Potential linkages between mineral magnetic measurements and urban roadside soil pollution (Part 2).

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Use of mineral magnetic concentration parameters (χ_{LF}, χ_{ARM} and SIRM) as a potential pollution proxy for soil samples collected from Wolverhampton (UK) is explored. Comparison of soil-related analytical data by correlation analyses between each magnetic parameter and individual geochemical classes (i.e. Fe, Pb, Ni, Zn, Cd), are reported. χ_{LF}, χ_{ARM} and SIRM parameters reveal significant (p <0.001 n = 60), strong (r = 0.632 – 0.797), associations with Fe, Cu, Zn and Pb. Inter-geochemical correlations suggest anthropogenic influences, which is supported by low χ_{FD}% measurements that infer an influence of multi-domain mineralogy are indicative of anthropogenic combustion processes. Results indicate mineral magnetic measurements could potentially be used as a geochemical indicator for soils in certain environments and/or specific settings that are appropriate for monitoring techniques. The mineral magnetic technique offers a simple, reliable, rapid, sensitive, inexpensive and non-destructive approach that could be a valuable pollution proxy for soil contamination studies.

Introduction

Urban sediments are an important source of pollution material in urban environments, forming a sink for vehicle exhaust, weathered material, soil and as a source of atmospheric particulate matter (PM).[1] Soil contamination by heavy metals,[2] radionuclides,[3] or persistent organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs),[4] and polychlorinated biphenyls (PCBs),[5] are also important public health concerns.[6,7] Urban sediment is composed of a wide range of grains, which are typically dominated by quartz, clay and carbonates, mainly due to underlying parent material.[1] In addition, abundant anthropogenic grains are present, including glass particles from industrial processes and high temperature combustion, metal slags, cement grains, metallic fragments and iron oxide particles.[1]

Assessment of the extent and severity of soil contamination requires thorough investigation before remediation can proceed.[8,9] However, soil-related analysis can be time consuming and expensive. In the study of sediments the most widely used techniques used are: Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS).[10-15] Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES),[16-18] Scanning Electron Microscope (SEM) techniques,[19,20] sequential extraction methods,[20-23] Graphite Furnace Atomic Absorption Spectrometry GFAAS,[11] Flame Atomic Absorption Spectrometry (FAAS),[21] and X-Ray Fluorescence (XRF) spectrometry.[10,19,24,25] Many studies investigating the geochemical composition of sediments have successfully revealed heavy metal concentrations, with a range of intensities indicating local and regional pollution. Traditional geochemical methods (e.g. AAS, ICP-MS) are relatively complex, time-consuming and expensive with cost of instrumentation and additional expertise required for successful operation. These instruments are bound to static locations and require specific laboratory environments and are therefore unsuitable for mapping or monitoring of large-scale pollution. Where a pollution proxy can be measured efficiently (that is, shorter analysis time or lower cost), it can offer potential advantages. To assess the suitability of an efficient pollution proxy, it is necessary that the nature of the relationship between the investigated parameters follow predictable patterns (like those of trace metals, radionuclides and poly-chlorinated biphenyls (PCBs)).

Mineral magnetic measurements are now considered a routine form of analysis when investigating the compositional properties of rocks, sediments and soils.[26] This technique has been applied to several depositional environments including marine, estuarine, and fluvial.[27] Recently a magnetic approach has been suggested for particle size proxy purposes.[27-30] In the study of coastal sediments,[28] marine, estuarine and fluvial sediments,[27,31] soil,[32] road deposited sediments,[33,34] and roadside dust on tree leaves,[35] mineral magnetic methods have been used as indicators of particle size and pollution. Many studies have explored relationships between mineral magnetic measurements and the physicochemical properties of soils, sediments and dusts.[34,33,36-38] Based on these investigations, mineral magnetic measurements have been identified as a suitable proxy for geochemical, radioactivity, organic matter content and particle size data.[27,28,30,31,37-41]

Anthropogenic particles in urban settings display distinctive magnetic properties such as magnetic enhancement.[26] Magnetic particles produced from anthropogenic processes have increased in abundance within the environment since the industrial revolution (*circa* 19th century), primarily from the combustion of fossil fuels.[42-44] Iron occurs as an impurity in fossil fuels, which unburned, has low magnetization.[45] However, on combustion (industrial, domestic, vehicular) carbon and organic material are lost by oxidation and highly magnetic iron oxide (magnetite and haematite) spherules are produced.[42,46,47] Combustion temperature and fuel type determines the magnetic grain size, mineralogy and concentration of these particulates.[20,45,48] Some studies have found strong relationships between certain magnetic properties (magnetic susceptibility χ_{LF}) and heavy metal concentrations.[25,30,42] Despite these advances, the approach of using mineral magnetic properties in the study of environmental pollution has not been fully explored.

