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Evaluation of the mobility and pollution index of selected essential/toxic metals in paddy soil by sequential extraction method

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ABSTRACT

Comparative distribution and mobility of selected essential and toxic metals in the paddy soil from district Sargodha, Pakistan was evaluated by the modified Community Bureau of Reference (mBCR) sequential extraction procedure. Most of the soil samples showed slightly alkaline nature while the soil texture was predominantly silty loam in nature. The metal contents were quantified in the exchangeable, reducible, oxidisable and residual fractions of the soil by flame atomic absorption spectrophotometry and the metal data were subjected to the statistical analyses in order to evaluate the mutual relationships among the metals in each fraction. Among the metals, Ca, Sr and Mn were found to be more mobile in the soil. A number of significant correlations between different metal pairs were noted in various fractions. Contamination factor, geoaccumulation index and enrichment factor revealed extremely severe enrichment/contamination for Cd; moderate to significant enrichment/contamination for Ni, Zn, Co and Pb while Cr, Sr, Cu and Mn revealed minimal to moderate contamination and accumulation in the soil. Multivariate cluster analysis showed significant anthropogenic intrusions of the metals in various fractions.

1. Introduction

Soil pollution is a significant environmental problem worldwide. With increasing population, the demand for food has tremendously increased, resulting in adaptation of agricultural practices that not only increase the production but also result in pollution of the surface soil (Bakircioglu et al., 2011; Fernandez-Ondono et al., 2017; Sungur et al., 2014). Pollutants once entered into the soil can be transferred to other compartments of ecosystem therefore posing serious environmental and health problems (Guillen et al., 2012; Hu et al., 2013; Qishlaqi et al., 2009). Over the years heavy metals accumulation can reduce the quality of agricultural products, crop yield, degrade soil quality and directly influences the physicochemical properties of the soil. Unlike most of the organic contaminants which lose their toxicity with biodegradation, the metals can result in long lasting toxic effects as these are not degraded (Oyeyiola et al., 2011; Tashakor et al., 2014). The need to have a good knowledge of the mobility and accumulation of heavy metals in the soil arises as agricultural soil either directly or indirectly influences the public health via food production (Qishlaqi et al., 2009). Generally, there are two main sources of the metals in the soil; natural contributions representing the metal concentration originated from parent rocks and anthropogenic contributions including application of minerals, agrochemicals, addition of organic amendments, sewage sludge and manures that contain heavy metals along with contaminates derived from industry and mining (Gabarron et al., 2017; Golia et al., 2007; Li et al., 2009). Fertilizers usage is among common agricultural practices that not only supply micro and macronutrients to the crops but also is a major source of toxic metals contamination (Reddy et al., 2013). Besides, environmental conditions such as pH, redox potential, silt, clay and organic matter contents play important role in the availability of the metals (Bakircioglu et al., 2011; Guillen et al., 2012; Sungur et al., 2015).

Generally total metal content is considered as a poor indicator of bioavailability, toxicity or mobility as these properties depend on the different chemical forms and binding between the metals and solid phases (Nemati et al., 2011; Olayinka et al., 2011; Tashakor et al., 2014). Numerous single and sequential extraction methodologies have been reported to determine the bioavailability and mobility of the metals in the soil (Abollino et al., 2006; Cui and Weng, 2015; Olayinka et al., 2011; Rao et al., 2010; Sahito et al., 2015). Sequential extraction procedures involve treating the soil with a series of extracting reagents with increasing vigour, resulting in the metals release from the sites of sorption with decreasing reactivity and therefore decreasing availability (Abollino et al., 2006; Altundag et al., 2016; Skipperud and

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Salbu, 2015; Zimmerman and Weindorf, 2010). These procedures provide information about the metal distribution among various soil phases and assist in predicting the potential outcomes of metal contamination in the soil (Arenas-Lago et al., 2014; Frentiu et al., 2009; Guillen et al., 2010; Karadas and Kara, 2012; Kennou et al., 2015).

The present study was conducted on the paddy fields of a selected irrigated area located within district Sargodha, Pakistan (32°00′29.99″ N, 72°31′39.59″ E). The objectives of the study were; (1) to determine the mobility and bioavailability of selected essential and toxic metals in the soil using mBCR sequential extraction procedure; (2) to find out the mutual relationships among the metals in various fractions; (3) to examine the metal pollution index in the soil in terms of contamination factor, geoaccumulation index and enrichment factor; (4) to identify the major pollution sources of the metals in the soil by multivariate methods. The soil samples were collected at sowing, tillering and maturity stages of the crop in order to evaluate the depletion or enrichment of the metals with plant growth and associated activities (fertilizers, agricultural sprays, irrigation, etc.). It is anticipated that the present study would furnish essential information regarding the management and monitoring process of the agricultural soil and related health risks.

