A multispectral remote sensing analysis of Danube delta and North-Western coastal zone of Black Sea

Maria Zoran
National Institute of R&D for Optoelectronics, Remote Sensing Department, Bucharest Magurele, MG5, Romania, e-mail: mzoran@inoe.inoe.ro

Liviu Florin Zoran
University Politechnica of Bucharest, Romania

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ABSTRACT: The Romanian North Western coastal zone of the Black Sea and Danube delta is a mosaic of complex, interacting ecosystems, rich natural resources and socio-economic activity, for which the comprehensive knowledge of the physical and biogeochemical processes in the near-shore area represents an important aspect of integrated zone management. Dramatic changes in the Black Sea's ecosystem and resources were registered due to natural and anthropogenic causes (increase in the nutrient and pollutant load of rivers input, industrial and municipal wastewater pollution along the coast, and dumping on the open sea). Remote sensing provides a means for locating, identifying and mapping certain coastal features and assessing of spatio-temporal changes and their environmental impact.

A scientific management system for protection, conservation and restoration must be based on reliable information on bio-geophysical and geomorphologic processes, coastal erosion, sedimentation dynamics, mapping of macrophyte fields, water quality, climatic change effects. A multispectral and multitemporal data set (LANDSAT MSS, TM, ETM; SAR ERS-1; MODIS, ASTER) images over some selected areas in the vicinity of the Danube mouths and North-Western coastal zone of Black Sea.

The main aim of this paper is to conduct a comprehensive analysis based on existing historical and more recent in situ and remote sensing data to establish the link between phytoplankton bloom development, increasing erosion and diminishing of beaches and related coastal zone harmful phenomena between 1975 and 2003, and also the sediment discharge and depositing regime in the delta near the Danube mouths and Black Sea.

1 INTRODUCTION

Marine and deltaic coastal zones contain that unique environmental triple point where the water, land and atmospheric components of the terrestrial surface converge and interact. Special hydrodynamic regimes are produced by the mixing of fresh with salt water resulting in complex features of the coastal zone. Due to the urgent need for effective monitoring programs in these regions in response to their high population levels, resource utilization, and disturbance levels, environmental assessment was developed specifically for coastal areas.

Marine and deltaic ecosystem properties such as vegetation structure, water exchange, carbon (C) fluxes and nitrogen (N) feedbacks to ecosystem dynamics respond differently when they are perturbed by land use or climatic changes. These differences are reflected in spectral, spatial and temporal features of the land use surface characterization. Ecosystem models are simulating changes of properties due to land use and climatic perturbations across different land cover classes. Danube River Delta was declared a Biosphere Reservation (August 1990) and more than 50% of it is a

World Heritage Site (1991), having legally established management bodies acting for biodiversity conservation and environmental protection. As the largest European wetland, the Danube Delta represents an important area for environmental studies. Fed by the Danube River which crosses nine nations, and drains watersheds of an additional four nations (total length 2,860 km), the Delta is the point of concentration of a 810,000 km^2 basin. On average, the Danube river delivers 6,300 m^3 of water per second through the delta and into the Black Sea. Efforts to restore and manage damaged marine and deltaic ecosystems require an interdisciplinary, international strategy to understand the events and processes that have led to current environmental problems. An important aspect of integrated coastal zone management is a comprehensive knowledge of the physical and biogeochemical processes and the availability of relevant, up-to-date, and reliable information on the environmental state in the near-shore area. Such information is related to geomorphologic processes, coastal erosion, sedimentation transport, mapping of macrophyte fields and derived estimation primary production, mapping of types of marine and delta floor, and assessment of the water-column quality (concentration of sediment, chlorophyll, terrigenous substances).

