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Spatial and temporal variation in magnetic properties of street dust in Lanzhou City, China

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Urban environmental problems are of increasing concern. Lanzhou is a large industrial city in Northwest China. Street dust samples representing different temporal and spatial scales were collected for magnetic properties study. Magnetic measurements indicate a high concentration of magnetic minerals in Lanzhou street dust, dominated by pseudo-single domain (PSD) magnetite. The concentration of magnetic materials is distinctly high in winter and spring, low in autumn. Similarly, higher concentrations associated with heavy industry, concentrated residential development, and vehicular traffic suggest mixed contributions of magnetic material from both anthropogenic and natural sources. χ_{lf} and SOFT% are effective magnetic parameters that denote seasonal differences among magnetic properties in street dust, convenient and economical methods for monitoring street dust pollution.

environmental magnetism, urban pollution, street dust, Lanzhou

Urban street dust studies began in the mid-1970s[1]. Street dust is a significant pathway for urban pollutants, acting as a sink for vehicle exhaust, aeolian deposits, weathered material, and soil, as well as a source of atmospheric particulates, house dust, and run-off particulates [2]. The two primary sources of street dust are previously suspended particulates and displaced urban soil[3]. Additionally, vehicular traffic, structural heating systems, structure deterioration, construction and renovation, corrosion, and so on, contribute directly to street-dust loads in their proximities. Street dust deposits do not remain in place for long, quickly resuspending into the atmospheric aerosol[4]. A significant component of suspended and dissolved solids in street run-off[5], street dust becomes a persistent pollutant of urban soil and water.

The present study of street dust is prompted by concerns about negative effects of human exposure to street dust, through inhalation, ingestion, and dermal contact. Numerous studies of street dust have focused on elemental concentration, source identification[6,7] and heavy metal pollution[8,9], resulting in a body of referential results[6−14]. The latter tend to focus on element lead in street dust, the relationship between street dust lead and child blood lead or human body lead[6,10], trace elements[11], organic content[2,12], and polycyclic aromatic hydrocarbons[13]. However, previous research offers little understanding of street dust as an environmental pollutant. The problem is just beginning to be scrutinized.

Now, simple, economical, quick, non-destructive magnetic methods can be used to monitor atmospheric particulates[14,15]. Magnetic technology has been used extensively to measure heavy metals pollution[16−20]. The distinct magnetic properties of street dust origins are foremost in street dust studies[21]. Various researchers[20−22] confirm the utility of magnetic techniques in

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discriminating fly ash and vehicular-derived particles in roadside samples. However, spatial and temporal variation of magnetic properties in street dust are little reported[12,19−24], notwithstanding their potential for source tracing. Lanzhou's air pollution is chronically severe. Based on previous work[22,23], the present paper discusses the magnetic parameters, spatial and temporal variations thereof, and origins of Lanzhou street dust.

1 Materials and methods

Lanzhou is located in the geographic center of China. The city hosts highly developed chemical and petroleum industries, non-ferrous metal works, heavy equipment manufacture, and electrical power generation plants. Discharge of industrial and domestic pollutants; a long, narrow, river valley location, and outlying, unvegetated countryside all conspire to assure conditions for severe pollution.

We looked at the street dust in four districts of Lanzhou: Xigu, Anning, Qilihe and Chengguan, obtaining a total of 178 dust samples (Figure l, Table 1). We swept dust from pedestrian streets, gardens, roadways of varying traffic density, and the grounds of factories and hospitals, using a brush and dustpan. Samples were taken in September 2005 (n = 46), January 2006 (n = 46), and March (n = 72). Thirty-three sites throughout the city were revisited during the three sampling periods, where one dust sample was obtained in each sampling period. All samples were air-dried in the laboratory, and then passed through a 1-mm sieve to remove refuse and small stones.

Once the samples were processed, magnetic meas-

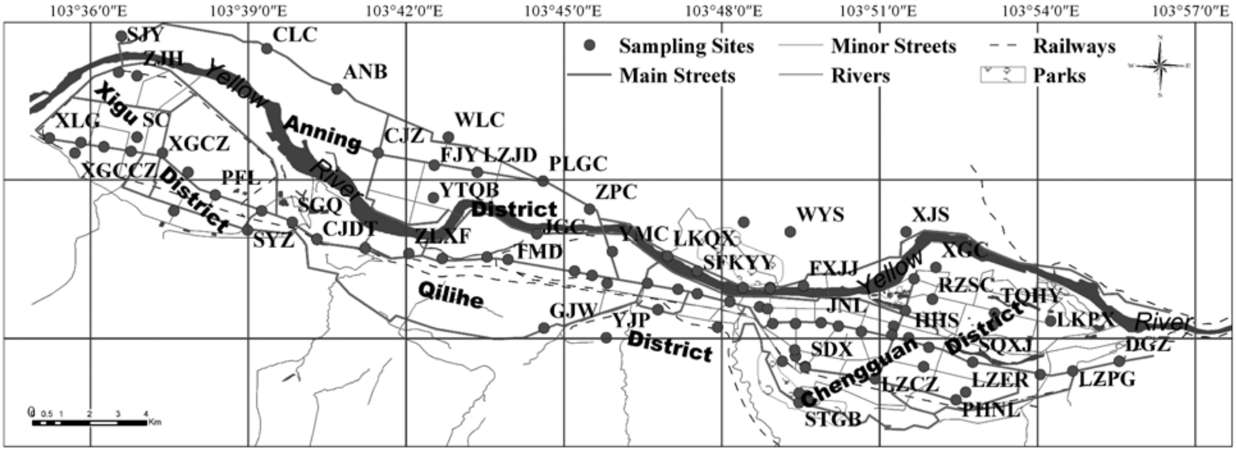

Figure 1 Sketch map depicting street dust sampling sites in Lanzhou.

