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Assessment of heavy metals and arsenic contamination in the sediments of the Moulouya River and the Hassan II Dam downstream of the abandoned mine Zeïda (High Moulouya, Morocco)

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ABSTRACT

To evaluate the sediment contamination level near the abandoned (PbZn) mine Zeïda, heavy metal concentrations were determined in sediment samples from the Moulouya River, the Ansegmir tributary and the Hassan II Dam located downstream of the abandoned mine. These samples were analysed for their geochemical properties: mineralogy by XRD, carbonate content, pH, particle size and the total concentrations of Pb, Zn, As and Cu elements by ICP-AES. The assessment of the sediment pollution extent was performed by using the multiple pollution indices: contamination factor (CF), pollution load index (PLI) and the geoaccumulation index (I_{geo}). The Highest CF values (>6) of Pb that have been observed downstream of the tailings promote a high Pb contamination in that specific area. The PLIs results showed that all stations, except for those upstream of the tailings and on the Hassan II Dam, have been found moderately to highly contaminated. The I_{geo} results confirmed the Pb high contamination but also the extreme As contamination. The potential ecological risk factor results and the comparison with the sediment quality guidelines revealed that the Pb and As levels are potentially toxic to the sediment-dwelling organisms. Based on the multivariate statistical analysis results and the spatial distribution of the sediment contamination level, the pollution of Pb and As have different sources. Pb contamination is located exclusively near and downstream of the tailings. These latter's may be considered as an important point source of Pb into the Moulouya River. The As contamination is derived from a larger scale input sources which can be related to anthropogenic and/or lithogenic effects.

1. Introduction

The excessive amounts of heavy metals in aquatic systems is mainly related to the past and ongoing mining activities (Silva et al., 2009; Ghrefat et al., 2011; Varol, 2011; Varol and Şen, 2012; Othmani et al., 2015). In developing countries including Morocco, mining wastes are often abandoned on sites due to the absence of post-mining site rehabilitation. Mining wastes have different environmental impacts depending on its amount, their physico-chemical properties and the storage methods (Silva et al., 2009). Tailings are easily eroded and usually contain high metal concentrations. These metals can be dispersed as particle-bound and/or aqueous solutions (Audry, 2003). This threatens the inhabitant's health and the ecosystems near the pollution sources (Jung, 2001). Acid mine drainage (AMD) is the most serious environmental mining impact (Younger, 1995); acidic water is formed under oxidizing conditions as a result of sulphide minerals oxidation process (Bussière et al., 2005; 2009). This acidity can be buffered with the presence of some particular minerals, such as carbonates and silicates, considered as the main neutralization minerals (Lapakko, 1994). Due to this process, the levels of heavy metal in water would be decreased by precipitation into sediments at high pH level (Prusty et al., 1994). The sediments contribute to transportation, mobilization and redistribution of contaminants in the environment (Csavina et al., 2012). Heavy metals can be absorbed by suspended materials, then greatly accumulated in sediments (Prusty et al., 1994; Blanquet et al., 2004) but they are not permanently stored and could be released in response to the

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environmental condition changes (James, 1978; Wen and Allen, 1999). The factors of pH, silicate and clay fractions, exchangeable carbonate fractions and alkalinity influence the sorption of heavy metals (Serpaud et al., 1994; Alloway and Ayres 1997; USEPA, 2005).

Heavy metal contamination of sediments is often assessed by determining the total metals content; the metal levels variations along the stream may point out different metal input sources (Pagnanelli et al., 2004). The potential hazard of the measured concentrations on the environment is widely assessed using different pollution indices and multivariate statistical technics (Varol, 2011; Kalender and Uçar, 2013; Equeenuddin et al., 2013; Tang et al., 2015).

The High Moulouya region is the main Pb deposits in the western part of Morocco. It has been an important exploitation area for many decades. Various geological outcrops of different ages are exposed in the High Moulouya (Fig. 1a), from the metamorphic schist and granites Palaeozoic basement exhumed during the Hercynian orogeny (Laville et al., 1991) to the quaternary cover which is mainly formed by sandstones and clays (Naji, 2004). The Pb mineralization at Zeïda is stratiform. It is hosted in sandstones and Triassic arkoses and consisted mainly by cerussite mineral ($PbCO_3$) (Mouttaqi et al., 2011). The Zeïda mine that has been active from 1972 to 1985 provided 630.373 tons of concentrated Pb at 40–70%. Quarrying was the main operating method in the Zeïda mine while the ore beneficiation was performed on site by gravimetric and flotation procedures. These practices left around 12 Mt of tailings and more than 70 Mt of waste rock stripping abandoned without any rehabilitation (D.M, 1990). Previous reports have classified the Zeïda mining district as an important contamination source (El Hachimi et al., 2005; Iavazzo et al., 2012).

