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Baseline

Metal concentrations in the beach sediments of Bahia Solano and Nuquí along the Pacific coast of Chocó, Colombia: A baseline study

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ABSTRACT

Thirty sediment samples from four different beaches along Bahia Solano and Nuquí (Department of Chocó) of eastern Colombia, with tourism and gold mining activities, were analysed to estimate the concentrations of fourteen different acid leachable metals. Metal distribution patterns showed elevated concentrations of Co, Cr, Cu, Pb and Zn compared with the upper continental crust values. Calculation of geochemical indices confirmed that the enrichment is due to periodic gold mining activities (severe to extremely severe enrichment of Cu, Zn, V, Co, Cr and Pb) along with natural (geological) contributions (minor and moderate enrichment of Ca, Mg, Fe, Ti, Mn and Li). Potential ecological risk index revealed that Pb posed the highest risk. Our results together with a global comparison suggest that the observed metal enrichments are mainly caused by mining and to a lesser extent by tourism in this region, thus instigating continuous monitoring of metal concentrations in this region.

Tourism is considered as one of the biggest global industries with beaches hosting free plays and people as potential revenue partners. Beach tourism results in large economic benefits, thereby increasing the demand for new construction of high rise buildings, resorts, cottages and recreation parks at beaches (Propín-Frejomil and Sánchez Crispín, 2007; Faggi and Dadon, 2011; Pérez-Maqueo et al., 2017). The impact of tourism invasion has often led to the disposal of various contaminants, thereby causing serious concerns to coastal ecosystem (Vikas and Dwarakish, 2015; Wang et al., 2016). Metals are one among the most toxic contaminants that have received considerable attention on global scale owing to their close relationship with human health (Chopra and Pathak, 2015; Ye et al., 2015; Ramachandra et al., 2018). They enter the coastal waters through various natural (weathering and erosion) and anthropogenic (mining, waste disposal, agricultural and industrial activities) sources, wherein they do not remain in soluble form for a long time and have a tendency to deposit in sediments (Xu et al., 2016; El Nemr et al., 2016). Therefore, sediments, being the potential storehouse of metals, are the best tools to assess the contamination status of a given aquatic ecosystem.

In the recent years, our research group has been exploring this storehouse with the vision of generating baseline data for understanding metal enrichments in various beaches located worldwide. We succeeded in generating a database for popular tourist destinations such as Mexico (Acapulco, Huatulco and Santa Rosalía), India (Chennai), South Africa (Richards Bay, South Durban, Sodwana Bay and St Lucia) and Malaysia (Miri), which have different geological characteristics. Acid leachable technique was effectively adopted as the fundamental method to determine metal concentrations for evaluating the potential environmental and ecotoxicological impacts in beach regions.

In this context, our vision now focuses on Columbia, where beach tourism symbolises one of the most important revenue income. During the period of 2009–2011, nearly 974,721 international (mostly from the U.S.A., Canada and the European Union) and 3,411,523 domestic tourists visited the coastal areas of Colombia (PROEXPORT - Ministerio de Comercio, Industria y Turismo, 2011). The capacity of rapid growth of this sector in the coming decades will bring economic strength to this region. Among diverse coastal regions, Chocó in Colombia is characterised with a unique ecosystem and unexploited natural resources. The richness of Chocó's landscape and its enormous biodiversity make this region quite overwhelming. It is the only region of Colombia that is lapped by the waves of two oceans: the Pacific and the Caribbean. In

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particular, the coast of Bahia Solano and Nuquí forms the economic and touristic corridor of Chocó. It offers plethora of activities such as scuba diving and sport fishing. This tourist capital of the Pacific coast of Colombia attracts a large number of visitors to explore the marine life, beaches and deep jungles with all the natural biodiversity that is different from other local destinations. Its additional economy relies on artisanal fisheries, agriculture and timber extraction (Matallana, 1999; Avila et al., 2008). Mining has precedented this region since the Spanish colonisation (Leyva, 1993). Numerous studies have focused on massive and uncontrolled gold mining activities in Chocó (Vallejo Toro et al., 2016; Gutiérrez-Mosquera et al., 2017; Salazar-Camacho et al., 2017; Palacios-Torres et al., 2018) and in adjacent regions (Olivero et al., 2002; Marrugo-Negrete et al., 2008; Cordy et al., 2011; Alvarez et al., 2012a, 2012b). Given this scenario, we ask whether the intense economic development associated with tourism, urban sprawl and mining are driving any geochemical changes to the beaches of Bahia Solano and Nuquí. On this background, the framework of this study involves the evaluation of metal concentrations in beach sediments along Bahia Solano and Nuquí to comprehend the natural and external (human-induced) impacts on the marine ecosystem.

