



Cadmium desorption behaviour in selected sub-tropical soils: Effects of soil properties



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ABSTRACT

To predict the environmental fate and mobility of contaminants, it is critical to study desorption behaviour of contaminants in soil system. Cadmium (Cd) desorption kinetics studies were conducted in ten sub-tropical soils of the northern part of Iran, with a wide range of physico-chemical properties. Treatments consisted of two levels of cadmium (15 and 30 mg kg⁻¹ as CdCl₂). Soils were incubated at 20% moisture (w/w) level and 25 ± 1 °C. After weeks, cadmium desorption pattern was investigated by Diethylene Triamine Pentaacetic Acid (DTPA) extraction with equilibration periods from 30 to 960 min. Results showed that two constant rate, parabolic diffusion and simple Elovich equations best described Cd desorption in these soils. The coefficients of kinetic equations had significant correlation with each other. The findings of this investigation indicated that pH, cation exchange capacity, organic matter, and oxalate extractable Fe are the most important soil characteristics in controlling Cd desorption behaviour in sub-tropical soils.

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1. Introduction

Environmental pollution due to development in technology is one of the most critical problems of this century (Agrawal and Sahu, 2006). Uncontrolled mining, manufacturing and disposal of metals and metal-containing materials inevitably cause environmental pollution. While there are vast differences in the amounts of different metals produced, soil concentrations of most metals, especially nickel, chromium, and cadmium, have increased over the last 60 years (Alloway, 1990; Naidu et al., 1997).

Bioavailability, and hence potential toxicity or deficiency, of trace metal ions in soil depends on its concentration in soil solution and on the soil's ability to release trace metal ions from the solid phase to replenish those removed from solution by plants (Backes et al., 1995). Of the heavy metals often found contaminating soil and groundwater, cadmium (Cd) is both readily available and highly toxic (Alloway, 1990; Wang and Xing, 2002).

Cadmium is one of the heavy metals emitted to the environment from industrial activities and from various chemical products, and can readily enter the human food chain, as it is weakly bound to soil constituents compared to other trace metals. Because of the association of Cd

with a number of human diseases, severe damages to kidney and lungs, and other pathological symptoms, there has been considerable interest in the behaviour of Cd in soil environments (Bruemmer et al., 1986; Nriagu, 1980; Zaman et al., 2009).

Fate and bioavailability of metals in soils are controlled by three main processes: (1) removal of metals from the soil solution by sorption onto soil particles, (2) release of metals from the soil particle to the soil solution (desorption), and (3) precipitation–dissolution of metals as an independent phase in the soil matrix (Sparks, 2003; Sposito, 1989). Therefore, knowledge of metal desorption characteristics of heavy metals from soils is of importance in determining their fate in soils (Shirvani et al., 2006). Understanding the mechanisms involved in retention, availability and mobility of Cd is important in determining the permissible leaching capacity for a given soil and its distribution in a soil profile. However, the environmental impact of soil Cd on plants and water table is governed by the dynamics of Cd concentration in the soil solution, and the latter is controlled by its desorption from the solid phase (Naidu et al., 1997).

In desorption experiments, the adsorbed metal ions are desorbed by multiple extractions with solutions of low electrolyte concentrations (Amacher et al., 1988; Dudley et al., 1988; Jarvis and Jones, 1980).

The factors that control desorption of soil Cd include Fe oxides content (Davis and Kent, 1990), type and contents of clay minerals (Jobstmann and Singh, 2001; Singh et al., 2000), organic matter (Hettiarachchi et al., 2003; Naidu and Harter, 1998) and the other solution conditions such as pH, temperature, ageing and Cd concentration (Glover et al., 2002; Gray et al., 1998; Mustafa et al., 2006; Srivastava et al., 2005).

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The knowledge of heavy metal desorption processes is mainly based on the study of equilibrium conditions. Using thermodynamic approach can predict only the final state of a soil system from an initial non-equilibrium state, while the analysis of the kinetics may yield important information concerning the nature of the reactions at a given time (Dang et al., 1994). In a desorption kinetics study, Mustafa et al. (2004) observed that Cd desorption decreased with an increase in pH from 5.0 to 6.0 in both Na and Ca electrolyte systems, and also, low Cd desorbability from goethite may be due to its entrapment in the cracks in goethite structure. Srivastava et al. (2008) examined Cd and Pb desorption from kaolinite and observed that the decrease in Cd and Pb desorption is likely due to inter- and intra-particle diffusion of these ions, which should be enhanced at elevated temperatures due to a reduction in the solvated ion radius at higher temperatures. There are relatively few studies that have examined desorption, and even fewer that have measured desorption kinetics (McLaren et al., 1998), particularly Cd desorption kinetics (Tran et al., 2002). Moreover, limited information is available on the effects of contaminant ageing (i.e., the contact time of Cd with the soil) on Cd desorption in soils (Seuntjens et al., 2001). The previous studies that examined metal desorption kinetics from soil (Dang et al., 1994 [Zn]; Ghasemi-Fasaei et al., 2006 [Cu]; Kuo and Mikkelsen, 1980 [Zn]; Lehmann and Harter, 1984 [Cu]) have all used complexing agents (ethylenediamine tetraacetic acid [EDTA], diethylenetriamine pentaacetic [DTPA], or sodium citrate) to desorb metals from the soil.

