

Accumulation, spatio-temporal distribution, and risk assessment of heavy metals in the soil-corn system around a polymetallic mining area from the Loess Plateau, northwest China



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ARTICLE INFO

Keywords:

Heavy metals
Soils
Corn grains
Spatio-temporal distribution
Risk assessment
Loess Plateau

ABSTRACT

To investigate the heavy metal concentrations in soil-corn system, 30 pairs of soil (0–20 cm) and corn grain samples were collected from Baiyin City, China, a typical industrial oasis in Loess Plateau. The results indicated that the mean concentrations of Cu, Zn, Cd and Pb in agricultural soils from the Dongdagou and Xidagou stream valleys exceeded the soil background concentrations of Gansu Province, China. Correlation analysis showed that the correlation among the total Cu, Zn, Cd and Pb in soils were significant at $P < 0.01$. Results showed that only a fraction of Cd and Pb in the corn grain samples exceeded the limits of eight elements in cereals, legume, tubers and its products and the maximum levels of contaminants in foods in China. The spatial distribution pattern of Cd in corn grains was highly similar to that in sampled soils. Correlation analysis revealed that the main source of Zn, Cd and Pb in corn grains was soils. Temporal distribution of heavy metals showed that heavy metal content in soils was still high, and the Cu, Cd, Pb content in corn grains showed a decreasing trend over 20 years. The values of pollution index (PI) and Nemerow integrated pollution index (NIPI) indicated that the heavy metal pollution level was $Cd > Zn > Cu > Pb$, and Cu, Zn, Cd and Pb belong to safe to heavy pollution. The results of hazard quotient (HQ) indicated that there was no obvious adverse health effect for children and adults.

1. Introduction

The non-ferrous metal mining and smelting in arid oasis has greatly promoted the rapid development of urban society and economy, meanwhile, it also brings serious pollution of heavy metals (Liao et al., 2006; Li et al., 2008; Xue et al., 2012). At present, mining and industrial activities have been one of the important reasons for heavy metals pollution in farmland soils and agricultural products (Obiora et al., 2016). Heavy metals in agricultural soils attract great attention as a result of their toxicity, non-biodegradable and persistent natures and their ability to accumulate in the food chain (Shah and Nongkynrih, 2007; Reynders et al., 2008; Xiao et al., 2015). Heavy metals in soils pose a serious health risk to food safety and human health in China (Chen et al., 2015; Ran et al., 2016). Corn is the most productive food crops in the world, is also an important source of feed and industrial raw material. As the beginning of the food chain, Corn absorbs heavy metals from soils and transports them to higher level of the food chain, especially human beings (Peralta-Videa et al., 2009; Ran et al., 2016).

At present, a large number of researches have reported the heavy metal contaminations in agricultural soils at home and abroad (Aelion et al., 2009; Cannon and Horton, 2009; Luo et al., 2012), including accumulation (Nicholson et al., 2003), spatial distribution (Xiao et al., 2015), pollution assessment (Sun et al., 2010), source analysis (L. Zhao et al., 2014), food safety (Dudka et al., 1994) and so on. However, most of these previous studies focus on the farmland, sewage irrigation area and metal smelting plants in the developed areas. Little is known about the spatio-temporal distribution of heavy metals in soils and corns in an arid area of northwest China, especially in less developed area.

Baiyin is an important copper resource-based city in China located in the central part of Gansu Province. This area is rich in mineral resources, such as copper, lead and zinc. It is divided into the Dongdagou and Xidagou stream valleys by a watershed. Nearly all of the non-ferrous metal mining and smelting plants and several other factories are located along the upstream reaches of Dongdagou stream (Wang et al., 2012). One copper processing plant and several other factories are located along Xidagou stream. Both Dongdagou and Xidagou streams

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accept treated and untreated domestic wastewater and industrial sewage (Nan et al., 2002a). The soils in the region are considered important farmland because many crops grown here, including corn. Due to the arid and semi-arid geographical location, this region had used industrial and domestic wastewater to irrigate farmland thereby accumulating heavy metals in the soils.

In this study, we measured heavy metals (Cu, Zn, Cd, and Pb) in agricultural soils and corn grains from Dongdagou and Xidagou stream valleys of Baiyin City, northwest China. The primary objectives of this study were to: (1) determine the accumulation of heavy metals in agricultural soils and corn grains; (2) identify the spatio-temporal distribution of heavy metals in soils and corn grains; (3) assess the pollution level of heavy metals in the soils and corn grains and related health risk.

