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Ecological Risk Assessment of Lead (Pb) after Waste Disposal from Metallurgical Industries

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Abstract: Not being available sufficient information about ERA of lead, this paper provides a brief critical review to the mentioned concept. Being presented in soils, heavy metals constitute serious environmental hazards from the point of view of polluting the soils and adjoining streams and rivers. Pb is generally the metal of great concern as well as being phytotoxic. Ecological risk assessment is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. Metallurgical waste like other waste materials consists not only of Pb, but also consists in large quantities relatively. The ubiquitous distribution and known toxicity of lead pollution in urban environment are posing great concern, in term of human health and environment. According to the importance and criticality of this issue, a holistic risk-based approach is inevitable at least for environmental health and monitoring (EHM). Reviewing literature, it is found that approximately most of the researches have been carried out in aquatic environments. From the other side, those carried out in terrestrial environment, are non-Pb focusing. Considering the researches pertaining to ERA, however few researches have been carried out in the field of metallurgical industries, none of them has addressed the Pb ERA in a holistic approach.

Key words: DSS, EHM, ERA, metallurgical industries, Pb

INTRODUCTION

Being a country with plenty of metallurgical industries, Iran is one of the regions that its metallurgical industries have a great potential in producing materials such as steel, iron and etc. From the other side, focusing on the great deals of raw materials containing different heavy metals, that one is lead (Pb), such industries dispose enormous amounts of sludge and sewage as well as waste water out into the living environment. Not having sufficient information about their fate, exposure, and effects as well as environmental risks posed to the environment, while not considering their hazardous nature, an ecological risk assessment is necessary to reveal such issues.

Heavy metals present in soils constitute serious environmental hazards from the point of view of polluting the soils and adjoining streams and rivers (Seignez *et al.*, 2008). Consequently not only the physical part of environment is affected by the heavy metals but also the ecological part of environment is seriously affected.

The ubiquitous distribution and known toxicity of lead pollution in urban environment are posing great concern, in term of human health and environment (Markus and McBratney, 2001). If heavy metals move too rapidly in a particular soil, they can pollute ground water supplies, especially in areas with high water table. Some factors including the properties of the metals, soil texture, pH and competing cations in the soil solution that enhance their mobility can result in more plant uptake or leaching of these metals to ground water. Pb like the other three elements of Zn, Cu and Cd is generally the metal of great concern as well as being phytotoxic (Udom *et al.*, 2003). Mobility of Pb is different from soil to soil leading to different amounts of ecological risk.

Risk assessment uses science, but is not science in the conventional sense, i.e., it does not seek to develop new theories or general knowledge. It rather uses scientific knowledge and tools to generate information that is useful for a specific purpose. In this sense, risk assessors are like engineers, and in fact much of the practice of ERA has been developed by engineers (Suter, 2007). In recent years, methodology of ecological risk assessment has been developed and applied frequently for addressing various circumstances where ecological impacts are suspected or have occurred due to environmental contamination (Chen and Ming-Chao, 2006). Ecological risk assessment is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The process is used to systematically evaluate and organize data, information, assumptions, and uncertainties in order to help understand and predict the relationships between stressors and

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ecological effects in a way that is useful for environmental decision-making. An assessment may involve chemical, physical, or biological stressors, and one stressor or many stressors may be considered. Descriptions of the likelihood of adverse effects may range from qualitative judgments to quantitative probabilities. Although risk assessments may include quantitative risk estimates, quantitation of risks is not always possible. It is better to convey conclusions (and associated uncertainties) qualitatively than to ignore them because they are not easily understood or estimated. Ecological risk assessments can be used to predict the likelihood of future adverse effects (prospective) or evaluate the likelihood that effects are caused by past exposure to stressors (retrospective). In many cases, both approaches are included in a single risk assessment (EPA, 1998).

Presented in radioactive form, Pb should be considered in metallurgical waste disposal sites like any other types of waste disposal site. Here is an example: According to the framework of site selection procedure of Brazilian waste disposal, some units are chosen for radioactive waste disposal, as the volcanic rocks and granites are considered to be suitable host rocks for high level radioactive waste in the USA, Canada, and Sweden (Iyer *et al.*, 1999).

