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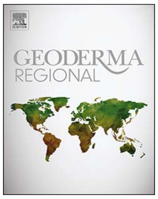

Assessment of spatial distribution pattern of heavy metals surrounding a lead and zinc production plant in Zanjan Province, Iran

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ABSTRACT

The present study aimed at characterizing the spatial distributions and investigating the contents of six heavy metals (Co, Ni, Cu, Zn, Cd and Pb) in top soils, surrounding the National Iranian Lead and Zinc Company (NILZ) in Bonab Industrial Estate (Zanjan-Iran) by Geostatistical analyst and Moran's *I* autocorrelation index. The soil samples (126) were collected from the area with a radius of 5 km of the NILZ Company. The average amount of Co, Ni, Cu, Zn, Cd and Pb metals were 4.16 mg kg^{-1}, 26.38 mg kg^{-1}, 18.31 mg kg^{-1}, 684.11 mg kg^{-1}, 5.79 mg kg^{-1}, and 119.59 mg kg^{-1}, respectively. Principal Components Analysis (PCA) classified the investigated heavy metals in two groups. These groups were Factor I (Pb and Cu) and Factor II (Co, Ni, Zn and Cd) that confirm exist the anthropogenic source of the pollutants. Moran's *I* autocorrelation index was cleared that the high–high spatial clusters of topsoils contaminated with heavy metal were located in the center of study area, near NILZ Company. It was deduced that the company activities have a big impact on distribution of heavy metal in study area. Geostatistical analysis revealed that the high values of all studied heavy metals were located near the NILZ Company. According to comparison the prepared and land use maps, it was cleared that pesticides and chemical fertilizers, geochemistry and anthropogenic sources are the main factors in spatial variation of heavy metals.

1. Introduction

Soil as one of the environmental components is a geochemical storage for pollutants. It is also controls transport the chemical substances and elements to the hydrosphere, atmosphere and biosphere.(Gallego et al., 2002; Huang et al., 2007). Soils can also be a source of pollution to surface and ground waters, living organisms, sediments and oceans (Facchinelli et al., 2001). Nowadays, soil pollution due to urbanization and rapid grows of industries is a substantial environmental issue that many researchers have focused on it. In all types of soil pollutants, heavy metals as the main environmental pollutants has an important role in producing notable disadvantages to the environment when are high concentrations (Gao et al., 2014; Varol, 2012; Zhang et al., 2012; Zhaoyong et al., 2015). Heavy metals could be transferred from soils to atmosphere, hydrosphere and biomass, and they could affect human health through water supply, food intake, direct ingestion and dermal contact (Kabata and Pendias, 2001; Sharma et al., 2007). The principal sources of soil heavy metal pollution are wastewater irrigation, industrial waste disposal, fuel consumption, urban waste disposal, chemical and metal industries, petroleum industries and gas and petro chemistry.

The lead and zinc Industrial Complex is a main source of soil heavy metal pollution located in North West of Iran in Zanjan province. There are still large reserves of lead (Pb) and zinc (Zn) in the area. Both mines and smelting units within the province increase a risk of pollution of groundwater, residential areas, vegetation and especially soils by transforming heavy metals by runoff and wind (Parizanganeh et al., 2010). Heavy metal contamination in Zanjan province has also been previously reported in the vicinity of Lead and Zinc mining and smelting sites (Chehregani et al., 2009; Golchin, 2005; Mohammadi and Eslami, 2007; Mohammadian et al., 2008). Assessment of contamination of soil becomes very difficult when encountering with various sources of pollution that variably distributed. In these cases, mapping and accurate assessment of spatiotemporal pattern of soils heavy metal is basic information for identifying the probable sources of pollution and to delineate the strategies of site remediation (Sollitto et al., 2010). Exploratory spatial data analysis (ESDA) is a collection of techniques for visualizing and describing the spatial dispersion; recognition the

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irregular locations or outliers (not cluster), coldspots or hotspots; and presentation the spatial patterns or spatial dissimilarity (Anselin, 1998). In this regard, geostatistical methods and Moran's *I* autocorrelation index are main factors for recognition the spatial variability of numerous environmental parameters by mapping (Anselin, 1995; Burrough et al., 2015). To date, geostatistics and spatial autocorrelation analysis, in combination with geographic information system (GIS) are widely used to display spatial variation of soil parameters to reduce costs of investigation and to recognize the contamination on sources (Liu et al., 2006; Zhang and McGrath, 2004; Zhang et al., 2009). This study aims to combination the Moran's *I* autocorrelation and geostatistical methods to identify the spatial variability of soil heavy metal contamination. Recently, analyzing the spatial pattern of the soils heavy metal pollution has been increasingly employed in many studies including (Cai et al., 2015; Facchinelli et al., 2001; Fu et al., 2011; Gallardo and Paramá, 2007; Huo et al., 2012; Imperato et al., 2003; Ming-Kai et al., 2013; Sadeghi et al., 2006; Yan et al., 2015; Zhang et al., 2008). The aims of present study are: (i) to characterize the spatial distributions of six key heavy metals (Co, Ni, Cu, Zn, Cd and Pb), (ii) to investigate the contents of mentioned heavy metal and (iii) to distinguish the natural and anthropogenic components of total heavy metal in the soil surrounding lead and zinc Industrial plant in Zanjan province.