Remote sensing provides a means for locating, identifying and mapping certain coastal features and assessing of spatio-temporal changes and their environmental impact. Danube Delta and Black Sea have experienced the worst environmental degradation during the last three decades (I. Salihoglu 2000). Extraction of land cover maps for mapping surface composition and assessment of changes in surface cover composition over time are requirements common to each investigation. Applied remote sensing became a more and more inevitable technology tool contributing to human's progress toward sustainability by support solving environment-related tasks on local, regional and global level. Moreover, regularly acquired satellite data may be used for long-term surveillance of certain features (Aubrey et al.1996). These data acquired by optical, infrared and microwave sensors yield information on chlorophyll content, the surface temperature, turbidity, hydrocarbon load respectively.

2 DESCRIPTION OF INVESTIGATED AREAS AND DATA USED

Study area (Fig. 1), placed on Romanian North-Western Black Sea coast , from the Southern border line with Bulgaria till the Northern border with Ukraine is bounded by latitudes 43.6 °N and 45.40 °N and longitudes 28.5 °E and 29.8 °E. It was selected along a climatic and environmental gradient and was characterized in terms of hydrology, geomorphology, soil and vegetation properties, that control or contribute to functioning. Romanian Black Sea shelf is a region of active biogeochemical interactions between land and the deep, interior basin. The north-west part of the Black Sea is a lacustrine coast. All the landmass adjacent to the littoral is lowland steppe while the marine sector

Figure 1. Test site positioning.

and its shores lie within platform structures where the water is shallow and the sea bottom is graded. Lagoon embankments stretch south from the Danube delta. The Razelm, Golovica and Sinoe, lagoons separated from the sea by longshore drift, are relics of the old Danube delta. South of Constantza, onward movement of the sediment is halted by a submarine platform and headlands, while harbor structures and coastal protection have been a bar to sediment transport in this direction. In the southern part of Romania, due to the dearth of river discharge, the coastline suffers abrasion. 10 separate abrasion sectors of coast were identified, of an overall length of 51 km (Y.D. Shuisky1993). The Romanian North-Western Black Sea coast of 247 km length, is representative of sandy coastal environments with long linear beaches boarding a large continental shelf. It is a mixed-energy environment with meso-tidal and long swell influences which is divided in two main sectors: a Northern one delimited by Danube River's Chilia branch and Cap Midia characterized by low level topography, beaches, sandy soils, sand banks and a Southern one delimited by Cap Midia and Vama Veche with high level sea wall (40-60 m) interrupted by beaches nearby lagoons and estuaries. Danube River Delta is placed in the North Western part of Romanian Black Sea coastal zone. The Danube River runs through 2850 kilometers of Central Europe, then splits up into three channels which empty into the Black Sea. The Chilia is currently the major one as well as the Romanian-Moldavian border. The nearly-rectilinear Lower Sulina is in the center, canalized to facilitate navigation, the sinuous Saint-Gheorghe, is strewn with lakes. The delta (5500 km^2), crossed by drainage canals is covered with large areas of reed, agricultural fields, and an exotic forest raised on sandy dunes soil. Danube Delta is a an alluvionary plain region, the average altitude of the delta is of +0,72 m. The area is covered with large areas of reed which are flooded during the early part of the growing season, agricultural fields with wheat and an exotic forest raised on sandy dunes soil. The climate is characterized by medium temperatures and low precipitation. This creates periodic water stress mainly on the polders areas. Although the climatic conditions in the study area can be considered constant, this leads to a large spatial inhomogeneity of surface-moisture conditions (A.S. Bologa et al. 1999; N. P. Nezlin et al. 1999).

A multitemporal and multispectral data set consisting of: Landsat MSS 24/07/1975, Landsat MSS 7/08/1981, Landsat TM 20/08/1989, Landsat TM 20/08/1993, Landsat TM 24/07/1998, and SPOT XS (21/07/1998), ERS-1 SAR data of 27/04/1993, 6/07/1993 and 11/09/1993, MODIS data from 16/09/2002; 12/08/2003, ASTER data 31/05/2003 was used for comparing and mapping landcover change via change detection. Radiometric measurements as ground truth profiles were also used, with Exotech 100 AX provided with Landsat MSS &TM filters and topographic maps (1 : 100000 scale) over the selected areas as well as in situ measurements and laboratory measurements.

