Magnetic properties of urban topsoil in Baoshan district, Shanghai and its environmental implication

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Abstract
Heavy metal contents and magnetic properties (χ_{lf}、 χ_{fd}%) in topsoil of 123 urban sites in Baoshan District, Shanghai were detected to study the significant correlations between heavy metals and χ_{lf}. The results indicate that spatial variation of χ_{lf} in the urban topsoil is significant: the highest χ_{lf} of $1127\times10^{-8}m^3/kg$ was observed in industrial soil while the lowest of $18\times10^{-8}m^3/kg$ in agricultural soil. Significant correlations between χ_{lf} and χ_{fd}% implies the soil is dominated by anthropogenic multi-domain (MD) and stable single domain (SSD) grains. A close relationship between χ_{lf} and heavy metal contents in the topsoil is found. χ_{lf} values in the topsoil are excellently correlated with Zn, Cr, Mn, Cu, Pb, Cd and Fe, with the coefficients (R) of 0.665, 0.416, 0.607, 0.533, 0.639, 0.520 and 0.503, respectively. Those in industrial soil, are roadside and topsoil are also significantly correlated with heavy metals; but those in the agricultural soil do not reach the significant level. It indicated that the magnetic techniques can be used for monitoring soil pollution in Shanghai.

Key Words
Baoshan District, Shanghai; urban topsoil; heavy metal; magnetic susceptibility.

Introduction
Recently, there is a growing interest in using magnetic techniques for monitoring environmental pollution (Wonnyon *et al.* 2009; Kim *et al.* 2007). Statistic assessment demonstrates by analyzing susceptibility values, heavy metal concentrations in large soil data set (Ruiping *et al.* 2006; Blundell *et al.* 2009; Monika *et al.* 2007; Tetyana *et al.* 2004) showed anthropogenic influence on the magnetic properties of soils. Many studies (Lu *et al.* 2006; 2008) have reported excellent relationships between χ_{lf} and the contents of some heavy metals in industrial/urban soils. Soils near urban and industrial zones have an increased magnetic susceptibility (Thompson and Oldfield 1986; Tadeusz *et al.* 2007; Blundell 2009; Xia 2008; Xie 2001). Magnetic measurements show that the main magnetic components in urban topsoil are multidomain grains of ferrimagnetic minerals, which are introduced by industrial activities(Flanders 1994), automobile exhaust(Matzka 1999; Muxworthy 2001; Shilton 2005; Maher 2008) and deposition of atmospheric particulates(Kim *et al.* 2007).

Methods
Close to the Yangtze River on the north, Baoshan District is the traditional industrial base in Shanghai as well as the main vegetable base. Soil samples were selected considering diversities of land utilization including agricultural soils (31), industrial soils (30), road side (31) and residential areas (31).

About 8 g. soil samples (<2.0 mm) were packed, and magnetic susceptibility was measured at low (0.47 kHz) and high (4.7 kHz) frequency by a Bartington MS2 dual frequency sensor. χ_{fd}% was calculated from the percentage of $(\chi_{lf}-\chi_{hf})/\chi_{lf}$. Soils (0.154 mm) were digested with a mixture solution of concentrated HNO_3-HF-$HClO_4$. Cu, Zn, Pb, Cr, Mn and Ni were analyzed by air–acetylene flame atomic absorption spectrophotometry (AAS), Cd by the graphite furnace AAS, while Fe (Fed) was determined according to o-phenonthroline spectrophotometry.

Results
Spatial variation of heavy metal accumulation in the urban topsoil is observed (Table.1). The χ_{lf} value ranged from $18\times10^{-8}m^3/kg$(agricultural soils) to $1127\times10^{-8}m^3/kg$(industrial soils) with the mean value of $148\times10^{-8}m^3/kg$. The mean concentrations of χ_{lf} in the agricultural soils and industrial soils were $52\times10^{-8}m^3/kg$ and $239\times10^{-8}m^3/kg$ respectively. It was measured that χ_{fd} of urban topsoil is less than 4%. The mean χ_{fd} value of industrial zones is 1.8%, which is similar to agricultural areas with a mean value of 1.8%. The value of χ_{lf} is increased in the order of industrial area> roadside > residential area> agricultural area, and in the order of agricultural area> roadside > residential areas> industrial area for χ_{fd}%.

Table 1. Statistic values of χ_{lf} and χ_{fd}% in the topsoil of Baoshan District, Shanghai.

