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Ecological risk of heavy metal hotspots in topsoils in the Province of Golestan, Iran

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ABSTRACT

Human activities, such as agriculture or mining, are a continuous source of risk for heavy metal pollution that seriously disturbs the soil environment. Massive efforts are being made to identify the tools to determine indicators of soil quality condition. This study characterises and evaluates the heavy metal (Cd, Cu, Ni, Pb and Zn) contents in the Province of Golestan (northern Iran). Pollution was assessed using the pollution index (PI) and the integrated pollution index (IPI). The potential harmful effects of these heavy metals were evaluated by the Potential Ecological Risk Index (PERI) Method. Kernel density estimation (KDE) and Local Moran's I were used for the hotspot analysis of soil pollution from a set of observed hazard occurrences. In all, 346 topsoils were examined, which represent three areas, approximately including the middle-south, west and north-east areas in this region. The heavy metal concentrations in the analysed samples did not generally present high values, despite anthropic heavy metal input. However, the potential ecological risk indexes (RI) indicated that approximately 68% and 5% of the study samples had medium and high pollution levels, respectively. Multiple hotspots for the above five heavy metals were located in the middle-south and west study areas. This anthropic heavy metal input is related to mining, agricultural practices and vehicle emissions. It was concluded that a moderate and high potential ecological risk covered about 90% of this province. In contrast, the natural origin input became more marked on a long spatial scale.

1. Introduction

The natural concentration of heavy metals like Cd, Cu, Zn, Pb or Cr in soils tends to remain low to ensure an optimum ecological equilibrium. However due to human activities, the heavy metal (HM) concentration in soils frequently rises. Indeed, problems relating to the presence of HMs in agricultural soils are well-known and affect many parts of the world (Kheir, 2010), including the Middle East. Concern about increasing levels of trace elements, especially Cd and Pb, in Iranian soils has recently led the Environmental Protection Administration (EPA) of the Islamic Republic of Iran to start a collaborative research programme to establish the presence of trace elements in Iranian soils and to obtain a meaningful picture of the spatial distribution of HMs in some selected provinces, such as Golestan.

The native metal concentration depends primarily on the geological parent material composition (Alloway, 1995). Moreover, soil properties can greatly influence the availability of HMs through processes such as adsorption or complexation, which affect their ability to extract nutrients from soils (Ross, 1994). Industrial activity, power generation, mining, smelting, waste spills or fossil fuel combustion (Li and Feng, 2012; Rodriguez Martin et al., 2014a,b; Shah et al., 2010; Weber and Karczewska, 2004) are the main sources of metal input into the environment. The most apparent result is Zn, Pb, Cd or Hg soil enrichment (Adriano, 2001; Gil et al., 2004; Ramos-Miras et al., 2011; Rodríguez Martín et al., 2007, 2013b). Metal input into agricultural soils takes place mainly through agrochemicals, manures, biosolids and compost amendments (Carbonell et al., 2011; Mantovi et al., 2003; Rodríguez Martín et al., 2013a), which substantially increase Zn, Cu and Cd content in soils (Nicholson et al., 2003). Irrespectively of the origin or contamination source, HMs can accumulate in crops and reach humans through the food chain (Burger, 2008; Rodríguez Martín et al., 2013a). In the last few decades, many soil pollution surveys on trace elements have been carried out on different scales and many studies are reported in the scientific literature (Amini et al., 2005; Rodríguez Martín et al., 2009; Weber and Karczewska, 2004; Yeganeh et al., 2013). However, very few research works have been conducted in developing countries such as Iran. To date, several attempts have been made to determine the concentration of HMs in Iranian soils (e.g., Amini et al., 2005; Dankoub et al., 2012; Dayani and Mohammadi, 2010; Geranian et al., 2013; Ghaderian and Ghotbi Ravandi, 2012; Karimi et al., 2011; Nael et al., 2009; Naimi and Ayoubi, 2013; Parizanganeh et al., 2010; Qishlaqi et al.,

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2009; Yeganeh et al., 2013). Except for one recent study (Yeganeh et al., 2013), research works into HMs concentrations in Iranian soils on the provincial scale are lacking. The interrelations among these soil HMs exhibit complex correlations and variations in space. There are numerous reported studies that have applied geostatistical techniques to natural resource distributions (Li and Feng, 2012; Rodríguez Martín et al., 2007, 2014a). Spatial data help scientists to define the areas at high risk and can help decision makers to identify locations where remediation efforts should be focused (Mass et al., 2010). In this context, the purpose of this research was to quantify heavy metal concentrations and spatial patterns in surface soils in the Province of Golestan in Iran. The specific objectives were to (1) determine the Cd, Pb, Cu, Ni, and Zn contents in topsoils in this province; (2) assess the ecological risk of HMs in the study area and (3) identify pollution hotspots by these HMs in the topsoils in Golestan.

2. Materials and methods

2.1. Study area

The province of Golestan is located in the northeast of Iran and on the south-eastern shore of the Caspian Sea. The study area is located between 53° 51′ to 56° 21′ of eastern longitude and 36° 30′ to 38° 7′ northern longitude, which comprises a region of approximately 20,437.74 km^2 with 11 districts and a population of some 1.6 million.

