Land Use Policy 38 (2014) 138–146

Contents lists available at ScienceDirect

Land Use Policy

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

Inventorying heavy metal pollution in redeveloped brownfield and its policy contribution: Case study from Tiexi District, Shenyang, China

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ARTICLE INFO

Article history:
Received 17 March 2013
Received in revised form 7 November 2013
Accepted 10 November 2013

Keywords:
Human–natural complex system
Land use policy
Heavy-metal pollution
Brownfield redevelopment
China

ABSTRACT

As the pollution of urban soil in brownfield redevelopment sites can adversely affect the surrounding ecosystems and human health, China's rapid urbanization and industrialization necessitates the remediation, treatment and redevelopment of contaminated urban soil. This study aims to address the policy implications of inventorying and mapping soil heavy-metal pollution in brownfield redevelopment sites in China, using the Tiexi district in Shenyang as a case study. Enrichment factors analysis of the soil samples proved that the soil in the brownfield sites was highly enriched with copper, cadmium, lead, zinc, arsenic and nickel relative to background values. Furthermore, the analysis of the pollution index and the integrated Nemerow pollution index also indicated that the soil was most heavily polluted by cadmium. The hot-spot metal contamination areas, determined using geographical information system technology, were mainly located near historical high-pollution enterprises. Based on our findings, policy recommendations for further brownfield management are proposed.

Introduction

The need for the remediation, treatment and redevelopment of contaminated urban soil is growing and will continue to be a major issue for sustainable urban development (De Sousa, 2002; Dye, 2008; Ren et al., 2012). This is especially the case for China because of the multiple demands on land resources in rapid urbanization (Güneralp and Seto, 2008) as well as increasing concern about implications for local public health (Sun et al., 2012).

Urban soil is an important component of urban ecosystems (Wang et al., 2012a,b) and differs greatly from natural soil in that has been more strongly influenced by human activities (Bullock and Gregory, 2009), such as land use change because of infrastructure construction for residential, commercial and manufacturing purposes; urban planning modification for site redevelopment; or artificial green land construction for leisure functions (Page and Berger, 2006; Civeira and Lavado, 2008). Thus, all of these considerations have led to an appreciation that the accumulation of harmful substances in urban soil is of great concern due to its propinquity to urban residents (Poggio et al., 2008; Maas et al., 2010). Considering that heavy metals are amongst the most widespread contaminants in the environment and ecosystem (Christoforou et al., 2000), urban soil is an important carrier of heavy metals in the urban terrestrial environment (Nriagu and Pacyna, 1988) and provides a significant index for investigating the potential risk to public health in the case of human exposure (Hough et al., 2004). Several studies have indicated that urban soils are contaminated by heavy metals. This phenomenon has been mainly attributed to modern industries, traffic and mining activities in urban areas (De Kimpe and Morel, 2000; Gallagher et al., 2008; Li et al., 2013). The heavy-metal contamination of urban soils has been and continues to be of interest to researchers, city administrations and planners worldwide (De Kimpe and Morel, 2000; Li et al., 2004).

In China, the heavy-metal pollution of urban soil has become increasingly serious due to the unprecedented industrialization and rapid urbanization since the Reform and Opening-up Policy of 1978 (Wei and Yang, 2010), which refers to the program of Chinese economic reforms called "Socialism with Chinese characteristics" in China. For historical and practical reasons, contaminated urban soil is primarily found in traditional industrial bases, regions of concentrated township enterprises and new resource-based industrial areas (Wu et al., 2008). Those areas that were selected for the development of heavy industries during the First and Second National Five-year Plans (1953–1962) are usually referred to as

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http://dx.doi.org/10.1016/j.landusepol.2013.11.005

traditional industrial bases; these efforts contributed strongly to the economy but also caused long-term pollution to urban soil. The second wave began in 1978, when the Reform and Opening-up Policy encouraged the development of Township and Village Enterprises, which are defined as the market-oriented public enterprises under the purview of local governments based in townships and villages in China. Due to lower environmental awareness and technological advancement, the extensive and swift development of township enterprises triggered a series of soil pollution problems, mainly in the southeast coastal region. In the 1990s, the GDP-oriented evaluation system caused the local governments to give less consideration to environment aspects, which contributed to the third wave of urban soil pollution. Since the year 2000, driven by the historical accumulation and practical needs, a large number of industrial enterprises originally located in urban areas moved out of the city center and relocated to industrial parks. This initiative normally left a great amount of used land with severe pollution. Numerous studies on the heavy-metal contamination of urban soil have been carried out in several cities over the past decade (Li et al., 2001, 2009; Lu et al., 2003; Chen et al., 2005; Zheng et al., 2005; Shi et al., 2008; Sun et al., 2010). The findings of these studies show that heavy-metal pollution in urban soil is present in various cities, such as Beijing, one of the oldest and most densely populated cites in the world. Heavy-metal contamination in Beijing's urban soil has been widely reported at different scales (Liu et al., 2005; Fu et al., 2006; Hu et al., 2006; Xia et al., 2011). Shanghai, an industrial city and the largest metropolitan area in China, has exhibited significant enrichment of lead (Pb), zinc (Zn), copper (Cu), chromium (Cr) and cadmium (Cd) in urban soil (Shi et al., 2008). Moreover, several review studies related to soil metal contamination in Chinese cities over the past decade also concluded that heavy-metal contamination is widespread in urban soils (Wei and Yang, 2010; Luo et al., 2012) and that the most heavily polluted cities are Shenyang in Liaoning province, Baoji in Shaanxi province, and Jinchang in Gansu province, all of which are traditional industrial bases.