Compared with other geochemical techniques, mineral magnetic methods are relatively quick and simple to prepare and analyse.[49] Measurements of magnetic susceptibility (χ_{LF}) can be made in ~1 minute, within either a laboratory or field environment.[27] This allows relatively large data sets to be acquired, adding statistical weight to any data collected.[49] Initial costs of magnetic susceptibility (χ_{LF}) instrumentation are low (Bartington MS2 susceptibility meter and sensor £3,960) when compared to XRF and ICP-MS.

It is timely for innovative technologies to be considered as an alternative, or in tandem, to those already employed to determine urban soil pollution. Ideally, they need to be rapid, reliable, dynamic and inexpensive. To assess the suitability of any analytical technique as an efficient pollution proxy, it is necessary that the nature of the relationship between the proposed parameters follow predictable patterns. To date, most work has not examined the extent to which mineral magnetic parameters are reliable indicators of differences in soil contaminants. This paper presents the second part of a study describing mineral magnetic methods as a pollution proxy in urban soils. The first part presented in Crosby et al.[50] and further referred to as 'Part 1', specifically investigated the potential for particle size indication in urban soils. Part 2 will further investigate the potential of mineral magnetic measurements as a geochemical pollution proxy in urban soils.

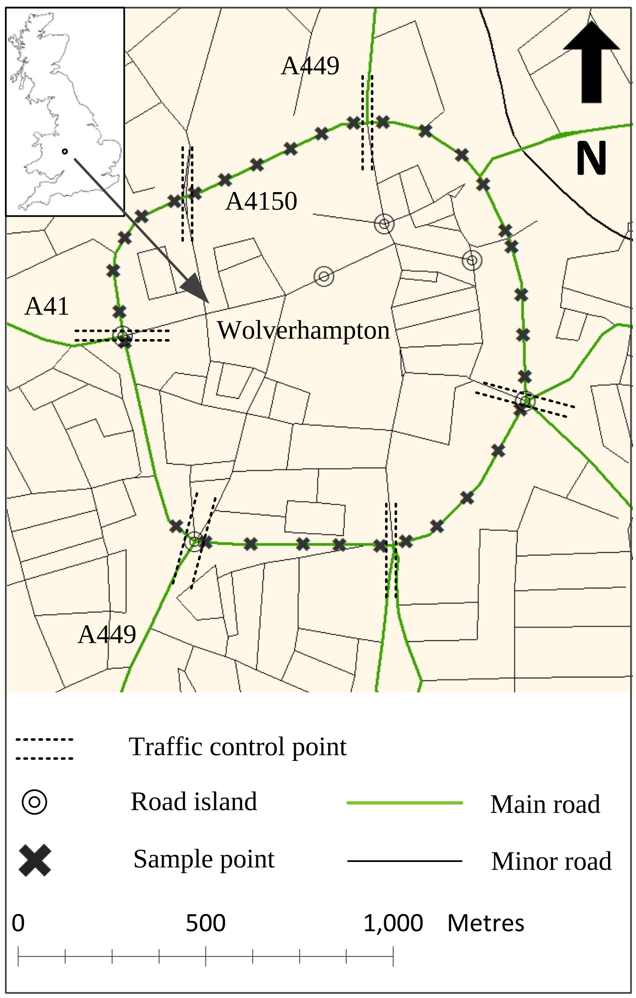
Materials and methods

A horizon, topsoil (0-20 cm depth) samples (n = 60) were collected from the City of Wolverhampton's (West Midlands UK (Fig.1)) main Ring Road (A4150). The main road encircles the city centre and is approximately 3.1 Km long with traffic counts of ~ >15,000 vehicles per day. Samples were collected along the A4150 covering the full circumference of the main road (sample points n = 30) (Fig. 1.) Samples were collected ~50 m along both sides of the central reservation to represent directional traffic (sample points n = 30 x 2; tn = 60). Topsoil was transferred to clean, pre-labelled, self-seal, airtight plastic bags. In the laboratory, samples were visibly screened to remove macroscopic traces of hair, animal and plant matter.

Magnetic analyses

All samples were subject to the same preparation and analysis procedure.[27,49] Samples were dried (<40 °C), weighed, packed into 10 ml plastic pots and immobilized with clean sponge foam and tape prior to analysis. Initial, low-field, mass-specific, magnetic susceptibility (χ) was measured using a Bartington MS2 susceptibility meter. By using a MS2B sensor, low and high frequency susceptibility was measured (χ_{LF} / χ_{HF}). χ_{LF} values are roughly proportional to the concentration of ferrimagnetic minerals within a sample. The resultant χ_{LF} and χ_{HF} can be used to show frequency dependent susceptibility ($\chi_{FD\%}$) and is a measure of the occurrence of very fine magnetic domains on the superparamagnetic (SP) to stable single domain (SSD) and multi domain (MD) boundary and is a good indicator of anthropogenic source (Fig.2). Anhysteretic Remanence Magnetisation (ARM) was induced with a peak alternating field of 100 mT and small steady biasing field of 0.04 mT using a Molspin A.F. demagnetiser. The resultant remanence created within the samples was measured using a Molspin 1A magnetometer and the values converted to give the mass specific susceptibility of ARM (χ_{ARM}). The samples were then demagnetized to remove the induced ARM and exposed to a series of successively larger field sizes up to a maximum 'saturation' field of 800 mT, followed by a series of successively larger fields in the opposite direction (backfields), generated by two Molspin pulse magnetisers (0–100 and 0–800 mT). After each 'forward' and 'reverse' field, sample isothermal remanent magnetisation (IRM) was measured using the magnetometer.