Lead phosphate glass is used as a stable medium for the immobilization and disposal of high-level nuclear waste (Sales and Boatner, 1984), thus lead is by itself hazardous for its surrounding environment as well as disposal from metallurgical industries and should be considered wholly to have a holistic risk assessment approach.

The knowledge of trends in the release of metals and other inorganic contaminants during the weathering processes of metallurgical waste materials is essential to determine the best dumping strategies (Ettler *et al.*, 2004). Zinc and lead metallurgical plants frequently generate partially vitrified wastes. Such wastes often are primary or secondary smelting slags. They are stemming from the barren part of the exploited ores and also contain some additives used in the smelters. The barren liquid is quenched just after the ore treatment. According to their residual heavy metal contents and the environmental hazards they represent, slags can be recycled or just landfilled. In the vicinity of old metallurgical plants, such wastes are generally landfilled on sprawling slag heaps and are exposed to weathering conditions. In this work, only Lead Blast Furnace (LBF) slags are taken into consideration (Seignez *et al.*, 2007). One thing to point out here is the word “waste” that mainly means slag as well as other types of waste in metallurgical waste industries.

Bioaccumulation is a chemical fate and transport process that frequently receives insufficient consideration in the Ecological Risk Assessment (ERA) process. Bioaccumulative chemicals of potential ecological concern (COPECs) require special consideration because they generally have the highest exposure potential, and subsequently risk potential, to upper trophic level organisms (Corl, 2001).

Contamination of soil with lead has occurred on a global scale. Exposure to lead may cause adverse effects to human health and the environment. It is therefore desirable to obtain a quantitative estimate of the potential risk of lead contamination. Numerous studies have been conducted collecting lead concentration data from both natural and contaminated soil on a range of scales. Very few of these studies have made serious attempts to spatially describe the data. In order to identify contaminated land and to enable development of appropriate environmental guidelines, it is essential to have an understanding of the universal range of lead concentrations. Such data also assists in assessing any potential risk to the environment or human health (Markus and McBratney, 2001).

An accurate risk assessment on contaminated landfills should consider the risk of vertical heavy metal transfer both to the groundwater and to the aboveground vegetation. The extent of such a transfer is closely dependent on metal concentration and speciation, but also on soil characteristics and plant species (Welch, 1995; Ernst, 1996 cited from Remon *et al.*, 2005).

In France and in other European countries the regulation is slightly different and remediation works are only carried out when a site poses a risk for human health, water resources or other known targets. Consequently according to this general guideline, an accurate risk assessment must be performed in a case by case approach taking into account not only total concentrations of heavy metals but also their actual mobility (Remon *et al.*, 2005).

Considering accurate risk assessment strategy, results of sequential extraction procedures are not inevitably correlated with the levels of heavy metals actually accumulated in plants. Thus determination of metal phytoavailability should be considered in an accurate risk assessment strategy. Consequently, in addition to chemical extraction methods, the study of plant communities in terms of species diversity, toxicity symptoms and metal concentrations in above ground tissues, should be performed to accurately assess soil metal phytoavailability and ecotoxicity (Remon *et al.*, 2005). In fact, such an approach has been already performed in a number of potentially hazardous sites, including mine tailings (Cobb *et al.*, 2000; Stoltz and Greger, 2002 cited from Remon *et al.*, 2005), municipal waste deposits (Gimmler *et al.*, 2002 cited from Remon *et al.*, 2005) or industrially contaminated soils (Dudka *et al.*, 1995, 1996 cited from Remon *et al.*, 2005).

The Ecological Relative Risk (EcoRR) is a composite scoring index for comparing relative risks between different plant protection products, and is used to assess the potential ecological impact their residues have after being applied to agricultural systems (Sánchez-Bayo *et al.*, 2002).

BACKGROUND

Carrying out a sequential extraction procedure, Remon *et al.* (2005) estimated the mobility of heavy metals in a risk-based approach. Considering the great harms of heavy metals for biological environment health, Klerks and Weis (1987, cited from Barnthouse *et al.*, 2008) reviewed the early literature on genetic changes in response to heavy metals in aquatic organisms. They cite numerous studies in a variety of organisms demonstrating differences between polluted and relatively clean sites.

A methodology for the assessment of ecological risks arising from pollution in water bodies has been developed and applied in the Dnipro basin countries within the framework of the UNDP-GEF Dnieper Program during 2002. The methodology has been developed considering Dnipro's basin peculiarities and directed for processing of data, collected according to a specially developed scheme of field investigations, based mainly on the biological parameters (Romanenko *et al.*, 2009).

