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Assessment of trace metal and rare earth elements contamination in rivers around abandoned and active mine areas. The case of Lubumbashi River and Tshamilemba Canal, Katanga, Democratic Republic of the Congo

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ABSTRACT

Active and abandoned mine activities constitute the sources of deterioration of water and soil quality in many parts of the world, particularly in the African Copperbelt regions. The accumulation in soils and the release of toxic substances into the aquatic ecosystem can lead to water resources pollution and may place aquatic organisms and human health at risk. In this study, the impact of past mining activity (i.e., abandoned mine) on aquatic ecosystems has been studied using ICP-MS analysis for trace metals and Rare Earth Elements (REE) in sediment samples from Lubumbashi River (RL) and Tshamilemba Canal (CT), Katanga, Democratic Republic of the Congo (DRC). Soil samples from surrounding CT were collected to evaluate trace metal and REE concentrations and their spatial distribution. The extent of trace metal contamination compared to the background area was assessed by Enrichment Factor (EF) and Geoaccumulation Index (I_{geo}). Additionally, the trace metal concentrations probable effect levels (PELs) for their potential environmental impact was achieved by comparing the trace metal concentrations in the sediment/soil samples with the Sediment Quality Guidelines (SQGs). Spearman's Rank-order correlation was used to identify the source and origin of contaminants. The results highlighted high concentrations of trace metals in surface sediments of CT reaching the values of 40152, 15586, 610, 10322, 60704 and 15152 mg kg^{-1} for Cu, Co, Zn, Pb, Fe and Mn, respectively. In the RL, the concentrations reached the values of 24093, 2046, 5463, 3340, 68290 and 769 mg kg^{-1} for Cu, Co, Zn, Pb, Fe and Mn, respectively. The ΣREE varied from 66 to 218 and 142–331 mg kg^{-1} for CT and RL, respectively. The soil samples are characterized by variable levels of trace metals. The EF analysis showed "extremely severe enrichment" for Cu and Co. However, no enrichment was observed for REE. Except for Mo, Th, U, Eu, Mo, Ho and Tm for which Igeo is classified as "moderately polluted and/or unpolluted", all elements in different sites are classified in the

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class 6, "extremely polluted". The trace metal concentrations in all sampling sites largely exceeded the SQGs and the PELs for the Protection of Aquatic Life recommendation. Cu and Co had positive correlation coefficient values ($r = 0.741$, $P < 0.05$, $n = 14$). This research presents useful tools for the evaluation of water contamination in abandoned and active mining areas.

1. Introduction

The deterioration of freshwater resources is essentially due to the important discharge of untreated industrial effluents, agricultural and urban runoffs, mining wastewaters, uncontrolled urban landfills, improperly processed hospital effluents and domestic wastewaters which in turn pose tremendous effects and health risk to populations and environment consumers (Atibu et al., 2013; Brayner et al., 2001; Devarajan et al., 2015; Förstner and Wittmann, 1979; Pardos et al., 2004; Schwarzenbach et al., 2006). The pollution of rivers, lakes and reservoirs by different types of contaminants including heavy metals, hydrophobic organic compounds and pathogenic organisms constitutes a major environmental concern in many parts of the world and a major threat for the world's freshwater resources (Haller et al., 2011; Mubedi et al., 2013; Poté et al., 2008; Thevenon et al., 2011a; Thevenon and Poté, 2012; Vörösmarty et al., 2010). In mining areas, for example the African Copperbelt regions such as Katanga, DRC and Zambia, the industrial wastes, local geochemical structure and mining effluent waters represent major sources of heavy metals and radioactive elements contamination of aquatic environments, including water and sediment compartments (Atibu et al., 2013; Banza et al., 2009; Cheyns et al., 2014; Kambole, 2003; Mees et al., 2013). On the one hand, the mining activities and artisanal mineral exploitation can cause dramatic metal contamination of surface waters, sediments, groundwater, soils and biota; and can also negatively affect local environment and water resources through both freshwater withdrawal and pollution from mine water discharge (Concas et al., 2006; Liu et al., 2011). Additionally, the abandoned mine activities have produced vast quantities of waste-rock dumps containing low-grade ore and tailings in several regions of the world and continue to pose potential or real threat to human health and environmental damage (Ferreira da Silva et al., 2004; Silva et al., 2014).