The aim of this study is to discuss the spatial evolution of metal river sediments content toward the Hassan II Dam and to assess the contamination of sediments using the following methods: 1- contamination indices: pollution load index (PLI), geoaccumulation index (I_{geo}) and potential ecological risk index (E^i_r), 2- comparison with sediment quality guidelines (SQGs) limit values, 3- statistical analysis.

2. Study area

The High Moulouya Valley, located in the western part of the Oranaise Meseta, is limited north by the Middle Atlas and south by the High Atlas folded chains (Piqué and Michard, 1989). The High Moulouya valley is characterised by a semi-arid climate with low annual average temperatures (12–14 °C), low precipitations (<350 mm/year) and strong winds reaching a top speed of 50 m/s.

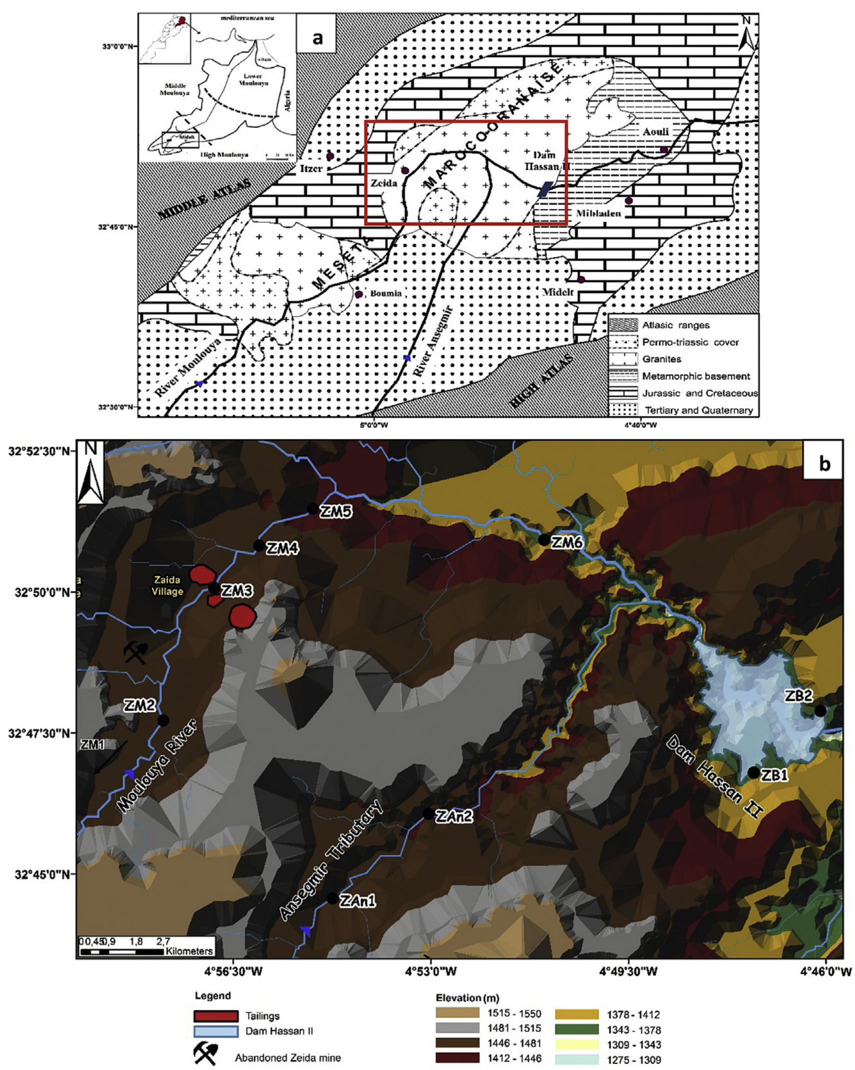

Fig. 1. a. Geological map with the location of the study area (Red rectangle); b. Location of tailings and sampling sites.