Considering existing and innovative remedial technologies for sediment, Naval Facilities Engineering Service Center, has provided the major disadvantages of those technology types. Thermal decomposition at high temperatures, incineration emits volatile metals (Hg, As, Se, Pb) to the atmosphere in gaseous form. Thus, in ERA we should consider not only the risks facing the solid phase but only the gaseous phase risks.

Wang *et al.* (2009) have investigated the distribution characteristics, probabilistic risk and possible sources of PAHs in the water column of the YRD (Yellow River Delta). In order to evaluate the integral PAH effects, BaP equivalency (BaPeq) of PAHs has been calculated based on the toxic equivalency factors (TEFs) for individual PAHs.

Sánchez-Bayo *et al.* (2002) developed a site-specific methodology to assess and compare the ecotoxicological risk that agricultural pesticides pose to ecosystems.

An ecological risk assessment has been conducted for Keelung River in northern Taiwan by Chen (2005). The objective of this study has been to assess the risk to fish, aquatic insects, and benthic macro invertebrates associated with Chemical-of-Potential-Concern (COPC) in the river and to rank ecological risk for these chemicals. The protection of at least 95% of the species 90% of the time from acute and chronic COPC exposures has been the defined assessment end point. Nine inorganic and organic contaminants have been selected to evaluate the impact to aquatic community in the Keelung River. The quotient method has been served as screen level estimation of risk. According to the results of this research, Pb overall has been not of high importance due to its chemical characteristics and indicates more significance of Pb in none-aquatic environments.

Chen and Ming-Chao (2006) carried out ecological risk assessment on a cadmium contaminated soil landfill. A possible risk scenario has been that groundwater contamination due to the leachate containing Cd and Pb from the landfill could result in pollution of coastal water, and subsequently produce toxic effects to aquatic organisms. Chemical dissipation in groundwater systems has been simulated and short-term chronic toxicity tests on larvae of three local aquatic species has been also performed to determine the No-Observed Adverse-Effect Concentrations (NOAECs), as well as the Predicted no Effect Concentrations (PNECs), of the two metals in the organisms tested. The Hazard Quotient (HQ), the ratio of Predicted Environmental Concentrations (PECs) to PNECs, has been used for risk characterization. In this research, for Pb, the highest concentration would be reached at a distance of 40 m and farther. This would only occur 80 years after the initiation of leakage as well as Cd.

A small but increasing number of studies has employed spatial prediction techniques such as kriging to map the distribution of lead concentrations in soil (Markus and McBratney, 2001).

Another concept to mention is the human health risk assessment of Pb that has been carried out as a case study by Jarosinska *et al.* (2004). A program of childhood lead poisoning prevention has been conducted in six cities of Silesia, the most industrialized region of Poland. In this research children's exposure to lead and associations of Blood Lead Levels (BLL) with season of sampling, questionnaire data, and environmental levels of lead has been analyzed. Air lead concentrations and lead fallout, as had been measured in the ambient air monitoring system, has been below current Polish air quality standards and gradually has decreased. Variables have been found to affect BLL in the Silesian children proposed as a must to be used to propose criteria to improve identification of children at risk and to focus prevention activities more effectively.

Based on the results of a study carried out by Bennett *et al.* (2007), risk calculations using kriging to estimate risk across "worst-case" species foraging ranges due to spent ammunition at outdoor rifle and pistol (RP) firing ranges has been performed.

