CHARACTERIZATION OF RECENT SEDIMENTS AND EVALUATION OF ENVIRONMENTAL EFFECTS IN THE LAGOON OF NADOR, MOROCCO

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INTRODUCTION

Humid environments are important sites for biodiversity and ecological richness but, at the same time, they are fragile areas, affected by general environmental conditions (Shahidul Islam & Tanaka, 2004; Lloret *et al.*, 2008; Abigail *et al.*, 2009). The increasing human pressure of the last few decades has required new policies and strategies for environmental management, targeted to preserve the characteristics of the wetlands. In this paper, we present the case study of Nador Lagoon in Morocco, the widest lagoon of Mediterranean African coast (115 km^2). The aim of this research is to define the quality of the recent sediment through mineralogy (XRD) and geochemical (XRF) analyses (Di Giuseppe, 2011).

The samples were collected during two different campaigns, in July 2010 and in January 2013; they were superficial sediments (maximum depth 10 cm) gathered along the coast and into the basin. The statistical processing of data (EF Enrichment Factor) has highlighted that the lagoon does not suffer from any particular risk of anthropic contamination, despite the presence of an extended urban area and of the highly developed steel plants of Nador. The geology of the Gourogou volcano (887 m asl), which dominates the north lagoon basin, determines the high content of heavy metals in the sediment: close to the Gourogou, the concentration of heavy metals is generally higher. Moreover, in comparison to the densely populated lagoons of other parts of the world, the concentration of Co, Cr, Cu, Ni, V, and Zn of Nador is within the average. Shells collected during the latter sampling campaign were analyzed by μ-XRF, in order to investigate bioaccumulation phenomena; the resulted spectra did not report any presence of heavy metals.

In addition to the information on the quality of the sediments, the analyses also highlighted the peculiarities related to the movement of the sediments. The samples, collected along an ancient tidal delta in the north, are different both in terms of mineralogy and particle size, suggesting that they do not come from the last stratigraphic surface but from a deeper level and they came to the surface subsequently to an erosive process affecting the area of the sandbar.

Furthermore, data distribution was shown on thematic maps through the use of GIS tool (ArcGis software, version 9.3) and thematic maps were created.

CASE STUDY

The lagoon of Nador (Fig. 1), called Sebka Bou Areg by local people (Guelorget *et al.*, 1987), is a coastal lagoon connected to the Mediterranean Sea by two openings; the oldest (called Bochana) is natural, whereas the other is artificial and it was built between 2011 and 2012 (Raji *et al.*, 2013) in conjunction with the redevelopment of the area called "Marchica Med". The basin is bounded on the NW by the volcanic products of the Gourougou (887 m); on the SE there is the carbonate succession of the Jurassic marine environment of the Kebdana complex (932 m asl) and, between the two massives, it stretches Bou Areg, a plain characterized by outcrops of Miocene-Quaternary deposits of arenaceous-pelitic composition (Mahjoubi *et al.*, 2003; Gilla *et al.*, 2004; Bloundi et al., 2008).

The study area, according to the index of De Martonne 1941 (Quan *et al.*, 2013), is characterized by a semiarid climate Ia 13.2, with dry summers and rainy winters: the daily rainfall average is 2 mm in July and 11 mm in November; the superficial aquifers, inactive for most of the year, are activated by the short and intense rains concerning the area (Bloundi *et al.*, 2009). The climate has the average thermal maximum in August of

26 °C and the minimum in January of 12 °C: the limited interannual variations are due to the thermoregulatory action of the Mediterranean. For the classification of the area, we referred to the data of the last 11 years (www.tutiempo.net); despite the limited amount of data, the statistical analysis led to a plausible thermo-pluviometric characterization.

From a socio-economic point of view, the area has seen an increase in population during the last 50-60 years, especially in the three major cities of the coast: Nador, Beni Enzar, and Kariat, with 132,000, 31,000, and 18,000 inhabitants, respectively (Bloundi *et al.*, 2008). The rapid increase in population was not accompanied by the realization of infrastructures and, most importantly, the lack of appropriate treatment facilities for wastewater entails caused environmental problems.