Many regions in DRC, especially in the provinces of Katanga, Maniema and Kivu, rivers and soils are under serious threat of degradation resulting from regular discharge of polluted effluents streaming from mineral industries, mining and artisanal exploitation activities, and pollution of air as a result of factory emanations and from the dusts raised by the active and abandoned mine activities. In relation to mining activities in these regions, mainly in Katanga, many studies have been conducted to evaluate the aspects related to environmental and human health exposure to metals (mainly Co and Cu) in Katanga mining areas (Atibu et al., 2013; Banza et al., 2009; Cheyns et al., 2014; Katemo Manda et al., 2010; Mees et al., 2013). However, there is not much information regarding the effects of abandoned mines as well as mining effluents on the distribution of trace metals and Rare Earth Elements (REE) in soils and sediments in Lubumbashi River (RL) and Tshamilemba Canal (CT). These rivers are used for several human activities including, bathing, industrial wastes and urban sewage, urban agricultural for fresh produces and several other domestic uses. According to studies mentioned above, RL, CT and abandoned mines and mining activities can cause damages related to the quality of groundwater, sediment and surface water located in the Lubumbashi Region. The assessment of sediment quality of these rivers can offer the opportunity for reconstructing the pollution history and mainly for evaluating the human and environmental impacts (Haller et al., 2011; Poté et al., 2008; Thevenon et al., 2011a; Thevenon et al., 2011b). The main environmental and human risks are the remobilization of the contaminants from sediment to water column, infiltration into the groundwater, their accumulation in aquatic living organisms or vegetables and their return to the human chain food (Ngelinkoto et al., 2014; Wildi et al., 2004).

The objective of this research is to assess the effects of abandoned and active mining activities on the sediment/soil quality of Lubumbashi River and Tshamilemba Canal receiving systems. This assessment is based on (i) the characterization of sediments/soils in respect to grain-size and total organic matter, (ii) quantification of trace metals (and metalloids) and REE including Sc, Ti, V, Cr, Co, Ni, Cu, Fe, Mn, Zn, As, Cd, Pb, Mo, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Th and U in sediment samples, and (iii) evaluation of sediment contamination based on probable effect levels (PELs), enrichment factor (EF) and Geoaccumulation Index (*Igeo*) estimation.

2. Materials and methods

2.1. Site description

This study was performed in the Copperbelt province of Katanga (Lubumbashi City), Democratic Republic of the Congo, Central Africa (Fig. 1 and Table 1). This province is well known for several abandoned mines, intensive mining activities and artisanal mineral exploitations that have intensified over the last decades. The geological aspects and the detailed mining activities of the province had been performed by several studies (e.g. Banza et al., 2009; Cheyns et al., 2014; Mees et al., 2013; Tshamala, 2008). Lubumbashi is located at the average altitude of 1230 m, on the tray along the Lubumbashi River (RL). Dismissals of slagheap scoria from pyrometallurgy exploitation of Gamines (GCM, the ex-factories), were made from 1924 to 1992. The size of this slagheap is considered as one of the biggest in the world. The composition of this slagheap can be subdivided in three different exploitation phases. The first phase (from 1924 to 1931) led to the formation of the slagheap heart. It is due essentially to treatments of oxidized ores from Lubumbashi surroundings. The second phase (from 1931 to 1970) led to the formation of the intermediate part. This phase contain the cupro-zincifereses sulphurized ores from the mining of Kipushi. The third and last phases (from 1970 to 1992) were performed to the formation of the outside envelope. It is composed with mixed cupro-cobaltifereses ores from Kolwezi city. The slagheap treatment society of Lubumbashi (STL) is reprocessing the scoria using pyro-metallurgy process to extract the cobalt. Subproducts such as copper, lead, zinc, nickel, silver, iron and sometimes, gold are also obtained (Tshamala, 2008).

2.2. Sample collection

The sediment sampling took place in May 2015, representing the end of rainy season with low water flow rate in Tshamilemba Canal (CT) and Lubumbashi River (RL). The samples from CT ($n = 10$) are labelled as CT01SO, CT02SO, CT04SO, CT05SO, CT08SO for the