Comparison of the multifractal characteristics of heavy metals in soils within two areas of contrasting economic activities in China

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Abstract

Industrial and agricultural activities can generate heavy metal pollution that causes a number of negative environmental and health impacts. This means that evaluating heavy metal pollution and identifying the sources of these pollutants, especially in urban or developed areas, is an important first step in mitigating the effects of these contaminating but necessary economic activities. Here, we present the results of a heavy metal (Cu, Pb, Zn, Cd, As and Hg) soil geochemical survey and use these data to evaluate and compare the characteristics of heavy metal pollution in soils within urban or developed areas. This survey focuses on Hefei, the provincial capital of Anhui Province, China, an area that contains a number of individual towns within a large municipal area. This study uses a multifractal spectral technique to identify the multifractality in the geochemistry of soils within the industrial Daxing and agricultural Yicheng areas of Anhui Province. Determining three multifractal parameters ($\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$) for these soil geochemical data indicates that overall amount of multifractality within the soil geochemical data for the Daxing area decreases as follows: Pb>Cd>As>Zn>Hg>Cu, whereas the overall amount of multifractality within the soil geochemical data for the Yicheng area decreases as follows: Hg>Zn>As>Cd>Pb>Cu. These differences in the degree of multifractality indicates that the soils in these areas have differing multifractal geochemical characteristics, suggesting that the differing economic activities in these areas generate very different heavy metal pollutant loads (e.g. Hg dominated agricultural pollution vs. Pb dominated industrial pollution). In addition, all of the elements barring Hg have larger $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$ values in the Daxing area compared to the Yicheng area. These larger values indicate that the higher concentrations of heavy metals present in soils within the Daxing area (compared to the Yicheng area) are more likely to be related to industrial activities than agriculture. The industrial Daxing area contains significant Pb and Cd soil contamination, whereas Hg is the main heavy metal present in soils within the Yicheng area, indicating that differing clean-up procedures and approaches to remediating these polluted areas are needed. The results also indicate that multifractal modeling and the associated generation of multifractal parameters can be a useful approach in the evaluation of heavy metal pollution in soils and the identification of major sources of heavy metal contamination.

Keywords: soil geochemistry; multifractal modelling, heavy metal pollution, Hefei**.**

1. Introduction and overview of the study area

Heavy metal pollution within soil poses a serious risk for human health and the environment, and thus soil pollution caused by anthropogenic activities (including industry and agriculture) has been the focus of a significant amount of research in recent years (McGrath et al., 2004; Wang et al., 2007; Leyval et al., 1997; Thomas and Stefan, 2002; Luo et al., 2011). Analyzing soil geochemistry and pollution using multifractal techniques has a lot of advantages, including the fact that these approaches can investigate many of the problems of nonlinear variability which commonly arise when dealing with pollutants and identify non-linear characteristics, yielding new information that can be used to understand the factors controlling the distribution of key elements within the objects or data being studied (Salvadori, 1997; Gonçalves, 2000; Zuo et al., 2012). This in turn means that using multifractal techniques to determine the multifractal characteristics of the distribution of heavy metals in soils can further our understanding of any heavy metal pollution that is associated with these differing activities.

Multifractal techniques include singularity mapping and multifractal interpolation that enable more detailed analysis of the spatial distribution of heavy metals, concentration-area modeling that can be used to define threshold values between background (i.e. geological) and anthropogenic anomalies (Lima et al., 2003), spectral density-area modeling that can be used to define thresholds to separate anomalies (i.e., anthropogenically derived heavy metal concentrations in this case) from background concentrations (i.e., geologically derived heavy metal concentrations; Cheng, 2001), and multifractal spectra that highlights non-linear characteristics and identifies anomalous behavior that reflects the characteristics of some multifractal sets (Gonçalves, 2000; Albanese et al., 2007; Guillén et al., 2011), such as identification of porous structures and the spatial variability in soil properties and so on (Dathe et al., 2006; Caniego et al., 2005). This means that multifractal techniques provide a lot of useful tools for the the analysis of heavy metals pollutantion within soils (Lima et al., 2003; Albanese et al., 2007; Guillén et al., 2011; Salvadori et al., 1997). These multifractal techniques are not only used in environmental science, but also be used in a number of differing fields, including geophysics (Schertzer et al., 2011), medicine (Jennane et al., 2001), computer science (Wendt et al., 2009), geology (Deng et al., 2011; Zuo et al., 2012, 2014; Cheng, 1995; Nazarpour et al., 2014; Yuan et al., 2012, 2015) and ecology (Scheuring and Riedi, 1994; Pascual et al., 1995), among others.

Hefei is the capital of Anhui Province, China, and has an urban area that includes the towns of Daxing and Yicheng, which focus on industrial and agricultural activities, respectively. Here, we use multifractal techniques to determine the multifractal characteristics of the distribution of heavy metals in soils in these areas, using three multifractal parameters ($\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$) to analyze and compare the degree and characteristics of the multifractality of heavy metal contamination in soils associated with the anthropogenic activities in this region. The results will further enable and inform future planning for any necessary remediation of these soils in the Daxing and Yicheng areas.