This investigation was carried out on a ~200-km-long coastal strip of Bahia Solano and Nuquí in Chocó department of eastern Colombia (6°19′9.40″N/77°22′41.20″W and 5°36′28.20″N/77°26′28.40″W). A total of thirty sediment samples were collected from different beaches during May 2016. Based on sample collection, the coastal stretch was categorised into four different regions, wherein 1 and 2 belong to the municipality of Bahia Solano, and 3 and 4 belong to Nuquí municipality: 1) Mutis beaches (S. Nos. 1–13), 2) El Valle beaches (S. Nos. 14–21), 3) Nuquí beaches (S. Nos. 22–26) and 4) Coqui beaches (S. Nos. 27–30) (Fig. 1). Region 1 hosts a port for cargo boats and passenger transportation services and stores trading provisions (materials and timber). Region 2 has a "*fishing village*" at the mouth of the Rio Valle, where fertile breeding ground results in abundant fishing activities. Region 3 is characterised with mosaic ecosystems such as hot springs, rivers and beaches. It also contains a protective coastal marine environment (*i.e.* Utría National Natural Park) with humpback whales and sea turtle nests. Region 4 hosts the best-preserved mangroves of Colombia and offers excellent ecotourism. The geology of all the four regions comprises tholeiitic basalt, dolerite, basic tuff and volcanic breccia of the late cretaceous, limestone, sandstone and calcareous mudstone of the Oligocene-Miocene, alluvial deposits of the Quaternary and gravel, and sand and mud rich in organic materials of the Holocene (Gómez Tapias and Almanza Meléndez, 2015).

Sediment samples were collected from the intertidal zone using a plastic spatula and placed in clean polythene bags. The collected samples were then transported to the laboratory and oven dried below 40 °C. Coning and quartering methods were applied to obtain a homogenous part of the sample, and the sample was powdered using an agate mortar for further analyses. Approximately 1 g of the sample was digested according to the modified EPA 3051A method (2007) and as described by Navarrete-López et al. (2012) using 2.5 ml of HNO_3, 0.8 ml of HCl and 1 ml of H_2O_2 acids (all analytical grade) in a closed vessel, which was made of a resistant material Poly(tetrafluoroethylene) (PFA) at 119 ± 1.5 °C for 40 min. The final solution was made up to 10 ml after filtration and analysed for concentrations of fourteen metals (Al, Fe, Mg, Ca, Ti, Co, Cr, Cu, Mn, Pb, Zn, V, Sr and Li) using an inductively coupled plasma optical emission spectrometer (ICP-OES 8300 PerkinElmer). Standard reference materials namely SRM No. 691029, Loam soil B and Marine Reference Standard (SRM 2702 – Inorganics in marine sediment) were run along with the samples. The recoveries were as follows: Al 97.89% (± 1.62 $\mu g\ g^{-1}$), Fe 98.82% (± 1.72 $\mu g\ g^{-1}$), Mg 110.88% (± 1.30 $\mu g\ g^{-1}$), Ca 98.01% (± 1.65 $\mu g\ g^{-1}$), Ti 97.39% (± 2.50 $\mu g\ g^{-1}$), Co 101.39% (± 3.10 $\mu g\ g^{-1}$), Cr 102.35% (± 2.10 $\mu g\ g^{-1}$), Cu 101.66% (± 3.20 $\mu g\ g^{-1}$), Mn 92.70% (± 0.08 $\mu g\ g^{-1}$), Pb 111.07% (± 2.81 $\mu g\ g^{-1}$), Zn 95.93% (± 1.10 $\mu g\ g^{-1}$), V 106.01% (± 1.55 $\mu g\ g^{-1}$), Sr 105.46% (± 2.10 $\mu g\ g^{-1}$) and Li 110.42% (± 1.05 $\mu g\ g^{-1}$). The detection limits for the analysed metals were Al 0.01%, Fe 0.01%, Mg 0.01%, Ca 0.01%, Ti 0.01%, Co 1 ppm, Cr 2 ppm, Cu 1 ppm, Mn 1 ppm, Pb 2 ppm, Zn 1 ppm, V 1 ppm, Sr 1 ppm and Li 0.0001–1%.