The soils in Guilan province, which is located in the northern part of Iran, are characterized by acidic to neutral pH, and higher Fe and Al oxide contents than soils from other parts of the country (Ghasemi-Fasaei et al., 2007). The climate is subtropical with high annual precipitation (~1000 mm) (Bahrami et al., 2010) which is distributed evenly throughout the year, and the underground water table is shallow. Under such climatic conditions, Cd desorption is crucial in controlling Cd mobility and transport in the environment. Little information is available about the chemistry of Cd release characteristics of the soils in this region. Therefore, this study was conducted to investigate (1) the efficacy of desorption kinetic models in predicting Cd desorption trend in sub-tropical soils, and (2) the effect of physicochemical soil properties on controlling Cd desorption behaviour.

2. Materials and methods

2.1. Soil experiments

In order to collect samples from different agricultural fields, first, the map of Guilan province was divided into 70 points with the grid size of $10 \times 10 \text{ km}^2$ (using map networking method) (Fig. 1). All soil samples (0–30 cm) were collected from the central point of each grid reference, and then transferred to the laboratory, air-dried, mildly ground with a wooden roller to pass through a <2 mm sieve, and stored in airtight polyethylene containers.

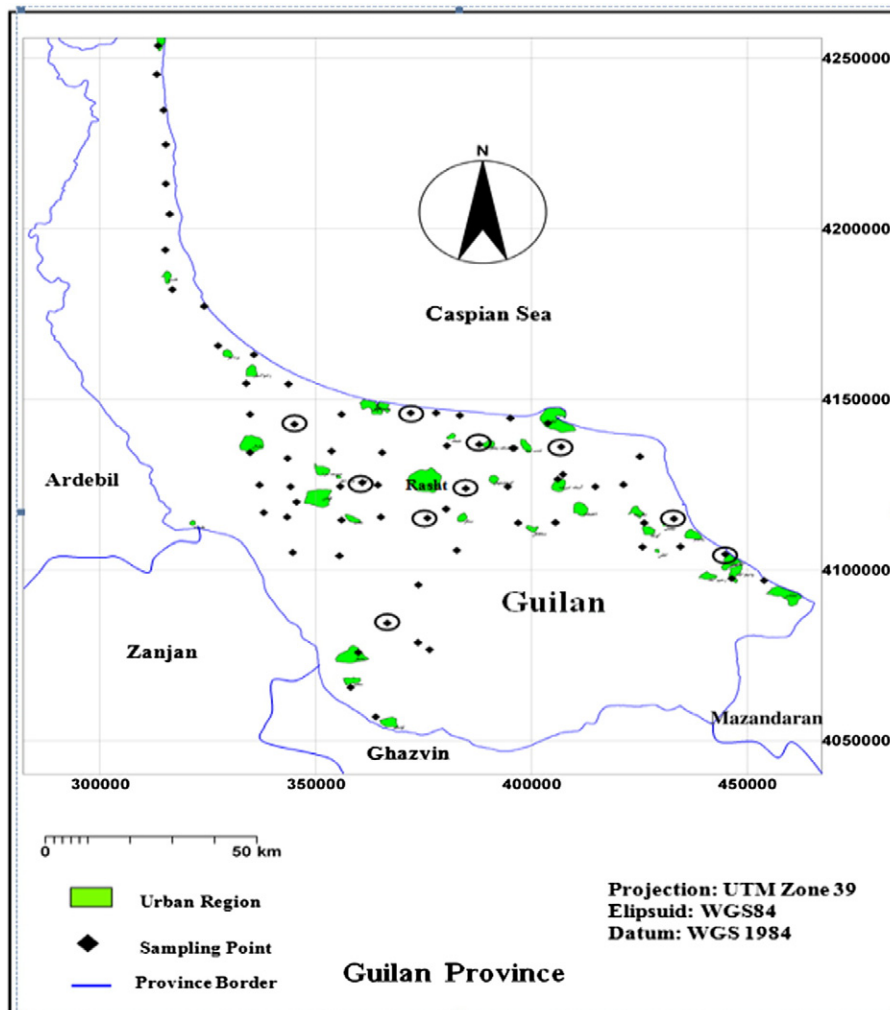


Fig. 1. Sample location map of study area in Guilan Province.

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