) = [3.85 * \rho_{\text{MIVIS}}(\text{band5}) - 0.29] \quad (5)$$

The equations (4) and (5) were finally introduced into the equation (3) to define the expression relating the suspended sediment concentrations values to the remote sensed reflectances:

$$[SS] = \{ 5.9838 * \{ [3.23 * \rho_{\text{MIVIS}}(\text{band2}) - 0.21] + [3.85 * \rho_{\text{MIVIS}}(\text{band5}) - 0.29] \} / [3.23 * \rho_{\text{MIVIS}}(\text{band2}) - 0.21] \} \} - 11.869 \quad (6)$$

This expression, applied on the June MIVIS frame, allowed the generation of a solid load distribution map which shows the influence of the river in causing a strong increase of the suspended sediments concentration in the tract of sea facing its outlet. The same expression, applied on the march frame, didn't supply reliable results probably due to its high empirical modelling and to its high dependence on the environmental conditions taking place during the image acquisition.

The multi-temporal analysis of the Adriatic sea water quality was however ensured by carrying out a chromaticity analysis<sup>8-10</sup>, relating the water transparency with the chromatic coordinate Z-blue, the suspended sediment concentration with the chromatic coordinate X-red and the chlorophyll concentration with the chromatic coordinate Y-green.

It was executed, on both the MIVIS frames, along two radiometric transects: the first (35 polygons, each one representing a cluster of 5\*5 pixels: 2500 m<sup>2</sup>) leaving from the outlet goes along the coast, the second (23 polygons) steers toward the open sea (figure 6).

The MIVIS bands 1,6 and 14 came out the most suitable for the computation of the chromatic coordinates, according to the Landsat Chromaticity system<sup>9</sup> which is the model most diffuse in literature:

$$Z\text{-blue} = L_{\lambda 1} / \Sigma L_{\lambda i} \quad X\text{-red} = L_{\lambda 14} / \Sigma L_{\lambda i} \quad Y\text{-green} = L_{\lambda 6} / \Sigma L_{\lambda i}$$

With regard to these three bands, the mean radiance values necessary for the computation of the chromatic coordinates were extracted from each pixel cluster belonging to the radiometric transects.

The chromaticity coordinates values allowed to deduce interesting qualitative considerations relatively to water transparency, suspended sediments and chlorophyll concentration, along the two transects.

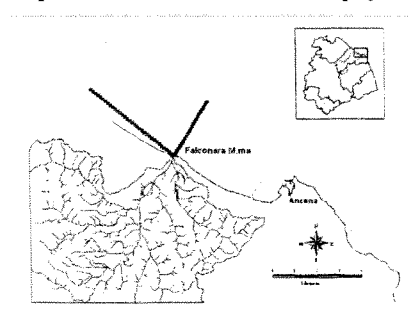


Figure 6: the two radiometric

. Transparency: the degree of clearness of water in June came out higher than in march, both in the open sea and near the outlet. The Esino river therefore seems to cause a considerable impact on the general degree of clearness of coastal waters in spring months, when it has its highest flows; in summer, on the contrary, the coastal environment less suffers its influence.

. Suspended sediments: over some distance from the outlet (about 1 Km) the suspended solid concentrations in March and in June came out practically equal, with a slight superiority of the summer values; getting near the outlet, the suspended solid concentrations considerably increase and the spring values definitely prevail over the June ones. By comparing the state of the suspended solid concentration with the general degree of clearness of waters, it came out the predominant role of suspended sediments in causing reductions in the general degree of clearness of coastal waters.

. Chlorophyll: in the open sea, the march concentrations definitely prevail over the summer ones; getting near the outlet, both in March and in June, they gradually decrease.

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