

# Vertical distributions of magnetic susceptibility of the urban soil profiles in shanghai and their environmental implications

Xue-Feng Hu<sup>A</sup>, Guo Zhang<sup>A</sup>, Xiao-Hong Wu<sup>A</sup>, Xu Cao<sup>A</sup>, Qi Jiang<sup>A</sup>, Shan Li<sup>A</sup> and Yang Li<sup>A</sup>

<sup>A</sup>Department of Environmental Science and Engineering, School of Environmental and Chemical Engineering, Shanghai University, Shanghai 200444, P. R. China, Email xfhu@shu.edu.cn

## Abstract

Magnetic susceptibility ( $\chi_{lf}$ ) and heavy metal contents in six soil profiles in one agricultural and two industrial areas in Baoshan District, Shanghai, were studied. The results showed that  $\chi_{lf}$  of the two soil profiles in the Luodian agricultural area ranges from  $12.6\text{--}54.6 \times 10^{-8} \text{ m}^3/\text{kg}$ , with a mean of  $24.1 \times 10^{-8} \text{ m}^3/\text{kg}$ , and is higher at the surface (0-30 cm) but rapidly decreases and tends to be stable below a depth of 30 cm.  $\chi_{lf}$  of soil profiles in the Shidongkou industrial area ranges from  $23.2\text{--}158 \times 10^{-8} \text{ m}^3/\text{kg}$ , with the mean of  $56.5 \times 10^{-8} \text{ m}^3/\text{kg}$ ; that in the Wusong industrial area from  $20.3\text{--}471 \times 10^{-8} \text{ m}^3/\text{kg}$ , with the mean of  $102.2 \times 10^{-8} \text{ m}^3/\text{kg}$ .  $\chi_{lf}$  in the two industrial areas reaches the highest in topsoils (0-5 cm) but fluctuates with increasing depth. The vertical distribution trends of  $\chi_{lf}$  in all profiles are similar to those of heavy metal contents. Moreover, the  $\chi_{lf}$  values of all the profiles are positively correlated with heavy metal contents. However, the correlation coefficients between  $\chi_{lf}$  and heavy metals in the industrial areas are much higher. This suggests that the magnetic signals in urban/industrial soils in Shanghai can indicate the presence and trends in heavy metal pollution effectively.

## Key Words

Urban/industrial soils, magnetic susceptibility ( $\chi_{lf}$ ), heavy metals, Shanghai.

## Introduction

Magnetic aerosols emitted from industries and vehicles are efficient absorbers and carriers of pollutants, such as heavy metals or organic pollutants, due to their large surface area (Hunt *et al.* 1984). When they deposit on the ground, both magnetic signals and pollutant loads in the soil will simultaneously be elevated. Many previous studies (Hay *et al.* 1997; Strzyszc and Magiera 1998; Durza *et al.* 1999) reported that there are significant correlations between  $\chi_{lf}$  and heavy metal contents in soils. Therefore,  $\chi_{lf}$  (or magnetic remanence) can indicate and delineate increases and potential decreases of soil pollution in regions (Hay *et al.* 1997; Hoffmann *et al.* 1999). Magnetic parameters of soil can also be used to discriminate different pollution sources (Lecoanet *et al.* 2003). In recent years, magnetic measurements of soil pollution also attracts much interest in China (Lu *et al.* 2001; Li *et al.* 2006; Lu and Bai 2006; Hu *et al.* 2007). However, most of these studies focus attention to topsoils, rather than whole soil profiles. For this reason, further studies on vertical variations of  $\chi_{lf}$  in urban soil profiles will be conducive to identifying and predicting sources of magnetic particles and the history of urban pollution. In this investigation, six soil profiles located in an agricultural area at Luodian Town and two industrial areas at Shidongkou and Wusong in Baoshan District were studied with the objectives for revealing vertical distributions of  $\chi_{lf}$  in the urban soil profiles in Shanghai and their environmental implications.