Fig.1 Map showing Wolverhampton Ring Road study area (n = 60).



Geochemical analyses

All samples were subject to the same textural preparation and analysis procedure.[25,51] Concentrations of elements were determined by using isotope source X-ray fluorescence (XRF) analysis using an ARL 8410 XRF spectrometer. Boyle,[51] reported that total concentrations of elements can be determined in soils and sediments with sufficient accuracy using XRF techniques. XRF analysis has high precision with short analysis time and minimal handling of samples. Prior to measurements, the instrument was calibrated using a range of reference materials.

Results and discussion

Mineral magnetic concentration and spatial variation

Mineral magnetic properties of Wolverhampton Ring Road top soil samples are summarized in Table 1. The Wolverhampton Ring Road soil samples contain moderate to high concentrations of magnetic minerals (χ_{LF} 4.84–58.46 x $10^{-7}m^3kg^{-1}$; χ_{ARM} 0.18-1.0 x $10^{-7}m^3kg^{-1}$; SIRM 61.41-855.30 x $10^{-5}Am^2kg^{-1}$), when compared to other urban soil studies.[52,53] χ_{LF} varies spatially across the sampling area, with high concentrations to the south west and directly east of the city centre (Fig. 3a (Fig.3 and 5 were generated by interpolating data with ARC view GIS v 10)). There appears to be bands of high and low concentration of magnetic material across the sampling area. Low concentrations are to the north, with an area of high and then low as you move east along the ring road (Fig.3a). Low-frequency magnetic susceptibility (χ_{LF}) represents the total contribution of ferromagnetic minerals. Susceptibility of Anhysteretic Remanent Magnetisation (χ_{ARM}) is roughly proportional to the concentration of magnetic grains of stable single domain size (e.g. ~0.03–0.06 μm). Saturation Isothermal Remanent Magnetisation (SIRM) is related to concentrations of all remanence-carrying minerals in the sample, but is also dependent upon the assemblage of mineral types and their magnetic grain size.[49]

The χ_{FD} results suggest the presence of MD and SP grain assemblages (Fig.2). $\chi_{FD\%}$ for top soils in England have been found to display a mean of 4.1%.[54] This suggests mean soil

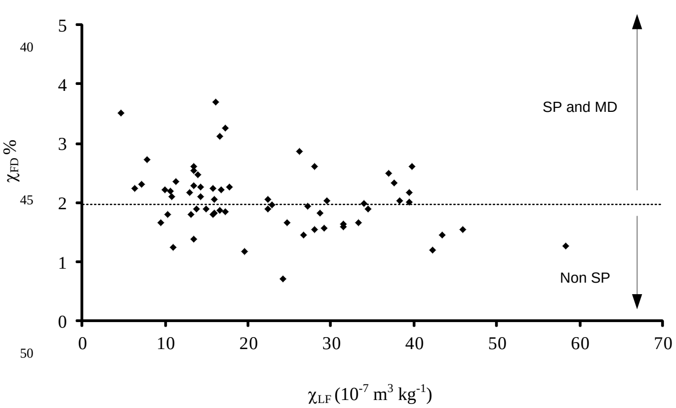


Fig. 2 χ_{LF} vs $\chi_{FD\%}$ for Wolverhampton Ring Road soils. Non superparamagnetic, superparamagnetic and multi-domain boundaries as defined by Dearing in Walden et al.[49]

Table 1 Mineral magnetic data for Wolverhampton ring road soils (*n* = 60 samples)

	χ_{LF}	χ_{ARM}	SIRM	χ_{FD}
Units	10^{-7} m^3 kg^{-1}	10^{-7} m^3 kg^{-1}	10^{-5} Am^2 kg^{-1}	%
Mean	22.00	0.44	291.65	2.03
Max	58.46	1.00	855.3	3.67
Min	4.84	0.18	61.41	0.69
Range	53.62	0.82	793.89	2.97
SD	11.69	0.19	164.93	0.54
CV	0.53	0.43	0.57	0.27

