Spatial variability of cadmium concentration in wheat farm soils

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Abstract

Heavy metals are naturally present in the environment, but increasing levels of these elements are becoming a serious problem worldwide. The objective of this study was to assess the spatial variability and availability of cadmium (Cd) in the topsoils of 4000 km^2 wheat farms. Consequently, 255 soil samples were collected from the study area. The DTPA-extractable and total Cd concentrations, pH, EC, organic carbon and clay contents of soil samples were measured. The total Cd concentrations in 95 percent of samples exceeded 0.8 mg/kg value. However DTPA-Cd concentrations in 25 percent of the samples were more than 0.1 mg/kg. The correlation between DTPA-Cd and both organic carbon ($r=0.63^{**}$) and soil pH ($r=0.58^{**}$) was significant ($p<0.01$). Also, a significant ($p<0.05$) correlation was obtained between DTPA-Cd concentration and clay content ($r=0.55^{*}$). A significant ($p<0.05$) correlation was obtained between total Cd and organic carbon ($r=-0.48^{*}$). The correlation analysis indicated that soil organic carbon alone explains 63 percent of DTPA-Cd variation in the study area. All the obtained semivariograms showed a high degree of spatial dependency. The semivariograms of total Cd and root square of DTPA-Cd were fitted well with a spherical model. Risk probability maps were made, using ordinary Kriging for both variables.

Key Words

Cadmium, soil pollution, soil properties, spatial variability, wheat farms.

Introduction

Rising levels of heavy metals are becoming a serious problem worldwide (Norvell *et al.* 2000). Cadmium is recognized as being one of the most mobile trace metals circulating in the environment and can readily enter the human food chain from agricultural and industrial sources and causes some problems for human health. Plants are the main pathways for cadmium entry into the food chain (Ingwesen and Streck 2005). The uptake of cadmium by plants and ingestion by humans depend on the bioavailability of Cd in the soil. Therefore, the knowledge on spatial variability and availability of Cd in agricultural soils are essential to develop effective management recommendations (Norvell *et al.* 2000). Predictions of polluted areas are often based on geostatistical methods, which calculate unbiased estimates of heavy metals at unsampled locations. Geostatistical methods have been widely used to document the spatial variability of soil properties. Wu *et al* .(2002) reported that the variation of grain cadmium and soil characteristics in a durum wheat field were spatially dependent with range distances that varied from about 30 to 55 m. A spherical model was fitted successfully to the variograms for the studied characteristics. In other study, Reis *et al.* (2005) predicted soil arsenic concentrations at unsampled locations of a mine in Portugal using a spherical model. In arid regions of Iran, farmers extensively use fertilizers to obtain more products. In addition, an abundance soil and water resources and suitable temperatures in Khuzestan province provide excellent conditions for crop production during the whole year. Therefore, high loads of heavy metals are imposed by fertilizer application into intensively farmed and overly irrigated soils, which can cause problems for food chain health. Up to now, no comprehensive survey of soil Cd contamination has been carried out in the region. In this study, a large scale investigation was conducted to assess the spatial variability and availability of Cd in wheat-farm soils of Khuzestan province. Since wheat is the main crop and food in Iran, the wheat farms were chosen for the study.

Methods

The designated soil samples (0-20 cm) were collected from 255 wheat farms in a study area of 4000 km^2 in Khuzestan province (47˚40'E to 50˚33'E and 29˚57'N to 30˚00'N), Iran, before plant harvesting in mid May, 2008. Soil samples were collected from different cities using a weighing method, i.e., the more wheat in a farm area, the more soil samples. The coordinates were recorded with a GPS apparatus. All soil samples were then air-dried and passed through a 2-mm sieve. Total Cd concentration were extracted, using concentrated HCl and HNO_3 and were analyzed by an atomic absorption spectrophotometer. Available cadmium was extracted by diethylenetriaminepenntaaceticacid (DTPA) and analyzed by a graphite atomic absorption spectrophotometer. Electrical conductivity and pH of soil samples were measured in a saturated extract. Clay content was determined using the hydrometric method. Organic carbon was determined by wet oxidation. Spatial variability was studied with semivariograms, which were created and evaluated according to standard geostatistical methods. Before creating semivariograms, a square root (sqrt) transformation was applied to the available cadmium data, which normalized the distribution. The best model for semivariograms was selected comparing statistical parameters, correlation coefficient (r^2), mean absolute error (MAE) and mean bias error (MBE), and was used for kriging of cadmium (total and available). The GS^+ (v3.1 for windows, Gamma Design Software, Plainville, MI) package was used for geostatistical analyses. Correlation and regression analyses between total and available Cd and soil parameters were done using the SPSS14 software.

