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Distribution and integrated assessment of lead in an abandoned lead-acid battery site in Southwest China before redevelopment

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ABSTRACT

Lead-acid battery sites have contributed enormous amounts of lead to the environment, significantly affecting its global biogeochemical cycle and leaving the potential risks to human health. An abandoned lead-acid battery site prepared for redevelopment was selected in order to study the distribution of lead in soils, plants, rhizosphere soils and soil solutions. In total, 197 samples from 77 boreholes were collected and analyzed. Single extractions by acetic acid (HOAc) were conducted to assess the bioavailability and speciation of lead in soils for comparison with the parts of the plants that are aboveground. Health risks for future residential development were evaluated by the integrated exposure uptake biokinetic (IEUBK) model. The results indicated that lead concentrations in 83% of the soil samples exceeded the Chinese Environmental Quality Standard for soil (350 mg/kg for Pb) and mainly occurred at depths between 0 and 1.5 m while accumulating at the surface of demolished construction waste and miscellaneous fill. Lead concentrations in soil solutions and HOAc extraction leachates were linked closely to the contents of aboveground *Broussonetia papyrifera* and *Artemisia annua*, two main types of local plants that were found at the site. The probability density of lead in blood (PbB) in excess of 10 μg/dL could overtake the 99% mark in the residential scenario. The findings provided a relatively integrated method to illustrate the onsite investigations and assessment for similar sites before remediation and future development from more comprehensive aspects.

1. Introduction

Lead (Pb) contamination has generated significant concern amongst the general community due to its potential risk to human health and its impact on the environment (Markus and McBratney, 2000). Notably, the recent discovery of clusters of lead poisoning affecting thousands of Chinese children has raised severe public concern. In numerous regions across the country, children are testing elevated positive blood lead (PbB) at ranges between 10,000 and 25,600 mg/dL (Ji et al., 2011). There are already more than 500 reported cases of lead poisoning since 2008 and high PbB levels were reported both in children and working populations within the lead smelter and mining area, as well as the lead-acid storage battery factories which are the currently major sources of lead contamination in China (Chuang et al., 2008; Chen et al., 2012).

In order to control the severe situation, the Chinese government has put lead battery factories as a top priority in its campaign to rectify the country's heavy metal pollution (Jiang, 2013). There are more than two thousand lead-acid battery factories in China, 1800 of them are small and medium scale plants without a production permission certificate. These factories failed to meet the national clean production standards, and contribute to the major environmental lead pollution (Chen et al., 2012). A number of factors including industry emissions, waste materials, gas, water and electronic products lead to the expansion of lead contamination in the soil environment. Previous external investigations and studies based around the lead-acid battery factories confirmed the high lead concentrations in soils and were subsequently verified as important evidence for the poisoning incidents (Li et al., 2015). Other studies indicate that lead contaminated house dust is also a primary source of lead exposure for children in urban areas and soil contributes significantly to maintaining an interior dust loading (Johnson and Bretsch, 2002). However, very few studies could be extended to the onsite investigation for factories in production due to permission not being granted, or else, local governments always choose to shut down factories after serious pollution occurs, then future onsite investigation, source and responsibility analyses, and remediation

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will not be considered or suspended with the change of the site owner or the land utilization. However, as lead was still treated as a hazardous contaminant, especially the threat of high lead content in children's blood, the Chinese government recently tried to consolidate the regulation and legislation for the rehabilitation of such kinds of sites with the requirement of risk assessment and remediation in land-use change. Risk assessment guidelines for lead contamination in soil were proposed in order to quantify the potential hazards to the onsite and offsite populations in different exposure scenarios.

This study aims to conduct the onsite investigation and risk assessment on a typical abandoned lead-acid battery factory in southwest China to study the distribution and bioavailability of lead in soil, two local plants and soil solutions to finally assess the risk of lead contamination in children based on the integrated exposure uptake biokinetic model (IEUBK) providing quantified results of risk probability density and remediation target.

2. Materials and methods

2.1. Site characterization

The studied site was in an abandoned lead-acid storage battery factory, located in the urban area of Chongqing, China (Fig. 1). The factory was set up in the 1940s and it had a battery production capacity of 1.0 million KVAH with lead usage of ten thousand tonnes per year. It was abandoned in 2009 and was under remediation for the redevelopment into residual land. This factory once operated five manufacturing workshops, two packaging workshops, one sewage treatment station, one machine shop and had scrap lead stacked area, totally covering an area of about 13,500 m^2.

The studied area has a sub-tropical monsoon climate, four distinct seasons, a mean annual temperature range of 17.5–18.5 °C, a mean annual precipitation ranges from 1187 to 1616 mm, a long frostless duration of around 330 days per year, and a prevailing wind in the northerly direction. The topography is high in the north and low in the south and varies from 45.4 m above sea level. The soil layer thickness of most areas is approximately 2–5 m, except for certain parts being more than 6 m. The strata from surface to bottom, in order, are demolished construction waste, miscellaneous fill, Quaternary Holocene plain fill (Q4ml) and bedrock. The bedrock is sandstone and mudstone of Jurassic Shaximiao Formation (J2s). Soil types are mainly classified as fluvo-aquic soil and red soil.

2.2. On-site sampling

Field study and collection of environmental samples took place in January 2013. In total, 197 soil samples each in different layers from 77 boreholes were collected following a triangular pattern (Fig. 1). Representative plants of *Broussonetia papyrifera* and *Artemisia annua* (respectively abbreviated to *'B. papyrifera' and 'A. annua'* for simplification), mainly growing in the contaminated site, were harvested at the maturation period. Plant samples aboveground (n=19) and underground (n=19) were collected in the same soil sampling points while rhizosphere soils in two selected plants were also collected. Soil solutions in each rhizosphere area were collected using Macro Rhizon sampler (Rizosphere Research Products, Wageningen/The Netherlands) consisting of 9 cm-long, 4.5 cm-diameter, and 0.2 μm filter membrane non-absorbent plastic pipette collected to a vacuum syringe at sampling depth of about 25 cm. Each sampling site carried out 3 parallel samplers to ensure the representativeness. The freshly collected soil solutions were refrigerated at 4 °C until analysis. Soil samples were air dried, ground to pass through a 2 mm plastic sieve, and chose a fraction to mill in an agate pot to form a fine powder (< 170 μm). The aboveground and underground materials of the plant samples were rinsed with distilled water, dried at 105 °C for 1 h and at 80 °C for 24 h, grounded, and finally stored in glass containers.

2.3. Chemical analysis and quality control

The pH was measured in a 1:1 (w/w) soil:water suspension using a glass pH electrode. The organic matter content was

Fig. 1. Map of the abandoned lead-acid battery site with the sampling sites of soils and plants.