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Geochemical characteristics of stream sediments from an urban-volcanic zone, Central Mexico: Natural and man-made inputs

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ABSTRACT

Geochemical characteristics of stream sediments [n = 31; Upstream section: Zahuapan River (1–12) and Atoyac River (13–20); Downstream section (21–31)] from Atoyac River basin of Central Mexico have been evaluated. The study focuses on the textural, petrography and chemical composition of the fluvial sediments with the aim of analyzing their provenance, the chemical weathering signature and their potential environmental effects. The fluvial sediments are mostly composed of sand and silt sized particles dominated by plagioclase, pyroxenes, amphiboles, K-feldspar, biotite, opaque and quartz. The sediments were analyzed for determination of major (Al, Fe, Ca, Mg, Na, K, P, Si, Ti), trace elements (As, Ba, Be, Co, Cr, Cu, Mo, Mn, Ni, Pb, Sc, V, Y, Zn, Zr, Ga) and compared with Upper continental crust (UCC), source area composition and local background values. The elemental concentrations were comparable with the average andesite and dacitic composition of the source area and the local background values except for enrichment of Cu (56.27 ppm), Pb (34 ppm) and Zn (235.64 ppm) in the downstream sediments suggesting a significant external influence (anthropogenic). The fluvial sediments of Atoyac River basin display low CIA and PIA values implying predominantly weak to moderate weathering conditions in the source region. Based on the provenance discrimination diagrams and elemental ratios, it is understood that the collected sediments are derived from intermediate to felsic volcanic rocks dominated in the study region. Metal contamination indices highlight the enrichment of Cu, Pb, Zn, Mo, Cr and S clearly indicating the influences from natural (weathering and volcanic activity) and external (anthropogenic) sources. Ecological risk assessment results indicate that Cr, Ni and Zn will cause adverse biological effects to the riverine environment.

1. Introduction

Fluvial systems are the most important dynamic systems, wherein their interaction with continental crust causes constant recycling of the materials of the Earth's crust. In that, rivers are the prime carrier of sedimentary materials from continents to the oceans, which result from continental denudation *i.e.*, the synergetic action of rock weathering and erosion. The deposited sediments preserve the imprints of all the processes in the passage from source to the sink. The geochemical composition of deposited stream sediments provide important information about their origins and can be therefore used to infer weathering trends, provenance of the sediment, depositional environment and sources of pollution in the region (Calvert et al., 2001; Glasby et al., 2004; Naimo et al., 2005; Wei et al., 2006; Liu et al., 2013).

Geochemical compositions of the fluvial sediments reveal the average composition of an entire drainage basin (Young et al., 2013). It is well-known that chemical weathering exerts a major control on sediment composition strongly affecting the elemental geochemistry and mineralogy of sediments (Johnsson and Meade, 1990; Van Loon and Mange, 2007; Schneider et al., 2016), where larger cations (Al_2O_3, Ba, Rb) remain fixed in the weathering profile

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preferentially over smaller cations (Ca, Na, Sr) which are selectively leached (Nesbitt et al., 1980). These geochemical signatures are ultimately retained in the sediments thus inferring the provenance as well as the source area weathering conditions (e.g., Nesbitt and Young, 1982; Bhatia, 1983; Wronkiewicz and Condie, 1987; Cullers et al., 1988; Feng and Kerrich, 1990; Fedo et al., 1996; Armstrong-Altrin et al., 2015; Nagarajan et al., 2014).

Atoyac River, a major river of south-central Mexico flowing through states of Tlaxcala and Puebla is delimited by tectonic features like Volcano Iztaccíhuatl, Popocatépetl (active) in the western side, and Volcano Malinche in the eastern side. The research area has witnessed potential industrial (textile, petrochemicals, rubber etc.) and economic development favoring a demographic growth of 154.6% during the last two decades (INEGI, 2010). It is one of the most contaminated rivers of the country (CONAGUA, 2010) influenced by the natural volcanic inputs in addition with wastewater discharges from urban, agriculture and industrial zones. The fluvial sediments of Atoyac River basin provides an opportunity to gain knowledge about the influence of different processes on sediment chemistry, which is used as a proxy in interpretation of provenance, weathering conditions, source rock characteristics and sources of pollution in this river basin.

We present in this paper the texture, petrography, major and trace element composition of sediments to reveal the provenance, weathering conditions and source rock characteristics. In addition, geochemical indices such as enrichment factor (EF), geoaccumulation index (I_{geo}), pollution load index (PLI) and ecological risk assessment have been calculated to identify any potential environmental effects.