2. Materials and methods

2.1. Study area

Sargodha district (32°00′29.99″ N, 72°31′39.59″ E) is one of the most productive agricultural areas of Pakistan (Fig. 1); however it also has fast-growing industrial setup. The district expands over an area of 5854 km^2 with population of about one million. Its eastern side is surrounded by Chenab River while river Jhelum flows on its western and northern sides. The area has a climate of extreme heat in the summer (> 40 °C) and moderate cold (10–15 °C) in the winter. The average temperature is about 24 °C while the average annual rainfall is almost 400 mm. Some of its chief crops include rice, wheat, sugar-cane and citrus fruits which are exported to local and international markets. Due to rapid urbanization and industrialization, the farm land is decreasing over last two decades. At the same time agro-environmental pollution poses a potential health risk in the area.

2.2. Sample collection

A multistage systematic random sampling (USEPA, 1995) was conducted in the paddy fields. Representative soil samples were collected at the three stages; sowing (Stage 1), tillering (Stage 2) and maturity (Stage 3) stages of the crop. Surface soil samples (5–25 cm) were collected with help of a stainless steel scope (USEPA, 2000); six to nine sub-samples (each covering an area of 30–50 m^2) were combined and homogenized into a composite sample (about 1 kg) and a total of 117 composite samples were collected at each stage from the study area (Fig. 1). The samples were stored in clean polyethene bags and transported to the laboratory where they were dried for 48 h at 70–80 °C until constant weight was achieved. Each sample was sieved to less than 2 mm in a plastic sieve and ground to fine powder. The samples were then stored in desiccators before further processing.

2.3. Physicochemical characteristics and soil texture

The physicochemical characteristics of the soil including pH, electrical conductivity (EC), sulphates, nitrates and chlorides were determined in water extract (1:10 ratio) (Arain et al., 2008). Soil texture was estimated using hydrometer and sieve following ASTM (1998) method in air dried samples. Sulphates, nitrates and chlorides were determined in the water extracts (5.0 g soil + 50 mL water) through ion chromatography (Radojevic and Bashkin, 1999).

2.4. Sequential extraction procedure

In the present study modified sequential extraction procedure recommended by community bureau of reference (mBCR) was performed on the soil samples (Rauret et al., 1999). The method is summarised below:

Step 1: The first step targets exchangeable and weak acid soluble metal fraction including carbonates. In this step, 40 mL of 0.11 M acetic acid was added to 1.0 g of previously dried soil sample taken in an Erlenmeyer flask (100 mL). It was subjected to mechanical shaking for 16 h at 320 vibrations per minute at room temperature. Continuous suspension of the mixture was ensured during shaking. The extract was separated from the solid residue by centrifugation at

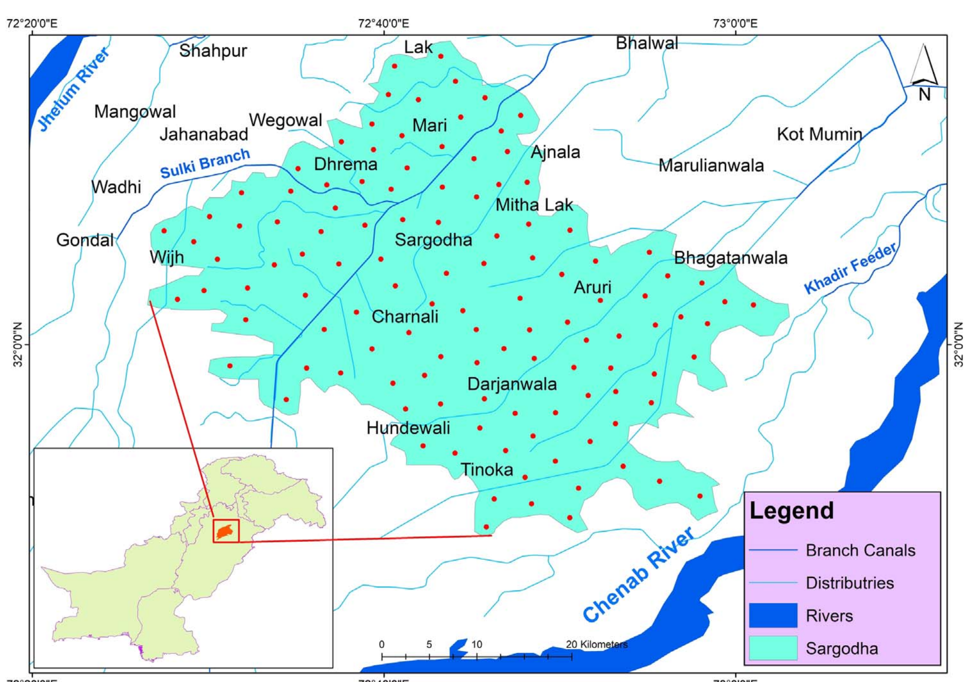

Fig. 1. Location map of the study area and sampling points (•).