## Methods

The terrestrial part of Shanghai is situated in the Yangtze Delta. The soil in Shanghai is mainly derived from the tidal sediments of the Yangtze River Estuary and classified as Entisols because of its young age and initial development. Baoshan district, situated at the northern part of Shanghai, is a well-known industrial area, where many large metallurgical and power plants are located, such as the Baoshan Steel Company. The industry and rapid urbanization in Baoshan district has exerted an adverse impact on soil environments (Hu *et al.* 2004). In spite of this, a certain amount of agricultural land, mainly cultivating rice and vegetables, is still left in the northwestern part of the district. In this investigation, six soil profiles were selected, two located in the Luodian agricultural area and two in Shidongkou and two in Wusong industrial areas. The profiles are coded as L1, L2, S1, S2, W1 and W2, respectively. Soil profiles were sampled at intervals of 5 cm in the topsoils (0-10 cm), and 10 cm at depth. Soil samples were air-dried, ground and passed through a 2 mm sieve after discarding gravel and crop residues, and through a 0.149 mm sieve for chemical analyses. About 10 g soil samples (<2 mm) were used to determine mass magnetic susceptibility at low frequency (0.47 kHz) ( $\chi_{lf}$ ) and high frequency (4.7 kHz) ( $\chi_{hf}$ ) using a Bartington magnetic susceptibility meter model

MS2 (Hu *et al.* 2007). Soil samples (<0.149 mm) were digested with the mixed acids (HNO<sub>3</sub>+HF+HClO<sub>4</sub>) and dissolved by 2% HNO<sub>3</sub> solution. The concentrations of heavy metals (Cu, Zn, Pb, Cd, Co, Ni, Mn and Fe) in the solution were determined by ICP-AES.

## Results

The  $\chi_{lf}$  values of the L1 and L2 profiles at the Luodian agricultural area are similar, with the maxima of  $45.2 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $54.6 \times 10^{-8} \text{ m}^3/\text{kg}$ , respectively, the same minima of  $12.6 \times 10^{-8} \text{ m}^3/\text{kg}$  and the mean of  $21.9 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $26.2 \times 10^{-8} \text{ m}^3/\text{kg}$ , respectively. The  $\chi_{lf}$  of the profiles is higher at the soil surface (0-30 cm) and reaches maxima at 5 cm in depth, but rapidly decreases and tends to be weak and stable below 30 cm depth (Figure 1). The profiles show a gleyed steel-gray colour because of the influence of a high groundwater table. The weak magnetism of the soils beneath the depth of 30 cm may be attributed to reducing conditions and dissolution of magnetic minerals under the anaerobic conditions.

The  $\chi_{lf}$  values of the S1 and S2 profiles at the Shidongkou industrial area are also similar, with a maximum of  $154 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $158 \times 10^{-8} \text{ m}^3/\text{kg}$ , a minimum of  $29.3 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $23.2 \times 10^{-8} \text{ m}^3/\text{kg}$  and mean of  $63.5 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $49.5 \times 10^{-8} \text{ m}^3/\text{kg}$ , respectively. The  $\chi_{lf}$  of profiles reaches the highest value at the surface (0-5 cm), which is likely to be attributed to deposition of magnetic aerosols emitted from power and metallurgical plants in the area. The  $\chi_{lf}$  of S1 tends to be stable beneath a depth of 40 cm, with a mean of  $40.0 \times 10^{-8} \text{ m}^3/\text{kg}$ ; that of S2, however, fluctuates and shows a maximum at a depth of 60 cm (Figure 1), which may be related to the anthropogenic disturbance of soil profiles.

The  $\chi_{lf}$  values of W1 and W2 profiles at the Wusong industrial area are different, with a maximum of  $471 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $172 \times 10^{-8} \text{ m}^3/\text{kg}$ , a minimum of  $48.6 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $20.3 \times 10^{-8} \text{ m}^3/\text{kg}$  and a mean of  $169 \times 10^{-8} \text{ m}^3/\text{kg}$  and  $45.4 \times 10^{-8} \text{ m}^3/\text{kg}$ , respectively. The  $\chi_{lf}$  curves of the profiles are also different in pattern: The  $\chi_{lf}$  of the whole W1 is high and particularly enhanced at 0-20 cm and 50-70 cm sections, with a maximum at 60 cm in depth (Figure 1). The  $\chi_{lf}$  of W2 is significantly enhanced at 0-10 cm, but decreases and maintains stable below a depth of 10 cm. The Wusong industrial area was established in the 1950s, where many metallurgical plants are located (Hu *et al.* 2004). As previously studied (Hu *et al.* 2007), the magnetic enhancement of the topsoils is mainly attributed to atmospheric deposition of anthropogenic magnetic particles from industrial or vehicular emissions. The  $\chi_{lf}$  fluctuations in profiles may be caused by the anthropogenic disturbance, or historical pollution.