2. Study area and geochemical data

2.1 Study area

The city of Hefei is situated in central–eastern China (Fig. 1(a)), has approximately 7.7 million inhabitants and covers an area of around 11,408 km^2. This paper focuses on the towns of Daxing and Yicheng (Fig. 1(b)), with the former representing one of the traditional industrial areas of Hefei and containing numerous factories that are involved in the steel industry, chemical industry, paper making, and the production of furniture and construction materials, among others. In contrast, the town of Yicheng focuses its economic activities on agricultural production, byproduct processing, livestock and poultry breeding, ornamentals, and other enterprises related to agricultural activity.

2.2 Sampling and analysis

The study areas are covered by Quaternary sedimentary soils and are free of both natural mineralization and mining-related contamination. A total of 169 surface (<20 cm depth) soil samples were taken from the towns of Daxing and Yicheng on 1 × 1 km grids, yielding 78 samples from Daxing and 91 samples from Yicheng (Fig. 1(c–d)). Sampling errors were minimized by splitting each sample into 3–5 sub-samples, each of which weighed more than 500 g. Each of these sub-samples was air-dried before being broken up using a wooden roller and then sieved to pass through a 0.85 mm mesh. The concentrations of 6 heavy metal elements (Cu, Pb, Zn, Cd, As and Hg) were determined during this study, with Cd, Cu, Pb and Zn concentrations determined by inductively coupled plasma–mass spectrometry (ICP–MS) and Hg and As concentrations determined by hydride generation–atomic fluorescence spectrometry (AFS). These techniques have detection limits of 1 ppm for Cu, 2 ppm for Pb and Zn, 30 ppb for Cd, 0.5 ppm for As and 5 ppb for Hg. The accuracy of these data was monitored by repeat determinations of standards and replicate determinations of sub-sets of samples using instrumental neutron activation analysis (INAA). Analytical precision was monitored using determinations of variance of the results obtained from duplicate analyses.

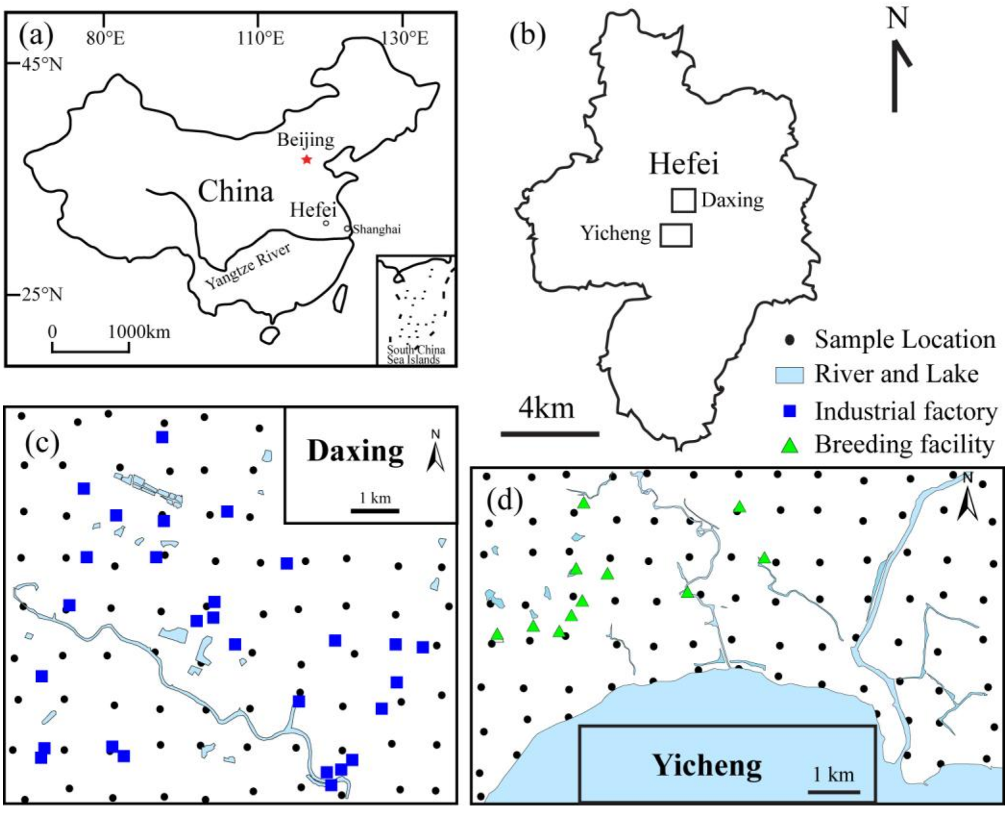

Fig.1. Location of Hefei in central-eastern China (a); location of the study areas within Hefei (b); the 1 x 1 km grids used for soil sampling in the towns of Daxing (c) and Yicheng (d)