Results and discussion

The descriptive statistics for topsoil Cd concentration (total and DTPA-extractable (available)) is presented in Table 1.

Table 1. Summary statistics of soil cadmium concentrations (mg/kg).

Variable†	Minimum	Maximum	Std	CV %	Skewness	Kurtosis
Cd_t	0.75	2.19	0.26	17.5	0.029	0.235
$sqrtCd_{DTPA}$	0.002	0.54	0.11	41	-0.15	0.22

†Cd_t: Total Cd concentrations, $sqrtCd_{DTPA}$: Square root of DTPA-extractable Cd

Total cadmium was distributed in an approximately normal distribution. Although DTPA-extractable Cd concentrations had a highly skewed distribution, the square root transformation caused a normal distribution for the available data. Based on the coefficient of variation, the DTPA-extractable Cd was nearly twice as variable as the total concentration of Cd on the regional scale. This indicates that the availability of Cd is being affected by different soil properties in this region. Total cadmium concentrations in 95 percent of the samples exceeded the suggested Swiss threshold of 0.8 mg/kg, while available cadmium concentrations in 25 percent of the samples were more than 0.1 mg/kg. Analysis of the correlation coefficients showed that there was no significant ($p<0.05$) correlation between total Cd concentration and soil properties (clay, EC and pH) in this study except for organic carbon ($r=-0.47^*$). However, the correlation between DTPA- extractable Cd and both organic carbon ($r=0.63^{**}$) and soil pH ($r=0.58^{**}$) was significant ($p<0.01$). Also, a significant ($p<0.05$) correlation was obtained between DTPA-extractable Cd concentration and clay content ($r=0.55^*$). All the obtained semivariograms indicate a high degree of spatial dependency (Figure 1).

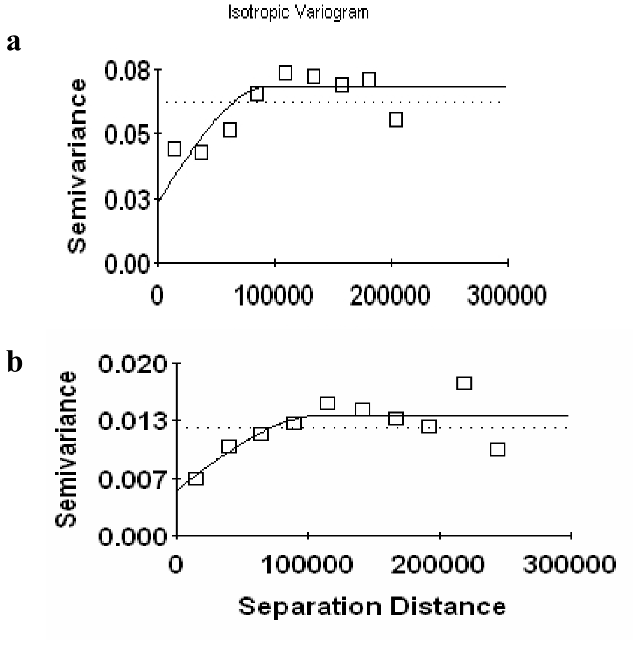

Figure 1. Semivariograms for the total (a) and available (b) soil Cd concentration.

The semivariograms of total Cd and root square of DTPA-extractable Cd were fitted well with a spherical model. This model had the largest r^2 and the least MAE and MBE values compared to other models. The nugget, sill and range values for the spherical model of total Cd were 0.025, 0.073 and 95000 m, respectively. The values for the spherical model of available Cd were 0.0053, 0.014 and 112000 m for nugget, sill and range, respectively. Regarding normal distribution of total and transformed DTPA-extractable Cd data, ordinary kriging was selected. The produced kriging map of DTPA-extractable Cd revealed two polluted zones in the study area. The first hot spot is located at the east of the province where dry land farming is the common practice, and this needs to be studied in more detail. The other hot spot is located at the south of the province where the farms were affected mostly by intensive irrigated agriculture and also 8 years of the Iraq-Iran war. As a consequence of these two reasons, a high amount of metals was added to agricultural soil.

Conclusion

Agricultural activities have significantly increased the Cd concentration in the topsoils of wheat farms in the study area. Both total and available Cd concentration exceeded the permissible threshold value in the study area (95% and 25% of the samples, respectively). Only organic carbon content significantly affected the total Cd concentrations, while clay content, organic carbon and soil pH showed significant contributions to Cd availability. The results also indicated that the risk of Cd availability for plants could not be quantified only by its total or available concentration. The other factors (in this study clay content, organic carbon and soil pH) should also be considered to assess the state of soil contamination by Cd. Future investigations should focus on the effect of clay mineralogy and the compounds of organic carbon on soil Cd availability.

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