**Table 1 Correlation coefficients (r) between  $\chi_{lf}$  and heavy metal contents in the soil profiles in Baoshan, Shanghai**

Profiles	Cr	Cu	Pb	Zn	Cd	Ni	Co	Mn	Fe
$\chi_{lf}$ L1+L2 (n=26)	0.678(**)	0.880(**)	0.796(**)	0.487(*)	0.299	0.665(**)	0.453(*)	-0.477(*)	0.530(**)
S1+S2 (n=26)	0.351	0.651(**)	0.857(**)	0.778(**)	0.806(**)	0.485(*)	-0.045	0.474(*)	0.573(**)
W1+W2 (n=18)	0.942(**)	0.961(**)	0.955(**)	0.736(**)	0.232	0.599(**)	-0.355	0.882(**)	0.654(**)

Note: “\*” means the correlation significant at  $P < 0.05$  level; “\*\*” means the correlation significant at  $P < 0.01$  level.

The vertical variations of  $\chi_{lf}$  of L1 and L2 are comparable to those of heavy metal accumulations: Both are high at the 0-30 cm section but rapidly decrease and tend to be stable below 30 cm in depth (Figure 1). Statistical analyses indicates that  $\chi_{lf}$  is significantly positively correlated with concentrations of Cr, Cu, Pb, Zn, Ni, Co and Fe, respectively (Table 1). The agricultural area has few highly polluted industries and is far away from traffic hubs but is located on the leeward side of the Shidongkou Industrial area and may accept a small amount of magnetic aerosols from the industries far away, which explains the magnetic enhancement of topsoils and the significant correlations between  $\chi_{lf}$  and heavy metals in the area.

The  $\chi_{lf}$  curves of S1 and S2 are also comparable to concentrations of heavy metals. Especially in the S2 profile, both show maxima at a depth of 60 cm (Figure 1). The  $\chi_{lf}$  of S1 and S2 is significantly positively correlated with Cd, Cu, Pb, Zn, Ni, Mn and Fe concentrations, respectively (Table 1). The  $\chi_{lf}$  curves of W1 and W2 are also similar to those of heavy metal concentrations except for Co (Figure 1). Both reach maxima in topsoils (0-5 cm). Especially in the W1 profile, both show peaks in the 60-70 cm section. The  $\chi_{lf}$  of W1 and W2 is significantly positively correlated with Cr, Cu, Pb, Zn, Ni, Mn and Fe concentrations, respectively (Table 1) – displaying highest correlation coefficients. Especially, those between  $\chi_{lf}$  and Cr, Cu and Pb concentrations reach more than 0.94 (Table 1).