2. Materials and methods

2.1. Study area and sampling

The study area is located in the Baiyin region, which is an important copper resource-based city in China located in the central part of Gansu Province. Baiyin is a calcareous soil zone with an arable acreage of approximately 107 km². Sierozem is the major soil type. Corn is a dominant crop here. Dongdagou and Xidagou streams are two important suburban drainages in Baiyin City. Nearly all of the non-ferrous metal mining and smelting plants and several other factories are located along the upstream reaches of Dongdagou stream, and one copper processing plant and several other factories are located along the upper reaches of Xidagou stream (Nan et al., 2002a; Li et al., 2006), both of which accept treated and untreated domestic wastewater and industrial sewage. The irrigation of farmland with the wastewater has a long history in the Dongdagou and Xidagou stream valleys because of the arid and semi-arid geographical location.

Thirty pairs of soil and corn samples were collected with the aid of a GPS along Dongdagou and Xidagou streams from the study area in October 2014. Fifteen pairs of samples were located in the Dongdagou stream valley (represented as E01–E15) and Xidagou stream valley (represented as W01–W15), respectively (Fig. 1). Each pair of samples

was collected at about 2 km intervals. Soil samples of the uppermost 20 cm of the soil surface were obtained. Samples were air-dried, powdered, passed through a 2 mm sieve, and homogenized before analyses. Corn grains were completely washed with tap water and deionized water. The corn grain samples were air-dried, ground and stored in sealed polyethylene bags for analysis.

2.2. Chemical analysis

The soil pH and electrical conductivity (EC) were measured in a soil:water suspension (1:2.5) at room temperature using a combined glass-calomel electrode and an EC-meter, respectively. Organic matter was measured using potassium dichromate oxidation (Lu, 2000). The total concentrations of Cu, Zn, Cd and Pb in soils were extracted by an acid digestion mixture (HNO₃ + HF + HClO₄). Corn grain samples were digested by a mixture of HNO₃ and HClO₄ (4:1, v/v). Then, heavy metal concentrations in the samples were determined using atomic absorption spectrophotometry (Thermo Fisher, SOLAAR M6).

2.3. Quality control

The chemical analysis of each sample was conducted in triplicate relative to a control for analytical precision. For quality control, standard reference samples GBW07408 (GSS-8) for soils, GBW10015 (GSB-6) for plants and blanks were included. The standard deviation was < 5% for all elements. All glassware and plastic containers were soaked in 10% (v/v) HNO₃ for at least 24 h and thoroughly cleaned with deionized water before utilization. All chemical reagents were guarantee reagent.

2.4. Pollution indicators

Pollution index was used to assess the quality of soil and to estimate the impact of anthropogenic activities (Loska et al., 2004). According to Lee et al. (2006), pollution index (PI) was defined as:

$$PI = C_i / C_{oi} \quad (1)$$

where C_i is the concentration of a given i th metal in soils (mg kg⁻¹),

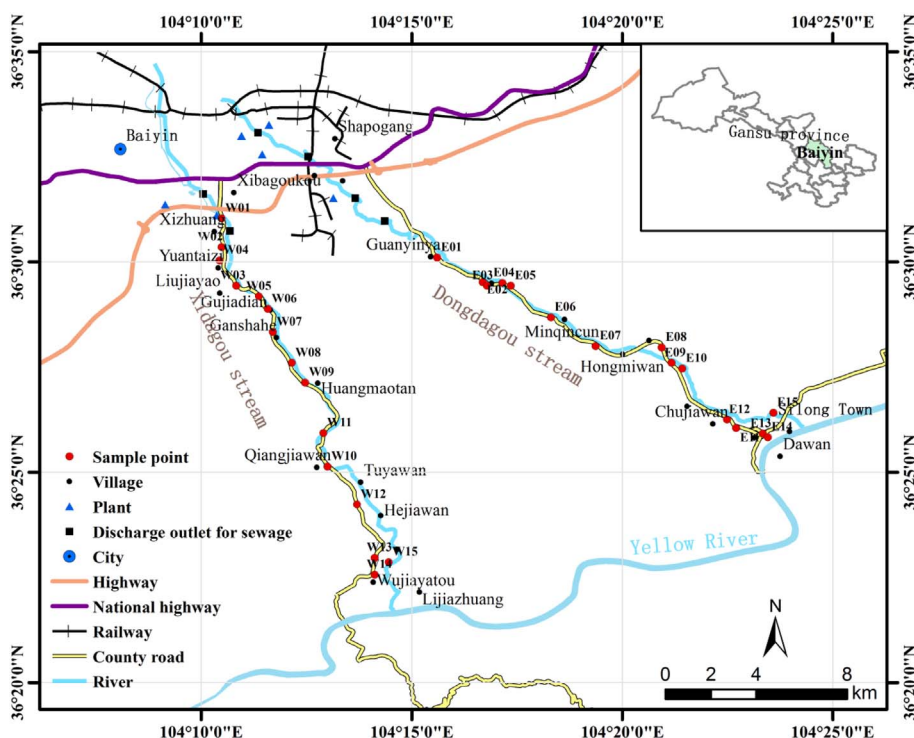


Fig. 1. Locations of the sampling sites in Dongdagou and Xidagou stream valleys, Baiyin City, Gansu province, China.

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