characteristics for the UK are predominantly superparamagnetic and naturally derived from weathering and erosion of background geologies. The Wolverhampton soil samples show considerably lower χ_{FD} mean values when compared (2.03% (Table 1). Frequency dependent susceptibility (χ_{FD}) measurements have previously been used to estimate magnetic grain sizes and potential sources of magnetic materials.[20,54] High $\chi_{FD\%}$ results represent SP grains derived from top soil material.[54] Low $\chi_{FD\%}$ measurements are indicative of predominantly MD magnetic grain size assemblages. Coarse MD grains contribute notably to a depression of high frequency susceptibility, therefore the closer the χ_{FD} to zero the more MD assemblages are expected to dominate the sample. Low MD assemblages are common in polluted and urban soils, due to anthropogenic Fe input from combustion and industrial processes. Soil generally contains a high concentration of naturally derived material, due to the nature of MD assemblages and high concentrations of χ_{LF} attributed to anthropogenic inputs, the soil samples here show specific signatures attributed to artificial input. The resultant Ring Road soils exhibit high χ_{LF} and low χ_{FD} values due to potential ferromagnetic loading and a high proportion of coarse grained minerals. These results correspond with Manchester concentrations,[20] with low χ_{FD} (mean 2%) and high χ_{LF} (27 x 10^{-7} m^3 kg^{-1}). Parent geologies beneath the selected soils are sedimentary in nature and suggest primary ferromagnetic minerals from weathering are unlikely to make significant contribution to susceptibility values.[55] However, natural soil material can dilute these values. Previous studies have noted increased concentrations of magnetic minerals in urban areas,[20,56] which can be directly related to anthropogenic activity. Combustion of fossil fuels are known to produce large crystals of MD state.[57] Blundell et al.[56] reported magnetic enhancement in locations with current and historic anthropogenic activity. High concentrations of χ_{LF} found within UK conurbations are expected to be derived from anthropogenic magnetic enhancement. Moreno et al.[58] and Sheng-Gao et al.[59] indicated high mineral magnetic concentrations and larger domain sizes of magnetic particles alongside roads with high volumes of vehicle traffic. The results of Wolverhampton soil samples suggested this may be the case in the study due to the magnetic characteristics and proximity of samples to the ring road.