3. Multifractal spectrum analysis

Multifractal formalisms can decompose self-similar measures into intertwined fractal sets that are characterized by singularity strength and fractal dimensions

(Cheng, 1999). Using multifractal techniques allows non-linear characteristics within datasets to be identified, enabling the extraction of information that can be used to understand the factors controlling the distribution of key elements within the data. Fractal spectra ($f(\alpha)$) are formalisms that can be used to describe the multifractal characteristics of a dataset and can be estimated using box-counting based moment, gliding box, histogram and wavelet methods, among others (Cheng, 1999; Lopes and Betrouni, 2009). The most widely used of these methods are the box-counting and gliding box methods, both of which are based on the moment method.

The initial step of the box-counting method estimates mass exponent function $\tau(q)$ values using a partition function as follows (Halsey et al., 1986):

$$\tau(q) = \lim_{\varepsilon \to 0}\left(\frac{\log(\chi^{q}(\varepsilon))}{\log(\varepsilon)}\right) = \lim_{\varepsilon \to 0}\left(\frac{\log \sum_{i=1}^{N(\varepsilon)} \mu_i^{q}(\varepsilon)}{\log(\varepsilon)}\right) \quad (1)$$

where $\mu_i(\varepsilon)$ denotes a measure with the i_{th} box of size ε and $N(\varepsilon)$ indicates the total number of boxes of size ε with $\mu_i(\varepsilon)$ values different from 0.

The calculation of the mass exponent function $\tau(q)$ for the gliding box method is different from the box-counting method, with the gliding box method providing a useful approach that can increase the number of samples that are available for statistical estimation within a dataset (Tarquis et al., 2006; Xie et al., 2010; Buczkowski et al., 1998). This means that the gliding box approach often provides better results with lower uncertainties than the box-counting method (Cheng, 1999). As such, we have used the gliding box approach during this study.

The calculation of the mass exponent function $\tau(q)$ for the gliding box method uses a partition function as follows (Cheng, 1999):

$$\langle \tau(q) \rangle + D = \lim_{\varepsilon \to 0}\left(\frac{\log(\mu^{q}(\varepsilon))}{\log(\varepsilon)}\right) = \lim_{\varepsilon \to 0}\left(\frac{\log\left(1/N^{*}(\varepsilon)\right)\sum_{i=1}^{N^{*}(\varepsilon)} \mu_i^{q}(\varepsilon)}{\log(\varepsilon)}\right) \quad (2)$$

where $\mu_i(\varepsilon)$ denotes a measure with the i_{th} cell of a gliding box of size ε, <> indicates the statistical moment, and $N^*(\varepsilon)$ indicates the total number of gliding boxes of size ε with $\mu_i(\varepsilon)$ values different from 0.

The values of $\tau(q)$ derived using this equation can be then used to determine a and $f(\alpha)$ values using a Legendre transformation, as expressed below:

$$\alpha(q) = \frac{d\tau(q)}{dq} \tag{3}$$

$$f(q) = q\alpha(q) - \tau(q) = q\frac{d\tau(q)}{dq} - \tau(q) \tag{4}$$

where $\Delta\alpha$ and Δf are essential parameters required to analyze the multifractal characteristics of the dataset in question. The widths of the left and right branches within the multifractal spectra are then defined using the following equations:

$$\Delta\alpha_L = \alpha_0 - \alpha_{min} \tag{5}$$

$$\Delta\alpha_R = \alpha_{max} - \alpha_0 \tag{6}$$

$$\Delta\alpha = \alpha_{max} - \alpha_{min} \tag{7}$$

and the height difference $\Delta f(\alpha)$ between the two ends of the multifractal spectrum is then extracted using:

$$\Delta f(\alpha) = f(\alpha_{max}) - f(\alpha_{min}) \tag{8}$$

Higher $\Delta\alpha$ and $\Delta f(\alpha)$ values are generally indicative of datasets with more heterogeneous patterns and higher levels of multifractality (Cheng, 1999; Kravchenko et al., 1999). In addition, multifractality associated with ordinary spatial analysis parameters, as represented by the $\tau''(1)$ parameter, can also be used as a measure to quantitatively characterize the multifractality of a dataset (Cheng, 2006) using the following equation:

$$\tau''(1) = \tau(2) - 2\tau(1) + \tau(0) \tag{9}$$

If μ is a multifractal and $-D < \tau''(1) < 0$, where D is the box-counting dimension, then smaller values of $\tau''(1)$ are indicative of higher degrees of multifractality, whereas otherwise $\tau''(1) = 0$ for a single fractal.

Here, we use the three multifractal parameters described above ($\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$) to better identify heterogeneous patterns and the degrees of multifractality within the soil geochemical data for the study area as well as enabling the comparison of the distribution of differing elements in the soils in this region.