Area	χ_{lf} ($10^{-8}m^3/kg$)			χ_{fd}%		
	max	min	mean	max	min	mean
Baoshan District	1127	18	147	10.2	0.02	1.6
Industrial area	1127	23	239	3.1	0.02	1.3
Roadside	629	19	185	10.2	0.11	1.6
Residential area	315	44	113	4.0	0.02	1.5
Agriculture area	167	18	52	8.2	0.26	1.8

The correlation between χ_{lf} and χ_{fd}% of Baoshan District topsoil(Table. 2) reached the significant level ($p<0.05$), while industrial areas reached extremely significant level($p<0.01$) with low χ_{fd}%(<3%), further indicating the pedogenic SP grains contribute little to the magnetic enhancement of the urban topsoil and dominant MD and SSD grains. In this study, χ_{fd}% of the agricultural soils does not correlate well with χ_{lf}, which may attributed to the fact that soil in Baoshan District was mostly derived from the tidal sediment of the Yangtze River Estuary, and belongs to Entisols because of its young age and weak pedogenesis.

Table 2. Correlation coefficient (R) for relationship between χ_{lf} and χ_{fd}% in the topsoil of Baoshan District, Shanghai.

	Baoshan District	Agriculture area	Roadside	Residential area	Industrial area
n	123	31	30	31	31
R	0.228*	0.314	0.024	0.350	0.559**

** $p<0.01$; * $p<0.05$

χ_{lf} values in the topsoil are excellently correlated with Zn, Cr, Mn, Cu, Pb, Cd and Fe, with the coefficients (R) of 0.665, 0.416, 0.607, 0.533, 0.639, 0.520 and 0.503, respectively(Table. 3). It was found that heavy metal contents (exclude Cr) of the industrial topsoil (Figure1) are positively significantly correlated with the corresponding χ_{lf} values (R[31,0.01]=0.456).Those in the roadside are also extremely significantly correlated with Zn, Cr, Mn, Cu, Pb and Fe($p<0.01$), and significant correlated with Cd ($p<0.05$); but the correlation between χ_{lf} and heavy metals in the agricultural soil (Figure 2) does not reach a significant level. Industrial and vehicular emissions often contain magnetic particles and produce many magnetic aerosols in the urban environment (Hay *et al.* 1997; Shu *et al.* 2001). Those of residential areas fall in between. The significant differences between the industrial and agricultural topsoil suggest that the extra magnetic materials accumulated in the urban topsoil are not inherited from the parent materials, but stem from anthropogenic activities.

Table 3 Correlated coefficients between χ_{lf} and heavy metal contents in the topsoil of Baoshan District, Shanghai.

Area	n	Zn	Cr	Mn	Cu	Pb	Cd	Fe
Baoshan District	123	0.665**	0.416**	0.607**	0.533**	0.639**	0.520**	0.503**
Agricultural area	31	0.074	0.025	0.237	0.037	0.186	0.264	0.158
Roadside	30	0.641**	0.537**	0.651**	0.636**	0.544**	0.449*	0.531**
Residential area	31	0.512**	0.524**	0.543**	0.305	0.537**	0.395*	0.281
Industrial area	31	0.727**	0.338	0.592**	0.783**	0.762**	0.724**	0.525**

** $p<0.01$; * $p<0.05$

Conclusion

In this work, we found that χ_{lf} of the urban topsoil in Baoshan District are extremely enhanced with the highest observed in industrial areas and the lowest in agricultural areas. χ_{fd} % of the topsoil is less than 4%, show that the main magnetic components in urban topsoil are multidomain grains of ferrimagnetic minerals, which are introduced by industrial activities, automobile exhaust and deposition of atmospheric particulates. The enrichment of magnetic particles and heavy metals in the topsoil is considerably obvious in industrial and roadside areas, while the correlation between χ_{lf} and heavy metals in the agricultural soil does not reach the significant level. The enrichment of residential areas falls in between. Thus it's possible to use magnetic technique as a simple, rapid, and nondestructive tool for the assessment of heavy metals contamination in urban.