Table 1 The full name of each sampling site shown in Figure 1

Abbreviation	Full name	Abbreviation	Full name	Abbreviation	Full name
ANB	Anningbu	LZJD	Lanzhoujiaotongdaxue	TQHY	Tianqinghuayuan
CJZ	Cuijiazhuang	LZPG	Lanzhoupigeshichang	WLC	Wanlichang
CJDT	Cuijiadatan	PFL	Paifanglu	WYS	Wuyishan
CLC	Chilunchang	PHNL	Paihongnanlu	XGCCZ	Xiguchengchezhan
DGZ	Donggangzhen	PLGC	Peiliguangchang	XGCZ	Xiguchengzhan
FJY	Feijiaying	RZSC	Rizashichang	XJS	Xujiashan
FXJJ	Fuxingjiaju	SC	Shuichang	XLG	Xiliugou
GJW	Gongjiawan	SDX	Shidangxiao	YJP	Yanjiaping
HHS	Hanhansuo	SGQ	Shengouqiao	YMC	Yimaochang
JGC	Jigangcheng	SJY	Shajingyi	YTQB	Yintanqiaobei
JNL	Jingninglu	SQXJ	Shengqixiangju	ZJH	Zhongjiahe
LKPX	Lankangpixiechang	STGB	Santaige	ZLXF	Zhongliangxifumenkou
LZCZ	Lanzhouchezhan	SYZ	Shiyouzhan	ZPC	Zhipeichang
LZER	Lanzhoudierdianrechang	TMD	Tumendun	SFKYY	Shifeikeyiyuan

urements were made. Low field magnetic susceptibility was measured on 4g samples using a dual-frequency (470 and 4700 Hz) Bartington Instruments MS2 sensor at 0.1 scales. A hysteretic remanent magnetization was induced in a steady field of 0.04 mT imposed on a peak AF field of 100 mT using a DTECH AF demagnetizing unit. Saturation isothermal remanent magnetization (SIRM) was grown by a Molspin pulse magnetizer and all remanences were measured in a Molspin spin magnetometer. Magnetic hysteresis loops and Curie temperature were measured on MMvftb produced by Petersen Instruments. Magnetic parameters are expressed on both mass-specific and quotient bases in order to give quantitative and qualitative information of χ_{lf} (0.47 kHz) χ_{lf} ($\times 10^{-8}/\mathrm{m}^3\cdot\mathrm{kg}^{-1}$), SIRM (SIRM=IRM$_{1000\mathrm{mT}}$) ($\times 10^{-6}\ \mathrm{Am}^2\cdot\mathrm{kg}^{-1}$), HIRM(HIRM=[(sirm+irm$_{-300}$)/2]/mass) ($\times 10^{-5}\ \mathrm{Am}^2\cdot\mathrm{kg}^{-1}$), SOFT (SOFT=[(sirm-irm$_{-20}$)/2]/mass) ($\times 10^{-6}\ \mathrm{Am}^2\cdot\mathrm{kg}^{-1}$), χ_{ARM} ($\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$), χ_{fd}% ($\chi_{\mathrm{fd}}\% = [\chi_{\mathrm{LF}}\text{-}\chi_{\mathrm{HF}}]/\chi_{\mathrm{LF}}\times 100$), SOFT% (SOFT = [SOFT/SIRM]×100), HARD% (HARD% = (HIRM/SIRM) ×100), $\chi_{\mathrm{ARM}}/\chi_{\mathrm{lf}}$, χ_{ARM}/SIRM ($\times 10^{-5}/\mathrm{m}\cdot\mathrm{A}^{-1}$), SIRM/$\chi_{\mathrm{lf}}$ ($\times\mathrm{kA}\cdot\mathrm{m}^{-1}$) and S-ratio (IRM-$_{300}$/SIRM).

2 Results and analysis

2.1 Variation of magnetic parameters in Lanzhou street dust

Table 2 summarizes our magnetic measurement results. The magnetic susceptibility χ_{lf} indicates the total contribution of magnetic minerals represented by the concentration of ferrimagnetic minerals in the sample [14]. Lanzhou street dust yields relatively high mean χ_{lf} values of $449.21\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$, ranging from $50.03\ 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$ to $1348.10\times\ 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$. The mean χ_{lf} values ($466.22\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$ and $484.49\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$) are considerably higher in spring and winter, about 1.2 times higher than in autumn, when the mean χ_{lf} is $376.55\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$. SIRM, SOFT and χ_{ARM} are also magnetic parameters related to magnetic minerals concentrations[25]. SIRM is controlled largely by ferrimagnetic and antiferromagnetic minerals but not by paramagnetic and diamagnetic materials[14]. SOFT approximately reflects magnetite content, particularly the contribution of magnetic grains at the multidomain (MD) range and the SP/SSD border, with low coercive force, while the content of stable single domain (SSD) and pseudo-single domain(PSD) ferromagnetic grains can be estimated by χ_{ARM}[26]. Mean values of SIRM, SOFT and χ_{ARM} are $6458.94\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$, $2246.81\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$ and $908.35\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$, respectively (Table 2). Consequently, the mean values of winter and spring samples are higher than mean autumn sample values. Since HIRM estimates antiferromagnetic components in a sample, HIRM demonstrates the same variation trend among the three sampling periods, with the mean HIRM values of winter and spring sampling periods higher than in autumn.