4. Geochemical analysis results

A statistical summary of the soil geochemical data for the study area are given in Table 1. Samples from Daxing have higher Cu, Pb, Zn, Cd and As maximum, standard deviation, skewness, and kurtosis values than soil samples from the Yicheng area. In addition, the soil samples from Daxing have much higher coefficient of variation (CV) values for Cu, Pb, Zn, Cd and As than the samples from the Yicheng area, indicating that soils in the Daxing area contain much higher and more variable concentrations of these elements. This also suggests that samples from the Daxing area containing elevated concentrations of heavy metals were probably contaminated by anthropogenic activity.

All of the elements (barring Pb and Cu in the Yicheng area) in both the Yicheng and Daxing areas yield histograms that are positively skewed and contain some outliers (Fig. 2), indicating that these data have non-normal and potentially fractal- or multifractal-type distributions. This means that multifractal techniques are highly suited for the characterization of the geochemistry of the contaminated soils in these areas.

Table 1. Summary statistics of soil heavy metal concentrations within samples from the Daxing and Yicheng areas.

Town	Element	Min	Max	Mean	Standard deviation	Skewness	Kurtosis	CV*
		(mg/kg)	(mg/kg)	(mg/kg)	-	-	-	(%)
Daxing	Cu	19.00	111.50	33.87	13.26	3.20	14.93	39.16
	Pb	18.90	291.30	39.57	35.03	5.37	35.41	88.51
	Zn	40.90	526.10	105.8	94.40	2.91	8.59	89.19
	Cd	0.045	1.48	0.23	0.24	3.45	13.81	108.23
	As	4.93	308.20	13.97	33.89	8.72	76.64	242.56
	Hg	0.03	0.60	0.11	0.11	2.68	7.78	107.29
Yicheng	Cu	9.60	37.80	24.34	5.77	-0.38	0.41	23.71
	Pb	10.40	46.30	22.77	4.91	0.87	5.51	21.56
	Zn	20.80	194.80	54.70	21.43	3.45	20.27	39.17
	Cd	0.054	0.43	0.15	0.08	1.84	3.49	51.85
	As	2.30	44.20	7.29	4.39	6.68	56.55	60.24
	Hg	0.02	0.62	0.06	0.07	5.75	41.26	113.09

*CV: coefficient of variation.

