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Long-term assessment of ecological risk from deposition of elemental pollutants in the vicinity of the industrial area of Puchuncaví-Ventanas, central Chile

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HIGHLIGHTS

- 5 years monitoring campaigns on Chilean soils impacted by industrial activities
- Trace element profiles, comparison with impacted areas and soil quality standards
- Temporal evolution and source assignment by cluster analysis and PCA
- Ecological risk assessment indexes calculated and critically discussed

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ABSTRACT

The present work investigates soil pollution by elemental contaminants and compares ecological risk indexes related to industrial activities for the case study of Puchuncaví-Ventanas: a relevant industrial zone located in central Chile. Selected elements (As, Pb, Cd, Ni, Hg, V, Mn, Zn, Sr, Sb, Cr, Co, Cu, K, and Ba) were analyzed during a long-term period (yearly sampling campaigns during 2007–2011), at 5 sampling stations representing different degrees of impact. PCA and cluster analysis allowed identifying a copper smelter and a coal-fired power plant complex as major pollution sources. Geoaccumulation index (I_{geo}), enrichment factor (EF), contamination factor (C_f), contamination degree (C_{deg}), and integrated pollution index (IPI) are critically discussed for quantitative ecological risk assessment. I_{geo}, EF and C_f indexes are producing comparable environmental information, showing moderate to high pollution risks in the area that demands further monitoring and adoption of prevention and remediation measures.

Capsule: Long term assessment of elemental pollution around an industrial area. New insight on ecological risk indexes for trace element pollution in soils, by critical comparison among them.

1. Introduction

Among the most significant soil pollutants, trace elements are relevant due to both acute and long-time toxic effects in the soils and related environmental media (Yaylah-Abanuz, 2011), since soil pollutants can enter the human body by ingestion, dermal contact, and inhalation, aside from the food chain pathway starting from plant uptake (Meza-Montenegro et al., 2012). The potential ecological risk associated to soil contamination is a very controversial issue in recent years (Meza-Montenegro et al., 2012), so ecological risk assessment aims to provide information to measure and predict soil pollutant threats for humans and the environmental health (Fairbrother et al., 2007; Wei and Yang, 2010). Different indexes have been proposed to predict the environmental quality of soil and sediments (Caeiro et al., 2005).

Punchuncaví-Ventanas, one of the main industrial areas of Chile, comprises a wide range of industrial factories and activities implying potential risks to human and environmental health. The most environmentally relevant factories in this area are the CODELCO División Ventanas copper refinery complex and the AES Gener coal-fired power plant complex (three operating units) facilities. For example, these activities are responsible for 68.1% (copper refinery) and 30.7% (coal-fired power plants) of SO_2 emissions in the area, according to the local authority's reports (UNTEC, 2012). Aside from these main

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sources, there is a wide set of less impacting industrial factories operating in the area, which are briefly described as follows. Puerto Ventanas is a provider of dock and port facilities. Cementos Melón is a producer of national construction materials which has three activity areas: cement, concrete aggregate, and mortars. Catamutún Import, sell coal, and steam division, which manages industrial systems from steam coal combustion. Panimex Química S.A. produces plastic and fumaric acid. Gasmar is a company dedicated to marketing of liquefied gas. Minera Montecarmelo is a plant for treating industrial wastes. Oxiquim is a maritime terminal. Cordex is a big factory for production of asphalt and is a fuel terminal also.

Studies about environmental impact of industrial activities on the elemental soil levels in the Puchuncaví-Ventanas area are scarce. Ginocchio (2000) analyzed the effect of copper smelter on grassland in terms of physicochemical soil characteristics, plant species diversity and abundance, founding a significant impact of industrial activities on plant species regeneration capabilities. De Gregori et al. (2002) carried out the redox speciation of selenium present at ultratrace levels in rainwater collected at the area. The same group (De Gregori et al., 2003) conducted a work aimed to the monitoring of copper, arsenic and antimony levels in agricultural soils impacted and non-impacted by mining activities, from three regions in Chile including the Puchuncaví-Ventanas industrial area. The high concentrations measured in impacted soils from Puchuncaví-Ventanas (300 mg kg^{-1} Cu, 34.5 mg kg^{-1} As and 5.3 mg kg^{-1} Sb) clearly showed the impact produced in this zone by the industrial and mining activities developed in their proximities. Ginocchio et al. (2004) reported Cu, Zn, Pb and Cd concentrations (among other parameters) in different soil layers around the area. The levels found in the 0–5 cm layer were 361.6 mg kg^{-1} for Cu, 157.8 mg kg^{-1} for Zn, 79.9 mg kg^{-1} for Pb and 0.8 mg kg^{-1} for Cd. Copper mobility in soil around the copper smelter was investigated by Neaman et al. (2009). The same author reported results about the effectiveness of lime and compost of in situ immobilization of trace elements in soil by using earthworms as bioindicators of toxicity (Neaman et al., 2009). These previous works in the area focused on a limited numbers of trace elements analyzed after single sampling campaigns. A more detailed evaluation of trace elements in soils, focused on the study of their distribution in particle size fractions has been recently published by Parra et al. (2014). In the present work, we describe the results of a systematic, long-term investigation about ecological risk from multi-element soil pollution at the Puchuncaví-Ventanas area, comprising spatial and temporal variability, source assignment and ecological risk index calculations.