SIRM/χ_{lf} and S-ratios are often employed as grain size and type indicators for magnetic minerals[14,27]. Frequency-dependent susceptibility χ_{fd} relates to the superparamagnetic (SP) ferrimagnetic component[28], while $\chi_{\mathrm{ARM}}/\chi_{\mathrm{lf}}$, χ_{ARM}/SIRM ratios can indicate ferrimagnetic minerals grain size. SOFT and HARD percentages can serve as approximate indicators of the relative dominance of ferrimagnetic and canted antiferromagnetic sample components. Compared with HARD percentage, the considerably higher SOFT percentage indicates ferrimagnetic minerals dominate the samples. The so-called S-ratio (=IRM$_{-300\mathrm{mT}}$/IRM$_{1\mathrm{T}}$) provides a measure of the relative amounts of high-coercivity ("hard") remanence to low-coercivity ("soft") remanence. In many cases, this allows a fair estimate of the relative incidence of antiferromagnetic versus ferrimagnetic material. Samples with a high S-ratio primarily contain magnetite; lower values indicate contributions of 'harder' magnetic minerals[29]. The mean S-ratio value of Lanzhou street dust is 0.974, and three seasonal variations are insignificant (0.943, 0.951, 0.946 in autumn, winter and spring, respectively), indicating that the dominant magnetic component comprises ferromagnetic minerals. Mean values of 33 revisited site samples demonstrate a pattern of relatively high χ_{lf} ($550.20\times 10^{-8}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}$) and SOFT percentage (34.19%), low HARD percentage (2.64%) and χ_{fd}% (2.21%), similar to returns from all samples obtained.

2.2 Thermomagnetic curve (J-T curve)

The J-T curves showing that magnetization varies with temperature can be used to determine magnetic mineral type and change during heating and cooling processes[14]. Hence, the thermomagnetic curve is extensively used in analyzing magnetic mineral types. Irreversible thermomagnetic curves on selected bulk samples are shown in Figure 2, demonstrating that cooling curves are sharply

Table 2 Magnetic parameter values of street dust samples taken in different seasons in Lanzhou[a)]

Measurement	2005-09		2006-01		2006-03	
	Range	Mean	Range	Mean	Range	Mean
χ_{lf}	50.03—1178.32	376.55	115.60—1348.10	466.22	141.94—1137.08	484.49
$(10^{-8}\mathrm{m}^3 \cdot \mathrm{kg}^{-1})$	(193.75—1178.32)	(427.40)	(157.45—1348.10)	(581.91)	(328.98—1137.08)	(552.35)
$\chi_{\mathrm{fd}}\%$	1.25—14.60	2.51	1.00—5.83	2.22	1.19—3.08	1.97
	(1.25—14.60)	(2.55)	(1.00—5.83)	(2.05)	(1.19—2.43)	(1.88)
SIRM	739.36—40378.44	5692.08	1873.96—15171.58	6688.13	2358.53—19277.93	6771.83
$(10^{-5}\,\mathrm{Am}^2 \cdot \mathrm{kg}^{-1})$	(2651.36—40378.44)	(6459.38)	(2499.09—15171.58)	(7847.77)	(4793.66—19277.93)	(7585.56)
HIRM	46.68—1107.82	126.14	65.85—435.27	156.69	86.18—1142.65	181.56
$(10^{-5}\,\mathrm{Am}^2 \cdot \mathrm{kg}^{-1})$	(50.37—1107.82)	(138.68)	(78.46—435.27)	(173.08)	(86.18—1142.65)	(217.95)
SOFT	187.55—20428.37	2010.33	609.04—6309.02	2344.50	770.34—6296.66	2310.89
$(10^{-5}\,\mathrm{Am}^2 \cdot \mathrm{kg}^{-1})$	(847.04—20428.37)	(2335.54)	(798.16—6309.02)	(2800.86)	(1657.44—6296.66)	(2596.02)
SOFT%	24.92—50.59	32.04	30.38—53.57	34.82	30.38—39.44	33.96
	(28.04—50.59)	(32.96)	(30.38—44.53)	(35.37)	(31.31—39.44)	(34.23)
HARD%	0.14—16.70	2.85	1.19—4.34	2.45	0.89—14.66	2.71
	(0.14—16.70)	(2.61)	(1.22—4.34)	(2.28)	(0.89—14.66)	(2.83)
χ_{ARM}	109.32—4538.76	741.31	292.83—3276.43	990.32	369.34—1990.69	938.04
$(10^{-8}\,\mathrm{m}^3 \cdot \mathrm{kg}^{-1})$	(436.53—4538.76)	(829.81)	(542.56—1860.91)	(1043.70)	(664.42—1990.69)	(1033.01)
$\chi_{\mathrm{ARM}}/\chi_{\mathrm{lf}}$	1.07—4.44	2.07	0.99—7.20	2.31	0.81—5.74	2.09
	(1.07—4.44)	(2.02)	(1.01—4.29)	(1.97)	(0.81—2.90)	(1.98)
χ_{ARM}/SIRM	0.10—0.20	0.14	0.08—0.65	0.16	0.10—0.35	0.14
$(10^{-3}\,\mathrm{m} \cdot \mathrm{A}^{-1})$	(0.10—0.20)	(0.14)	(0.08—0.27)	(0.14)	(0.10—0.18)	(0.14)
SIRM/χ_{lf}	7.95—39.46	14.95	7.35—19.53	14.93	6.96—18.96	14.42
	(7.95—39.46)	(14.78)	(7.35—17.46)	(14.19)	(6.96—18.96)	(14.18)
S-ratio	0.666—0.997	0.94	0.913—0.976	0.95	0.707—0.982	0.95
	(0.666—0.997)	(0.95)	(0.913—0.976)	(0.95)	(0.707—0.982)	(0.94)

a) Bracketed values are measurement results of samples from revisited sites.