3 RESULTS

The methodology involved the integration of data recorded by different satellite sensors, optical and microwave, through newly developed algorithms for land and water changes monitoring as well as to monitor the environmental state of marine and deltaic coastal zone as well as the progress of restoration or of continued degradation. The registration-synergism between the Landsat MSS, TM, SPOT XS, SAR ERS-1 and MODIS, ASTER images was subsequently performed. The use of Landsat TM visible bands 1, 2, 3, (0,452-0,518 μm; 0,528-0,609 μm; 0,626-0,693 μm) allows to represent with good correlation, the chromatic components of the observed area (Ipolliti & Poli 1997). Analogously to the possibility to emphasize spatial and linear structures by filtering in the spatial domain, spectral characteristics of multispectral data have been enhanced by the adaptation of the adequate filters as linear transformation. Two different approaches were used: Principal Component Analysis and Relative Channel Analysis. Thematic maps have been produced to control the parameters under consideration during the study periods.

Local observations were selected on an annual basis and at a similar time of year to minimize the effects of seasonality in the data. In regions where rates of vegetation change are low or less easily detected, observations over 5-year periods were considered. Spectral bands MSS (4, 5) and TM (2, 3) are the best for assessing sediment concentration, while SAR ERS-1 images are very suited for mapping of sea surface features and dynamics (Serban et al. 1996).

3.1 *Coastal zone erosion and changes*

Waves play an important role for shoreline configuration. Wave pattern could induce erosion and sedimentation. Three multitemporal ERS-1 data from 1993 over the selected Black Sea near-shore areas were processed and analyzed. A quasi-linear model was used to model the rate of shoreline changes. The vectors of shoreline were used to compare with wave spectra model in order to exam the accuracy of coastal erosion model. The shoreline rate modeled from vectors data of ERS-1 have a good correlation with a quasi-linear model. Wave refraction patterns are a good index for shoreline erosion. The integration of SAR data is considered as a good tool for investigation of wave effects on shoreline change.

Remote sensing data and in situ measurements performed during the last 28 years over the Romanian seashore of the Black Sea have shown a continuous increase in the advancing speed of sea towards land. Main anthropogenic activities which perturb the natural ecosystem equilibrium are: the building of nonproperly harbour strucures, coastal zone highway constructions, river run-off regulation and beach sediment removal. An active and almost continuous retract of the beach as much as 15-20 m/year is attributed to factors as: decrease in sediment supply, rise in sea level and anthropogenic effects. Such a retreat could have severe economic and environmental impact in deltaic river and marine coastal zones like the Danube river Delta and the Northwestern Black Sea coastal zone at Danube river mouths Chilia, Sulina and Sfantul Gheorghe. Erosive coasts on low-standing plateaus and plains have active cliffs in loess and loess like deposits with very narrow beaches in front of the cliffs. The rates of coastline retreat are less than those of low accumulative beaches averaging 1-2 m/year. The environmental and economic impact is very severe. The coastline changing was analyzed according to the results obtained from different methods comparatively. Essential differences were detected at the Northwestern part of the Black Sea coastline over years (1975-2003) as RGB-PCA 1/2/3. Based on Landsat MSS and Landsat TM data Figure 2 is presenting coastal zone changes and retract over this period. This intensive erosion process is taking place over almost 100 km of the Romanian littoral, over 70 km of which are placed in an area including Danube Delta. An area of about 100 ha is yearly lost, 70% of which is in the Northern part of Cap Midia.