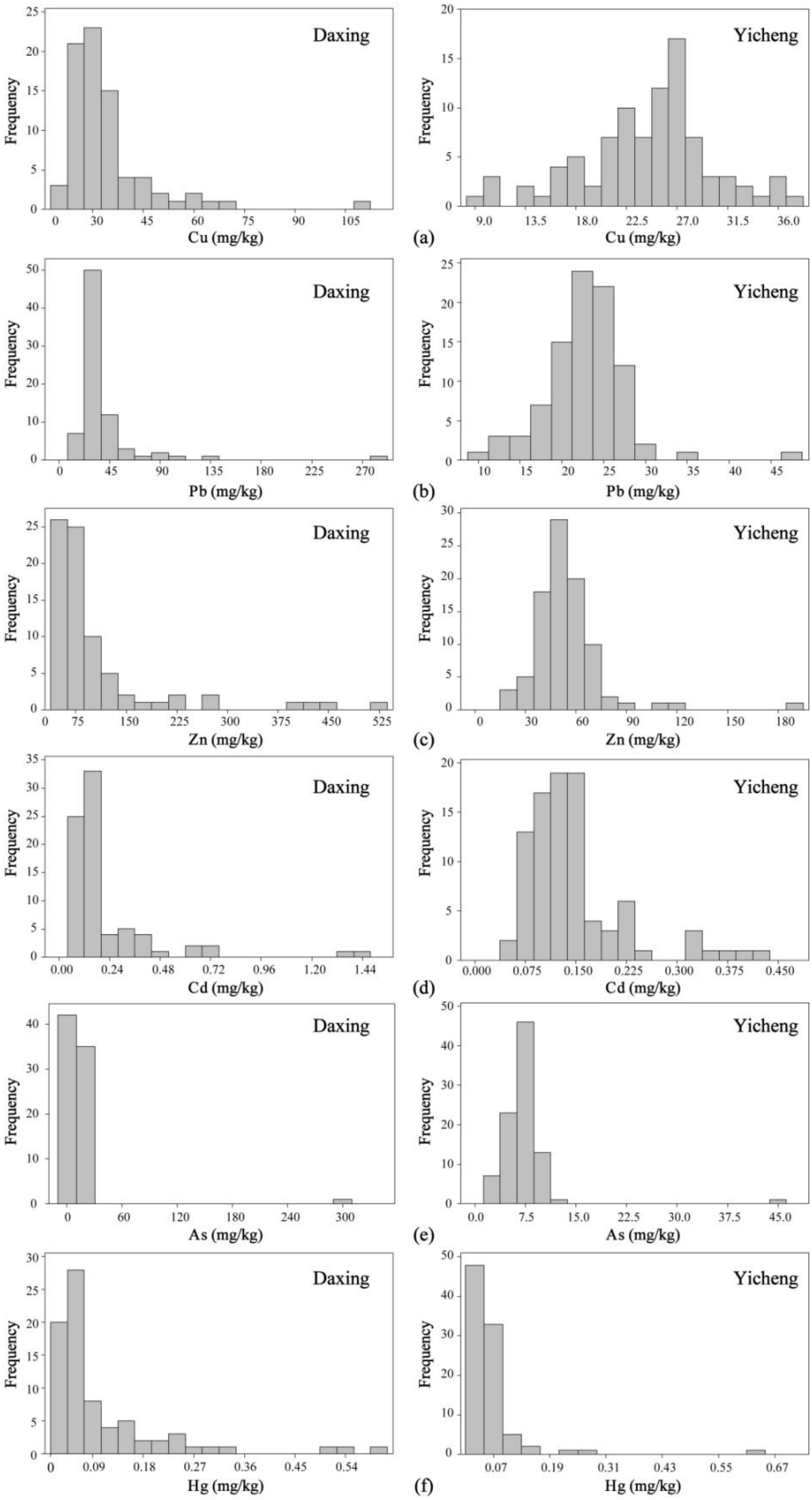

Fig. 2. Histograms showing the distribution of Cu (a), Pb (b), Zn (c), Cd (d), As (e) and Hg (f) concentrations within soils from the towns of Daxing and Yicheng.

5. Calculation processes of multifractal spectrum and discussion

Here, we use the gliding box method to calculate multifractal spectra for the geochemical data from the study area. This calculation used a range of q values from −10 to 10 with an interval of 1, yielding the multifractal spectra (in the form of an α–$f(\alpha)$ diagram) shown in Fig. 3.

