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Characterizing heavy metal pollution of different soil profiles in Beijing (China) using magnetic parameters

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Magnetic methods, as a fast and cost-effective measurement technology, have been successfully applied in environmental pollution research. However, most case studies were related to surface measurements integrating signal from certain soil volumes, which cannot provide the details of each layer, especial the magnetically enhanced layer. To better understand the magnetic parameters and their links to heavy metals for screening different kinds of contaminated soils and different migration of pollutants with depth, magnetic susceptibility (MS) distribution in three dimensions was investigated from top soil measurements at 237 sites and 150 cores (30-50cm deep) scanned from 71 sites in Beijing urban and suburban area. The high resolution results reveal that there is a big regional difference of magnetic susceptibility not only on surface but also in different depth. Top soil measurements show that MS is highest in the western Beijing industrial area (steel mill, coal-fired power plants), lower within the city centre, and lowest in the eastern countryside. MS values from MS2 C-sensor measurements at different depths in the western industrial area exhibit the highest values of 400-1000$\times 10^{-5}$SI in the upper 5cm layer. There is a gradual decrease to 250-300$\times 10^{-5}$SI at 15-20cm depth, followed by background values of 150-200$\times 10^{-5}$SI below 20cm. The values from the city centre and eastern countryside are much lower (around 150-200$\times 10^{-5}$SI in the upper 5cm layer), and relatively stable along the profile. Additionally, rock magnetic investigation and geochemical analysis were carried out on three selected soil profiles from the steel mill area, the airport highway and

a site with dumped soil. Data from three soil profiles reveal significant correlation between magnetic parameters (χ and SIRM) and heavy metal contents. Both χ and SIRM show a linear positive correlation with Pb, Zn, Cu ($R^2 > 0.8$) at all the profiles. However, for different sites, other heavy metals (i.e., Fe, Mn, Al, Cr, Co, Ni) exhibit strong or weak correlation with magnetic parameters, which suggests that the soils might be affected by different pedogenic, biogenic processes, and different inputs of anthropogenic sources. Nevertheless, compared to the background values, the magnetic enhancement can provide information about pollution by heavy metals. Tree linkage analyses also indicate relationship between magnetic parameters and heavy metals. Fuzzy C-means cluster analysis (FCM) integrates magnetic parameters and heavy metals, characterizes the accumulation depth of pollutants i.e., enrichment, migration and background. Our work demonstrates that magnetic parameters can be used to delineate anthropogenic pollution in soil profiles and to characterize the migration depth and the depth of unpolluted soil.