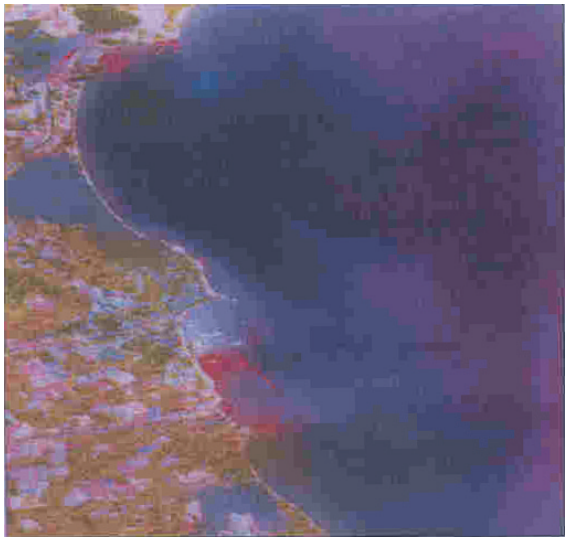

Figure 2. Romanian Black Sea littoral changes during time period of 1975-2003.

As erosion is responsible for almost irreversible consequences on the environmental and economic impact of the Romanian Black Sea coast. It is an urgent task to assess the most efficient actions to minimize the coastal erosion by considering the real value of land and property loss over time, the negative impact on economy in coastal zone (tourism, transportation, harbors, industry, agriculture),

the total costs of building defensive structures and secondary costs associated with implementing the defense structures and the costs for restoring the beaches and coastal zone.

Developments in change detection using compressed multiband image data provide increased flexibility and practicality for systematic change detection on a regional basis. As an indication of land use/cover change, the extension of the road network and the urban areas is compared between 1975 and 2003. Also the change in the position of the coastline is examined and linked to the urban expansion in order to determine if the changes are mainly human induced or natural. A distinction is made between landfill/sedimentation processes on the one hand and dredging/erosion processes on the other. Satellite data and field investigations allowed describing more than 30 classification units and complexes in relation with natural and anthropogenic factors, soils evolution prognosis, ground and surface water characterization in connection with the soil's salinization – desalinization processes.

3.2 *Blooming events*

One of the more dramatic events in the marine and deltaic environment is the red tide. This phenomenon originates as a natural bloom of reddish dinoflagellates, which is exacerbated by nutrient enrichment from non-point pollution. Remote sensing is of interest for direct investigation of bloom phenomena and for indirect indication of nutrient pollution. The qualitative increases in nutrient inputs (domestic, agricultural, and industrial sources) in North Western Black Sea resulted in an increased number, magnitude and areal distribution of phytoplankton blooms. Within the same time interval, increases in the number and areal extent of water column hypoxia and anoxia were observed. It is clear that significant changes in benthic animal populations and the loss of large areas of the benthic habitat for both animals and plants have occurred. Based upon these and many additional ecological indicators of nutrient overloading/eutrophication, was concluded that the eutrophication of the Western shelf of the Black Sea is the single most important ecological problem in the Black Sea. A special interest was focused on using Landsat TM6 for thermal plumes studies in Romanian coastal waters of Black Sea. Thus, MODIS data were used to map the distribution of phytoplankton and quantify their physiological state. Both Danube Delta and North-Western Black Sea coastal zones have been subject to a considerable anthropogenic impact. This led to an increased flux of nutrients, heavy metals, pesticides and hydrocarbons, contributing to massive eutrophication and toxicity in the Danube Delta basin as well as along coastal boundaries of North-Western Black Sea. Figure 3 illustrates a blooming event in the North-Western part of the Black Sea

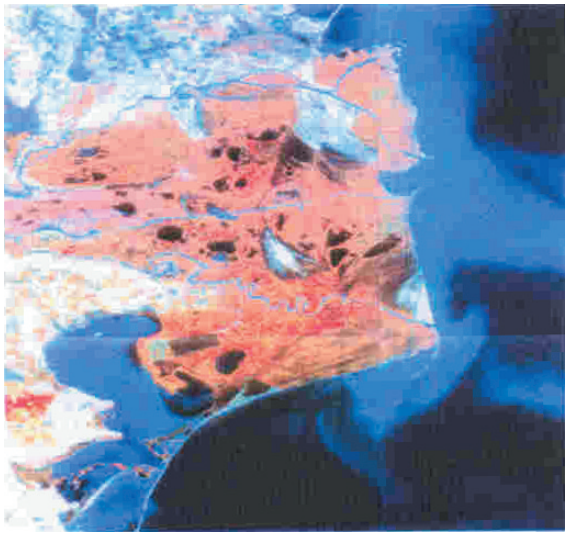

Figure 3. RGB-PCA 1/2/3 Landsat TM 24/07/1998 for North-Western Black Sea and Danube delta areas blooming event.

and Danube delta on a RGB-PCA 1/2/3 Landsat TM image from 24/07/1998. Figure 4 presents a blooming event in the Danube delta on an ASTER image acquired on 15/05/ 2003.

