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International Soil and Water Conservation Research 3 (2015) 196–208

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# Acid leaching of heavy metals from contaminated soil collected from Jeddah, Saudi Arabia: kinetic and thermodynamics studies

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Received 25 May 2015; received in revised form 3 August 2015; accepted 10 August 2015
Available online 22 August 2015

**Abstract**

Urban soils polluted with heavy metals are of increasing concern because it is greatly affecting human health and the ecological systems. Hence, it is mandatory to understand the reasons behind this pollution and remediate the contaminated solid. The removal of heavy metals from contaminated soil samples collected from the vicinity of the sewage lake in Jeddah, Saudi Arabia, was explored. The leaching process was studied kinetically and thermodynamically for better understanding of the remediation process. The results showed that the soil samples were slightly basic in nature, and tend to be more neutral away from the main contaminated sewage lake area. The total metal content in the soil samples was measured using the aqua regia extractions by ICP-OES and the results showed that many of the heavy metals present have significant concentrations above the tolerable limits. In general, the metal concentrations at different sites indicated that the heavy metal pollution is mainly due to the sewage discharge to the lake. The results showed excellent correlation between the concentrations of Co, As, and Hg with the distance from the main contaminated area. The leaching of Co, As, and Hg using 1.0 M hydrochloric acid from the soil was studied kinetically at different temperatures and the experimental results were fitted using different kinetics models. The experimental data were best described with two-constant rate and Elovich equation kinetic models. Also, the thermodynamic study showed that the leaching process was spontaneous, endothermic and accompanied with increase in the entropy. In general, the polluted soil could be remediated successfully from the heavy metals using the acid leaching procedure in a short period of time.


*Keywords:* Acid leaching; Contaminated soil; Heavy metals; Kinetics; Thermodynamics

## 1. Introduction

Since the industrial revolution, anthropogenic activities introduced various hazardous heavy metals into soil. Heavy metal pollution of soils is an increasingly urgent problem all over the world, resulting from the intensive use of wastewater for irrigation, sewage sludge, pesticide and emissions from vehicle exhausts, mining, and smelting (Shi,

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Peer review under responsibility of IRTCES and CWPP.

http://dx.doi.org/10.1016/j.iswcr.2015.08.002

Shao, Li, Shao, & Du, 2009). Generally, heavy metals are persistent, and undegradable unlike other organic pollutants (Islam, Jo, & Park, 2012). Normally, soil works as a natural adsorbent which immobilizes heavy metals and decreases their bioavailability through different mechanisms (precipitation, adsorption process and redox reactions), but when the concentrations of heavy metals exceed the soil capacity, the heavy metals become mobilized, resulting in serious contamination of agricultural products or ground water. Contamination of the soil by heavy metals has a great impact on the soil parameters, and it may negatively affect the soil characteristics and limit their productive and environmental functions. For example, heavy metals decrease the microbial activity of the soil microorganisms. These microorganisms usually contribute significantly to the degradation and mineralization of organic matter and consequently to the recycling of nutrients in the soil (Castaldi, Rutigliano, & Virzo De Santo, 2004). Also, the immobilization of the heavy metals within different organic and inorganic colloids present in the soil may decrease their availability as nutrients for other living organisms including plants (Nannipieri, Badalucco, Landi, & Pietramellara, 1997). Furthermore, the presence of heavy metals in the soil may lead to a great change in the physiological and biochemical processes in plants, which causes growth reduction, and accordingly reduces crop yield (Chibuike & Obiora, 2014). Hence, remediation of polluted soils from heavy metal contamination is crucial (Rosestolato, Bagatin, & Ferro, 2015; Qi, Szendrak, Yuen, Hoadley & Mudd, 2011). Soil washing using chemical reagents is considered as one of the few permanent treatments to remove heavy metals from polluted soils (Dermont, Bergeron, Mercier, & Richer-Lafl'eche, 2008). Chemical reagents such as acids/bases, and chelating agents are usually employed to remove the heavy metals from the soils into an aqueous solution. Hydrochloric acid, EDTA, and subcritical water are the most used reagents used for soil washing and removal of metals from contaminated soil due to their high metal removal efficiency (Fedje, Yillin, & Strömvall, 2013; Wasay, Barrington, & Tokunaga, 2001; Isoyama & Wada, 2007; Rao, Sahuquillo & Lopez Sanchez, 2008; Udovic & Lestan, 2007; Voglar & Lestan, 2013). Many of the research studies mentioned the higher efficiency of soil washing using HCl compared with other leaching agents including EDTA, $H_2SO4$ and $HNO_3$ (Moutsatsou, Gregou, Matsas, & Protonotarios, 2006; Moon, Lee, Wazne, & Park, 2012). Generally, soil washing with acids such as HCl relies on ion exchange and dissolution of soil components/discrete metal compounds to extract metals, whereas chelating agents such as EDTA solubilize metals through complexation. One of the important factors which affects the soil's washing efficiency is the extraction time with the chemical reagent as the rate of metal extraction is a factor of time. However, despite the fact that many studies focus on the soil washing using different chemical reagents, the number of researches focused on the leaching process kinetically and thermodynamically are still scarce in literature. Kinetic studies are crucial to understand the factors and means of transport for metals from the soil to the aqueous phase. Thermodynamic calculation of the washing process is required to understand the mechanism of dissolution and mobilization and their spontaneity by calculating the different thermodynamic parameters.

There has been a considerable increase in the population of Jeddah, Saudi Arabia, during the last few decades. Most of the collected treated sewage in Jeddah, usually treated in several sewage treatment plants, is usually discharged into the Red Sea and/or a sewage lake. This sewage lake was established in 1992, and stretched over an area of 2.6 $km^2$. It became the main sewage downstream, which makes the lake a direct source of pollution in the city, especially to residential areas around the lake. The hypotheses of this research is that the sewage discharge is the main source of contamination of the soils around the sewage lake, and this contamination reached its maximum in the vicinity of the lake and decreased as we go further from the lake. Also, the acid leaching could be an effective procedure for the environmental remediation of the polluted soil from heavy metals.

The objectives of this research were to investigate the heavy metals contamination and remediation of three soil samples collected from different areas in the vicinity of the sewage lake in Jeddah, Saudi Arabia, in addition to studying the correlation between the heavy metal contamination and the distance from the main contamination site. This research also focused on the remediation of the contaminated soils using the acid leaching procedure using 1.0 M hydrochloric acid and explore the effect of leaching time, and temperature kinetically and thermodynamically in order to achieve a better understanding of the metal leaching and mobilization process from the contaminated soil samples.

## 2. Material and methods

### 2.1. Chemicals

All chemicals used in this study were obtained from Sigma-Aldrich (analytical grade), and all solutions were prepared using deionized water.