2. Study area description

2.1. Regional setting

The Atoyac River basin, lying between 18°57′02″ N and 98°15′37″ W in Central Mexico, constitutes Zahuapan River and Atoyac River flowing through the rural, urban, agricultural, and industrial regions of Tlaxcala and Puebla City, where it finally drains into the Manuel Ávila Camacho dam (Fig. 1). This basin has an extension of 4395 km^2, flanked by volcanoes Iztaccíhuatl and Popocatépetl (active) in the western side and volcano Malinche in the eastern side. Zahuapan River is fed by the runoff from Sierra de Tlaxco in the north and several minor channels originating from inland waters and the La Malinche volcano. Atoyac River originates from the Sierra Nevada de Toluca as a result of snow melt on the northern rim of Iztaccíhuatl volcano. The downstream section in the study area includes the confluence of both the rivers near Santo Toribio Xicohtzingo entering into the plains of Puebla. The river basin experiences sub-humid climate with an average annual precipitation of 800 mm and temperature of 22 °C. The dry season corresponds to the months of March-May, the rainy season from June-September and winter during October-February (National Meteorological Service, 2010).

2.2. Geological setting

Geologically, Tlaxcala region belongs to "*Tlaxcala Block*" consisting of Tertiary volcano-lacustrine sequence, which includes well-bedded sandy to silty pyroclastic material and it is overlaid by ignimbrites (Erffa von et al., 1976; Castro-Govea and Siebe, 2007). Upper Cenozoic intermediate tuffs and 2.6 Ma old Andesitic Spills out crop towards the top of the section (Castro-Goeva, 1999; INEGI, 1981; Ramírez Rojas, 1986). The Puebla basin is located in the central part of the Trans Mexican Volcanic Belt and is surrounded by Neogene-Quaternary stratovolcanoes like Iztaccíhuatl (extinct), Popocatépetl (active since 1994) and Malinche (dormant) (Nelson and Sanchez-Rubio, 1986). The metamorphic Acatlán complex (Paleozoic) forms the basement rocks overlain by sedimentary carbonaceous deposits (cretaceous) and terrigenous deposits from Maltrata and Balsas formations (Siebe et al., 1996). The products of recent volcanic activity (Quaternary) as lava flows, pyroclastic deposits and laharic flows from Popocatépetl and Iztaccíhuatl are covering a part of the basin. Calc-alkaline, alkaline and numerous inter-layered pyroclastic deposits of andesitic to dacitic composition are also present in the study area (Schaaf et al., 2005; Larocque et al., 2008). The carbonate rocks in some sections are part of the mafic replenishment and magma mixing with andesitic-dacite origins (Goff et al., 2001). Pink Pumices of 1150 yr B.P and Tutti Frutti Pumice of 14,000 yr B.P of pyroclastic sequences is also present in the foot hills of the volcanoes (Siebe and Macías, 2004). The region is also fed by a number of small springs, which cuts through the quaternary gravels of different sequences overlying the Tertiary Balsas Conglomerate with modern terrestrial fresh water molluscs (shells) present in the region (Stevens et al., 2012).

2.3. Industrial set-up

The Puebla and Tlaxcala states are the fourth largest metropolitan area of Mexico and it forms the major industrial corridor in the center of the country. These states form the major grounds for automobile manufacturing and they are the prime sites for the origin of textile industry in Latin America, which favored an increase in the demographic growth (154.6%) during the last two decades (INEGI, 2010). On the industrial front, the State of Puebla and Tlaxcala are dominated with manufacturing units of aluminum, ceramic, food, transport sector, wooden materials, dyes, electrical, petrochemical, chemicals, adhesives, colorants, fertilizers, oil lubricants, synthetic and printing industries, rubber, textile, heavy machines and automobiles. These industrial complexes are easy sources for rapid discharge of industrial effluents into the fluvial systems.

3. Materials and methods

3.1. Sample collection

A total number of 31 surface sediment samples were collected from the main river channels, which includes Zahuapan River (sample nos. 1–12), Atoyac River (sample nos. 13–20) and downstream section (sample nos. 21–31) respectively (Fig. 1). The samples were divided into three sections based on the geomorphological and the drainage basin features in the mountainous terrain. The samples were collected using plastic spatula and a small Van-veen grab was also used where the depth (0.5–2.3 m) of water column was more. The samples were immediately packed and transferred to the lab, where the samples were oven dried at <40 °C. Larger particles (>256 mm) were eliminated manually before the pulverization process. The sediments (<2 mm) were pulverized using agate mortar and sieved through ASTM 200 sieves for geochemical study.

Some of the collected samples, especially 1–4 (Zahuapan River), 13, 14 (Atoyac River), were collected from the drainage basins (considered as non-polluted) in the mountainous region, where smaller springs feed the main rivers. The above mentioned samples were used as local reference values to estimate background values in the present study.

3.2. Grain size and petrographic analysis

The bulk sample was reduced to the known quantity by coning and quartering method and a portion (~100 g) of the sample was used for grain size analysis. Grain size analysis was conducted by the dry sieving technique (Folk, 1980). Samples containing