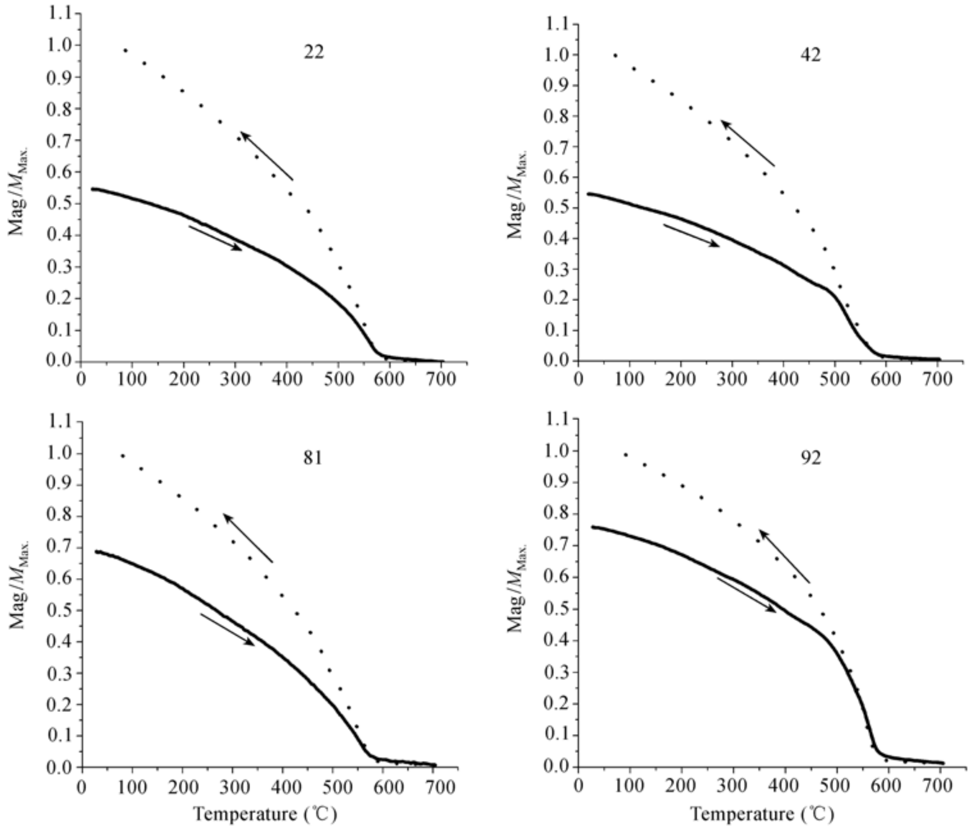

Figure 2 Thermomagnetic curves of selected Lanzhou street dust samples. Solid and dashed lines represent heating and cooling processes, respectively. Nos. 22 and 92 were taken in January 2006 and Nos. 42 and 81 in March 2006.

higher than heating curves. The heating cycle up to 500℃ is characterized by a gradually decreasing curve and a rapid decrease in magnetization as the sample was heated over 500℃. The value of magnetization decreases to almost zero at 580℃, suggesting that the dominant magnetic mineral is magnetite. The magnetization on the cooling curve gradually increased from 570℃ or 580℃ to room temperature, indicating formation of some new ferrimagnetic minerals during these cycles. The sharp reversible increase of magnetization in the temperature interval 520－585℃ on the cooling curve shows that the newly formed ferrimagnetic mineral is magnetite, consistent with the magnetite Curie temperatures of 580℃ on four selected samples.

2.3 Magnetic hysteresis loop

Hysteresis is a unique physical phenomenon of ferromagnetic material, used to describe the relationship between magnetic remanesence obtained in a pulsed direct current magnetic field and the density of the external magnetic field. There is considerable variation in the hysteresis of different natural materials, which can be used to identify ferromagnetic minerals[14]. The magnetic field within the hysteresis loop can indicate the magnetic minerals that dominate hysteresis behaviors[29,30]. The mean magnetic field within the hysteresis loop in Lanzhou street dust samples is 250 mT (Figure 3). Therefore, the main magnetic mineral with low coercivity affecting hysteresis behaviors in the samples is magnetite.

3 Discussions

3.1 Magnetic minerals types and grain size characteristics of Lanzhou street dust samples

S-ratio mean values, J-T curves, and hysteresis loops indicate the dominant magnetic mineral of Lanzhou street dust is ferrimagnetic material, which is consistent