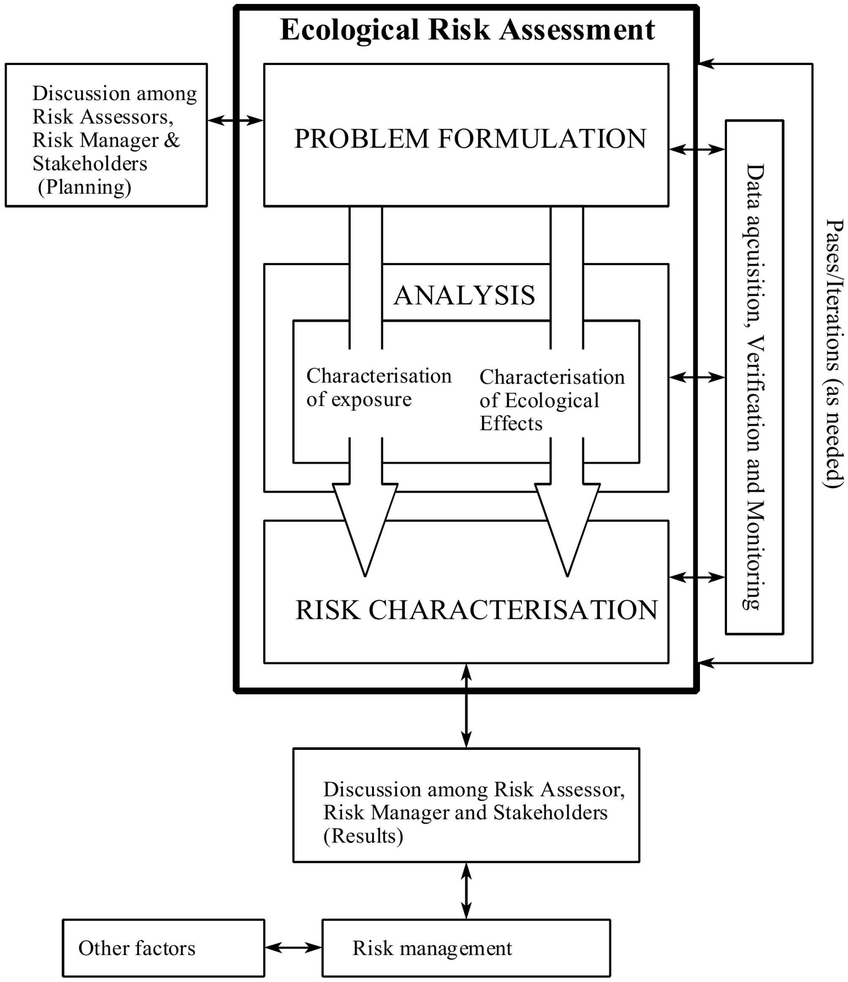

Fig. 1: EPA process for ERA (EPA, 1998 cited from Murray and Claassen, 1999)

Considering urban lead exposure, risk factors have been investigated and the impact of lead abatement measures has been assessed in an urban community by de Freitas *et al.* (2007) in battery recycling plant located in an urbanized area contaminated the environment with lead oxides.

MATERIALS AND METHODS

In order to quantitatively predict the fate and transport of a pesticide once it is introduced into the environment, OPP (Office of Pesticide Programs) scientists review laboratory and field studies that measure how pesticide active ingredients interact with soils, air, sunlight, surface water, and ground water (Jones *et al.*, 2004). Thus, as a whole due to the common point of contamination, Pb like pesticides can be approached as well but of course partly. The scope of this risk assessment is metallurgical waste disposal sites.

In risk assessment methodology we should consider these steps:

- Hazard Identification, which collects existing human health and ecological benchmarks for the metallurgical waste disposal sites constituents to identify lead (Pb) with benchmarks for constituent screening.
- Constituent Screening, which compares very conservative estimates of exposure concentrations (e.g., whole waste concentrations, leachate concentrations) to health-based concentration benchmarks to quickly and simply eliminate constituents and exposure pathways that do not require further analysis.
- Full-Scale Analysis, which uses a site-based Monte Carlo analysis to characterize at a national level the risks to human health and ecological receptors from onsite disposal (in waste disposal sites and surface