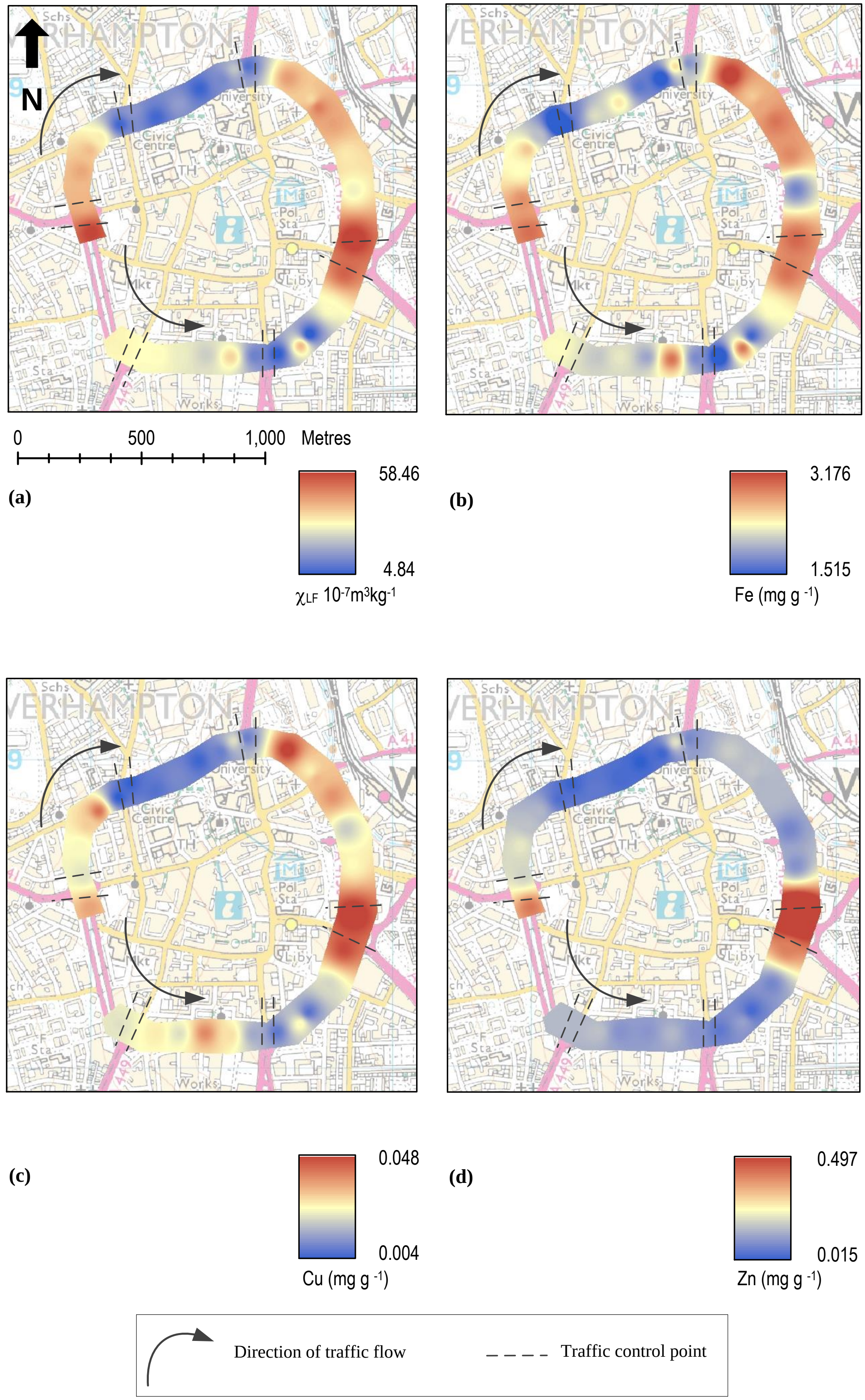


Fig. 3 Spatial distribution of a) χ_{LF}, b) Fe, c) Cu and d) Zn for Wolverhampton Ring Road soils.

Table 2 Geochemical data (mg g^{-1}) for Wolverhampton Ring Road soils (n = 60 samples)

	Fe	Cu	Zn	Mn	Pb	Ni	Cd	Si	Ti	Ca	K
Units	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}
Mean	2.509	0.017	0.059	0.017	0.017	0.002	0.002	15.716	0.193	1.323	1.050
Max	3.716	0.048	0.497	1.292	0.043	0.005	0.008	20.700	0.247	5.970	1.525
Min	1.515	0.004	0.015	0.010	0.004	0.001	0.001	7.645	0.118	0.525	0.581
Range	2.201	0.044	0.482	1.282	0.039	0.004	0.007	13.055	0.129	5.445	0.944
SD	0.420	0.010	0.067	0.252	0.009	0.001	0.002	2.664	0.028	0.773	0.196
CV	0.167	0.588	1.136	0.803	0.529	0.500	1.000	0.170	0.145	0.584	0.187

Geochemical results for Wolverhampton Ring Road top soil samples are summarized in Table 2. Wolverhampton Ring Road soil samples contain moderate levels of Fe, Pb, Ni, Cu and Cd when compared to other studies,[20,23,37,60] with noatble variation between sites. Higher Fe and Cu concentrations are found to the north east and west of the City Centre (Figure 3b c). High concentrations of Cu (max = 0.048 mg g^{-1}) are also found to the west and south of the city centre (Figure 3c). High concentrations of Zn (max = 0.497 mg g^{-1}) are located directly to the east of the Ring Road and appear to be associated with the traffic island located at this position (Figure 3d).The Wolverhampton Ring Road samples are dominated by Si (mean 15.716 mg g^{-1}), Fe (mean 2.509 mg g^{-1}) and Ca (mean 1.323 mg g^{-1}). Heavy metal concentrations of Fe, Pb, Zn and Cu are comparable with other urban soil studies. Concentrations of Fe are similar to those of Manchester,[20] Buenos Aires,[61] and Wuhan.[60] Whereas, concentrations of Pb, Zn and Cu are similar to those found in Birmingham (UK),[23] Luanda (Angola),[12] and Seoul (Korea).[62] In contrast, mineral magnetic concentrations (χ_{LF}) differ between soil and road dust due to the diluting effects of soil geochemistry,[55] (enhanced silica concentrations) and are generally not suitable for concentration comparison. Road dusts generally have shorter residence times and have been reported to display concentrated magnetic material in urban areas[20,37].

Fig. 4a shows Spearman's rank correlation coefficient values (rs) between Fe and $\chi_{LF,}$ other selected mineral magnetic and geochemistry parameters are shown in Table 3a. Moderate to strong positive correlations (p <0.001) exist between each mineral magnetic parameter and specific elements (Fe, Cu, Zn and Pb) (0.680 to 0.885). These elements are of particular importance to urban soil and sediment studies, due to contributions from anthropogenic sources. Several studies have identified mineral magnetic and geochemical linkages.[32,58,63-66] Strong relationships have been found with anthropogenically-produced particles (Mn, Cu, Fe, Ni, Zn and Pb.[32,58,63,66,] Wang et al.[67] found moderate correlations (p <0.01) between heavy metals (Fe, r = 0.770; Zn, r = 0.481; Cu, r = 0.464; Mn, r = 0.546; Pb, r = 0.458) and χ_{LF}. Schmidt et al.[32] found strong correlations between χ_{LF} and heavy metals, when χ_{LF} was found at sites with concentrations >17.6 x $10^{-7} m^3 kg^{-1}$. Beckwith et al.[63] and Schmidt et al.[32] found this relationship was due to the enhanced magnetic signature of the samples, which indicated anthropogenic sources.

