Journal of Geochemical Exploration 139 (2014) 31–52

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

journal homepage: www.elsevier.com/locate/jgeoexp

Overview of trace metals in the urban soil of 31 metropolises in China ☆

Hangxin Cheng [a,b,c,*], Min Li [d], Chuandong Zhao [a,b], Kuo Li [a,b], Min Peng [a,b], Aihua Qin [a,b], Xiaomeng Cheng [c]

[a] Key Laboratory of Geochemical Cycling of Carbon and Mercury in the Earth's Critical Zone, Institute of Geophysical & Geochemical Exploration, Chinese Academy of Geological Sciences, Langfang 065000, China
[b] Geochemical Research Center of Soil Quality, China Geological Survey, China
[c] School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[d] China Geological Survey, Beijing 100037, China

ARTICLE INFO

Article history:
Received 4 February 2013
Accepted 18 August 2013
Available online 28 August 2013

Keywords:
Trace metal
Contamination
Urban soil
Cities
China

ABSTRACT

This overview provides an up-to-date assessment of the trace metal contamination (As, Cd, Cr, Cu. Hg, Ni, Pb, Sb, Se, and Zn) in urban soils of 31 metropolises in China. This systematic soil geochemical survey summarizes the characteristics of trace metals in Chinese urban soils, including concentration, accumulation, spatial distribution, and major sources. Mercury was ranked first followed by Cd and Se in geo-accumulation among all of the contaminant metals in urban soils in China; this finding is likely due to the Hg and Se emissions from fossil fuels. However, the lack of studies on Se contamination in urban soils, not only in China but also in the rest of the world, implies that Se contamination may have been unobserved for a long time. Shanghai, Kunming, Shenyang, and Changsha may be some of the most heavily contaminated Chinese cities based on the concentrations, spatial dimensions, and associations among the contaminant metals. Numerous hotspots with high concentrations of metals were found in Changsha, Shanghai, and Shenyang, clearly indicating a significant contribution from both the metallurgical industry and smelt mining to the contamination of urban soils. Conversely, the levels of Sb, Cu, and Cd in Kunming originated from their naturally high geochemical background in soils. Heavy Se contamination was found in Guiyang and Taiyuan. The natural source of Se may be important in defining the pattern of pollution in Guiyang, whereas anthropogenic sources are likely more accurate than is the natural background in Taiyuan city. We review the existing limits and types of pollutants in the current soil guidelines and find that an international agreement on the range of the limits and the types of pollutants contained in the soil guidelines is urgently needed.

1. Introduction

The scale and pace of urbanization and industrialization have rapidly increased since China underwent an overall reform 34 years ago. Statistics show that the number of cities in China grew from 122 in 1978 to 655 in 2011, whereas the urban population unpredictably rose from 17.9% of the total population in 1978 to 51.3% in 2011 (National Bureau of Statistics of China, 2011, 2012). Consequently, a steady rise in the emission of trace metal contamination in urban areas has been observed. The pattern of contamination is evident not only in local, highly concentrated sites in urban areas, but also in areas of low contamination that are widely dispersed throughout soil, atmosphere, water, and plants in the Earth's critical zones. The contamination has resulted in the deterioration of the air, soil, and water quality in China (Chan and Yao, 2008; Cheng, 2003; Fu et al., 2012; Luo et al., 2012; Rose and Shea, 2007; Shao et al., 2006; Wong et al., 2006).

Urban areas are the most densely populated regions of the world because of their strong industrial and economic activities. Urban soil, which is strongly influenced by anthropogenic activities, differs greatly from natural soils (Bullock and Gregory, 2009) and receives a major proportion of trace metal emissions from industrial, commercial, and domestic activities. Urban soils continuously accumulate organic and inorganic pollutants from either localized or diffuse sources (Luo et al., 2012). The typical diffuse pattern of these contaminations and the proximity of urban soils to humans increase the risk of human exposure through inhalation, ingestion, or dermal contact (Abrahams, 2002; Ajmone-Marsan and Biasioli, 2010). Therefore, recognizing the spatial distribution and concentrations of toxic and potentially toxic elements in urban soils in China is vitally important.

Approximately 32 urban soil contamination and geochemical surveys or projects have been initiated in China since the 1990s, covering cities in areas such as the Yangtze River Delta and the Pearl River Delta in Eastern and Southern China, the Bohai Rim in the north, the

---

* Corresponding author at: Key Laboratory of Geochemical Cycling of Carbon and Mercury in the Earth's Critical Zone, Institute of Geophysical & Geochemical Exploration, Chinese Academy of Geological Sciences, Langfang 065000, China. Tel.: +86 316 2267630; fax: +86 316 2014156.
E-mail address: hangxin@vip.sina.com (H. Cheng).

0375-6742/$ – see front matter © 2013 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gexplo.2013.08.012

Old Industrial Zone in the northeast, the Chengdu–Chongqing Plain in the west, and some cities in the northwest (Table 1). The methodological approaches employed in the majority of the studies show that the sampling schemes and analytical procedures used in these urban soil geochemical surveys vary (Luo et al., 2012). The sampling strategies can be divided into the following two categories based on their sampling patterns:

(i) A random sampling pattern reflects different land use purposes or functional zones such as residential, commercial, and industrial areas. The soil samples are randomly collected from urban parks, green lands, and city roadsides (Cai et al., 2013; Chen et al., 2010a, 2010b; Guo et al., 2012; Liang et al., 2009; Lu and Bai, 2010; Lu et al., 2007; Sun et al., 2010; Wang and Qin, 2007; Zhang and Ke, 2004; Zhang et al., 2009; Zheng et al., 2008; Zhou et al., 2008). In most cases, the sampling points in this pattern are heterogeneously distributed throughout areas with serious contamination and do not cover the entire city area. However, trace metals usually accumulate in the urban topsoil and appear to be more concentrated in the central or older areas of cities because of their longer development history compared to the suburbs. The concentration of metals in urban soils obtained for this sampling pattern may not give an accurate overview of the concentration and distribution of trace metals in an entire city area.

