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Evaluation of potentially toxic element pollution in the benthic sediments of the water bodies of the city of Addis Ababa, Ethiopia

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ABSTRACT

The concentrations of toxic and potentially toxic elements (As, V, Cr, Fe, Co, Ni, Cu, B, Ba, Sr, Zn, Mn, Pb and Cd) collected from benthic sediments in the water bodies of the city of Addis Ababa were investigated to evaluate their distribution and pollution levels. The average concentration of Cr, Mn, Pb, Ni, Fe, Cu, Zn and Cd exceeded the threshold effect level of the sediment quality guidelines. Many of the concentrations were higher than previously reported. The sediments were moderately to heavily polluted with Cr, non-polluted to severe with Cu, Zn and Pb elements, moderate to heavily polluted with Ni and non-polluted by As and Cd. The sediments were enriched with these elements in the increasing order As < Ba < V < Ni < Cu < Cd < Co < Zn < Mn < Pb < Cr. The geo-accumulation index values for Pb, Cu, Cr and Mn indicate that at some sites unpolluted to strongly polluted. The first three principal components represented about 79% of the total variance in the sediment data sets. The significant positive correlation between elements indicates their common anthropogenic origin most likely from industrial effluents, municipal wastes and domestic wastewater inputs to the river. Since the polluted environment significantly impacts the beneficial uses of the water body and has health implication, remedial actions (e.g. capping or removal of the sediments) need to be considered. A comprehensive environmental management strategy should be formulated to address the pollution of the sediments. In parallel, there should be a strict prohibition of discharges of contaminated wastewater into the river.

1. Introduction

Aquatic ecosystems are the main recipient of toxic trace element pollution from various sources such as industrial wastewater, domestic effluents, urban surface water runoff, landfill leachate, discharges through natural resources, mining of coal and ore, agricultural practices, geological formation and weathering [1–3]. Toxic and potentially toxic elements can be present in amounts several times higher than natural background concentrations and pollute water bodies and sediments and impact aquatic organisms [4]. Many potentially toxic elements are readily absorbed by sediments, and only small amounts get dissolved in water. These contaminants are of concern due to their potential toxicity to aquatic organisms and human beings [5–7] at certain concentrations. The toxicity, bioavailability and reactivity of many trace elements such as arsenic and chromium depend on their chemical speciation [8]. The contamination of sediment by potentially toxic elements is a serious ecological problem, since elements such as Hg, As, Pb, Sb, Ni, Sr and Cd are toxic even at low concentrations. Though some elements such as Cu, Fe, Mn and Zn are essential as micronutrients for living organisms, they can be detrimental to their physiology at higher concentrations [5,9].

Addis Ababa city with a population of approximately 5 million, hosts a large number of industries whose wastewaters are discharged into the small river network, most often untreated. Accordingly, old as well as new factories, commercial, public and domestic utilities in Addis Ababa release untreated wastes into nearby rivers and streams. The common pollutants include toxic and potentially toxic heavy metals and metalloids, oils, detergents, solvents, pesticides, nitrates, phosphates, sulfates and chlorides [7,10,11]. Because of industrial, economic businesses and other development the Little Akaki River is one of the most polluted rivers in the Ethiopia. Kebede et al. [12] studied some freshwater bodies in Ethiopia and found that the concentration of Cr, Mn, Co, Ni, Ag, Hg and Pb were generally elevated because of the disposal of domestic and factory wastes. Melaku et al. [10] reported that the

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potentially toxic elements pollution levels in the bottom sediments of the Little Akaki River and some of its tributaries are alarming due to mainly industrial activities, and disposal of domestic and municipal wastes. Later, Aschale et al. [7] determined the concentrations of potentially toxic elements in the water of the Little Akaki River in Addis Ababa and the results indicated that the concentrations of Cr, Mn, Sb, B, Fe, Sr, Zn, Cu and Pb exceeded the permissible limits in drinking water guidelines [13] and the levels of Cr, Mn and Sr in most water samples surpassed irrigation water guideline limits [14]. Even though the Little Akaki River is considered as the most polluted river in Ethiopia, very little information exists regarding the levels of potentially toxic elements in its sediments. Therefore, the objective of this work was to quantify the levels of Sr, As, V, Cr, Mn, Fe, Co, Ni, Cu, B, Ba, Zn and Cd in the sediment and to apply multivariate statistical analysis to identify relationships between potentially toxic elements.

