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Impact of terrestrial mining and intensive agriculture in pollution of estuarine surface sediments: Spatial distribution of trace metals in the Gulf of Urabá, Colombia

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ABSTRACT

The Gulf of Urabá (northwestern Colombia) is a geostrategic region, rich in biodiversity and natural resources. Its economy is mainly based on agribusinesses and mining activities. In this research is determined the impact of these activities in bottom surface sediments of the estuary. Thus, grain size, total organic carbon, total nitrogen, carbonates, Ag, Al, Ca, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb and Zn concentrations from 17 surface sediment samples were obtained and enrichment factors (EF) as well as geo-accumulation indices (Igeo) were calculated to determine the contamination level in the gulf. EF and Igeo values revealed that the estuary is extremely contaminated with Ag and moderately contaminated with Zn. Therefore, the observed enrichment of Ag may be explained as a residue of the extraction of gold and platinum-group metals and the enrichment with Zn associated mainly to pesticides used in banana plantations.

1. Introduction

Heavy metals are of particular concern worldwide due to their environmental persistence, biogeochemical recycling and ecological risks (Gonzalez-Macias et al., 2006; Nobi et al., 2010). Marine sediments are the ultimate reservoir for heavy metals in the coastal environments (Santos et al., 2005; Sin et al., 2001). Thus, contamination of estuarine sediments by trace elements is a worldwide problem, acting as sinks and sources of contaminants (Houda et al., 2011; Nasrabadi et al., 2010; Uba et al., 2009).

The spatial distribution of heavy metals in marine sediments is usually the result of both natural (i.e., parental rock weathering and climate) and anthropogenic factors (i.e., industrial wastewater, transportation, agriculture) (Morillo et al., 2004). As metal concentrations in marine sediments increase, more heavy metals will return to water bodies via chemical and biological processes (Sin et al., 2001). It is therefore essential to distinguish between natural and human sources on the accumulation of heavy metals in marine sediments.

In Colombia, most of the studies regarding mercury pollution have been focused on the gold mining (Alvarez et al., 2012a, 2012b; Cordy et al., 2011; Marrugo-Negrete et al., 2008; Olivero et al., 2002; Olivero and Solano, 1998), Mercury amalgamation process is widely used in the Urabá region (NW of Colombia) in the gold and silver mining because of the convenience, simplicity, fast results and low operating costs. Mining activities happen in the region since the Spanish colonization (Leyva, 1993) and they were intensively increased in the last century. In fact, Colombia was the largest supplier of platinum in the world market from 1916 to 1926, when its price was exceptionally high, mostly mined by the *Chocó Pacífico Mining Company* in the Condoto River, Department of Chocó located in the left side of the Gulf of Urabá (Leal León, 2009). Currently, mining continue to be the main economic activity of this Department.

Mining is responsible for soil degradation and forest clearing at a rate of approximately 3–4 ha yr-1. Artisanal mining processes (locally known as "*entables*") significantly alter the landscape and cause air, soil and water pollution. On average, each *entable* remove between 2000 and 3000 tons yr^{-1} of sediments, employs approximately 35 kg yr^{-1} of mercury, generates 1249 l yr^{-1} of waste oil, and modifies the morphology of river beds. *Entables* are also associated with forced migration and loss of biodiversity, destruction of fragile ecosystems and the development of endemic diseases (Cújar-Couttín, 2005; Ponce Muriel, 2005). Additionally, during ore processing is produced inputs of mercury, cooper and silver to the rivers and coastal environments.

The semi-closed coastal area of the Gulf of Urabá (Fig. 1) is an estuary rich in natural resources, with a wide diversity of ecosystems (such