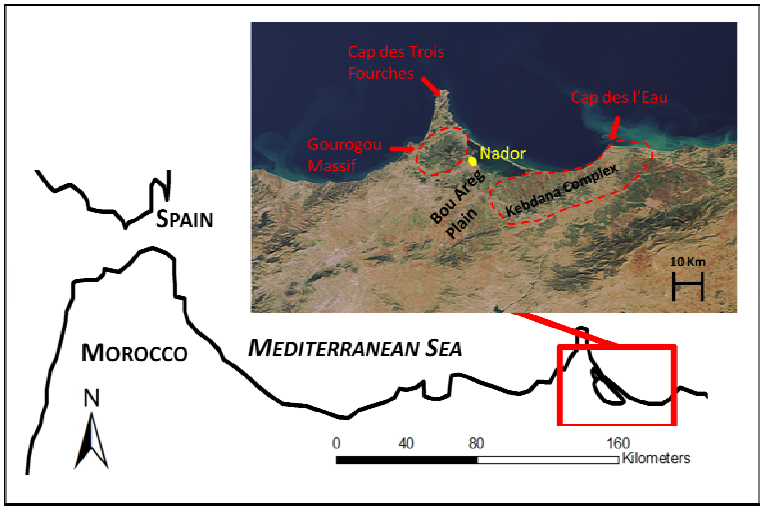

Fig. 1 - Overview of the study area.

The internal flows of the lagoon have low intensity; this factor and the shallow water depth determine insufficient water supply and oxygenation. In the past few decades, the lagoon has been affected by eutrophication problems associated with environmental and hygienic discomforts. For these reasons in 2012 a new channel between the lagoon and the Mediterranean Sea was opened with the aim of improving the water oxygenation (Abouhala *et al.*, 1995).

The most important economic sectors of the area are agriculture (mostly practiced in the Bou Areg Plain), fishery (both traditional fishing and aquaculture), and steel industry, which was once supplied by the iron mines along the banks of Gourogou; currently the raw materials come from the hinterland and from the scraps of the old mines, whose leaching flow directly in the lagoon with high environmental risks (Gonzales *et al.*, 2007; Bloundi *et al.*, 2009).

RESULTS

The particle size of the arenitic phase

Because of the small mass of the sampled materials, it was not possible to carry out detailed analysis about the particle size. The grain sizes corresponding to the arenitic phase were separated by dry sieving with mesh screens. The samples were divided according to the following dominant particle size (Fig. 2): group 1 (0.125- 0.355 mm), group 2 (0.355-0.600 mm; ≤ 40% and poorer in the finer fractions), group 3 (the better classed samples).

Despite the premises, the survey was useful to demonstrate how the sandbar is affected by erosive action: the grain size of N005 and

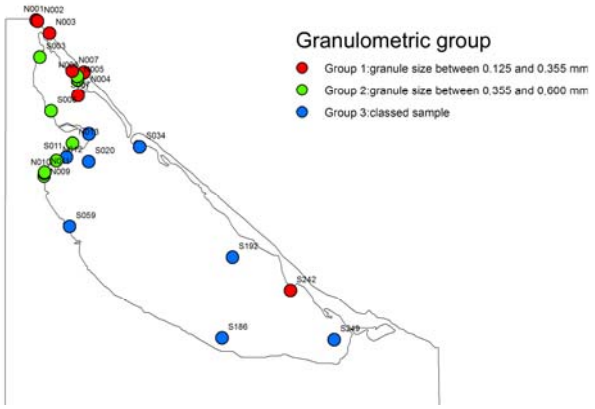

Fig. 2 - Thematic map of the particle size distribution in the Nador lagoon.

N006 is out of range because they were collected in an ancient tidal delta, which currently is in regression because of the erosive action of the currents within the lagoon; then, these two samples come from older stratigraphies than the other of the surroundings. The morphodynamic evolution of the recent years is mainly due to the anthropic factor, influencing the balance of sedimentation with the construction, modification and regimentation of the openings along the sandbar, where most of the currents that affect the sediment depositional regime inside the lagoon pass through (Louaya & Hamoumi, 2011).

