The LCIA Method Applied To Heavy-Metal Contamination: An Assessment of Aquatic Ecotoxicity in a Lagoon Environment

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INTRODUCTION

Coastal environments are often extensively affected by anthropogenic activity, receiving varied pollutants such as heavy metals, mainly via river supply (e.g., Ruiz-Fernandez et al., 2003). Metal bioaccumulation and aquatic toxicity are known to be controlled especially by their speciations in waters: not very water soluble in superficial environments, they mainly remain associated with solid phases, which explains why geochemical studies on heavy metals in lagoon waters are still scarce (e.g., Martin et al., 1994).

Alternatively, controlling environmental quality by collecting data on metal contents of varied types of waters in order to complete a reliable "aquatic ecotoxicity indicator" data basis becomes a prime objective. The present study reports on a trace metal pollution in lagoon waters and sediments, based on aquatic ecotoxicity score that can be quantified by Life Cycle Impact Assessment (LCIA). This original application is experemented here to evaluate the aquatic ecotoxicity of metals from waters of El Melah lagoon near Slimane in Tunisia.

Evaluation of the metal aquatic ecotoxicity is based here on the determination of Pb, Cu, As, Cd, Cr, Ni in the seawater as a reference, the lagoon waters near and away from the two major contaminants: a wastewater treatment plant, and the waters of El Bey creek. The lagoon sediments as another potential source of metal supply by adsorption/desorption were also analyzed. A sequential leaching method was used to identify also the mineral and organic phases that trap temporary the metals (Tessier et al., 1979).

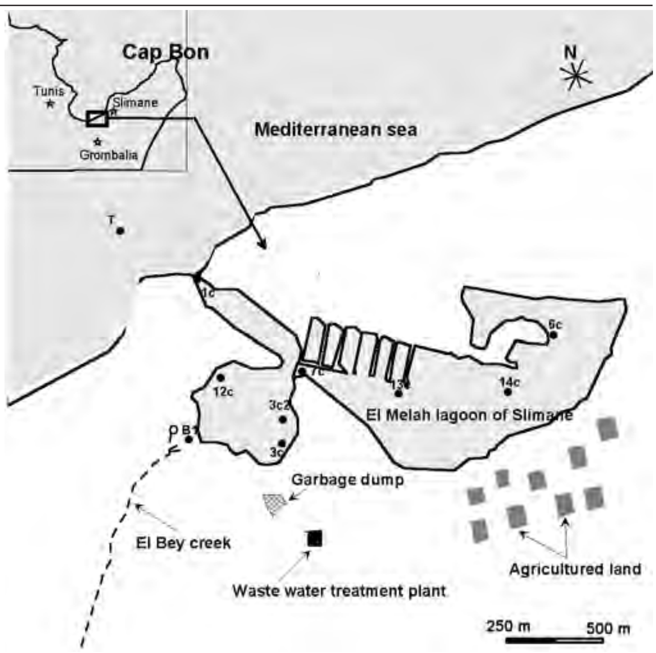

Fig. 1. Location of the El Melah lagoon and of the water sampling stations and of the pollution places around the lagoon (after Hadj Amor et al., 2008).

Major potential pollutants, the nearby solid garbage dump, a fertilized soil and mud from wastewater plant, were also studied.

THE AQUATIC ECOTOXICITY METHOD IN THE LIFE CYCLE IMPACT ASSESSMENT

According to the SETAC-Europe, any study based on the LCIA should include the fate of the substances, as this is an important information in the attempt to reduce the hazardous impact of any type of activity, and consequently to modify the human behavior in the matter. The equation is (Jolliet, 1996):

$$S^m = \sum_i F_i^m \, E_i^m \, M_i^m$$

where m is the medium in which an effect occurs, i is the selected substance, S is the category indicator, F is the fate factor, E is the effect factor and M is the mass emitted. Here, the ecotoxicity score is calculated according to following formula:

$$S_{aquatic} = \sum AEP_i \cdot M_i^w$$

where $S_{aquatic}$ is the aquatic ecotoxicity score (for instance, kg of Zn supplied to water), AEP_i is the aquatic ecotoxicity potential of the substance i supplied to water (kg Zn/kg substance).

