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Metal concentrations in recent ash fall of Popocatepetl volcano 2016, Central Mexico: Is human health at risk?

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ABSTRACT

The present study addresses the metal concentration pattern and associated human health risks in ash samples of Popocatepetl volcano. In this regard, 12 ash samples from different regions of Puebla City were collected and analyzed for 28 major and trace metals, out of which exclusively 8 metals of potential risk (Cd, Co, Cr, Cu, Mn, Ni, Pb & Zn) were selected for human health risk validation. The metal concentration pattern showed an enriching trend for ferromagnesium and carbonate elements compared to previous ash eruptions. Enrichment factor and geoaccumulation indices displayed a least significant enhancement of metals from baseline concentrations. More likely, the potential ecological risk index suggested no harmful biological effects due to the presence of these metals in ash. Concurrently, in the human health risk assessment model, the hazard quotient and hazard index values < 1 indicated safe levels and no carcinogenic effects. All-inclusive, this study highlights the context of metals in ash fall of Popocatepetl which presents no adverse effects over the human population.

1. Introduction

Human inhabited areas close to volcanoes are susceptible to pyroclastic flows, volcanic ash deposition, lahar deposition and several other emissions. Of all eruptive hazards, ash fall largely affects public for its ability to spread vast distances and stay in environment for years or even decades. For instance, the deposited tephra instigates rapid biogeochemical changes on soil, aquatic systems and atmosphere, thereby altering the entire ecosystem (Jones et al., 2008; Lieke et al., 2013; Escudey et al., 2015). Additionally, the metals present in volcanic ash can be either re-suspended into atmosphere or get into contact with humans through ingestion, inhalation and dermal adsorption (Zheng et al., 2010; Mohmand et al., 2015). Metals become bioaccessible only when released in a body fluid and possibly cause a damage such as reproductive failure, genotoxicity, gastro-intestinal problems (Banerjee, 2003; Maas et al., 2010; Wei and Yang, 2010; Kong et al., 2011; Tang et al., 2013; Gu et al., 2016). Children usually have higher rates of health risk in comparison with adults due to their low tolerance to toxins, hand-to-mouth activities and fast growth rates (Kurt-Karakus, 2012; Ali et al., 2013; Peña-Fernández et al., 2014). Though the adverse health effects of metals have been well-known from a long time, they are yet to be explored in population group exposed to frequent volcanic ash fall areas.

Of our interest in this present study, the Popocatepetl volcano, meaning “Smoking Mountain” in native Náhuatl language, located in Central Mexico, is one of the highest active volcanoes in North America. Approximately 25 million people inhabit in less than 100 km distance from the crater. The eruption history dates back to ~ 23,000 years ago with a major collapse of previously existing cone by Mount Saint Helens type eruption (Macías, 2007). At least 6 high-magnitude Plinian eruptions were observed among which, 14,100 y BP Tutti Frutti, 4965 y BP Ochre Pumice, 2150 y BP Lorenzo Pumice, and the 1100 y BP Pink eruptions were most powerful. The subsequent extreme natural calamities were found from artifact findings and archaeological excavations (Seele, 1973; Plunket and Uruñuela, 1998, 2000). Major ash eruptions were reported during A.D. 1351, 1519, 1549, 1571, 1592, 1642, 1663–1665, 1720 and 1919–1927 (Siebe et al., 1996; Martín-Del Pozzo et al., 1997; Delgado et al., 2008; Rodríguez-Espinosa et al., 2015). Popocatepetl entered a period of dormancy for more than 60 years and was active again on Dec 21, 1994. It discharged ash that draped the Puebla City creating a huge threat to the people. More than 50,000 people within the vulnerable zone were ordered for immediate evacuation by government authorities. In due course of time, the volcanic activity peaked and on June 30, 1997, there was a strong explosion

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emitting vigorous amounts of ash and pumic fall. Up-to-date, the eruption seems unremitting with multiple emissions of steam, gas and large amounts of ash fall that usually occur every month or two posing an ominous warning to the humans (Global Volcanism Program, 2017).

Hence, the frequent emissions and ash spews in Popocatepetl volcano is certainly an alarming concern. Several papers have already addressed the geological processes, eruptive history, seismicity and deformation of Popocatepetl, while there is a lack of information regarding the metal concentrations and associated health risks in ash fall. Taking this into account, this first investigation sheds light over metal concentrations in which, our main objectives include: 1) determination of metal concentrations in ash samples, 2) enhancement levels of metals using geochemical indices (geoaccumualtion index and enrichment factor), 3) identification of potential ecological risks posed by metals, 4) estimation of human health risk by metal exposure via ash and, 5) ascertain the interrelationship among different geochemical elements through multivariate statistical techniques.

2. Materials and methods

2.1. Study area

The study area covers the heart of the Puebla city, surrounded by Volcano Iztaccíhuatl, Popocatépetl (active) in the western side, and Volcano Malinche in the eastern side. The active Popocatepetl volcano (19°1′19.96"N, 98°37'40.46"W, 5452 m) is located 71 km south-east of megapolis Mexico City and 40 km west of the Puebla city in Central Mexico. This quaternary strato-volcano in the central part of Trans-Mexican volcanic belt (TMVB) is formed by subduction of the oceanic Cocos plate beneath the continental North-American plate (Carrasco-Núñez et al., 1986). Geologically, the basement of Popocatepetl volcano comprises Cretaceous marine limestones (Cuautla and Morelos formations) that were folded during Laramide orogenesis and unconformably covered by terrigenous sediments of Eocene-Oligocene Balsas group (Fries, 1960). Numerous interlayered lava and pyroclastic deposits of andecitic to dacitic composition form the modern stratocone of Popocatepetl (Robin, 1984; Robin and Boudal, 1988; Kolisnik, 1990; Schaaf et al., 2005).