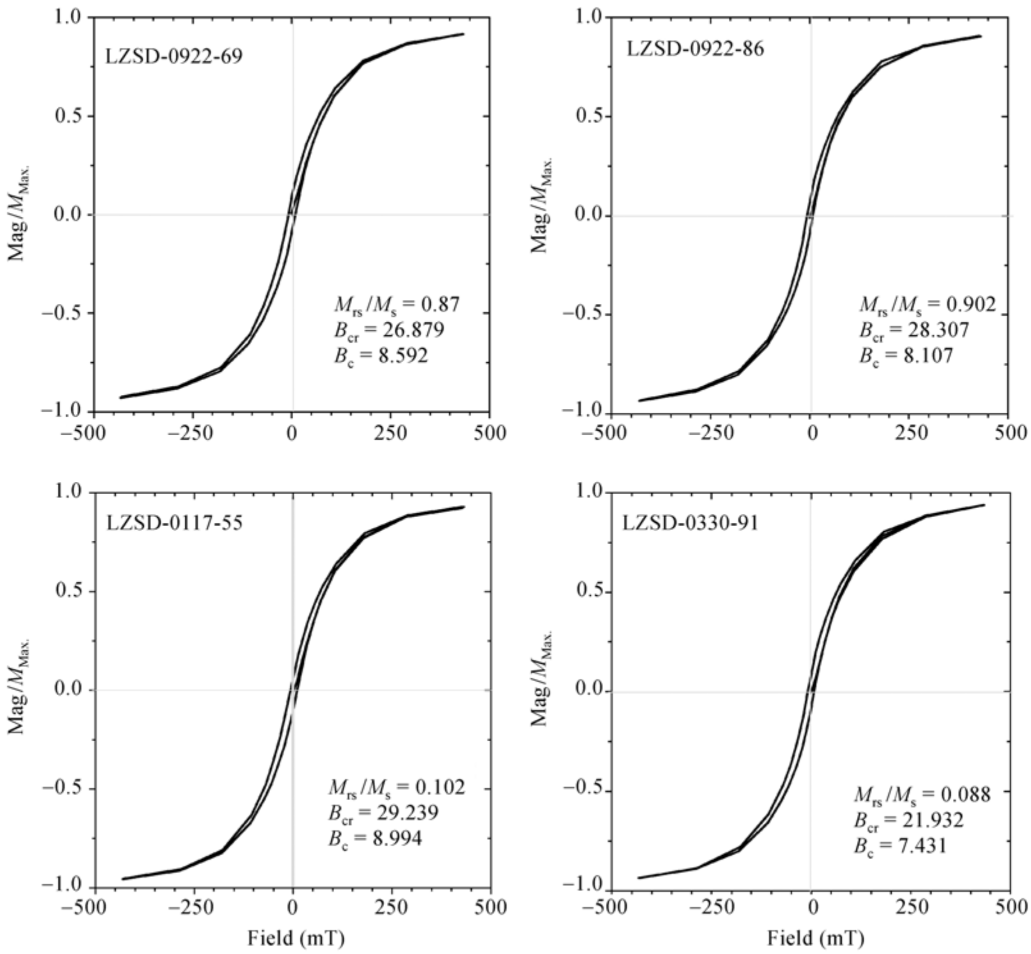

Figure 3 Magnetic hysteresis loop of street dust in Lanzhou. M_{rs} is saturation remanence, M_s is saturation magnetization, B_r is coercive force, and B_{cr} is coercivity of remanence.

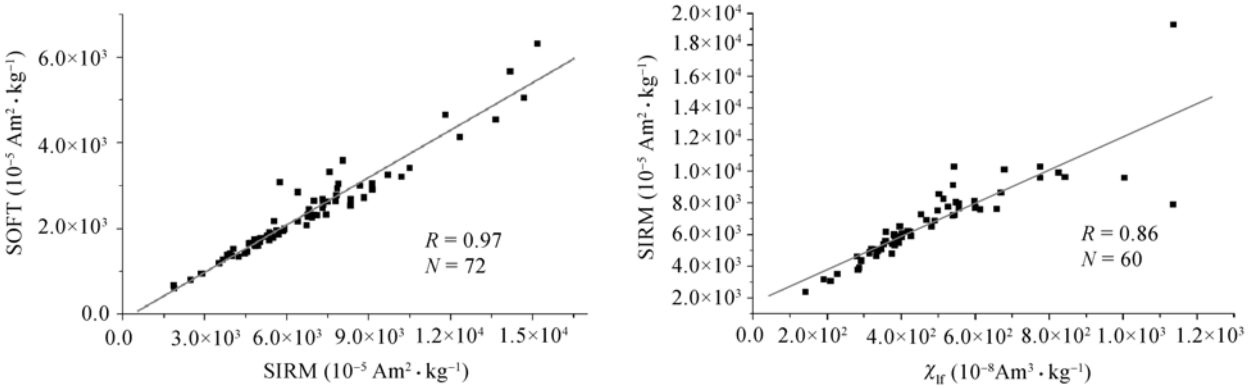

Figure 4 Correlations between SIRM, χ_{lf} and SOFT; R is the correlation coefficient.

with the low coercivity of remanence between 20 mT and 40 mT[14].

SIRM is largely controlled by ferrimagnetic and canted antiferromagnetic minerals, without the influence of paramagnetic and diamagnetic material, while SOFT approximately reflects the concentration of ferrimagnetic minerals. SIRM shows a highly positive correlation with χ_{lf} (R=0.86) and SOFT (R=0.97) (Figure 4), further suggesting dominance of ferrimagnetic minerals in the samples.

Other evidence pointing to magnetite as the dominant magnetic mineral in the samples is illustrated in Figure 5, where a graph of the ratio $M_{\mathrm{rs}}/M_{\mathrm{s}}$ against the ratio $B_{\mathrm{cr}}/B_{\mathrm{c}}$, referenced as a Day plot[31], discriminates grain size. The ratio of saturation remanence to saturation magnetization, $M_{\mathrm{rs}}/M_{\mathrm{s}}$, against the ratio of remanent coercive force to ordinary coercive force, $B_{\mathrm{cr}}/B_{\mathrm{c}}$ was calculated by measurement results. We see that most ratios fall into the PSD field, with two in the MD field. These magnetic characteristics are consistent with previous street dust studies[22].