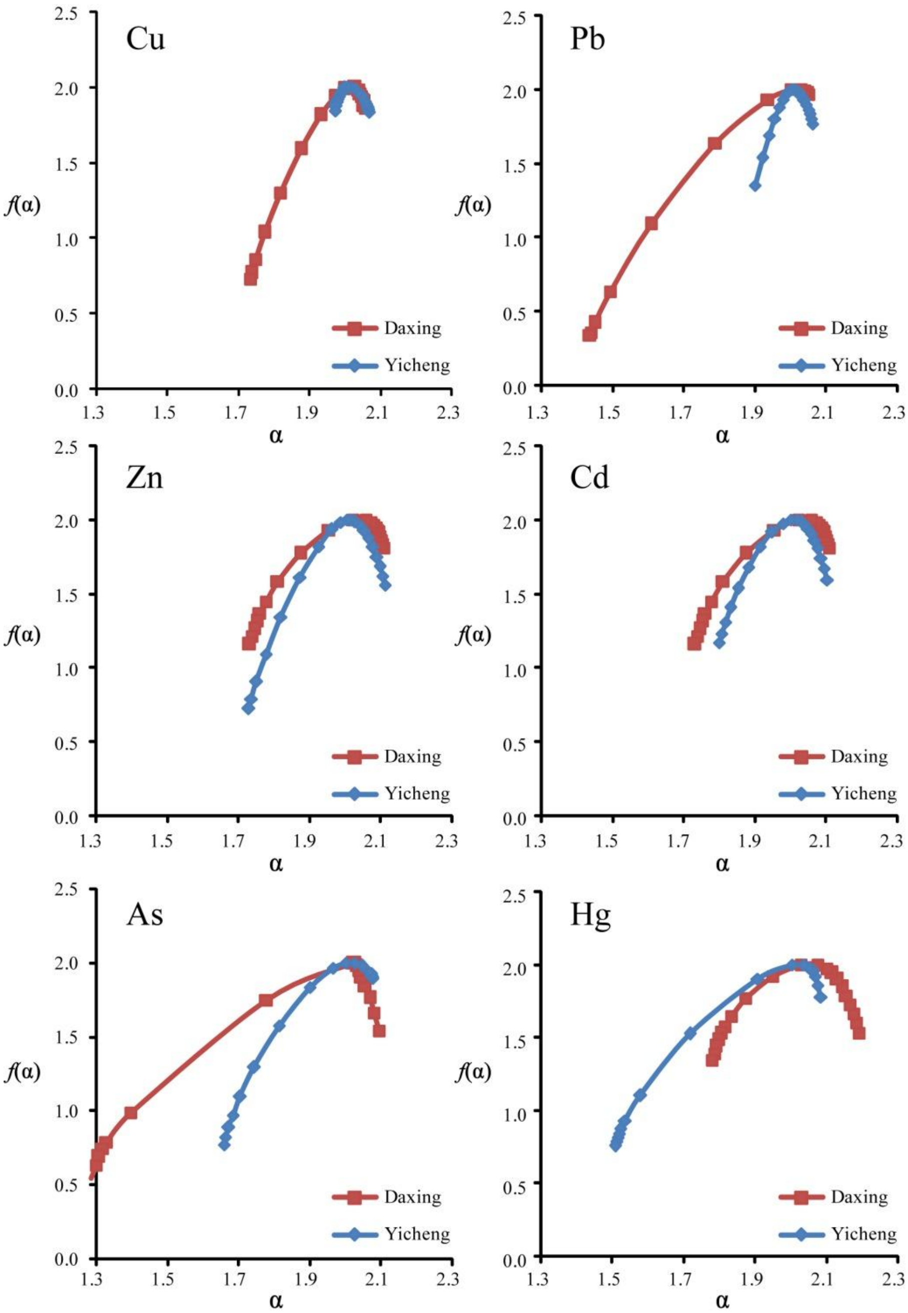

Fig. 3. Multifractal spectra ($f(\alpha)$ vs α) showing the multifractal characteristics of all of the soil

geochemical data (barring Cu) from the Yichen area.

Multifractal spectra combine the singularity exponent α and the corresponding fractal dimension $f(\alpha)$ to generate a multifractal spectrum with an inverse bell shape (Fig. 3). All of these multifractal spectra are also asymmetric ($\Delta\alpha_L$ is significantly different from $\Delta\alpha_R$, equations 5-6) (barring the Cu data for soils from the Yicheng area), indicating that the soils containing low and high concentrations of these elements are not evenly distributed within the study area (as is expected for areas containing point source pollutants like factories or animal breeding facilities).

The multifractal analytical results shown in Table 2 indicate that all of the elements (barring Cu in the Yicheng area) are characterized by a wide range of α values (i.e. have high $\Delta\alpha$ values), have $\tau''(1)$ values less than –0.01 (barring Cu and Pb in the Yicheng area) and have $\Delta f(\alpha)$ values larger than 0.5 (barring Cu in the Yicheng area), all of which indicate that these elements have highly multifractality within the soils in these two areas. All of the elements analyzed during this study (barring Hg) have higher $\Delta f(\alpha)$ and α values (except Zn) and lower $\tau''(1)$ values in soils from the Daxing area, with Hg having higher $\Delta f(\alpha)$ and α and lower $\tau''(1)$ values in soils from the Yicheng area (Table 2). This suggests that the industrial activities in the Daxing area generate multi-element heavy metal soil contamination, whereas the significant heavy metal pollution associated with the agricultural activity in the Yicheng area would be Hg contamination. The $\Delta f(\alpha)$ and α values of Hg in Yicheng area are larger than all of the other elements in this area as well as some of the elements in the Daxing area, indicating both the prevalence and significant degree of agricultural Hg contamination in the Yicheng area. This is important, primarily as Hg pollution can seriously impact human health because this element is preferentially concentrated upward in the food chain (e.g. (Jiang et al., 2006)), meaning that this contamination needs to be evaluated further and remediated to avoid any deleterious effects.

Table 2. Multifractal parameters of the elements within the soil samples analyzed during this study.

Town	Element	α_{min}	α_{max}	$\Delta\alpha_L$	$\Delta\alpha_R$	$\Delta\alpha$	$\Delta f(\alpha)$	$\tau''(1)$
Daxing	Cu	1.733	2.057	0.280	0.044	0.324	1.270	-0.015
	Pb	1.439	2.050	0.567	0.044	0.611	1.659	-0.068
	Zn	1.733	2.109	0.288	0.088	0.376	0.841	-0.066
	Cd	1.482	2.285	0.499	0.304	0.803	1.358	-0.066
	As	1.285	2.094	0.739	0.070	0.809	1.490	-0.243
	Hg	1.780	2.191	0.248	0.163	0.411	0.656	-0.079
Yicheng	Cu	1.971	2.067	0.036	0.060	0.096	0.168	-0.007
	Pb	1.900	2.062	0.104	0.058	0.162	0.646	-0.005
	Zn	1.729	2.112	0.275	0.108	0.383	1.275	-0.016
	Cd	1.800	2.103	0.201	0.102	0.303	0.829	-0.023
	As	1.659	2.076	0.343	0.075	0.418	1.224	-0.036
	Hg	1.507	2.084	0.497	0.080	0.577	1.243	-0.096

Different elements were sorted by $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$ parameters in order to compare variations in multifractality, in addition to sorting by basic statistics such as standard deviation and coefficient of variation values (Table 3). The data shown in Table 3 indicates that the Zn data within the Daxing area has largest standard deviation value but only a moderate coefficient of variation, but the $\Delta\alpha$ and $\Delta f(\alpha)$ values for these Zn data are indicative of only weak multifractality compared to the other heavy metals in the soils of the Daxing area. In comparison, the Hg data for soils in the Yicheng area yielded the lowest standard deviation value but the largest $\Delta\alpha$ and $\tau''(1)$ values, indicating these Hg data have strong multifractality. These differences indicate that the multifractal parameters $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$ reveal new information about the nonlinear variability and the characteristics of these geochemical data compared to the analyses afforded by classic basic statistics. In addition, the data given in Table 3 indicates that these elements have different orders depending on whether they are sorted by $\Delta\alpha$, $\Delta f(\alpha)$ or by $\tau''(1)$ values, all of which reflects differing aspects of the multifractality of these data. Here we first averaged the ordering of these elements by $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$ before sorting again to compare the overall multifractality of these data.