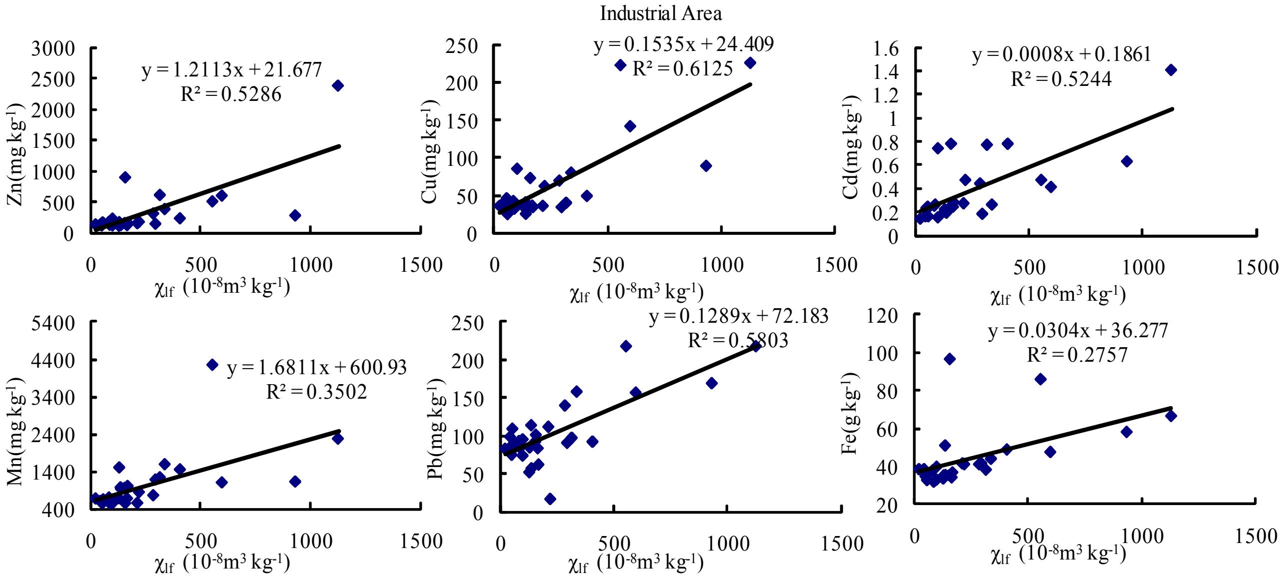

Figure1. Correlation between χ_{lf} and contents of heavy metals in the topsoil of industrial areas in Baoshan District, Shanghai.

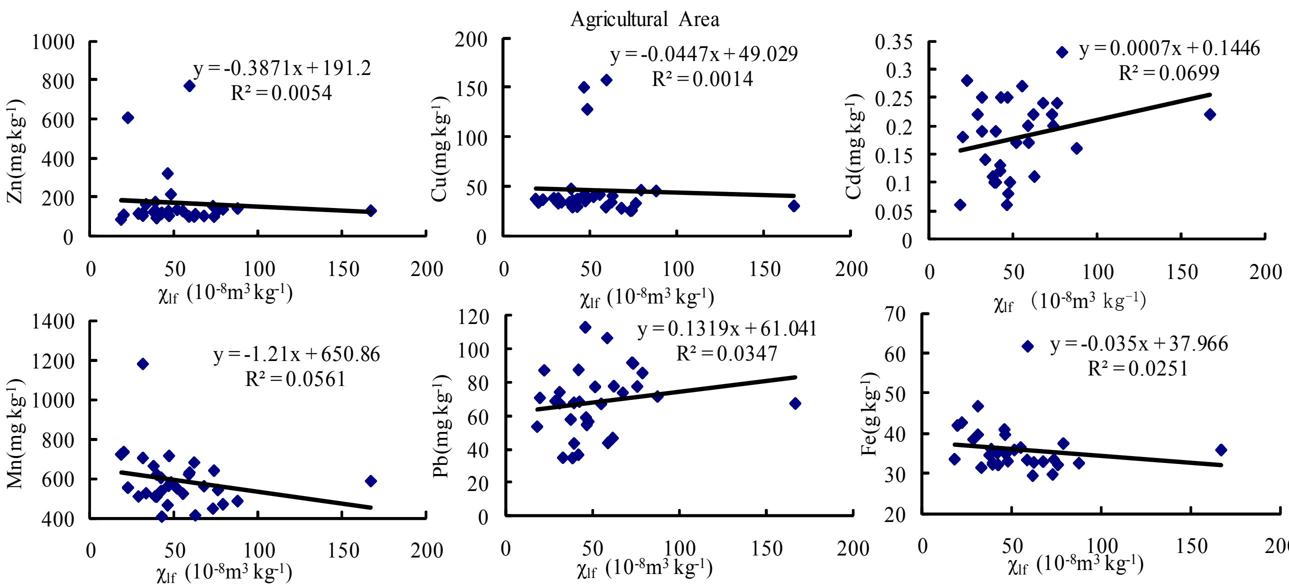

Figure2. Correlation between χ_{lf} and contents of heavy metals in the topsoil of agricultural areas in Baoshan District, Shanghai.

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