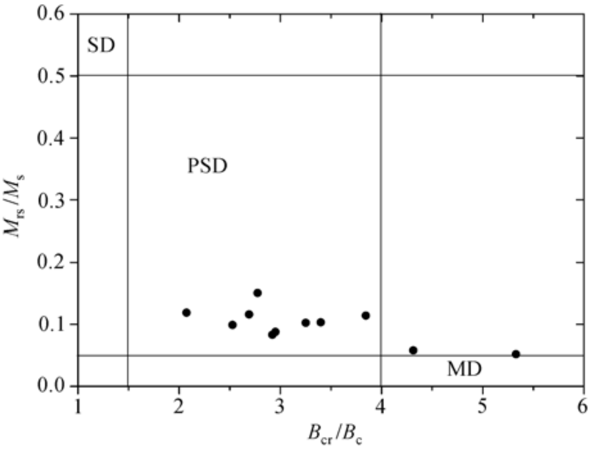

Figure 5 Day plot.

3.2 Seasonal variation of magnetic properties in Lanzhou street dust

Variations in magnetic parameters and ratios, based on the selected 33 street dust samples obtained during autumn, winter and spring in Lanzhou, are shown in Figure 6, where two probability ranges (1%—99% and 25%—75%) confine the distribution of magnetic parameters under seasonal variation. The obvious seasonal variations in magnetic parameters reflecting the concentration of magnetic minerals (e.g. χ_{lf}, SIRM and χ_{ARM}) are the considerably higher values of spring and winter compared to those of autumn. However, distinctions of these magnetic properties between spring and winter are not great, related, perhaps, to the cold season indoor heating period extending from November through April. This phenomenon indicates increased contributions from anthropogenic activity, such as industrial and domestic combustion processes (mainly coal burning) that release coal dust containing magnetic material. These results are consistent with those of Chen et al.[32,33]. Moreover, the thermal inversion typical of Lanzhou winters reduces ground temperatures, which prevents cross-ventilation and consequent diffusion of contaminates. Therefore, the high values of χ_{lf}, SIRM and χ_{ARM} in January and March 2006 probably reflect increased magnetic minerals from increased industrial and communicant contaminates deposited in the street dust. The seasonal variations of HIRM, SOFT and SOFT% are similar to χ_{lf}, SIRM and χ_{ARM}, with higher values during the indoor heating period, compared with non-heating periods. Thus, more "hard" magnetic minerals and ferrimagnetic minerals are induced in the indoor heating seasons (i.e., winter and spring). An increased input of aeolian dust in spring contributes to increased magnetic minerals concentra-

