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Trace element concentrations in schoolyard soils from the port city of Talcahuano, Chile

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ABSTRACT

It is well documented that infants and children have a greater intake per unit of body weight of soil, air and water. The objective of this study was to determine the occurrence and concentrations of potentially toxic metals/metalloids in soils to which children are exposed to during outdoor school activities. A total of 76 soil samples from 38 schoolyards throughout Talcahuano, Chile were collected. For each schoolyard site, a sample of the topsoil (ts, 0 to 10 cm) and subsurface soil (ss, 10 to 20 cm) was collected for analysis. The processed samples were analyzed by ICP-emission spectrometry following aqua regia digestion for the following elements: As, Cr, Cu, Ni, Pb and Zn. The median concentrations (mg kg^{-1}) obtained include: As 6 (range 1–24), Cr 29 (14–253), Cu 40 (11–190), Ni 30 (7–79), Pb 26.5 (3–349), and Zn 172 (29–1865). Different methods were evaluated in order to facilitate the best diagnosis of contamination. First, the trace element geochemical background was determined using basic descriptive statistics. Second, the basic descriptive statistics were then compared with Dutch guidelines, in order to evaluate whether the concentrations measured in soils were abnormally large. By comparing the results of the different methods, we estimate that 34% of the schoolyards demonstrate contamination.

1. Introduction

The origin of trace elements in soils is diverse and is generally categorized as lithogenic elements, pedogenic elements and anthropogenic elements (Kabata-Pendias, 2001; Tume et al., 2008a). Soils in urban environments, particularly in parks, schoolyards and gardens may have a direct influence on public health. This is due to potentially harmful trace elements that may occur in the soils may easily come in contact with humans and transferred to them, either as suspended dust or by direct contact (De Miguel et al., 1997; Madrid et al., 2002). Urban soils can serve as a recipient for a large amount of trace elements from multiple sources, including, municipal wastes, vehicular emissions, industrial wastes and the combustion of coal and fuel to name a few (Guo et al., 2012). These may lead to the emission of trace elements into the air and their subsequent deposition and addition to urban soils (Chen et al., 2005). Furthermore, the layout of a city, the location of buildings and the dominating wind directions have an influence on the spread of dust particles (Kumpiene et al., 2011). Buildings act as wind and dust barriers and can prevent the spread of air-born contaminants. Buildings can also become secondary sources of soil contamination through the washing, removal and deposition of accumulated dust from wall surfaces (Mielke et al., 1997). Several researchers have pointed out the need for a better understanding of urban soils in order to assist in developing strategies to protect urban environments and human health against the long-term accumulation of trace elements (Giaccio et al., 2012; Guo et al., 2012; Madrid et al., 2002). It has been found that certain trace elements in urban soils may have toxic effects on human health, especially on children (Erickson and Thompson, 2005; Ljung et al., 2006a; Presley et al., 2010).

During the last few years, studies of urban soils in cities have been carried out, in Athens (Argyraki and Kelepertzis, 2014; Chronopoulos et al., 1997), Beijing (Wang et al., 2012), Berlin (Birke and Rauch, 2000), Changchun (Yang et al., 2011), Copenhagen (Li et al., 2014), Hong Kong (Li et al., 2001), London (Thornton, 1991), Madrid (De Miguel et al., 1998), Napoli (Albanese et al., 2011; Cichella et al., 2008), Seville (Madrid et al., 2002), etc. In certain other studies, the focus was more towards urban soils in parks, playgrounds and schoolyards; in cities such as Athens (Massas et al., 2010), Hong Kong (Ng et al., 2003; Wong and Mak, 1997), New Orleans (Presley et al., 2010), Madrid (De Miguel et al., 2007), Murcia City (Acosta et al., 2009), Uppsala (Ljung et al., 2006b; Ljung et al., 2007) and Vilnius (Kumpiene et al., 2011). The abovementioned studies refer mainly to established cities in developed countries and few studies have been carried out on cities in developing countries (Figueiredo et al., 2011; Tume et al., 2008b). In Chile, research

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on trace element concentrations in soils has been conducted in the northern and central zones of the country and on the Antarctic Peninsula (Ahumada et al., 2004; Badilla-Ohlbaum et al., 2001; De Gregori et al., 2003; Flynn et al., 2002; Higueras et al., 2004; Pizarro et al., 2003; Richter et al., 2004; Schalscha and Ahumada, 1998). A very limited number of studies are available in the literature on the distribution of trace elements in Chilean cities (Tume et al., 2008b).

In the Talcahuano area, several anthropogenic activities (industrial production, vehicular emissions, residual disposal, fossil fuel combustion, steel industry, cement factory, etc.) can be found, emitting metals (such as As, Ca, Cd, Co, Cu, Hg, Mn, Ni, Cr, Pb, Zn) into the atmosphere (Bermudez et al., 2010; EPA, 1988; Hissler et al., 2008). Subsequently, these metals are deposited and incorporated into the soil as particulate matter. Within the framework of the Regional Development Strategy 2000–2006, the Bío Bío Regional Government has made public its decision to move forward with an environmentally sustainable regional development plan and acknowledges as one of the most important priorities (because of its magnitude, environmental significance and its effect on the quality of life) is the atmospheric industrial pollution associated with some urban areas like Talcahuano (CONAMA Región del Bío Bío, 2005). As indicated, industrial activity releases trace elements into the atmosphere, which are subsequently deposited and incorporated into the urban soils.