The distribution pattern of analysed metals is presented in Fig. 2 a–n. The descending order of metal concentrations (all values in $\mu g\ g^{-1}$) in all the four regions is as follows: 1) Mutis beach: Fe (34,111) > Ca (9871) > Al (8846) > Mg (6494) > Ti (1699) > Pb (391) > Mn (372) > Cr (239) > V (176) > Zn (125) > Co (108) > Sr (49) > Cu (44) > Li (15); 2) El Valle beach: Fe (34,581) > Al (16,839) > Mg (15,070) > Ca (6152) > Ti (801) > Mn (556) > Pb (399) > Cr (279) > V (143) > Zn (127) > Co (111) > Cu (85) > Sr (51) > Li (30); 3) Nuquí beach: Fe (25,067) > Mg (15,788) > Al (10,684) > Ca (9388) > Ti (1099) > Pb (430) > Mn (416) > Cr (302) > Zn (124) > Co (109) > V (104) > Cu (36) > Sr (28) > Li (17) and 4) Coqui beach: Fe (20,875) > Mg (9661) > Ca (8068) > Al (7735) > Ti (963) > Pb (467) > Cr (309) > Mn (284) > Zn (130) > Co (110) > V (83) > Cu (45) > Sr (30) > Li (16). The above-mentioned array displayed no significant variations in metal concentrations in all the four regions. For a better understanding of the enrichment pattern, metal concentrations were compared with the upper continental crust

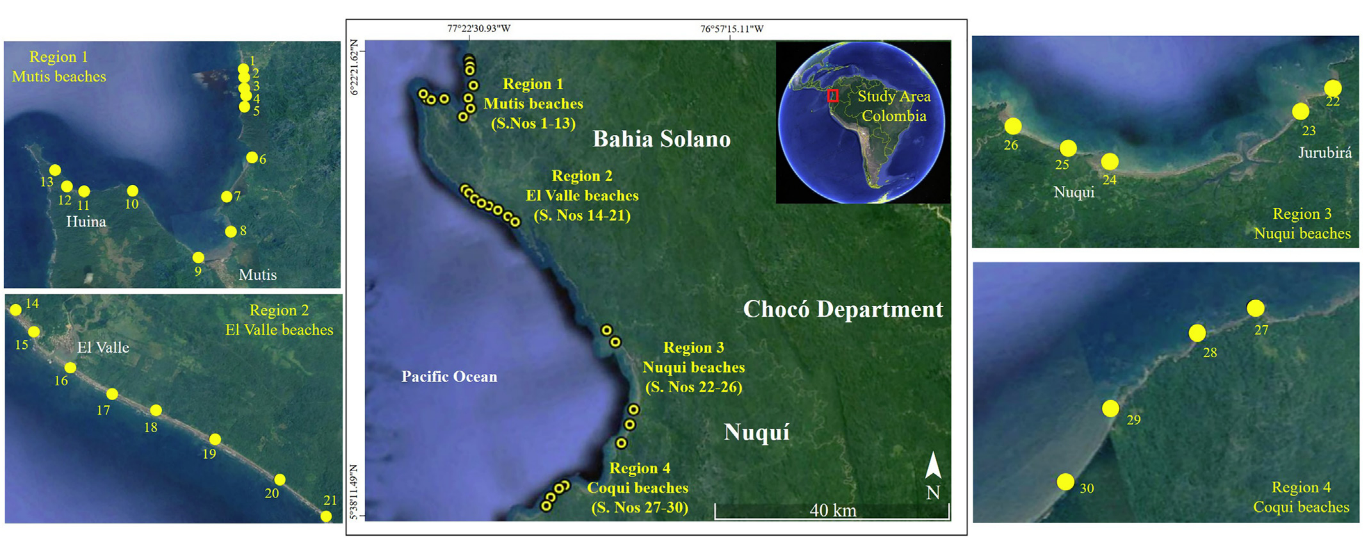

Fig. 1. Locations from which sediments were collected in four different beaches along Bahia Solano and Nuquí, Department of Chocó, Colombia.