On the anthropogenic front, apart from the two big cities Mexico (~ 23 million people) and Puebla (~ 2 million people), there are many small villages and towns around the volcano. There are plenty of renowned magical towns locally termed as “pueblos magicos” surrounding this volcano attracting a huge number of national and international tourists. A vast area of agricultural land, urban-industrial region and aquatic environments (Zahuapan-Atoyac river basin) are found nearer to this active volcano.

2.2. Analytical methodology

A total number of 12 volcanic ash samples were collected during April 2016 from different regions of the Puebla City, Central Mexico (Fig. 1). The ash samples were taken during the real-time hours of explosion and collected while falling on the ground using containers. Approximately 50–100 g samples were collected in dry conditions i.e. no meteoric rain or water from plume condensation and no frozen aggregates were evidenced. The sampling stations were selected based on the criteria where huge population was exposed to this ash fall, thereby covering widespread areas throughout the Puebla City close to Popocatepetl volcano. 28 Major (Al, Fe, Mg, Ca, Na, K, P, S & Ti) and trace elemental (Ag, Ba, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sc, Sr, V, Zn, Zr, Ga, Li, Te, U & Y) concentrations were analyzed in ACT Labs, Ontario, Canada. A total digestion technique ($HClO_4$–HNO_3–HCl–HF) was applied and the metal concentrations were determined using inductively coupled plasma-mass spectrometry (ICP-MS). Following the quality-control procedures, various Geochemical Reference Standard Materials (SRMs: GXR-1; GXR-4; GXR-6; SDC-1) were run along with the samples. The detection limits for the analyzed metals were Al = 0.01%, Fe = 0.01%, Mg = 0.01%, Ca = 0.01%, Na = 0.01%, K = 0.01%, P = 0.001%, S = 0.01%, Ti = 0.01%, Ag = 0.3 ppm, Ba = 7 ppm, Cd = 0.3 ppm, Co = 1 ppm, Cr = 1 ppm, Cu = 1 ppm, Mn = 1 ppm, Ni = 1 ppm, Pb = 3 ppm, Sc = 4 ppm, Sr = 1 ppm, V = 2 ppm, Zn = 1 ppm, Zr = 5 ppm, Ga = 1 ppm, Li = 1 ppm, Te = 2 ppm, U = 10 ppm & Y = 1 ppm respectively.

2.3. Geochemical indices

In order to evaluate the degree/level of metal enrichment and identify their ecological risks in volcanic ash of Popocatepetl, we employed three geochemical indices namely, geoaccumulation index, enrichment factor and potential ecological risk index. In this research work, the background values were calculated from the mean concentrations of metals in previous Popocatepetl's ash eruption during 1995–1996 studied by Schaaf et al. (2005).

2.3.1. Geoaccumulation index (I_{geo})

To determine which elements are more enhanced in the volcanic ash, we calculated I_{geo} values for each element using the formula: $I_{geo} = (\log_2 C_n/1.5\ B_n)$ originally developed by Muller (1979); where, C_n = measured concentration of the element “n”, B_n = background concentration for the element “n” and 1.5 = background matrix correction factor. Muller (1979) has defined seven classes of the geoaccumulation index ranging from class 0 to class 6 reflecting 100 fold enrichment above the background values.

2.3.2. Enrichment factor (EF)

Buat-Ménard and Chesselet (1979) developed EF for determining the metal enrichment using the following equation: $EF = (Me/Al)_{sample}/(Me/Al)_{baseline}$; Where, $(Me/Al)_{sample}/(Me/Al)_{baseline}$ represent ratio of metal to Al concentrations in the studied samples and in the background sample respectively. Seven tiers of enrichment levels were categorized: no enrichment (EF < 1), minor enrichment (1 < EF < 3), moderate enrichment (3 < EF < 5), moderately severe enrichment (5 < EF < 10), severe enrichment (10 < EF < 25), very severe enrichment (25 < EF < 50), extremely severe enrichment (EF > 50).

2.3.3. Potential ecological risk index (RI)

Potential ecological risk index (RI) introduced by Hakanson (1980) was applied to evaluate the potential toxicity of metals in volcanic ash of Popocatepetl over the biological community. The RI is calculated as

$$RI \sum_{f}^{i} ER_f^i$$

$$ER_f^i = Tr^i \times C_f^i = Tr^i \times \left(\frac{C_s^i}{C_n^i}\right)$$

where ER_f^i is the potential ecological risk factor for a given element i; Tr^i is the biological toxicity factor for element i; which is defined as As = 10, Cr = V = 2, Cu = Ni = Pb = 5, Zn = Mn = 1 (Hakanson, 1980); C_f^i, C_s^i and C_n^i are the contamination factor, the concentration in the sample and the background reference value for element i respectively.

2.4. Human health risk assessment

Human health risk assessment model developed by United States Environmental Protection Agency (USEPA) (1996) was utilized in the present study to understand the nature and probability of adverse health effects in humans exposed to metals.

2.4.1. Exposure dose

As mentioned previously, human exposure to metals via ash occurs