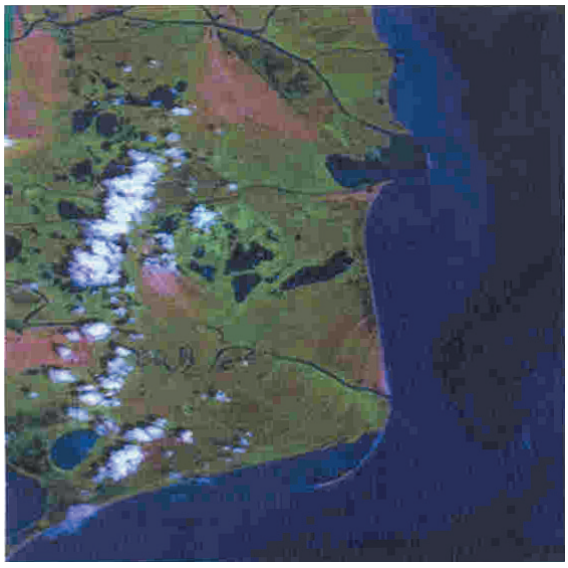

Figure 4. ASTER image for Danube Delta area 31/05/ 2003.

Based on satellite data some test areas in the vicinity of the Danube mouths were analyzed where the nutrient concentration was highest, being assimilated with an expected oxygen depletion, sulfate reduction and methanogenesis in the bottom waters and the superficial sediments. Oil pollution, as a result of accidental and operational discharges in Danube river and through land-based sources continues to threaten Danube Delta ecosystems with severe impact.

3.3 *Turbidity*

The shallow coastal zone of the North-Western part of Black Sea is most impacted by marine pollution, being the area of highest contamination originating from human activities on land, including sewage disposal in rivers and coastal ecosystems, industrial discharges, agriculturally derived nutrients (of nitrogen and phosphorus), heavy metals (toxic elements such as cadmium or mercury, or organotin compounds), persistent organic pollutants, and discharges of radionuclides from coastal nuclear plants. Coastal discharge plumes are often visible on satellite imagery acquired by optical, infrared, and microwave sensors, because they may change the local chlorophyll content, the sea surface temperature (SST), or carry surface-active substances, like hydrocarbons. Suspended sediment and phytoplankton particles in contrast with most dissolved chemicals are very well detected by satellite data. Through scattering and absorption they affect the general clarity of water and hence the optical depth, as well as the color. The simplest methods of suspended particulate material detection are optical measurements via Secchi disk depth. However, fresh water studies indicate that Landsat data and Secchi depth have a correlation coefficient of about 0.9. Due to the frequent success of measuring suspended sediment in both fresh and marine waters using Landsat data, it is widely held that broad intervals of turbidity can be discriminated with Landsat even without calibration. The best wavelengths for passive solar measurement of suspended sediment are between 550 nm and 650 nm; shorter wavelengths introduce greater atmospheric noise, while longer wavelengths suffer high absorption by water restricting data collection to the upper few centimeters of the water column. Table 1 presents the reflectance correlation coefficients for linear simple regression (TSM – Total Suspended Matter, PPO_4 – phosphorous concentration, S – salinity, Chl – Chlorophyll a, OM – organic matter) for Cap Midia area for Landsat MSS (07/08/1981) and TM (24/07/1998) spectral bands respectively MSS4,5,6 and TM1,2,3,4. Salinity is another parameter which is well correlated, too. There is a good correlation between suspended sediments and phosphorous

Table 1. Reflectance correlation coefficients for linear simple regression function of TSM, PPO_4, S, Chl concentrations for Cap Midia on Romanian Black Sea coastal area.