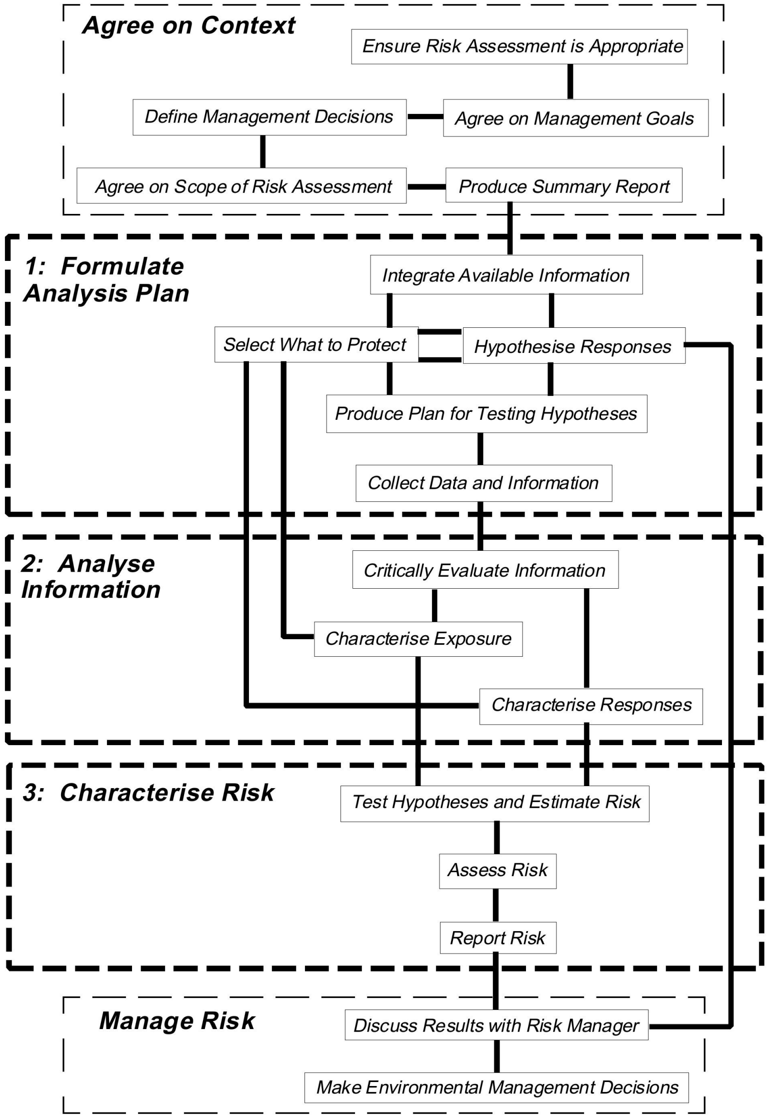

Fig. 2: High-level actions in ERA process (EPA, 1998 cited from Murray and Claassen, 1999)

impoundments) of metallurgical waste disposal sites constituents that are not eliminated in the screening analysis (RTI, 2007).

As showed in Fig. 1, Ecological Risk Assessment Process Diagram has three stages including: 1) problem formulation, 2) risk analysis and 3) risk characterization, however a more detailed method is following the high-level actions in ERA process.

One thing not to forget is a kind of innovative method that only can be approached by try and error through real research on the subject to make it general as a Decision Support System (DSS) parallel to the summarily mentioned methods.

The interpretation of the US EPA process has been distinguishes between actions in the process (using verbs or phrases that are unambiguously actions) and the issues they are intended to influence. This distinction should clarify communication and hence understanding of the process. Accordingly, tasks have been re-worded (where necessary) specifically as actions. The process is divided into high-level (Fig. 2). These are summarized here in text with adjacent pictorials. Each high level task consists of a number of lower-level tasks, which, in turn, may comprise even lower-level tasks. The text provides a degree of detail one level below the level depicted in the task diagrams (EPA, 1998 cited from Murray and Claassen, 1999).

DISCUSSION, CONCLUSION AND RECOMMENDATION

Reviewing literature, it is evident that approximately most of the researches have been carried out in aquatic environments (Barnthouse *et al.*, 2008; Chen and Ming-Chao, 2006; Romanenko *et al.*, 2009; Wang, 2009). From the other side, those carried out in terrestrial environment, are non-Pb focusing. Considering the researches pertaining to ERA, however few researches have been carried out in the field of metallurgical industries, none of them has addressed the Pb ERA in a holistic approach (Iyer *et al.*, 1999). Another aspect to consider is a lack in a holistic approach not only for the lead ERA, but also for most of the heavy metals disposed from industries and especially metallurgical industries as well. A risk assessment must examine not just current conditions, but also future consequences followed by probable situations. This is also evidence of indicating the lack of a holistic approach in lead ERA.

A significant tool that can be parallely used in assessing the ecological risk is to adapt the obtained data in GIS environment and making it compatible in spatial systems.

Given evidence on importance of lead hazards in terrestrial environments, it is worthwhile proposing the multidiscipline ERA approaches to not only lead but also to every heavy metal endangering human health.

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