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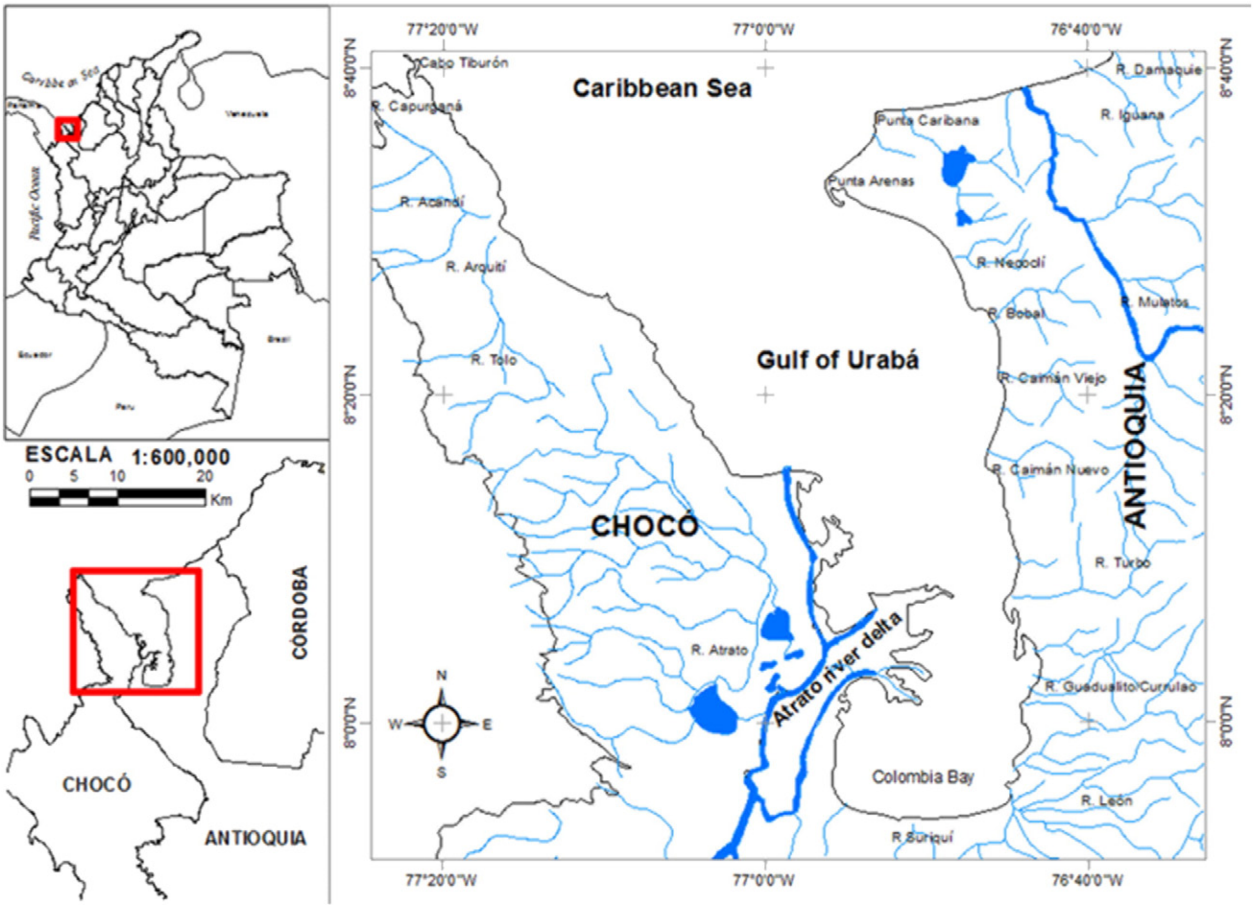

Fig. 1. Study area.

as mangroves and coastal lagoons) that are highly productive, breeding many aquatic resources that are the subject of artisanal and industrial fishery (Zamora and García Valencia, 2007).

In the western side of the gulf flows the Atrato River, which crosses the Chocó region that is one of the main areas devoted to gold mining in Colombia (Díaz and Gómez, 2000) carrying with all the pollutants derived from this process.

Moreover, in the eastern side of the gulf flow several small rivers: León River receiving the input of pollutants coming from the banana plantations, which play a very important role in the economy of the region; Turbo River supplying contamination due to both urban sewage and banana plantations too; and Caiman River, carrying the contaminants associated to extensive cattle raising activities (Garay et al., 2001; Zamora and García Valencia, 2007). The input of sediments and pollutants coming from these rivers are later modulated by the estuarine circulation in the gulf.

This study assesses the impact of mining and intensive agriculture activities in the Gulf of Urabá, by the analysis of trace metals concentration in their bottom surface sediments, considering not only the relationship with this activities, but also the locations of the inputs of pollutants, the circulation patterns and the grain size distribution of sediments. This approach will help to evaluate the impact of human activities and the potential ecological risks of trace metals on coastal areas as the result of to combine anthropogenic forcing and oceanographic processes.

2. Study area

The Gulf of Urabá is located on the southern Caribbean Sea, between latitudes 7°54′N–8°40′N and longitudes 76°53′W–77°23′W, with a total length of 80 km (Fig. 1). It has a maximum width of 48.5 km and an average depth of 25 m (Garcia Valencia and Sierra Correa, 2007). The Gulf of Urabá is characterized by a muddy bottom due to the strong sediment loads supplied by rivers (Chevillot et al., 1993).

In its southwestern flank flows out the Atrato River, which is considered one of the greatest in the world according to its ratio between water discharge and basin area, with a length of 650 km, and discharges in average 81.08 km^3 $year^{-1}$ of water and 11.3×10^6 t $year^{-1}$ of sediments, being the second one with more sediments supply into the Caribbean Sea (Restrepo and Kjerfve, 2000).

The Atrato River has formed a delta of approximately 400 km^2 that currently isolates the southern part of the gulf known as Colombia Bay, which maintains communication with the rest of the Gulf through a 5.9 km passage at its narrow-gauge (Velásquez, 2005).

Besides Atrato River, there are others important rivers in the eastern margin, such as León River in the inner southeastern, flowing into Colombia Bay and discharging in average 2.01 km^3 $year^{-1}$ of water and 7.7×10^5 t $year^{-1}$ of sediments (Restrepo and Kjerfve, 2000), Caimán Viejo, Caimán Nuevo and Turbo River which have a lesser water flow, but may have a local influence especially in coastal geomorphology (Álvarez Láinez, 2008; Alvarez Laínez and Bernal Franco, 2007; Bernal Franco et al., 2005a; Correa, 1992).

The dynamics of the gulf is mainly influenced by solid and liquid discharges from tributaries, winds, waves, tides, and density gradients (Escobar, 2011; Lonin and Vasquez, 2005; Montoya, 2010). These factors are different during the dry (December to April) and rainy (May to November) seasons, which occur in the area as a response of the latitudinal migration of the Intertropical Convergence Zone (Hastenrath, 1990).

Marine circulation in the Gulf of Urabá follows a complex circulation pattern, comprising simultaneously typical estuarine circulation, one- to three-layer flows, and even inverse circulation. (Escobar et al., 2015) (Fig. 2).