2. Materials and methods

2.1. Sampling area and soil characteristics

The Puchuncaví-Ventanas industrial area is located in a district (Fig. 1) belonging to the V Region of Chile, Valparaiso Province. The area is located in the Chilean mainland coast (34° 45′ S, 71° 29′ W), 58 km North from Valparaíso (Regional Capital Region V), 45 km North from Viña del Mar and 160 km North-West from Santiago de Chile. It comprises an area of 301 km^2, with a population of 13,000. The main communication ways are the F-30E Road, Highway 5 North (via Catapilco), and Nogales-Puchuncaví way. Specific locations for soil sampling were selected in the area as depicted in Fig. 1. La Greda (LG) sampling point (32° 44′ 57″ S, 71° 28′ 30″ W) is located 1.69 km NE from the main emission sources in the area, whereas Los Maitenes (LM) sampling point (32° 45′ 41″ S, 71° 27′ 18″ W) is located 2.39 km E. These two locations are expected to be the most impacted points. Puchuncaví village (PU) sampling point (32° 43′ 17″ S, 71° 24′ 43″ W) is located 8 km NE from the industrial area and Valle Alegre (VA) sampling sites (32° 48′ 30″ S, 71° 26′ 10″ W) is 6.72 km SE around the

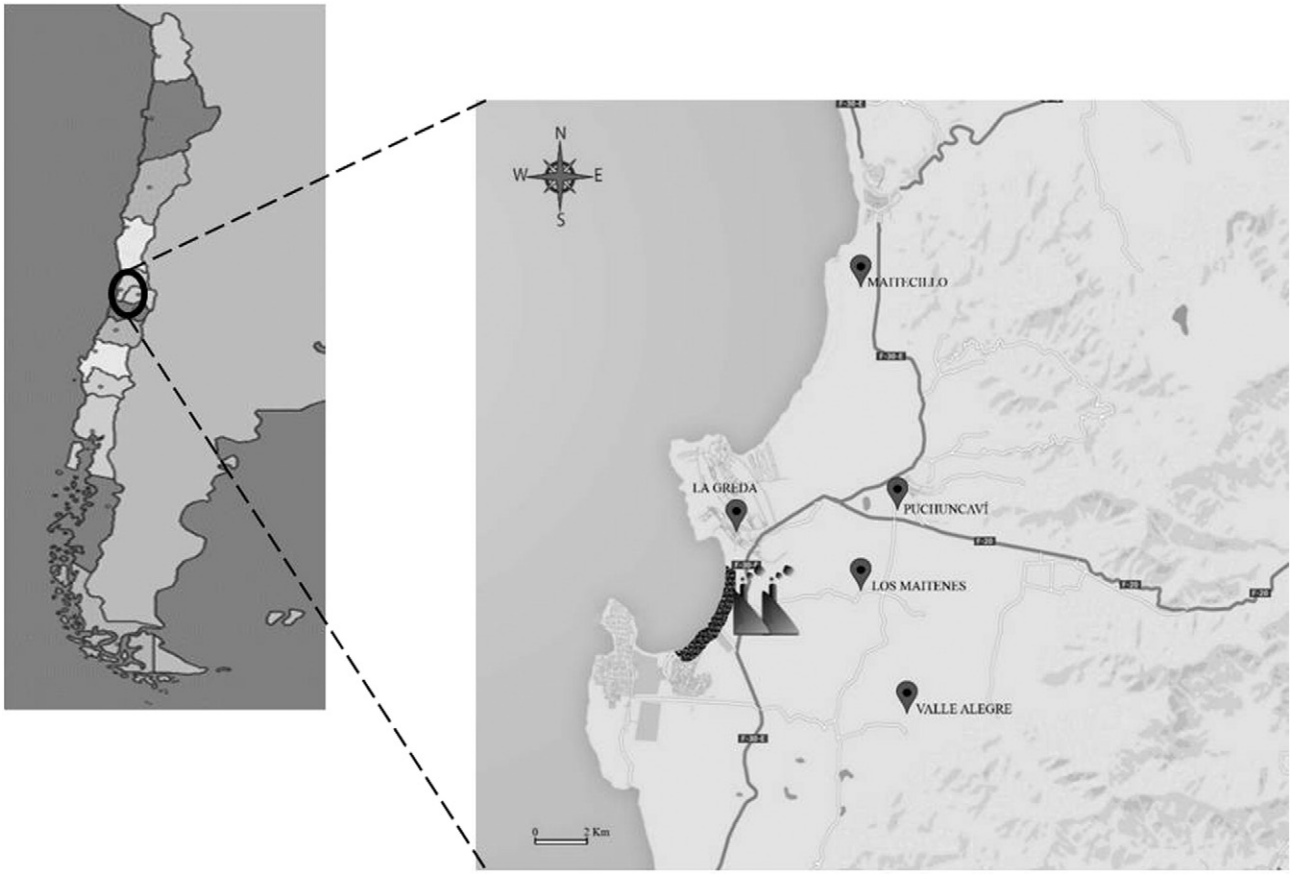

Fig. 1. Punchuncaví-Ventanas industrial area and soil sampling points.