Table 3. Elements sorted by multifractal parameters and coefficient of variation values.

Town	**Element**	**Order**

		Basic statistics		Multifractal parameters			
		Standard deviation	Coefficient of variation	$\Delta\alpha$	$\Delta f(\alpha)$	$\tau''(1)$	Overall*
Daxing	Cu	4	6	6	4	6	6
	Pb	2	5	3	1	1	1
	Zn	1	4	5	5	2	4
	Cd	5	2	2	3	3	2
	As	3	1	1	2	5	3
	Hg	6	3	4	6	4	5
Yicheng	Cu	2	5	6	6	5	6
	Pb	3	6	5	5	6	5
	Zn	1	4	3	1	4	3
	Cd	5	3	4	4	3	4
	As	4	2	2	3	2	2
	Hg	6	1	1	2	1	1

Overall: the overall order of $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$

The overall amount of multifractality within the soil geochemical data for the Daxing area decreases as follows: Pb>Cd>As>Zn>Hg>Cu, whereas the overall amount of multifractality within the soil geochemical data for the Yicheng area decreases as follows: Hg>Zn>As>Cd>Pb>Cu. The overall orders indicates that the Pb and Hg soil data have the highest degree of multifractality in the Daxing and Yicheng areas, respectively, whereas Cu has the weakest multifractality irrespective of the area.

We further analyzed the spatial distribution of contamination within soils from the Daxing and Yicheng areas and evaluated whether there is any significant correlation between multifractality and anthropogenic activity. Filled contour maps showing the distribution of Pb in the Daxing area and Hg and Cu in the Yicheng area were calculated using inverse distance weighted interpolation (Fig. 4–6). These maps indicate that areas with elevated levels of Pb contamination within the Daxing area are directly correlated to the location of industrial factories, whereas the Hg contamination in the Yicheng area is spatially correlated with the location of agricultural breeding facilities. The Hg contamination in the Yicheng area is of significance, especially as this form of contamination can cause serious health issues (e.g. Minamata disease). As such, the soils in this area may well require remediation, especially as Hg can be concentrated up the food chain and the Yicheng area is heavily agricultural, indicating that this activity may both be concentrating Hg as well as contaminating soils in this area.

This distribution of soils with elevated concentrations of Hg also contrasts with the symmetrical distribution and weakest multifractality for Cu within the Yicheng area (Fig. 3, 5-6). We used a plot showing the rank of concentration contour vs number of agricultural facilities within the same rank of concentration contour to demonstrate the spatial correlation between the location of agricultural facilities and heavy metal concentrations in soils (Fig. 7). This diagram shows an significant correlation between agricultural facilities and high concentrations of Hg, whereas there is an anti-correlation when comparing agricultural breeding facilities and areas of high Cu concentrations. This indicates that very little Cu has been anthropogenically added (or removed) from the soils in the Yicheng area, suggesting that these soils maybe contain only natural background concentrations of Cu and that the agricultural activity in this area does not produce significant Cu contamination.

All of the above suggests that the multifractal parameters for the heavy metal concentrations within soil geochemical data can efficiently reflect the multifractality associated with by industrial and agricultural activities in the Daxing and Yicheng areas, respectively. These results also indicate that multifractal modeling and the associated generation of multifractal parameters are a useful approach in the evaluation of heavy metal pollution in soils and the identification of major element of heavy metal contamination. In addition, the differing orders of the geochemical data for soils within the Daxing area and Yicheng area are indicative of a significant difference in the geochemical characteristics (and heavy metal pollution) in the soils within these two areas. This indicates that differing clean-up procedures and approaches to remediating these polluted areas are needed, rather than a single cover-all approach to the remediation of heavy metal pollution. A significant amount of different remediation approaches can be used to resolve the issues of heavy metal soil contamination (e.g., Bech et al., 2014; Koptsik, 2014), with the results presented in this study suggesting that physical and chemical approaches (soil removal, soil vitrification, soil consolidation, electroremediation, soil washing) are more appropriate for the remediation of heavy metal contaminated soil in the Daxing area, especially in areas with significant heavy metal pollution. In comparison, the differing (i.e. Hg-dominated) type of soil contamination in the Yicheng area could be more efficiently treated using microremediation and phytoremediation, primarily as the agriculture in this area requires a rapid reduction in the mobility and biological availability of heavy metals in the soils in this area (Mulligan et al., 2001;Wang et al., 2006).

