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The geochemical signature of rare-metal pegmatites in the Central Africa Region: Soils, plants, water and stream sediments in the Gatumba tin–tantalum mining district, Rwanda

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ABSTRACT

We studied trace elements in soils, plants, water and stream sediments in the Gisuma–Kibilira catchment of the Gatumba area of western Rwanda which has a long tradition of artisanal to small-scale tin–tantalum mining from rare-metal pegmatites. The geochemical fingerprint of soil, plant, water (springs and surface water in dry and rainy seasons) and stream sediment samples reveals elevated concentrations of Li, Rb, Cr, and Cs, but low As and U abundances at or below the global average. Trace element contents of soils and most plant materials are below internationally accepted guideline values. All water samples analyzed meet the World Health Organization (WHO) drinking water guidelines, and the stream sediments are below critical values of Dutch environmental standards. These data provide a baseline for environmental impact studies for rare-metal mining projects in the Central Africa Region.

1. Introduction

There are numerous sources of trace elements in soils, plants, stream sediments and waters. Trace elements in naturally occurring soils accumulate during the weathering of rocks and ores that compose geologic parent materials. Background concentrations of trace elements in soils are thus determined by the concentrations in the underlying parent materials. Most trace elements in soils exhibit strong adsorption by clays. However, under certain conditions, small portions become soluble. Among the factors that determine trace element solubility and bioavailability are pH, cation exchange capacity (CEC), anion exchange capacity (AEC), soil organic matter (SOM) content, clay content and quality, oxide content and type, and redox potential (Adriano, 1986; Gregor, 2004). Humans cause accumulation of trace elements in soils from different sources. They have been added to soils from atmospheric deposition, by land application of (in)organic fertilizers and pesticides, and are common in industrial goods, as components of paints, as a constituent of industrial waste or by mining activities.

Toxic elements in soils, with residence times of up to thousands of years, pose numerous health hazards to higher organisms. They are known to affect plant growth and have a negative impact on soil microflora (Castaldi et al., 2004; Giller et al., 1998; Lasat, 2002; McGrath et al., 2001). In view of the health risks posed by metals entering the food chain, the elements Ag, Cr, Sn and Ti may pose little risk because owing to their low solubility in soil, uptake and translocation by plants may be negligible (McLaughlin et al., 1999). Elevated concentrations of these elements in foods usually indicate direct contamination by soil or dust. The elements As, Hg and Pb are strongly sorbed by soil colloids. While they may be absorbed by plant roots, they are not readily translocated to aboveground plant tissues and therefore pose risks to human health only when root vegetables are grown on contaminated sites. In contrast, elements such as Cd, Cu, Mn, Ni and Zn are readily taken up by plants (McLaughlin et al., 1999).

A significant relationship exists between the presence of toxic elements and the incidence of serious human diseases (Lottermoser, 2007; Magbagbeola and Oyeleke, 2003). Toxic elements are known to be persistent in the human body, with excretion half-lives that last for decades and can lead to a wide range of toxic effects (Järup et al., 2000; Putila and Guo, 2011; Thomas et al., 2009; Tong et al., 2000).

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Mining of ores has drastically increased the prevalence and occurrence of toxic elements, through mine drainage, discharge of mine or processing waste, tailings dam failures and remobilization from mining-contaminated floodplains (Hongyu et al., 2005; Osher et al., 2006). Toxic elements originating from mining activities have been widely found in various environmental media, including soil, water, air and food products (Nadal et al., 2005). Sites affected through mining waste disposal are considered specific areas that require environmental risk assessment including metal toxicity monitoring, especially for land reclamation and recultivation for agriculture.

The Great Lakes region of Central Africa hosts one of the major tantalum–tin ore provinces of the world (Pohl, 1994). Rwanda has hundreds of mostly small-sized deposits of tantalum, tin, tungsten, and gold (Pohl et al., 2013). The minerals are mainly extracted via artisanal (small-scale) mining. Tin occurs as cassiterite [SnO_2] and tantalum as tantalite [$(Fe,Mn)(Ta > Nb)_2O_6$], commonly referred to as coltan. The tin–tantalum mineralization is related to granite pegmatites (e.g. Varlamoff, 1954, 1972) of the rare-metal lithium–cesium–tantalum (LCT) class (Cerny and Ercit, 2005).

We studied the environmental impact of coltan mining in the Gatumba area of western Rwanda which has a history of about 80 years of artisanal and semi-industrial tin–tantalum mining. Specifically, we tested soils, spring and stream waters, stream sediments and vegetation for a number of environmentally relevant elements (including As, U, base metals) from the Gisuma–Kibilira catchment within the Gatumba mining district. As the local population in the Gatumba mining district lives directly on what is cultivated on farmland in and adjacent to coltan mines and consumes untreated water from springs, the aims of this study were to systematically investigate the trace element status of i) soils (total amounts in different soil units and horizons) under direct, indirect, and no mining influence, ii) plants (vegetable, fruit, animal feed and wild plants) currently growing on the respective sites, and iii) spring water, stream water and stream sediments from sampling sites homogeneously distributed over the study area. As western Rwanda has dry and rainy seasons, we also tested whether the seasonality had an influence on the trace element status of soils, plants, water and stream sediments. The results are important to clarify if there is any toxic element enrichment in this mining area, and may also provide a baseline for environmental impact studies for other coltan mining areas in Central Africa.