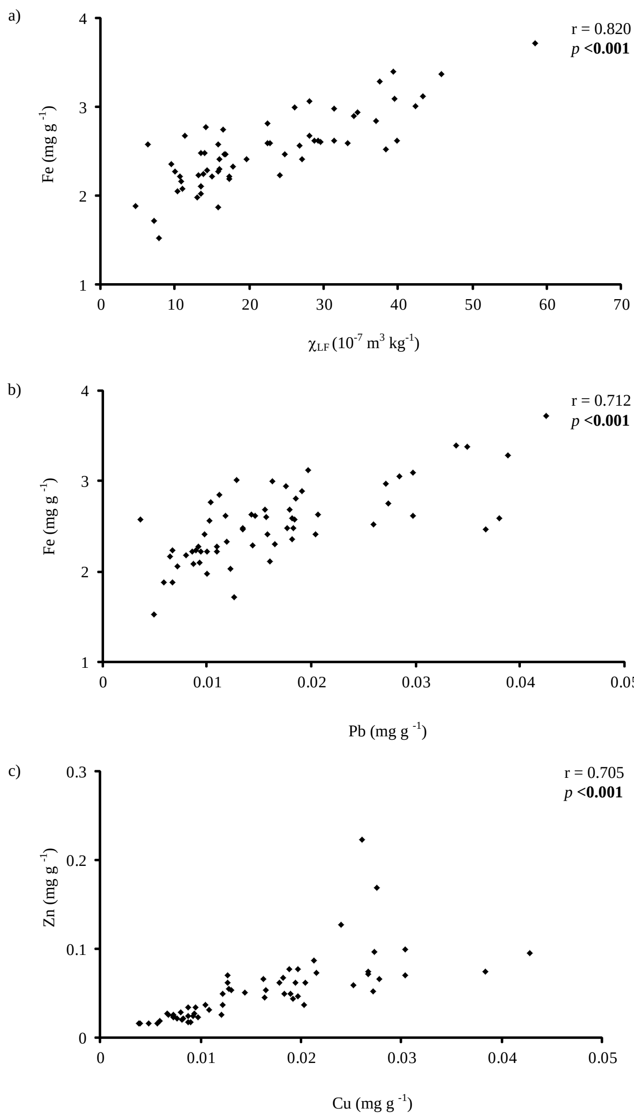


Fig. 4 Correlation plots of a) Fe vs χ_{LF}; b) Fe vs Pb and c) Zn vs Cu for Wolverhampton Ring Road soils (n = 60).

Table 3 Pearson's correlation coefficients (r) between; (a) mineral magnetic concentration and geochemical parameters for Wolverhampton Ring Road top soils and (b) inter geochemical parameters (*p <0.05; **p <0.01; ***p <0.001; NS = Not Significant (n = 60 samples)).

(a)	Ti	Mn	Fe	Ni	Cu	Zn	Cd	Pb
χ_{LF}	0.090^{NS}	0.201^{NS}	0.820***	0.232^{NS}	0.885***	0.680***	0.106^{NS}	0.649***
χ_{ARM}	0.122^{NS}	0.142^{NS}	0.814***	0.013^{NS}	0.769***	0.640***	0.088^{NS}	0.613***
SIRM	0.171^{NS}	0.196^{NS}	0.255^{NS}	0.047^{NS}	0.026^{NS}	0.006^{NS}	0.227^{NS}	0.138^{NS}

(b)	Ti	Mn	Fe	Ni	Cu	Zn	Cd
Mn	0.526**						
Fe	0.430*	0.607***					
Ni	0.355*	0.397*	0.756***				
Cu	0.010^{NS}	0.376*	0.746***	0.710***			
Zn	0.545**	0.358*	0.637***	0.586**	0.705***		
Cd	0.415*	0.056^{NS}	0.052^{NS}	0.232^{NS}	0.029^{NS}	0.072^{NS}	
Pb	0.105^{NS}	0.414*	0.712***	0.593***	0.145^{NS}	0.634***	0.145^{NS}

Inter correlation of Fe, Pb, Zn, Cu and Ni (Table 3b (Fig.4b-c)) have been identified with strong correlations (p <0.001) between each parameter (Fe vs Pb, r = 0.712; Fe vs Ni, r = 0.756; Fe vs Zn, r = 0.637, Fe vs Cu, r = 0.746; Zn vs Cu, r = 0.705; Ni vs Cu, r =0.710) and are good indicators of anthropogenic sources in soils and sediments.[20,68] Apeagyei et al.[69] and Lopez,[70] also attributed Fe, Pb, Zn and Cu linkages to combustion and vehicles. Fe and Pb are typically by-products of the combustion process and Cu and Zn are sourced from tyre and brake linings.[71] Linton et al.[72] and Robertson et al.[20] demonstrated strong correlations between Fe and Pb. Although use of lead in fuel had significantly reduced between the studies of Linton et al.[72] and Robertson et al.[20] due to fuel additive legislation and reduction of Pb from petroleum regulation; (1978 - EC Directive 78/611/EEC and 1981 - The Motor Fuel (Lead content of Petrol)) Regulation; limited the maximum amount of lead in petrol to 0.4 gl^{-1}). However, the ratio of Fe/Pb in the magnetic fraction remains relatively consistent.[20] This supports the assumption that, in addition to concentrations, ratios between specific elements indicate potential source.

