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Fate of hazardous elements in agricultural soils surrounding a coal power plant complex from Santa Catarina (Brazil)

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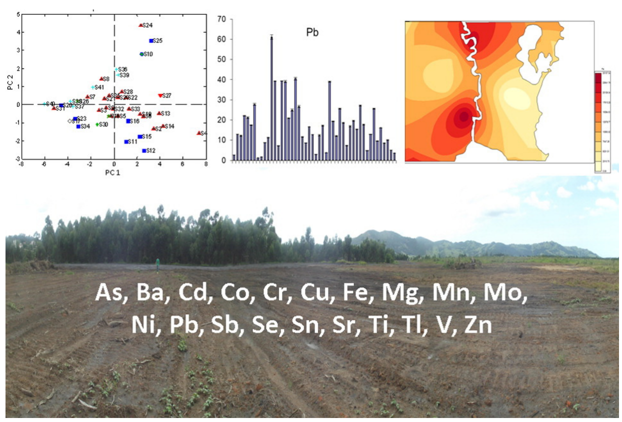
HIGHLIGHTS

- Heavy metal contamination coming from different pathways to an agricultural area
- Identification of areas of the highest contamination using a zero to ten score
- Spatial extrapolation to detect hotspots regarding trace elements
- Multivariate statistical analysis to identify contamination sources

GRAPHICAL ABSTRACT



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ABSTRACT

Hazard element contamination coming from coal power plants is something obvious, but when this contamination is accompanied by other contamination sources, such as, urban, coal mining and farming activities the study gets complicated. This is the case of an area comprised in the southern part of Santa Catarina state (Brazil) with the largest private power plant generator.

After the elemental analysis of 41 agricultural soils collected in an extensive area around the thermoelectric (from 0 to 47 km), the high presence of As, Co, Cr, Cu, Fe, Mn, Mo, Pb, Sb, Sn, Tl, V and Zn was found in some specific areas around the power plant. Nevertheless, as the NWAC (Normalized-and-Weighted Average Concentration) confirmed, only soils from one site were classified as of very high concern due to the presence of potential toxic elements. This site was located within the sedimentation basin of the power plant. The spatial distribution obtained by kriging in combination with the analysis of the data by Principal Component Analysis (PCA) revealed three important hotspots in the area according to soil uses and geographic localization: the thermoelectric, its area of influence due to volatile compound deposition, and the area comprised between two urban areas. Farming practice turn out to be an important factor too for the quantity of hazard element stored in soils.

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1. Introduction

According to numerous studies soil–crop system is one of the most important pathways of human exposure to hazardous elements. Soil–crop system may suffer different contamination inputs such as, traffic, industry, atmospheric deposition, mining leaching, waste disposal, urban activities, pesticides, and fertilisers (Wei and Yang, 2010). As in other terrestrial ecosystems industrial activities are highly present in agricultural areas. Taking into account that coal is the most abundant fossil fuel on the planet, coal power plants are the principal origin of environmental pollution and one of the principal anthropogenic causer of hazardous volatile elements to the environment (Dragović et al., 2013).

Coal burning exhaust is characteristically enriched in nanoparticles; toxic and greenhouse gases; volatile organic compounds; and volatile inorganic species, including As, B, Cd, Hg, Se, organometallic compounds, and other gas components (Hower et al., 2013; Ribeiro et al., 2010). The products of burning of coal or coal waste may include solid residue derived from the interaction between volatilized compounds and the overlying material (Pone et al., 2007; Querol et al., 2011), and from gas emissions into the atmosphere. In the case of metals and metalloids atmospheric emissions and the leaching of solid combustion by-products during their disposal or sedimentation, are the main pathways to soils of the surrounding area.

In the 2000s, coal storage, processing procedures and activities related to coal ash transportation and discard have become a theme of growing relevance. According to Mandal and Sengupta (2006) the increase of trace elements (As, Cu, Mn, Ni, Pb and Zn) in the surface soils around a thermal power plants in India, was attributed to the ash from the discard pond. An enrichment of Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb and Zn was observed in soil surrounding a coal fired power plant in Serbia (Dragović et al., 2013) and of As in soils around a coal-burning power station in Slovakia (Keegan et al., 2006). An investigation carried out in forest ecosystems near the largest coal power plant in Galicia (Spain) showed that mercury stocks up to five times greater than the observed in soils for approximately 20 km from the plant (Nóvoa-Muñoz et al., 2008).

In Brazil coal burning by power plant is a well-known global phenomenon that may cause significant environmental and health problems (Oliveira et al., 2013; Martinello et al., 2014; Quispe et al., 2012). Although the potential risk for high environmental and human health impacts, coal burning has not been accurately quantified in terms of national or global emissions and only a few field studies have quantified the associated emissions (O'Keefe et al., 2011; Engle et al., 2012; Hower et al., 2013).