Mineralogy

The mineralogical characterization was carried out by X-ray diffraction (XRD) with a Philips PW1860/00 diffractometer, using graphite-filtered Cu*K*α radiation (1.54 Å). Diffraction patterns were collected in the 2θ angular range 3-30 °2θ, with a 6 s/step (0.02 °2θ). Both qualitative and semi-quantitative analyses of the mineral phases were determined by QualX software.

From this study, it was found the presence of three broad groups, on the basis of the dominant mineral species (Fig. 3).

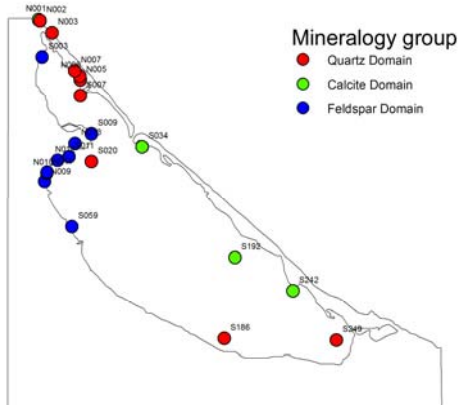

Fig. 3 - Thematic map of the mineralogical groups in the Nador lagoon.

GROUP I (Quartz Domain). These samples are rich in quartz (between 50 and 70%) and calcite (between 10 and 25 %); the mineralogy of these sediments is due to the strong influence of marine sands, since these samples come from the northern area of the sandbar, where most of the ancient tidal deltas are located. One sample was collected near the Bochana (S020) and two on the southern area along the coast.

GROUP II (Calcite Domain). These samples are the richest in calcite, (25-40 %) and they are located in the southern sandbar. The calcite presence is due to the Pleistocenic calcareous facies which constitute this area, and to the biogenic action of the colonies of cyanobacteria.

GROUP III (Feldspar Domain). These samples are the richest in feldspar (17 and 58%). The abundance of feldspar is due to the alteration of the volcanic rocks of the Gourogou. In addition, the samples collected here are rich in oxides (hematite, magnetite) and iron sulfides (pyrite) originating from the scraps from the old mines.

Both granulometry and mineralogy confirm a certain zoning of the sediments, due to the geology and the structure of the lagoon itself.

Geochemistry of sediments

Major and trace elements (Si, Ca, Al, Fe, Mg, K, Na, P, Mn, S, Sr, Ba, V, Zr, Zn, Rb, Cr, La, Cu, Pb, Ni, Nd, Ce, Co, Nb, Sc, Ga, Th, Y, and Hf) were analyzed by X-ray fluorescence (XRF) on powder pellets, using a wavelength-dispersive automated ARL Advant'X spectrometer at the Department of Earth Sciences of the University of Ferrara. As in previous cases, the geochemical data have been revised and studied through the GIS instrument. The data demonstrate that the lagoon is characterized by an internal zoning and that the area close to the Gourogou is more contaminated by heavy metals, with average concentrations of 79, 53, 27, 45, 156 and 124 ppm for Cr, Cu, Ni, Pb, V and Zn, respectively (compared to 44, 30, 21, 28, 94 and 68 ppm of the average value of the sediment of the entire lagoon). However, the data of the lagoon of Nador are consistent with those of other lagoons linked to the same problems of anthropization. In this particular case it was decided to look for comparison to literature data from similar lagoons of different parts of the world, all affected by important anthropogenic impacts (*i.e.*, Bay Moulay, Sidi Moussa, and Oualidia in Morocco; Agiasma, Greece; Berre,

France; Szczecin, Poland; Bohai Bay, China; Goro and Venice in Italy), paying particular attention to the concentration of the most studied heavy metals: Cr, Cu, Ni, Pb, V and Zn (Fig. 4).