Schoolyards, parks and playgrounds are some of the areas where the majority of urban children spend much of their free time outside the home and also where children most frequently come into physical contact with soil (Figueiredo et al., 2011). Children are particularly vulnerable to trace element poisoning for two reasons. First, children are more likely to ingest significant quantities of dust and soil than adults because of their natural behavior of inserting into their mouth non-food objects and also repetitive hand/finger sucking. Second, the child's digestion system possesses a much greater absorption rate of trace elements and also a larger hemoglobin sensitivity to trace elements compared to adults (Ng et al., 2003). Some trace elements (such as Cu and Zn) in small amounts are harmless, in contrast other trace elements, notably Pb and Cd, even at extremely low concentrations are toxic and are potential cofactors, initiators or promoters of many diseases, including cardiovascular diseases and cancer (Ng et al., 2003; Nriagu, 1988).

In agreement with the contamination definition of ISO (2005) "Contamination is simply a substance present at or above background values". The background level or content of a chemical element is the sum of natural geochemical and pedogenic processes, including moderate diffuse source input (ISO, 2005). To date no universal contamination assessment method is currently available (Desaules, 2012; Redon et al., 2013). Different data analyses were applied in order to detect the presence of trace element contamination in the schoolyard soils of Talcahuano. Regulatory reference values (RRV) to assess soil contaminations are a different approach merging into soil contamination. The RRV introduce the notion of toxicity. They are normative values, and sometimes have a legal character. They are generally based on background values in combination with toxicity levels (Desaules, 2012). As long as the pollutants in the soil remain below the established target values, the soil is considered to be multifunctional, i.e., fit for any land use, bearing in mind any limitations due to the natural composition of the soil. Once the soil reaches the intervention values, indicating the need for soil remediation, its functionality for humans, plants, and/or animals is jeopardized or limited; when these values are exceeded, contamination is said to be serious (VROM, 2000).

The objectives of this study were (1) to define the background levels of the trace elements in schoolyards and (2) to evaluate the sites contaminated by trace elements. The present work is the result of a sampling campaign aimed at obtaining for the first time knowledge on the distribution and concentrations of trace elements in soils and ascertains whether potentially hazardous trace elements are likely to exist in soils in the city of Talcahuano.

2. Materials and methods

2.1. Geographic location

The study area is located in the port city of Talcahuano (36° 43′S–73° 07′W), approximately 600 km south of Chile's capital, Santiago. The Municipal District of Talcahuano has a population of 163,628 and a surface area of 94.6 km^2 (Fig. 1).

2.2. Geological setting

In the broad area of Metropolitan Concepcion within which the city of Talcahuano is located, the general geology consists of metamorphic, igneous intrusive and clastic sedimentary rocks as well as unconsolidated fluvial deposits. The oldest rocks in the area correspond to metamorphic and intrusive igneous rocks grouped within a unit denominated the "Basamento Cristalino" (crystalline basement). The unit has an Upper Carboniferous age. Overlying the basement in discordant form, are clastic sedimentary rocks of the Quiriquina Formation (Upper Cretaceous) and the Curanilahue Formation (Eocene). Disconcordantly overlying the Quiriquina and Curanilahue formations are conglomerate and sandstone units of the Plio-Pleistocene Andalien Formation. Much of the surface area of Metropolitan Concepcion and Talcahuano is located on the bottom of the Mochita valley, which forms an intense geomorphological plain in the region. This plain is mainly composed of sandy material (up to 150 m thick in certain places), provided by the Bio Bio River and demonstrates the intense activity of this fluvial system during the Upper Pleistocene to the Recent. During this time period, the river formed an extensive deltaic system, depositing great amounts of sediments. The nature of these sediments is predominantly volcanic. The intense human occupation of much of the physical space that covers much of the area of Metropolitan Concepción has brought as a consequence, the total transformation of the natural landscape. It should be noted that throughout the years, many sectors of Talcahuano have been subject to uncontrolled landfill with both construction (i.e. concrete) and/or industrial wastes. This underlying waste which many sectors are built upon is another potential source to contamination which has to be taken into consideration. However, because of the uncontrolled nature there are no records of the location, size and distribution of these clandestine sites.

2.3. Climate

Based on data provided by the Direccion Meteorologica de Chile, the mean annual precipitation in the region is on the order of 1.130 mm per year. The warmest month is January with an average high of 22.1 °C and the coolest is July with an average low of 5.9 °C. The summer maximum recorded is 33.2 °C and the coldest temperature has been −3.0 °C. The cool waters of the Pacific Ocean help to maintain mild temperatures throughout the year. In the six-month period between May and October, the area receives approximately 83% of its total annual precipitation, while the months from November to April have been rainless on occasions. During the winter, the prevailing winds are from the north; while as of September, the prevailing winds are from the southwest.

2.4. Soil samples

Soils were sampled from 38 municipal schoolyards in the Talcahuano area (Fig. 1). At each sampling site, samples were collected from two depths: topsoil (ts: 0–10 cm) and sub-surface soil (ss: 10–20 cm). Composite samples, consisting of five soil cores, were collected at each site (approximately 1 × 1 m). This sampling strategy was adopted in order to reduce the possibility of random influences from urban waste. All the samples were collected with a clean spatula and kept in sealed plastic bags.