Table 4 χ_{LF} concentration data at specific sites, as referred to in Figure 5

a							b						
Site	Stationary	Moving	Mean	Range	SD	CV	Site	Stationary	Moving	Mean	Range	SD	CV
1	38.39	7.93	23.16	30.46	21.54	0.93	1	29.62	9.6	19.61	20.02	14.16	0.72
2	43.44	13.29	28.36	30.15	21.32	0.75	2	28.09	13.52	20.80	14.57	10.30	0.50
3	58.45	13.51	35.98	44.94	31.78	0.88	3	37.67	27.21	32.44	10.46	7.40	0.23
4	42.36	10.42	26.39	31.94	22.58	0.86	4	34.58	7.3	20.94	27.28	19.29	0.92
5	45.97	22.53	34.25	23.44	16.57	0.48	5	33.34	14.09	23.71	19.25	13.61	0.57
6	39.55	15.93	27.74	23.62	16.70	0.60	6	31.56	17.36	24.46	14.2	10.04	0.41

a+b				
Site	Mean Stationary	Moving Mean	Range	SD
1	68.01	17.53	50.48	35.69
2	71.53	26.81	44.72	31.62
3	96.12	40.72	55.40	39.17
4	76.94	17.72	59.22	41.87
5	79.31	36.62	42.69	30.19
6	71.11	33.29	37.82	26.74