(ii) The systematic sampling pattern is also known as "grid or cell sampling" in China. The sampling points in studied areas are randomly distributed based on a regular grid of n × n km (usually 1 × 1 km), with each grid having at least one sampling point (Cheng et al., 2013; Lee et al., 2006; Li and Huang, 2007; Li et al., 2010, 2013; Yang et al., 2011). This sampling strategy is used to reduce the possibility of a sampling bias that may result from collecting an unrepresentative average sample because of the high portion of subsamples from the same region. Several subsamples are taken and mixed thoroughly to obtain a bulk sample for the sampling site. The profile of the top 0 to 10 cm or 0 to 20 cm of soils at each sampling point is taken using sampling tools from the two sampling patterns (Table 1).

The trace elements determined in these studies are highly diverse in both type and number and vary from city to city and from project to project in the same city. Except for those shown by Fuzhou, Fujian Province, less than eight heavy metal elements (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) have been reported in all of the 32 existing urban soil geochemical surveys (Table 1). The elements most commonly studied in the 32 projects are Cu and Pb (29), Zn (26), Cd (22), and Cr (20); As (9), Hg (10), and Ni (15) received less attention.

These differences in the variability of the sampling schemes, analytical procedures, and areas covered hinder meaningful comparisons among these studies. An international agreement on the range of elements and standardized methodologies to produce comparable datasets in different locations is urgently needed (Ajmone-Marsan and Biasioli, 2010; Luo et al., 2012). Nevertheless, the distribution, dispersion, and geochemical characteristics of some trace metals in the urban soils of Chinese cities and many other cities around the world have been widely compared and discussed in recent reviews (Ajmone-Marsan and Biasioli, 2010; Luo et al., 2012; Wei and Yang, 2010).

Systematic geochemical mapping is the best method available for assessing and monitoring changes in the levels of chemical elements on the Earth's surface. As a result, in 1999 China launched a new soil geochemical mapping project called the National Multi-Purpose Regional Geochemical Survey (NMPRGS) (Li et al., 2014).

Table 1
Sampling methods and heavy elements found in the 32 existing urban soil geochemical surveys.

	No of samples	Sampling pattern	Sampling depth/cm	Determined elements								Reference
				As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	
Baoji	10	Systematic	10			✓	✓		✓	✓	✓	Li and Huang (2007)
Beijing	773	Random	20		✓	✓	✓		✓	✓	✓	Zheng et al. (2008)
	261	Systematic	20					✓				Cheng et al. (2013)
	285	Systematic	20					✓				Li et al. (2010)
	127	Random	20		✓	✓	✓	✓	✓	✓	✓	Chen et al. (2010a), Xia et al. (2011)
Changchun	352	Systematic	20	✓	✓	✓	✓	✓		✓	✓	Yang et al. (2011)
Changsha	112	Random	20	✓	✓	✓	✓	✓		✓	✓	Zhou et al. (2008)
Chongqing	48	Random		✓	✓	✓	✓	✓	✓	✓	✓	Li et al. (2006)
Fuyang	286	Random	20		✓		✓		✓	✓	✓	Zhang et al. (2009)
Fuzhou	179	Systematic	20	✓	✓	✓	✓	✓	✓	✓	✓	Chen (2008)
Guangzhou	40	Random	10		✓		✓		✓	✓		Lu et al. (2007)
	78	Random	20		✓	✓	✓		✓	✓	✓	Cai et al. (2013)
Guiyang	50	Random	5		✓		✓		✓	✓	✓	Li et al. (2012)
Haerbin	23	Random	10		✓	✓	✓			✓		Meng et al. (2009)
Hangzhou	82	Random	10		✓	✓	✓		✓	✓	✓	Zhang and Ke (2004)
	182	Random	10		✓		✓			✓	✓	Lu and Bai (2010)
Hefei	169	Systematic	20		✓	✓	✓			✓		Yuan et al. (2010)
Hong Kong	48	Systematic	15		✓	✓	✓		✓	✓	✓	Li et al. (2004)
	594	Random	10		✓		✓			✓	✓	Li et al. (2001)
Lanzhou	88	Random	10				✓			✓	✓	Zhao et al. (2010)
Nanjing	138	Random	20			✓	✓			✓	✓	Lu et al. (2003)
Shanghai	273	Random	10		✓	✓	✓		✓	✓	✓	Shi et al. (2008)
Shenyang	93	Systematic	15	✓	✓	✓	✓	✓		✓	✓	Li et al. (2013)
	36	Random	5		✓		✓			✓	✓	Sun et al. (2010)
Shijiazhuang	220	Systematic	20	✓	✓	✓	✓	✓		✓	✓	Cui et al. (2011)
Ürümqi	428	Systematic	20	✓	✓	✓✓	✓		✓	✓	✓	Tan et al. (2012)
Xi'an	53	Random	15	✓		✓	✓			✓	✓	Yin and Zhao (2006)
	78	Systematic	20			✓	✓		✓	✓	✓	Chen et al. (2012)
Xiamen	20	Random						✓				Liang et al. (2009)
Xuzhou	21	Random	10		✓	✓	✓		✓	✓	✓	Wang and Qin (2007)
Yibin	63	Random	5	✓			✓			✓	✓	Guo et al. (2012)
Zhengzhou	30	Random	20				✓			✓	✓	Gu et al. (2009)
				9	22	20	29	10	15	29	26	