2. Materials and methods

2.1. Study area and sampling

In this study, Bonab Industrial Estate (BIE) and its neighborhood was selected for detailed study. The research was focused on the environmental impacts of NILZ Company (36° 66′ N, 48° 48′ E) located within BIE, about 12 km east of Zanjan city (Fig. 1). The NILZ Company was established in 1992, with a current consumption of about 300,000 tons of raw ore and an annual production of 55,000 t of Pb and Zn (Parizanganeh et al., 2012). The tailings from NILZ, estimated to be about 2.5 million tons, contain a variety of toxic elements, notably Pb, Zn, and Cd (Mohammadi and Eslami, 2007). One hundred twenty six composite samples were collected based on a network in the study area divided into two sections. Section 1 was limited to the boundaries of the NILZ Company. In this Section 38 samples were collected at two different soil depths of 0–15 and 15–30 cm. Section 2, with a total number of 88 samples, was a circle with a radius of 5 km around this plant. In this Section the samples were collected only at a depth of 0–15 cm (Fig. 1). Each sampling station represents a square block grid (2 m dimensions) where five topsoil samples (from the center and the corners) were collected, mixed and were used as one composite sample.

2.2. Spatial autocorrelation analysis

The Spatial autocorrelation can be analyzed using the local Moran's *I* index as a commonly used indicator of spatial autocorrelation. Local Moran's *I* index can be expressed as (Anselin, 1995; Levine, 2004):

$$I_i = \frac{Z_i - \overline{Z}}{\sigma^2} \sum_{j=1, j \neq i}^{n} \left[W_{ij} (Z_j - \overline{Z}) \right.$$

where z_i is the value of the variable z at location i; $\overline{Z}$ is the average value of z with the sample number of n; z_j is the value of the variable z at all the other locations (where $j \neq i$); σ^2 is the variance of variable z; and w_{ij} is a weight which can be defined as the inverse of the distance d_{ij} among locations i and j. Moran's I values ranges are from -1 to 1, representing perfect positive spatial autocorrelation (high values or low values cluster together) and perfect negative spatial autocorrelation (a checkerboard pattern) respectively. When the value of Moran's I approaches 0, it signifies no spatial autocorrelation or the spatial autocorrelation in values nearby the mean.

A high positive local Moran's *I* value implies that the target value is similar to its neighborhood, which means the locations are spatial clusters including high–high clusters (high values in a high value neighborhood) and low–low clusters (low values in a low value neighborhood) On the other hands, a high negative local Moran's *I* value means that the location under study is a spatial outlier that the values are obviously different from their surrounding locations. Spatial outliers include high–low (a high value in a low value neighborhood)

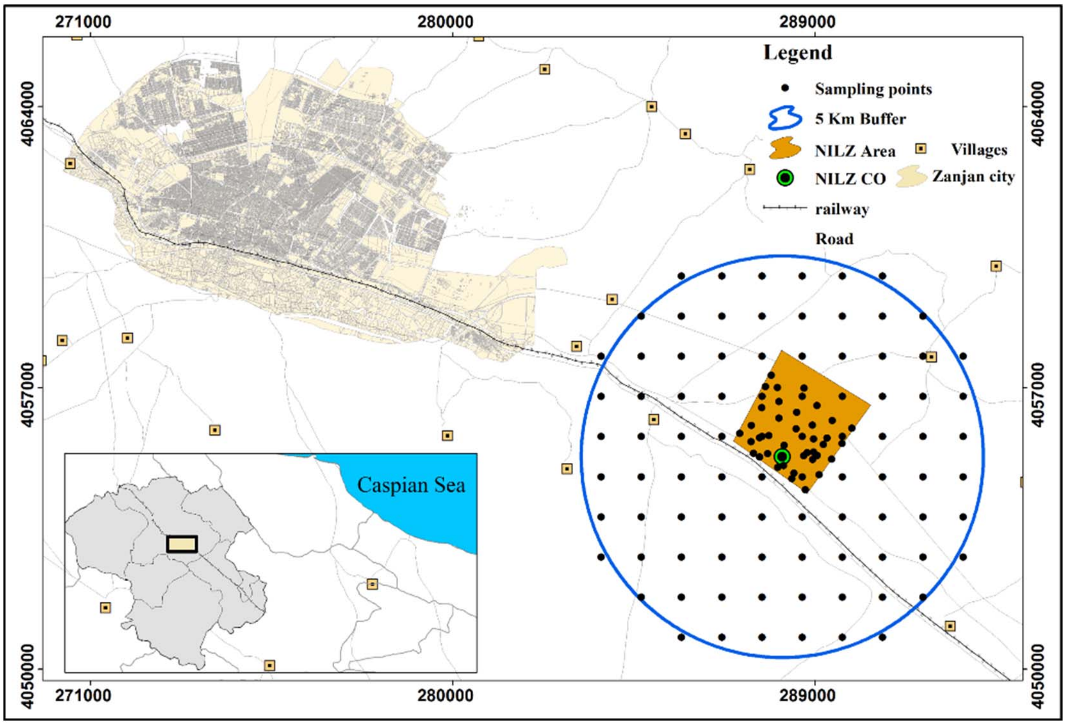

Fig. 1. Location of study area and distribution of soil sampling points.