2. Material and methods

2.1. Study area and sampling sites

The Gisuma–Kibilira catchment has an area of approximately 20 km^2 (Fig. 1). It is located in the Muhororo Sector of the Ngororero District (western part of the Central Plateau of Rwanda, ca. 50 km west of Kigali), between the longitudes 29°37′ and 29°40′ E and the latitudes 1°53′ and 1°56′ S. The altitudes range from 1600 to 2100 m AMSL and the annual mean temperature is about 19 °C (Verdoodt and van Ranst, 2003). The Ruhanga tin–tantalum mine is located in the upper part of the catchment where water is transported via a network of small artificial canals for the typical mining method of the region, i.e. ground sluicing. The Gisuma joins the Kibilira in the middle of the catchment after approximately 3 km (Fig. 1). Gisuma and Kibilira are relatively small streams with no more than 2 m and 4 m, respectively, in width, and, except after heavy rain falls, not deeper than 30 cm. To the west of Gatumba, mountains rise to the Congo–Nile watershed divide at around 3000 m altitude. The study area is part of an east-dipping flank of a

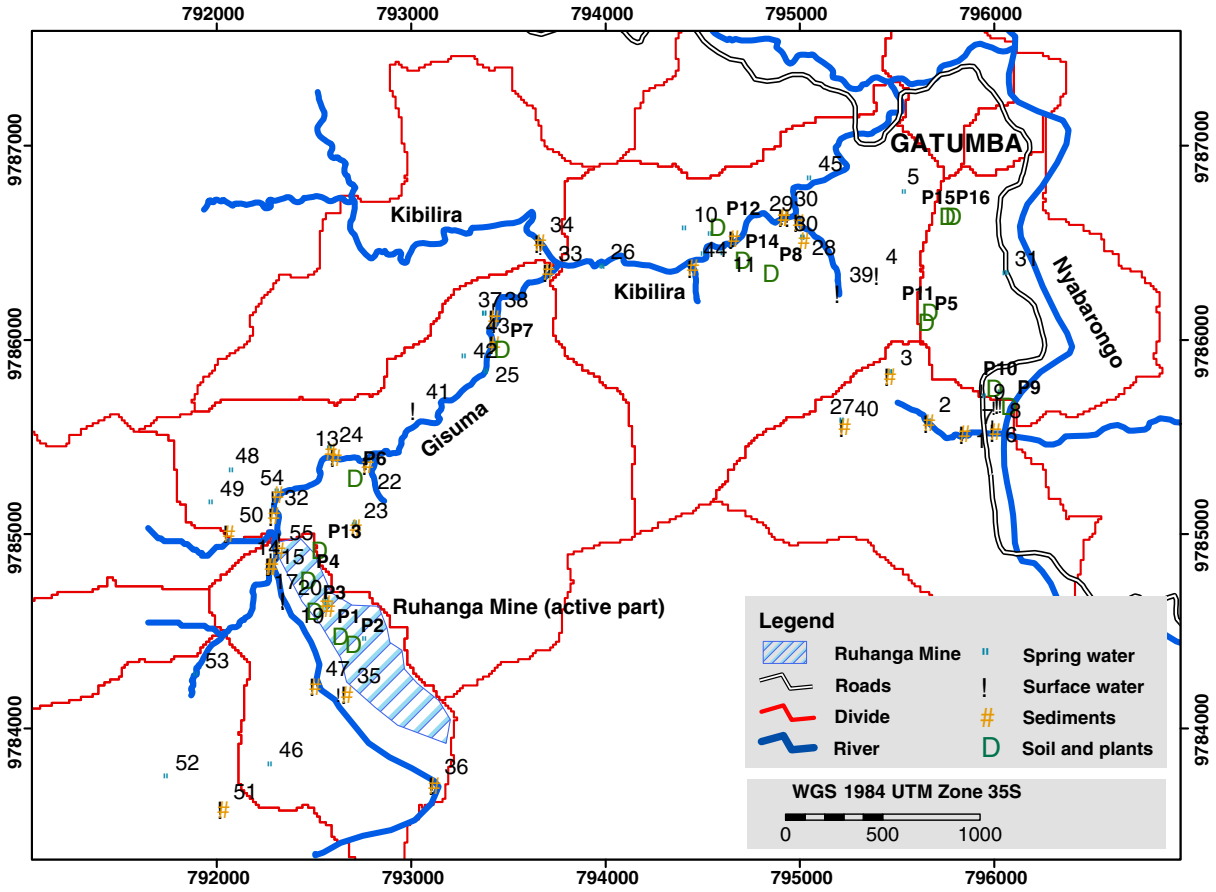

Fig. 1. Soil, plant, water and stream sediment sampling sites in the Gisuma–Kibilira catchment of the Gatumba Mining District, Rwanda.