At the present, the presence of brownfields has become a major soil-related problem, and their redevelopment has been a major challenge for policy-makers and the scientific community (Thornton et al., 2007; Vanheusden, 2009). Between 1980 and 2010, a total of 185 Chinese cities exceeded the 500,000 population threshold, accounting for more than one quarter of the total global number of such cities (United Nations, 2012). As the holding of over 120 million hectares of farmland is strictly enforced by the central government, the expansion of urban land in China will be transferred from extensive sprawl to intensive vertical growth (Chen, 2007; Gong et al., 2012); the redevelopment of contaminated soil is therefore a core issue in urban China. However, the redevelopment of urban spaces, especially in old industrial areas, often results in high risks for ecological and human health due to the reasons mentioned in the previous paragraph (Hough et al., 2004). In many industrial cities in China, most of the key enterprises with high pollution emissions that were originally located within the city's core have relocated to the suburbs due to urban planning and the redesigning of this area. The used land left after enterprises relocate is referred to as "brownfield" and typically contains high concentrations of trace metals such as cadmium, copper, zinc and lead from past industrial activities (Dudka et al., 1996). Often, old contamination pollutants are strongly partitioned onto (or otherwise associated with) the soil and have "aged" in ways that have reinforced immobilization (Jennings et al., 2002). Hence, the problems of "old contamination" and lingering environmental liability are significant challenges to brownfield redevelopment. However, brownfield redevelopment studies and practice in China are in their infancy (Zhang et al., 2007); thus, a basic investigation and inventory of heavy-metal pollution in brownfield redevelopment sites is necessary and useful for supporting policy-makers.

Tiexi district, located in Shenyang city in Liaoning province, is one of the most famous old industrial bases in both China and the world. As one of the earliest industrial bases in China, Tiexi has experienced industrialization since 1938 and has successively experienced four stages, including initial, flourishing, recessionary and revitalization stages, which are representative of a life cycle of a typical industrial city. Thanks to the Revitalizing Northeast China Campaign Project launched in the early 2000s, from 2002 to 2012 in Tiexi, approximately 370 enterprises have been shut down or moved out from the urban heart and relocated in the suburbs, where a new industrial park was established. This program created nearly 9 km^2 of brownfield in Tiexi. All of this brownfield, which is polluted by heavy metals, organics and other pollutants, has been redeveloped into residential, commercial and green spaces. The brownfield redevelopment in Tiexi has become a model for redeveloping industrial bases in China and other developing countries as well (Ren et al., 2012). However, the question remains of whether soils in redevelopment sites exhibit heavy-metal pollution even after being declared remediated. To address this question, a study combining both qualitative and quantitative analyses was performed. Total of 71 topsoil samples from the brownfield soils in the Tiexi old industrial zone were collected to investigate the current state of the soil environment in old industrial redevelopment sites, identify possible heavy-metal pollutants and discover hot-spots using geographical information system technology (GIS).

Materials and methods

Study area

The Tiexi district, located in the western part of Shenyang city in Liaoning province, Northeast China (Fig. 1), was founded as an industrial base in early 1938. In the establishment of the new China in 1949, Tiexi was selected as one of the first national industrial development areas, which made a solid foundation for Tiexi to be the most famous industrial base for the whole of China. During China's first and second Five-year Plan periods (1953–1962), nearly one-sixth of the national budget was invested in Tiexi to support its heavy industrial development. However, due to the traditional development model, which focuses more on economic growth using less advanced technologies and neglecting environmental protection, the Tiexi district experienced decline in the late 1990s. Nearly all of the enterprises in this area lost their competiveness, resulting in many bankruptcies. To change the development model, the municipal government decided to implement a revitalization plan through relocating the enterprises to the newly established neighboring industrial zone. From 2002 to 2012, the municipal government of Shenyang has conducted a large-scale project aimed at promoting local sustainable development by relocating enterprises and re-planning urban functions. Although the government had taken action to eliminate soil contamination, such as via excavation and liming stabilization, it is unknown whether the soil quality has returned to the standard set forward by the relevant national department. Hence, we estimated the soil quality in terms of heavy-metal pollution in these brownfields.

The studied area is shown in the right part of Fig. 1, located above Jianshe Road (brown line in Fig. 1) and covered with red points. This 34-km^2 area is one of the most representative brownfields in China due to its history as a cluster center of industrial enterprise before 2012 and its current residential and commercial function land use.

Sampling and analysis

The study area was divided into 130 cells using a 400 m × 400 m grid, and in 2011, one composite topsoil sample (depth = 0–20 cm)