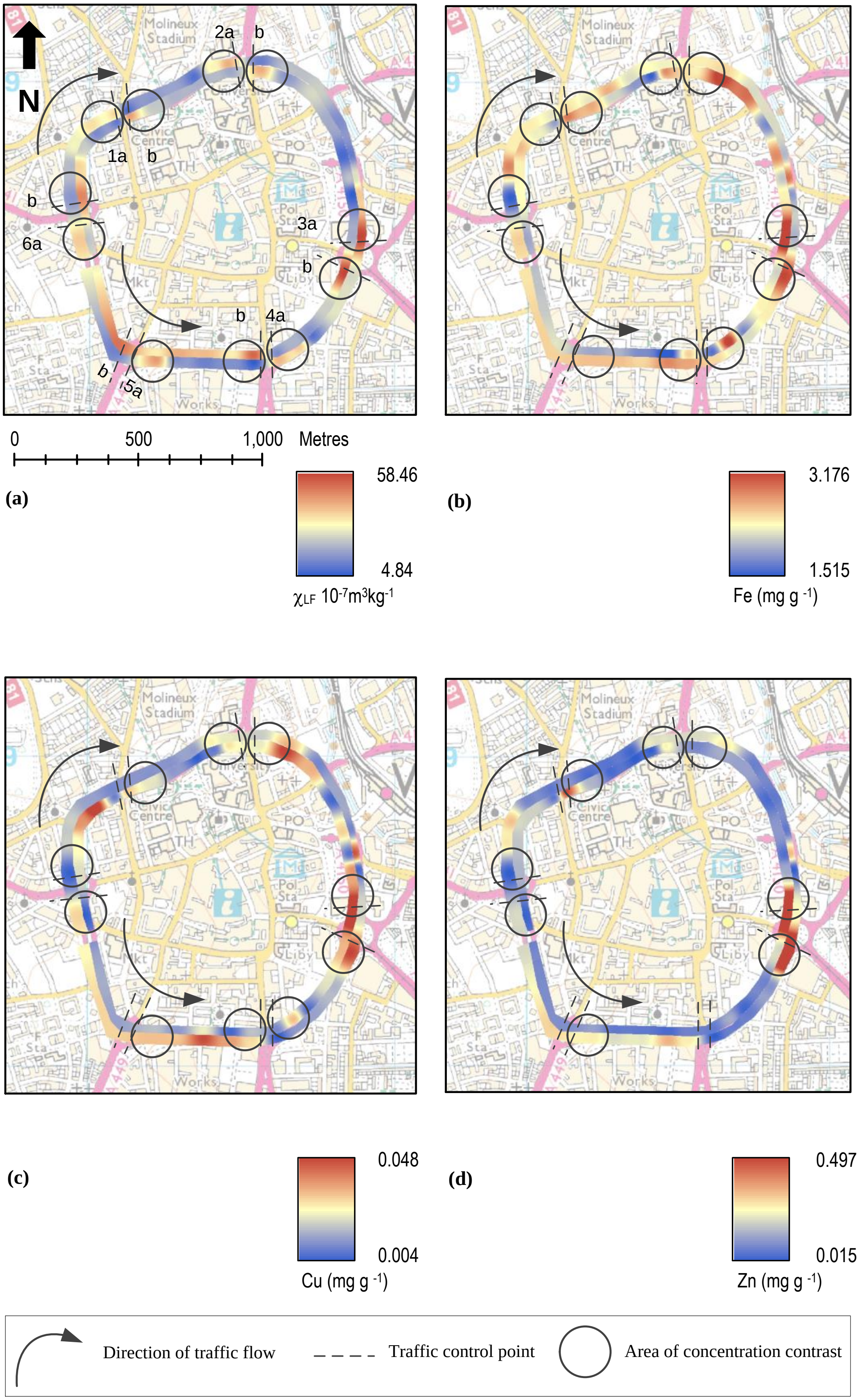


Fig. 5 Spatial distribution of a) χ_{LF}, b) Fe, c) Cu and d) Zn for Wolverhampton Ring Road soils, showing directional differences (Numerical sites refer to Table 4).

Anthropogenic influence on mineral magnetic and geochemical concentrations

Results have demonstrated how mineral magnetic measurements can be used to indicate high and low concentrations of mineral magnetic and geochemical material in urban road side soil along the A4150. Table 4 (Fig. 5) further demonstrates how mineral magnetic measurements have captured inter-spatial differences, which infer traffic intensities and traffic flow direction. Inter-spatial patterns appear to indicate high and low concentrations of magnetic minerals at specific traffic control points (areas with traffic control lights, round about systems and road junctions). Figure 5a shows χ_{LF} concentrations for clockwise and anti-clockwise traffic flows along the Ring Road. Results for χ_{LF} concentrations are presented in Table 4 and correspond to Figure 5a. High concentrations are found at traffic control points at all notable locations when compared to areas of traffic movement (Table 4, Fig. 5). Correlations of Cu and Zn suggest the influence of vehicle braking and tyre wear and show areas of high concentrations near to major road junctions (Fig. 3c d, Fig. 5c, d). Although χ_{LF} displays good characteristics in terms of traffic flow, not all geochemical properties correspond as well, with some crossover of material present (Fig. 5d). The relative low correspondence of Zn found to the north and south could be due to natural processes attributed to the high susceptibility of zinc leaching and not representing original deposition.[20] Due to the mineral magnetic and geochemical concentrations and associations, it is proposed that natural sources of magnetic minerals have minimal contribution to the distinct magnetic-geochemical signal found at these sites, but are present in high concentrations due to the nature of the material and suggest some dilution of the magnetic signature. When compared to 'purer' sediment sources, like those found in Road Deposited Sediment (RDS), χ_{LF} signatures of RDS are a magnitude higher than that found in surrounding soils. These results indicate high inter-site variations which appear to be associated with road conditions and depositional environment.

Previous studies have identified spatial distributions of metal concentrations in urban sediments.[15,20,23] Spatially metal concentrations differ over small areas and can reflect contrasting levels of vehicle activity,[1,20,23,73] Robertson et al. (2003),[20] demonstrated the use of mineral magnetic measurements to identify spatial trends with enhanced concentrations of magnetic material in inner city samples. Moreno et al. (2003),[58] and Sheng-gao et al. (2008),[59] identified high mineral magnetic concentrations and relatively large domain sizes within urban sediments linked to areas with high traffic volumes. The mineral magnetic approach demonstrated here shows some potential for application of initial assessment to potential urban pollution hotspots. This study has shown primarily mineral magnetic measurements giving an indication of Fe within a sample. With the resultant concentration of Fe and depositional environment reflecting other contributing elements to that sample. However, caution should be used when using these methods to identify specific geochemical signatures and at this time should only be used as an estimation of potential metal loading.

Conclusions

Analyses indicate magnetic concentration parameters could be potentially employed as a suitable pollution proxy for urban soils. Of the three magnetic parameters, χ_{LF} and χ_{ARM} has the strongest and most significant correlations (p <0.001) with Fe, Pb, Zn and Cu and with inter-geochemical correlation suggesting anthropogenic input, with Fe loading dominating the signature. Spatial variation has been identified at inter-site scales and shows the potential for sensitive small area sampling. Low levels of $\chi_{FD\%}$ and MD mineralogy further suggest anthropogenic influences. In most cases, these data associations follow the predictable trends of other environmental studies. Given the speed, low-cost and sensitivity of the measurements, this suggests magnetic techniques could be used as a rapid alternative exploratory technology for initial assessment of urban soil pollution investigations.

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‡ Footnotes should appear here. These might include comments relevant to but not central to the matter under discussion, limited experimental and spectral data, and crystallographic data.

1 A. Name, B. Name and C. Name, *Journal Title*, 2000, **35**, 3523; A. Name, B. Name and C. Name, *Journal Title*, 2000, **35**, 3523.