SAMPLING AND ANALYTICAL METHODS

The El Melah lagoon is a coastal, exoreic lagoon located to the East of the town of Slimane (Tunisia); its surface is of 225 ha and its average depth of 0.5

palabras clave: método LCIA, ecotoxicología acuática ***key words:*** LCIA method, aquatic ecotoxicity

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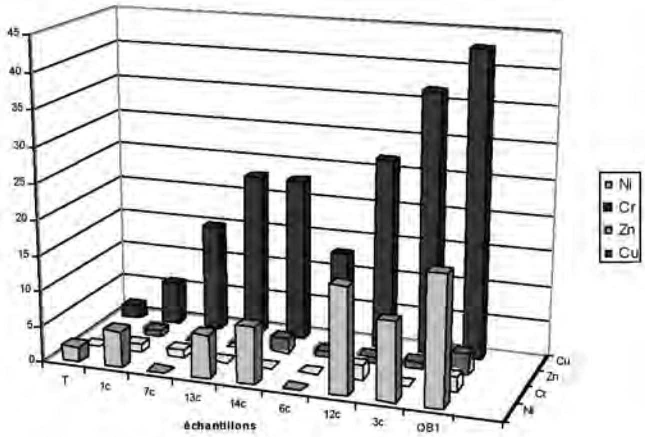

Fig. 2. Ni, Cr, Zn and Cu contents of the lagoon waters. The sample identification corresponds to the locations in figure 1

m, and it connects with the Mediterranean Sea through an 8-m large artificial grau (*Fig. 1*). It is polluted by diverse anthropogenic sources, such as the rejections of a wastewater plant, a solid-garbage deposit, fertilizers used in agriculture, and varied industrial wastes carried by the El Bey creek, which catchment area is about 464 km^2.

Water samples were collected during the 2004 and 2005 summers at 9 stations in the lagoon: next to the opening to the sea, next to the waste fluxes, and in a somewhat protected zone behind the construction of a road on cement cylinders. Two additional samples were collected on the seaside, close and far from grau. The samples were collected in 1L polyethylene bottles, acidified with supra-pure HNO_3 right after collection, and frozen until analysis of the heavy metals. The analytical uncertainty of the metals are 4 µg/l for Fe, 0.6 µg/l for Zn, 0.01 µg/l for Cd, 0.05 µg/l for Cu, 0.1 µg/l for Ni, 0.06 µg/l for Pb, 0.02 µg/l for Co, and 0.1 µg/l for As.

The bottom sediments of the lagoon and the El Bey creek were collected at the same locations as the waters. The leachates and residues of the sequential extraction were determined with an analytical uncertainty of ± 5 % by repetitive measurement of standards.

RESULTS

The concentrations of the metals in the lagoon waters are generally high in the “polluted” areas (samples 3c, 3c2, 12c and O Bey I) and low in the far marine sample (T) and in that from the lagoon outlet (1c) (*Fig. 1*). The creek water (O Bey I) yields high concentrations of Cr, As and Ni. The concentrations of Zn are highest near the wastewater plant (3c). The sample 12c yields a metal distribution close to that of the creek water. The sample 3c2 has the highest Mn content. The isolated part of the lagoon (7c, 13c, 14c and 6c) yields intermediate metal contents between those of the polluted area and of the open sea.

The sediments of marine influence (10c and 1C) contain less metals distributed as Cu>Cr>Ni>Zn>Co. In the lagoon away from sea influence, the metals follow a slightly different trend: Cr>Zn>Ni>Co>Cu. In the highly polluted part of the lagoon, the contents follow almost the same trend: Cr>Zn>Ni>Cu>Co, except for the El Bey water in which Zn is dominant. The two dominant metals of the creek sediments are Zn and Cr, with the lower Zn amounts (<20 µg/g) in the upper course of the creek, and the highest (80 µg/g) at the lower.

The three reference samples representing the dumping garbage, the agricultural soil and the residual mud from wastewater plant point to the mud to be the most enriched in metals with 500 µg/g Zn, while the garbage and the soils contain 200 µg/g Zn and 100 µg/g Cu.

THE AQUATIC ECOTOXICITY POTENTIAL

The Aquatic Ecotoxicity Potential calculated for the selected metals shows that Cu, Cd and Pb are potentially the most ecotoxic for the lagoon waters. In 2004, Cu and Pb provided the highest aquatic score of ecotoxicity (*Fig. 2*). In 2005, all the scores were lower, except for Ar and Ni. The contribution of El Bey creek in metals, especially in Pb, Cu, Cr and Ni, is higher than that of the wastewater plant. The amount of the available metals in the sediments was estimated from water-soluble fraction and from exchangeable fraction (Filgueiras et al., 2002). According to the sequential metal extraction, the contribution of the lagoon sediments to these scores shows that Cu and Ni are mainly released by water leaching, which is of concern. These metals are labile and may, therefore, be potentially bio-available. Cu is also the most exchangeable metal fraction adsorbed on the particle surfaces by electrostatic interaction; it can be released by ion-exchange processes.

In summary, Cu and Ni represent the most mobile metals in the El Melah lagoon, being readily available and contributing potentially to its aquatic ecotoxicity. The other metals were found to be less mobile: they are more strongly associated to the sediment fractions, which makes that they are relatively stable under normal conditions.

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