2. Materials and methods

2.1. Study area

Addis Ababa, Ethiopia, the nation's capital and largest city, lies high in the foothills of Mount Entoto in central Ethiopia. It is geographically located at 9°N and 38°E between 2200 and 2500 m above sea level. It is the country's commercial, manufacturing and cultural center. Geologically, Addis Ababa lies on volcanic rocks varying in composition and structure from rhyolitic to basaltic types. The major stratigraphic units are composed of rhyolitic, trachytic, basaltic and trachy-basaltic lava flows and welded tuffs found in different localities and ages [15]. The two major rivers in the city are the Little Akaki River, locally known as Tinishu Akaki River, which flows through the western part of the city and Big Akaki River, locally known as Tiliku Akaki River, which flows through the eastern part of the city (Fig. 1). Most of the industries are established along the course of the river and its major tributaries. These include leather/tanneries, food and beverages, wood works, textiles, pharmaceutical, wineries, battery and paints, rubber and plastic products, non-metal and metal products, paper and printing products whose wastewaters are discharged into the small river network, most often untreated. At the same time the river is used for irrigation, washing, livestock watering and other domestic needs by the rural people living in downstream locations.

2.2. Reagents and standard solutions

All chemicals used were of analytical grade. High-purity water (18.2 MΩ/cm) from a Milli-Q water purification system (Millipore, France), concentrated nitric acid (BDH, England), 30% H_2O_2 (BDH, France) and argon of 99.999% purity were used. Analytical multi-element standard solutions were prepared by appropriate dilution of single and multi-element standard solutions containing the metal ions of interest supplied commercially for inductively coupled plasma-mass spectrometry (ICP-MS). The Multi-element standard of Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, Ba, V, As, Sr and Co and internal standard solutions of Ge, Sc and Bi were purchased from VLG labs (Manchester, USA). The matrix of all samples, standards, wash solutions and quality control standards were made in a 0.5% HNO_3. San Joaquin soil (SRM, 2709a) obtained from the National Institute of Standards and Technology (Gaithersburg, MD, USA) was used as a reference material. The analysis of the sediment samples was carried out using ICP-MS (ELAN DRC-e ICP Mass Spectrometer Axial Field Technology, PerkinElmer SCIEX, Concord, Ontario, Canada) in the laboratory of Inland Fisheries Ireland in Dublin, Ireland.

2.3. Sediment sampling and preparation

The location of the sampling sites and details of each is given in Fig. 1 and Table 1, respectively. Composite samples which are

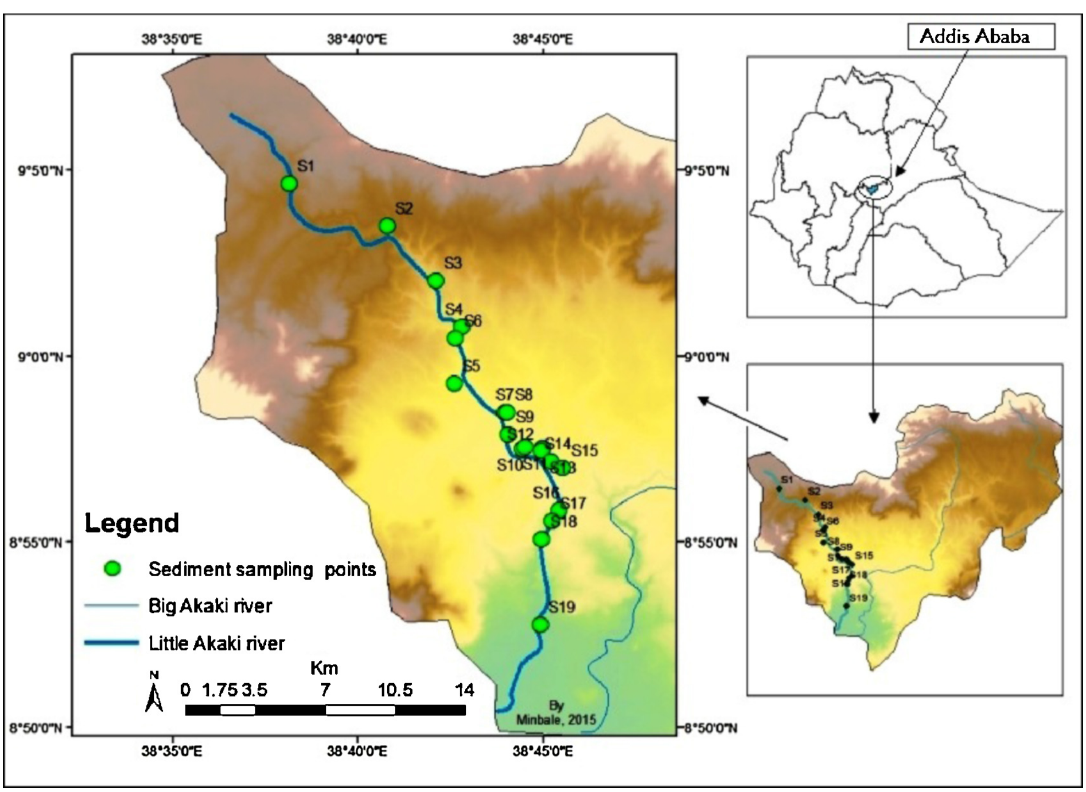

Fig. 1. Sampling sites of the studied sediment along Akaki River in Addis Ababa.