Parameter	R (MSS4)	R (MSS5)	R (MSS6)	R (TM1)	R (TM2)	R (TM3)	R (TM4)
TSM	0.74	0.80	0.83	0.70	0.78	0.85	0.68
PPO_4	0.70	0.82	0.79	0.68	0.74	0.83	0.60
S	–0.58	–0.65	–0.70	–0.40	–0.58	–0.55	–0.45
Chl a	0.64	0.55	0.85	0.59	0.68	0.80	0.89

input in the Cap Midia area, due to the fact that both of these have as main source the polluted waters of the petrochemical industry there. Figure 5 presents the classification of zones with different turbidity level for Romanian Black Sea coastal area on Landsat TM image acquired 24/07/1998. The main conclusions of our analysis showed: phytoplankton bloom development and related harmful phenomena in the Danube watershed (land use, fertilizer utilization, waste water treatments) as well as NW Black Sea coastal zone changes (hydraulic managements of the Danube and Constantza harbor); high level of contaminant sources; a continuous process of the sediment transfer and deposition in the Danube Delta and on the North-Western shelf and an increased pollution in Black Sea waters nearby Capul Midia-Navodari petrochemical industry. The integrated approach to the eutrophication problem of the North Western Black Sea involves the development of an hierarchical system for analysing the data.

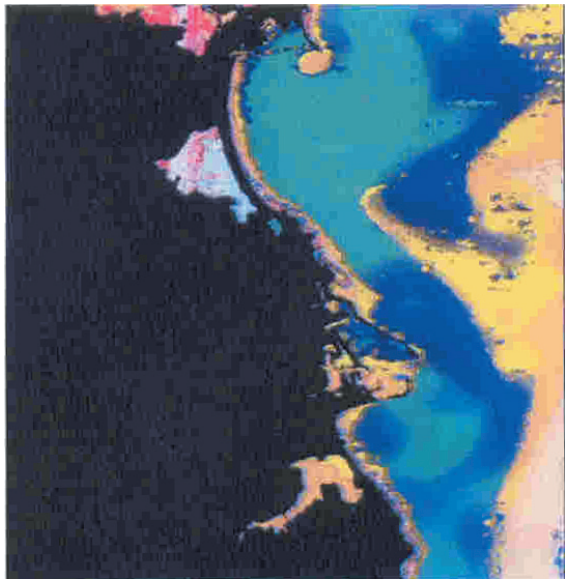

Figure 5. Classification of zones with different turbidity level on Landsat TM image 24/07/1998.

4 CONCLUSIONS

The combination of quasi-simultaneously acquired multi-sensor data is used for a better classification. The low reflectance of water in the infrared bands of SPOT, Landsat MSS, TM, and ETM satellites is very useful to map the extent of surface water. In the case of forested wetlands the extent of flooding will be most efficiently detected on visible and infrared (VIR) imagery. On the other hand, the vegetation cover and composition that can be observed on visible and infrared imagery may provide indirect information about the floodwater boundaries. As open water acts as a specular reflector in the microwave spectrum, Synthetic Aperture Radar (SAR) data are useful for deltaic and flood mapping because of its sensitivity to moisture differences and its potential to penetrate clouds and vegetation. MODIS is able to measure the photosynthetic activity of marine plants

(phytoplankton) by using a unique new band at 683 nm to measure chlorophyll fluorescence. The more plants fluorescence, the less energy they are able to use for photosynthesis. The near-daily coverage of moderate resolution data from MODIS, coupled with the planned increase in high-resolution sampling from Landsat 7, provide a powerful combination of observations for improving marine and deltaic coastal zones monitoring.

Future researches must develop more operational approaches to catchments management through the integration of the computer models, the GIS and high resolution satellite and LIDAR remote sensing data for the functional assessment procedures of marine – deltaic environment.

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