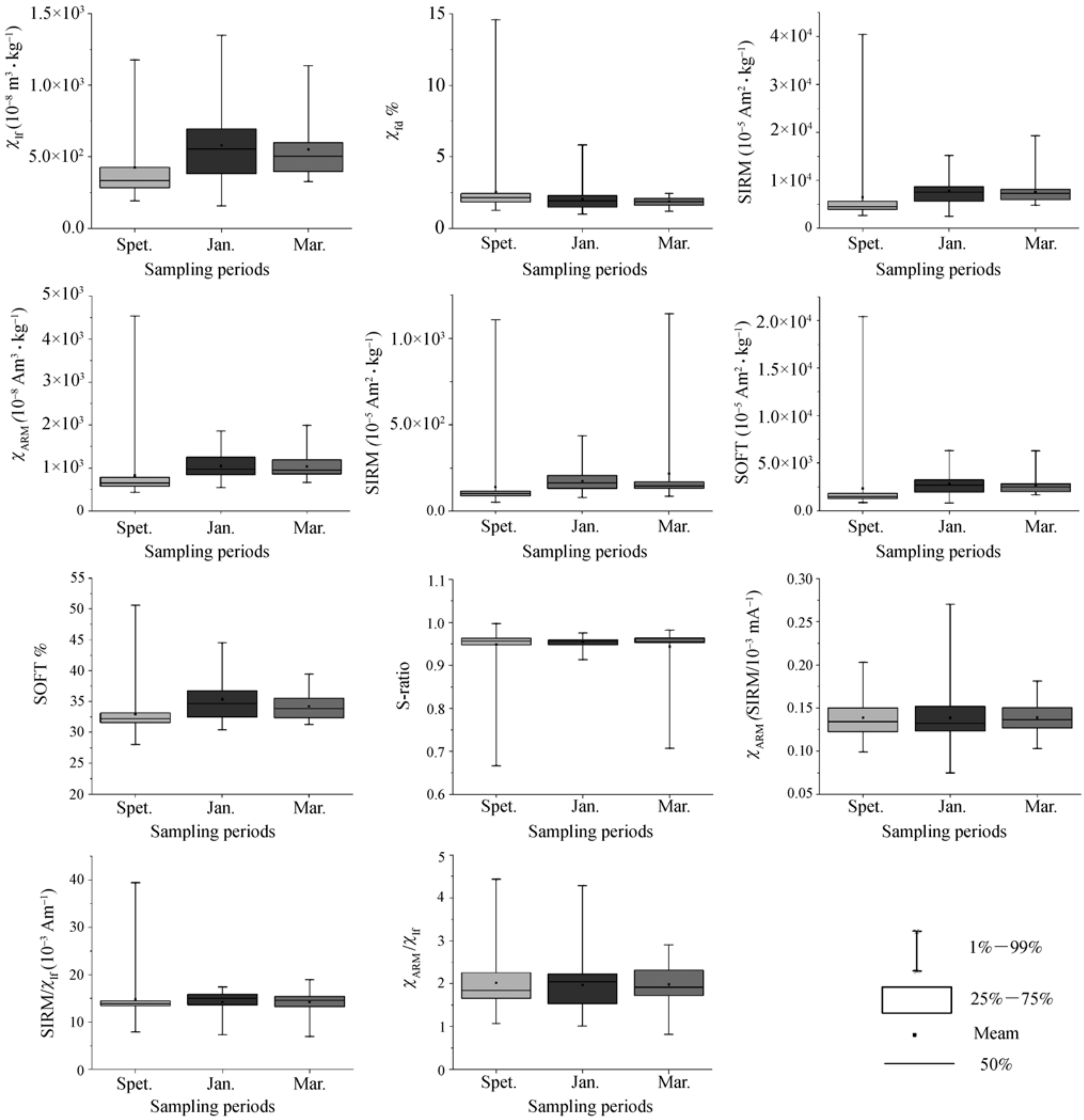

Figure 6 Seasonal variation of magnetic parameters and ratios.

tions. The HIRM values of the street dust samples in Lanzhou are higher than the values of topsoil in Northwest China[34]. And the seasonal variations of HIRM indicate that the contribution of heating and input of aeolian dust in spring to the "Hard" magnetic particles. The SOFT values in winter are higher than other sampling seasons which show the contributions of the anthropogenic activity to the ferrimagnetic magnetic minerals.

The χ_{fd}% values of the samples in three seasons are not obviously different, indicating that seasonal variations of SP grains are indistinct. Nor distinct are seasonal variations in the ratios of S-ratio, χ_{ARM}/SIRM, SIRM/χ_{lf} and χ_{ARM}/$\chi_{lf.}$ This may be explained in two ways. On one hand, most magnetite fall into the PSD/MD field, therefore, the grain size of the magnetic particles could not be used to distinguish the origin of the pollution. On the other hand, the sources of the magnetic minerals in dust of Lanzhou are comparatively single. It needs more study on the magnetic characters of the pol-l-ution sources to identify these two mechanisms.

We applied a one-way statistical analysis of variance (ANOVA) to test differences of mean measurement values significant in temporal variation analysis. Comparison of mean values among 33 revisited samples in the different sampling seasons shows that differences are not significant at the 0.05 level, except for χ_{lf} and SPFT percentage. This is consistent with reporting from Xie et al.[35]. The differences in SOFT percentage values and χ_{lf} values in the different seasons are significant at the 0.05 level, with F values of 3.57261 and 4.40817, respectively. The χ_{lf} and SOFT percentage means are significantly different, suggesting that the concentration of ferrimagnetic minerals varies with season, becoming more concentrated in winter and spring when the release of magnetic spherules caused by fossil-fuel combustion (such as coal) results in enhanced suspension of magnetic particles in dust and soil. Numerous studies show that the concentration of magnetic minerals increases in sediments near power stations and iron and steel plants[15 – 18,30,35 – 37]. Coal exhaust usually comprises atmospheric particles abundant in iron and sulphide[30,38]. Therefore, increased concentrations of ferrimagnetic minerals in street dust samples could be related to incremental increases in industrial coal consumption, along with the affects of indoor heating, weather, and landform conditions.

Thus, we infer that the variation of magnetic properties is due to the collective influence of anthropogenic activities and natural factors. Among the magnetic parameters and ratios, χ_{lf} and SOFT percentage can indicate seasonal variation in the concentration of magnetic minerals in street dust.

3.3 Spatial variation in magnetic properties of Lanzhou street dust

The geographic distribution of factories, residential and business enterprises, public institutions and commercial centers in Lanzhou can be generally characterized as follows: Petroleum and chemical industries are found mainly in the Xigu district; public institutions mainly in the Anning district; a mix of properties such as petroleum and chemical plants, manufacturing and public institutions occur in the Qilihe district; the Chengguan district is the residential and business center of Lanzhou, and this district includes the forest belt of Gaolan Mountain, Jiuzhoutan, Baitashan and Xujiashan.

The magnetic susceptibility χ_{lf} represents the total contribution of magnetic minerals in a sample, which can indicate the seasonal variations of magnetic properties effectively. Therefore, combined with correlation analysis, the spatial distribution of some measurements may provide useful information about the source of dusts[32]. The spatial distribution of χ_{lf} values was examined through use of SURFER software. It shows the isoline of χ_{lf} of Lanzhou street dust (Figure 7). Mean χ_{lf} value of $466.22\times10^{-8}\ \mathrm{m^3\cdot kg^{-1}}$ shows high value in Lanzhou. Sampled areas in the Xigu and Chengguan districts present, overall, high χ_{lf} values, except in some low value areas in the Chengguan district, such as Landong timbering market, Lanzhou leather factory, Xingang Co., Lankang shoes factory and Xujiashan, which are distant from the city center. The Anning district (especially Jiuzhou development zone and Wuyishan) also show low χ_{lf} values. In contrast, the main traffic arteries and areas of dense residential use show high χ_{lf} values. The spatial distribution of χ_{lf} in Lanzhou street dust shows that residential use, industrial development and heavy traffic represent high magnetic susceptibility χ_{lf} value distribution areas, consistent with previous studies[16,20−22,38,39]. Furthermore, the high values of the magnetic difference between the heating periods and non-heating periods are centralize in the Xigu District and Chengguan District. The mean value and the max value of the difference are $139.73\times10^{-8}\ \mathrm{m^3\cdot kg^{-1}}$ and $638.14\times10^{-8}\ \mathrm{m^3\cdot kg^{-1}}$ separately. It indicates the anthropogenic activity (such as heating) is a prominent contribution to the high magnetic mineral concentrations in Lanzhou street dust. And then the special variation is distinct.