The largest private power generator in Brazil is located in the state of Santa Catarina and it has an own installed capacity of 6965 MW, equivalent to about 6.1% in Brazil. The power plant Complex Jorge Lacerda–Tractebel Suez (PPCJL) has an installed capacity of 857 MW and it burns medium-sulphur coal (<2% total S) with approximately 40% ash (45–50% mineral matter; Silva et al., 2010). The coal used by the power station represents a blend of material from many different suppliers; blend components are mainly drawn from deposits in Santa Catarina but also from some mines in Rio Grande do Sul.

The most important research works carried out in the area of Santa Catarina regarding trace element contamination have been focused in three prime aims: i) the effects of acid mining drainage, ii) the pressures coming from farming activities and iii) the contamination impact within the power plant. With respect to mining drainage contamination, soils and sediments have been analysed (Dias et al., 2013; Silva et al., 2013). Farming activities in the area are mainly centred in husbandry and rice harvest. In fact, the effects (Cu and Zn) in soils after a long-term application of pig slurry have been studied (Tiecher et al., 2013). In this line of work, the potential environmental impact of the emission of the particulate matter coming from the thermoelectric have been analysed in some surface soils (Giarola et al., 2002; Godoy et al., 2004). Nonetheless, a deeper environmental assessment is required; not only in the surroundings of the power plant, also in the near vicinity, to reveal possible health risks to living organisms in all the area via soil–crop system.

The present work describes chemical analysis of soils covering a large zone (more than 47 km) around the biggest South American power plant. The study is not exclusively focused on the environmental effects of the power plant; this study is the first providing data from bulk soil characterisation, which contributes to assess the element contamination produced as a consequence of the combination of different pressures placed around a coal power plant. To achieve this, Principal Component Analysis (PCA) and kriging method was employed on the results obtained of soil samples.

PCA is an unsupervised pattern technique that provides meaningful and visual information about samples (scores) and their connections with the studied variables (loadings). The principle of PCA is finding a transformation that reduces the dimensionality of the dataset by conversion of a set of correlated variables (element contents) to a new set of uncorrelated variables (called principal components, PCs) (Gredilla et al., 2013).

The kriging method is a spatial modelling that extrapolates information from discrete stations to cover the whole area of study. As some other non-interpolators kriging generally produces a smoother surface over the area of interest and it assumes stationary and isotropy within the sampling sites, which implies that spatial correlation within the sampling points is independent of direction (Leecaster, 2003; Fdez-Ortiz de Vallejuelo et al., 2014).

In summary, the principal components of the research described in this contribution are: i) determine the concentrations of elements and metalloids that are of prime environmental interest (Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sb, Se, Sn, Sr, Ti, Tl, V and Zn) in soils around the PPCJL and near of five urban areas; ii) study the spatial distribution of the contaminants within the area of study and identify hotspots, iii) investigate a potential statistical method to estimate the real origin of the hazardous elements emissions based on Principal Component Analysis (PCA), and finally, iv) provide the scientific community with initial order-of magnitude hazardous elements emission estimates from Brazilian coal power plant zone.

2. Materials and methods

2.1. Study area and soil sampling

The power plant complex Jorge Lacerda, comprises part of Tubarão and Capivari de Baixo, totaling 85.29 km^2 and bounded by the coordinates 28° 24′ and 28° 30′ S and 49° 02′ 06″ and 48° 56′ 35″ W. According to Pozzobon (1999), for every 100 tons of coal consumed in thermoelectric complex, is generated 42 tons of ash, of which 70% fly ash and 30% bottom ash.

A total of 41 soils, represented in Table 1 and Fig. 1, were collected in the area under study. 34 soils, codified from S1 to S34, were from an agricultural area (including rice crops and husbandry areas) nearby the thermoelectric plant ("Complexo Termoelétrico Jorge Lacerda") and located between the municipalities of Tubarão, Jaguaruna and Capivari de Baixo, and 6 soils, codified from S35 to S41, correspond to the municipalities of Imbituba and Imarui. The sampling sites were selected according to the use of the soil, proximity to highly contaminated areas, etc.

All the samples were taken in the upper 5 cm of soil using an element shovel. The samples were deposited in plastic bags and wrapped in aluminium foil for their transportation to the laboratory. In order to avoid cross contamination or losses by adsorption, plastic materials were avoided during sampling, transportation and storage.

2.2. Analytical procedure

The analytical determination of metals and metalloids in soil samples were carried out following the US Environmental Pollution Agency