Pedosphere **26**(4): 431–450, 2016
doi:10.1016/S1002-0160(15)60055-8
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Risk Assessment of Metal Contamination in Soil and Groundwater in Asia: A Review of Recent Trends as well as Existing Environmental Laws and Regulations

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(Received November 27, 2015; revised April 12, 2016)

ABSTRACT

Asia is experiencing a more rapid economic growth compared to any other regions. The contamination of soil and groundwater with metals can mainly be attributed to human activities; therefore, risk assessments to characterize the nature and magnitude of risks to humans and ecological receptors from contaminants are important. Risk assessments are often iterative processes, which involve identification and filling data gap. Experimental samplings, geostatistical and multivariate statistical methods as well as multimedia risk assessment modeling are the three major methodologies used in the assessment of metal contamination in soil and groundwater. This review highlights a number of measurements for improving risk calculation methods and expounds scientific approaches that involve the identification of the major source of contamination, exposure pathways and bioavailability of metals. In general, risk assessments of metals in soil and groundwater worldwide are mainly focused on the levels of contamination, identification of exposure pathways, and prediction of the probability of contamination. To date, very limited studies have reported the development of relevant environmental laws and policies in the regulation of soil and groundwater contamination in Asia. The development, variations and limitations in the regulations of soil and groundwater contamination among developed countries may provide helpful guidance for the developing countries in Asia.

Key Words: bioavailability of metals, environmental regulation, exposure pathway, levels of contamination, source of contamination

Citation: Teh T L, Nik Norulaini N A R, Shahadat M, Wong Y S, Mohd Omar A K. 2016. Risk assessment of metal contamination in soil and groundwater in Asia: A review of recent trends as well as existing environmental laws and regulations. *Pedosphere.* **26**(4): 431–450.

INTRODUCTION

Risk assessment is a conceptual framework that provides the mechanism for a structural review of information that is relevant to estimate environmental outcomes. The risk assessment paradigm divides the risk assessment process into four distinct steps: hazard identification, dose-response assessment, exposure assessment and risk characterization. The "weakest link" in the risk assessment process is the exposure assessment. Exposure assessment requires the determination of the emission, pathways and rates of movement of a substance to which environmental spheres may be exposed to (Sipter *et al.*, 2005). Typical contaminants include trace metals, which pose potential threats to human health and to the ecological systems as well (Luo *et al.*, 2011).

In the last four decades, the study of metal contamination risks has emerged as an important frontier in environmental research. In developed countries, frameworks and mechanisms for assessing and managing the risks posed by contaminated sites have already been established (Rodrigues *et al.*, 2009). Developed countries, such as USA, Canada, and European countries have always relied on maps, historical risk studies, industrial permits, assessments of surface and groundwater quality and site inspections to provide indications that a site may be potentially polluted (EEA, 2007).

Asia is experiencing a much faster economic growth compared to any other regions. Poverty forces people to overexploit natural resources, leading to degradation (Jalal, 1993). Despite the progress in risk assessment in Asia, the foundation of this work is still relatively inadequate. Relevant technical resources such as technical guidance for chemical assessments are insufficient and they do not have appropriate prediction models to

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carry out proper chemical hazard assessments and exposure assessments. In addition, developed risk assessment methodologies, model tools and exposure scenarios from some developed countries could provide helpful references. With the implementation of new regulations, governments are paying attention towards developing better risk assessments of metals.

This paper provides an extensive review based on recent literature, particularly on the methodologies used in the assessment of trace metal contaminations and risks to soil and groundwater. This review summarizes the sources of contaminants together with the factors affecting the mobility of contaminants. It also details a critical analysis of the historical developments, current status, and limitations of existing environmental laws and regulations for soil and groundwater from around the world. This analysis may act as a guideline for risk assessment as well as for proposing recommendations for the environmental management of soil and groundwater, especially for the developing countries in Asia.

METHODOLOGIES USED IN ASSESSMENT OF METALS IN SOIL AND GROUNDWATER

Sampling and analysis

The locations of sampling were very diverse, reflecting the variety of urban landscapes and different study objectives. The usual procedure was followed when collecting representative soil samples from different functional zones including industrial, commercial, residential and recreational areas. In addition, extensive soil surveys, such as those that employed a systematic sampling strategy or grid method, have been adopted to investigate current conditions of trace metal contamination at a municipal scale (Li *et al.*, 2004; Lee *et al.*, 2006; Li *et al.*, 2009). Several studies that have focused on the assessment of metals at real sampling sites and chemical analyses are listed in Table I. Comprehensive sampling of soils, waters, vegetation, crops and sediments has been implemented in order to better investigate the effects and transport pathways of metals. The presence of metals such as aluminum (Al), arsenic (As), cadmium (Cd), cromium (Cr), copper (Cu), mercury (Hg), magnesium (Mg), manganese (Mn), lead (Pb), titanium (Ti) and zinc (Zn) were determined using flame atomic absorption spectroscopy (FAAS), X-ray fluorescence (XRF), graphite furnace atomic absorption spectrometry (GFAAS), atomic absorption spectrometry (AAS), hydride generation atomic fluorescence spectrometry (HG-AFS), cold vapor atomic absorption spectrometry (CVAAS), inductively coupled plasma mass spectrometry (ICP-MS), or inductively coupled plasma atomic emission spectrometry (ICP-AES).

Geostatistical and multivariate statistical methods

The selection of the appropriate level of details is necessary during risk assessments, which depends on the complexity and particular circumstances of the sites, costs and other constraints (USEPA, 1990). The need to quantify and minimize investigation costs can be effectively overcome with the use of geostatistical and multivariate statistical methods (Carlon *et al.*, 2001). Geostatistics is a collection of different methods for the analysis and estimation of data correlated in space or time. It is based on the theory of regionalized variables. The fundamental thought is that both the value of the variable and the location have important roles (Einax and Soldt, 1999). Multivariate statistical methods can be used when there is another possibility of analyzing multidimensional datasets without any information on the spatial location. Multivariate statistical techniques, such as principal components analysis (PCA), factor analysis (FA), cluster analysis (CA) and geostatistical analysis, are powerful tools to segregate sources contributing to the observed contamination (Yay *et al.*, 2008). These techniques have been used to differentiate between different natural sources that cause variations in soil composition and to identify pollution sources affecting the metal content of soils (Li and Feng, 2012). Multivariate and geostatistical analyses have also been applied in the studies of spatial uncertainty and hazard assessment (Liu *et al.*, 2006; Chen *et al.*, 2009; Hang *et al.*, 2009).

Multimedia risk assessment models

Multimedia models have been developed as valuable tools to calculate overall persistence and long-range transport potential of metal contaminants, which are widely used to determine the chemical fate and potential environmental concerns across large geographical regions (Zhu *et al.*, 2014). The multimedia risk assessment models, such as the multimedia environmental pollutant assessment system (MEPAS) model and the multimedia contaminant fate, transport and exposure model (MMSOILS), have become increasingly popular over the past few years due to their wide applicability and consideration of multiple contaminants and contact media. The MEPAS model, developed by the Pacific Northwest National Laboratory of the United States Department of Energy in 1995 (USEPA, 1996; Strenge and Smith, 2006), is commonly used in the risk assessments of soil, groundwater and