The spatial variation of magnetic susceptibility in Lanzhou street dust indicates the contribution of anthropogenic activity to magnetic properties results which are consistent with those of previous studies[21,40].

4 Conclusions

Magnetic minerals in Lanzhou street dust samples are PSD-range magnetite in high concentrations. Ferrimag netic minerals dominate the magnetic properties of the samples.

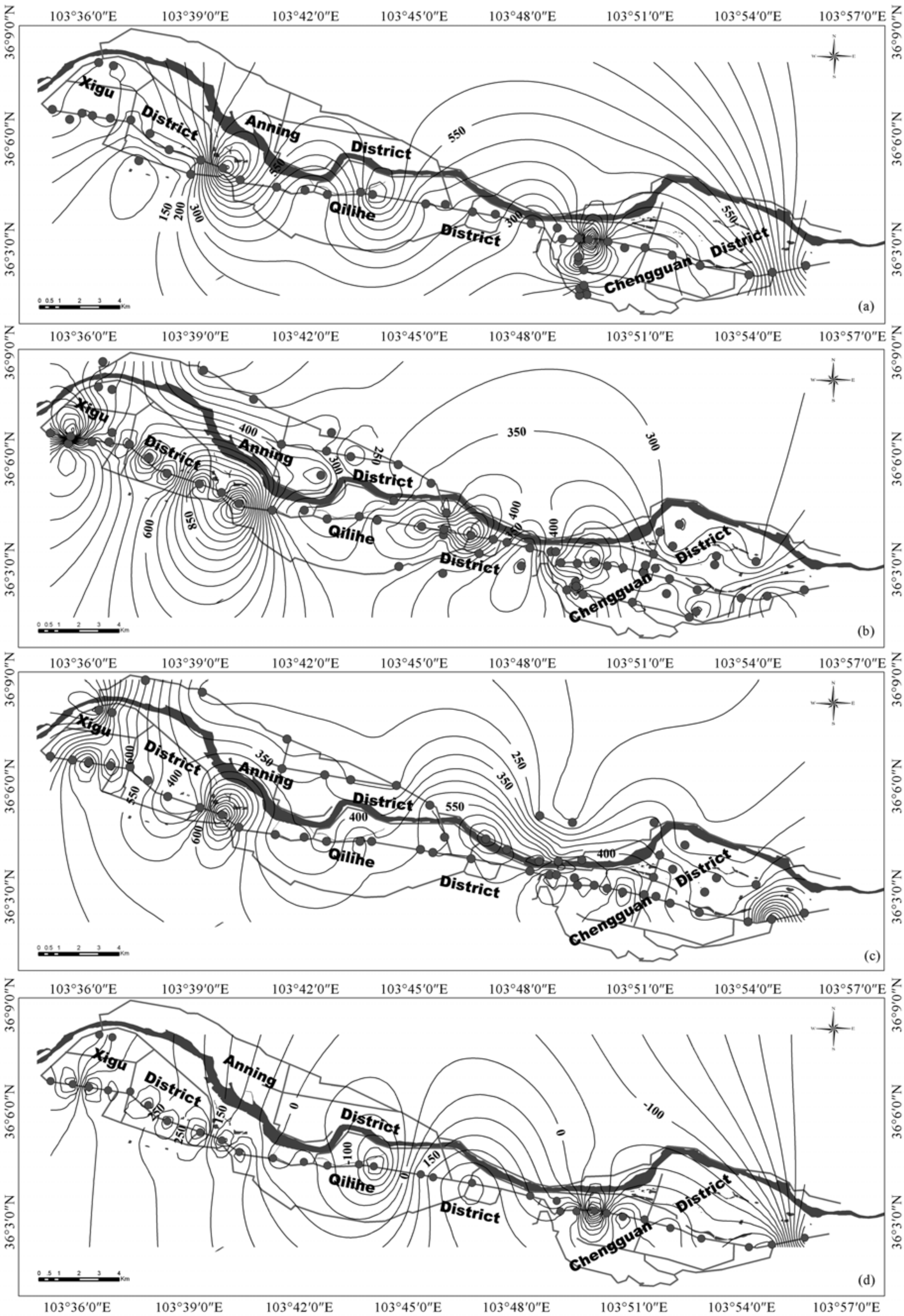

Figure 7 Spatial variation of χ_{lf} in Lanzhou street dust samples. (a) September 2005; (b) January 2006; (c) March 2006 and (d) the magnetic difference between the heating periods and non-heating periods.

The spatial distribution of $\chi_{\rm lf}$ in Lanzhou street dust is concentrated in those areas with more heavy industry, higher residential density, and heavier traffic than elsewhere in the city.

The distinct seasonal variation in magnetic minerals concentrations, we infer, are induced by indoor heating, and local weather and atmospheric conditions. The concentration of magnetic minerals in winter and spring is higher than in autumn. $\chi_{\rm lf}$ and SOFT percentage can be used to denote seasonal variation of magnetic properties in urban street dust. Magnetic methods are inexpensive, technically uncomplicated, and convenient for monitoring urban street dust pollution.

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