The province is bounded to the south by the elevated mountains covered by dense forests (highest altitude: 3881 m), the Caspian Sea to the northwest and the alluvial plain to the north. In general, Golestan has a moderate, humid climate known as “the moderate Caspian climate”. The effective factors behind this climate are: the Alborz mountain range, the direction of the mountains, the altitude in the area, and proximity to the sea, vegetation surface, local winds, and altitude and weather fronts. As a result of these factors, three different climates exist in the region: plain moderate, mountainous, and semi-arid. Average annual rainfall and temperature in the region are 556 mm and 18.2 °C, respectively.

The area includes different land uses, which include agricultural, industrial, urban, forest, range and uncultivated lands. Agricultural, industrial and urban areas are located mainly in the central and western parts of this region. The most important manufacturing establishments in the province of Golestan are manufacturers of food products and beverages, chemicals and chemical products, rubber and plastic products, and other non-metallic mineral products and paper and paper products. The most important crop types in Golestan are wheat, barley, cotton, soya beans, rice and citrus fruits. Most of the mines that operate in Golestan, including the mining of coal and mining of ballast, are located in the central south and the northeast of this province (Fig. 1).

2.2. Sampling and chemical analyses

In all, 346 surface soil samples (0–30 cm) were collected in the study area (Fig. 1). The coordinates of sampling locations were recorded with a GPS. About 1 kg of each sample was sent to the laboratory for an element analysis. Soil samples were dried indoors at room temperature, and impurities such as stones and tree leaves were removed from them. They were passed through a 2-nm nylon sieve. Portions of soil samples (about 50 g) were finely ground manually using a pestle and mortar to be passed through a 0.149-mm sieve and stored in closed polyethylene bags for the HM concentration analysis.

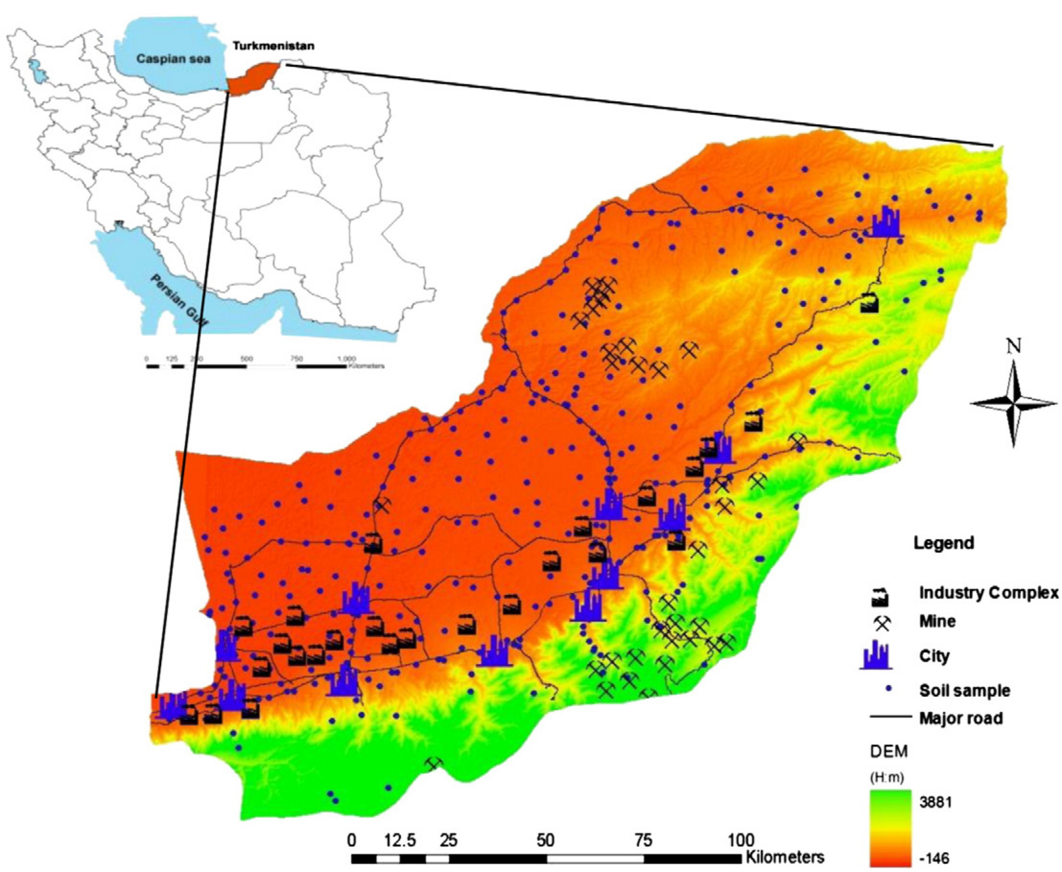

Fig. 1. The study area and the distribution of soil samples.