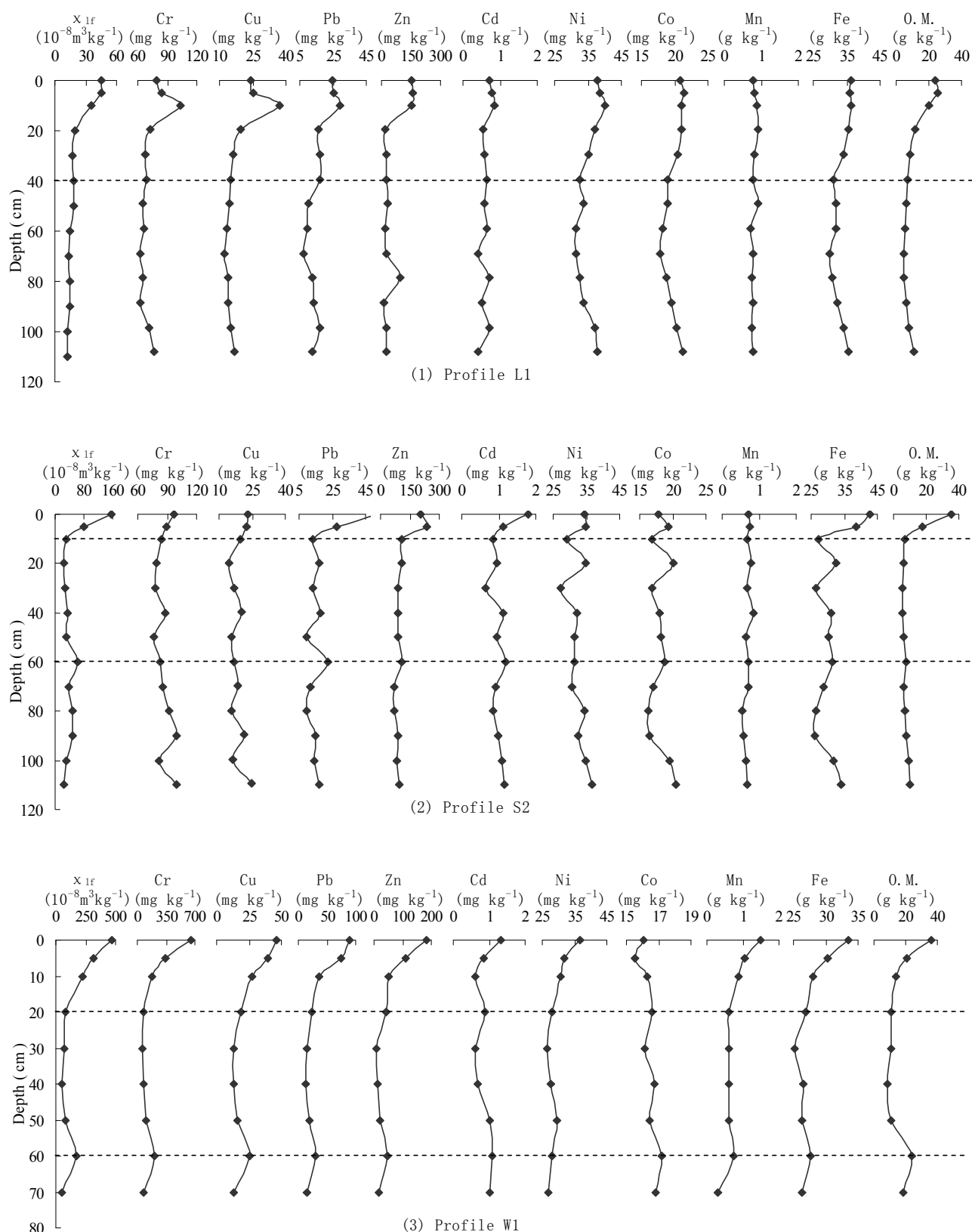


Figure 1. Vertical distributions of  $\chi_{lf}$  and heavy metal contents in the soil profiles in Baoshan District, Shanghai

## Conclusion

The  $\chi_{lf}$  of soils in industrial areas much higher than in the agricultural area, which is in agreement with previous studies (Hu *et al.* 2007). Moreover, the soil  $\chi_{lf}$  in the older industrial area of Wusong is significantly higher than that of the new one of Shidongkou. Soil profiles in the agricultural area are mostly natural and undisturbed, with  $\chi_{lf}$  being higher at the topsoils and becoming weak and stable at depth. The  $\chi_{lf}$  curves of soil profiles in the industrial areas mostly reach maxima in the topsoils and show fluctuations at depth, which may be caused by anthropogenic disturbance. The soil  $\chi_{lf}$  in the three areas is mostly significantly positively

correlated with heavy metal concentrations. However, the correlation coefficients between them in the industrial areas are much higher, which suggests that the  $\chi_{lf}$  in the urban/industrial soils in Shanghai can indicate heavy metal pollution more effectively.

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