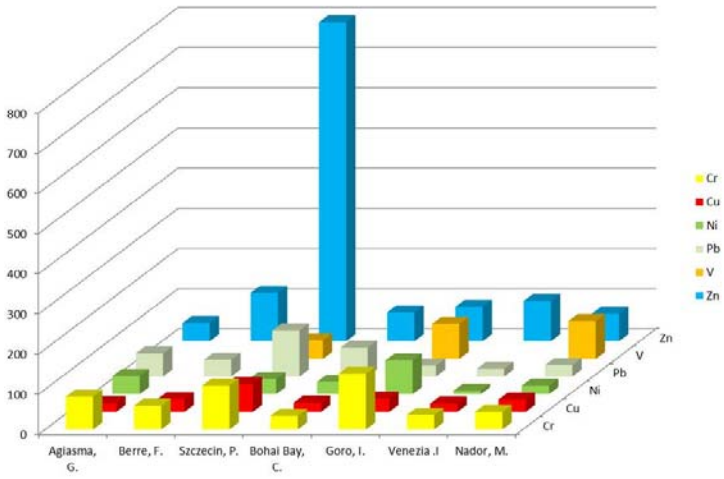

Fig. 4 - Histogram with the average distribution of heavy metals (Cr, Cu, Ni, Pb, V and Zn) in different anthropized lagoons.

Bioaccumulation

We also analyzed the shells of bivalves and gastropods which, despite the limitation of the study of specimens collected *post-mortem* (Zuykov *et al*., 2013), gave positive results. In fact, the analysis, obtained by µXRF Spectrometer Artax Bruker, show no abnormalities for bioaccumulation of heavy metals (Glasby *et al.*, 2004; Szefer *et al.,* 1998), such as Fe, Cr, or Pb, considered adverse to the health of the mollusk (Fig. 5).

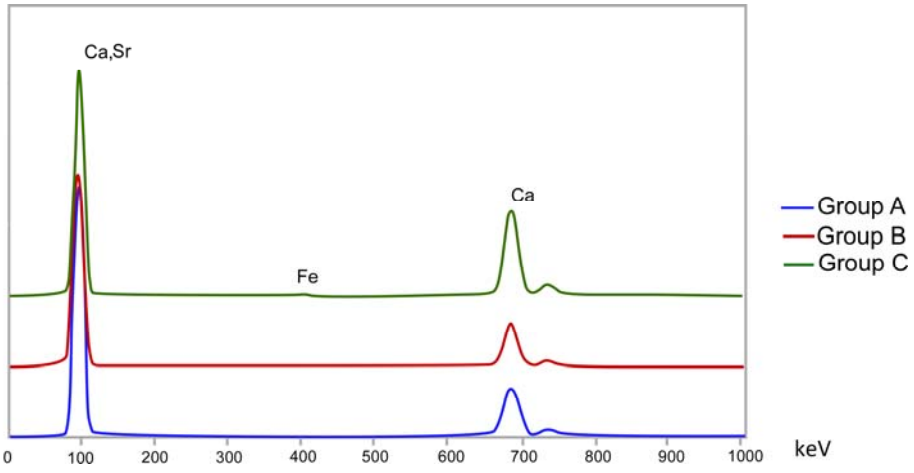

Fig. 5 - Spectrum of the average values obtained by µXRF analyses on shells of mollusks. Group A: Mediterranean beach area; Group B: Coastal Barrier; Group C: Gourogou area.

CONCLUSION

In conclusion, this study outlines how the quality of the bottom sediments of the lagoon of Nador is weakly affected by the increasing anthropogenic pressure at least less than by the intrinsic geochemical characteristics of the local sediment (Bellucci *et al.*, 2003; Bloundi *et al.*, 2009; Gonzales *et al.*, 2007;

Rodriguez-Barroso *et al*., 2009). In general, the geochemical data about the recent sediment of the lagoon show values similar to those of other lagoons and the enrichment factor of heavy metals is due more to the geological and petrographic characteristics of the area than to the anthropogenic pollution.

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