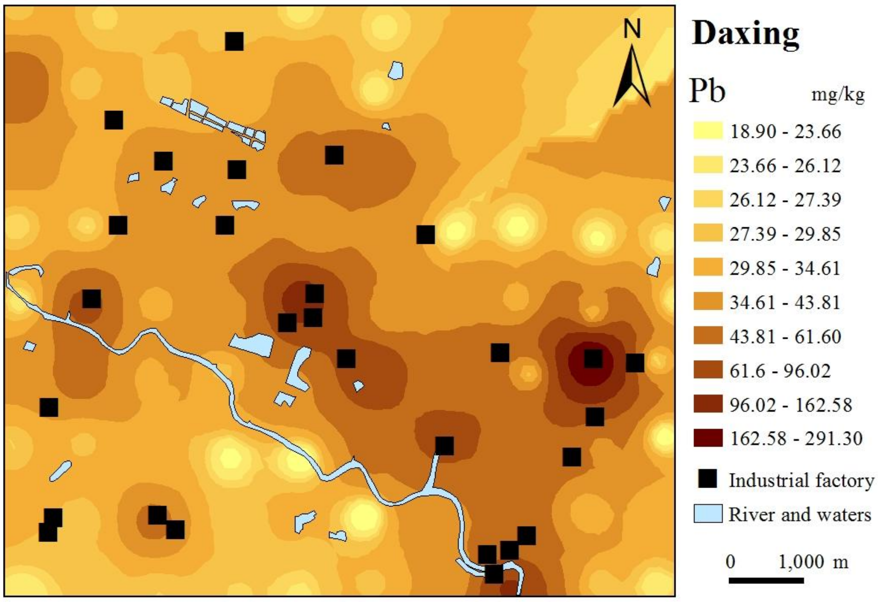

Fig. 4. Filled contour map generated by inverse distance weighted interpolation showing the spatial distribution of soil Pb concentrations in the Daxing area.

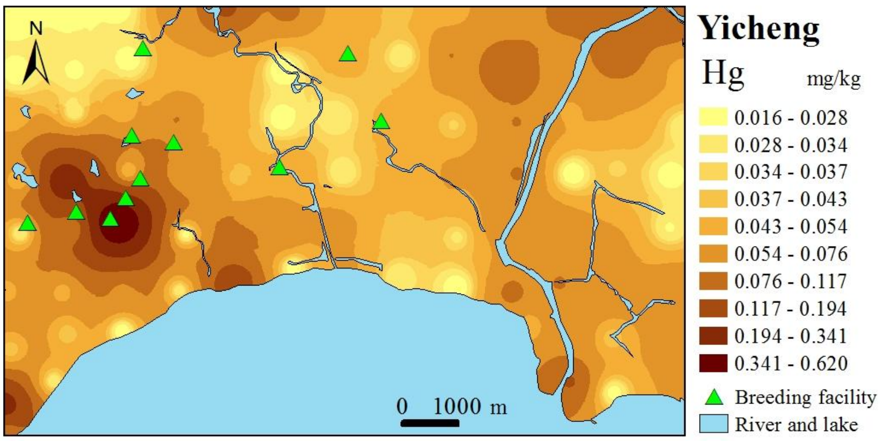

Fig. 5. Filled contour map generated by inverse distance weighted interpolation showing the spatial distribution of soil Hg concentrations in the Yicheng area.

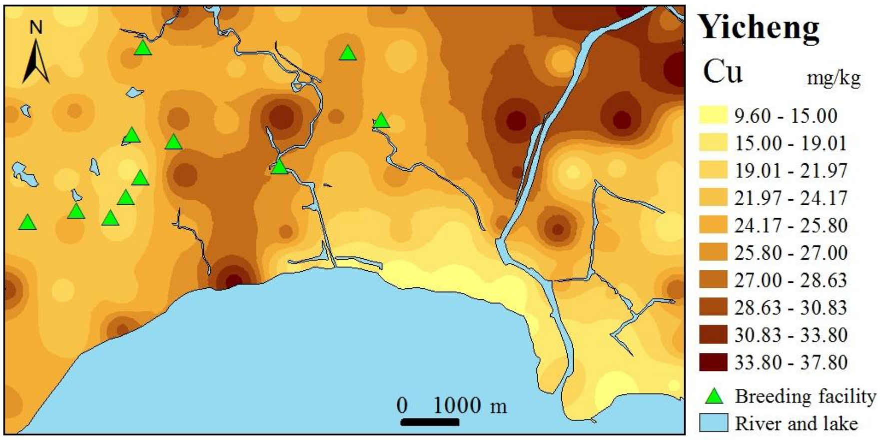

Fig. 6. Filled contour map generated by inverse distance weighted interpolation showing the spatial distribution of soil Cu concentrations and the location of breeding facilities in the Yicheng area

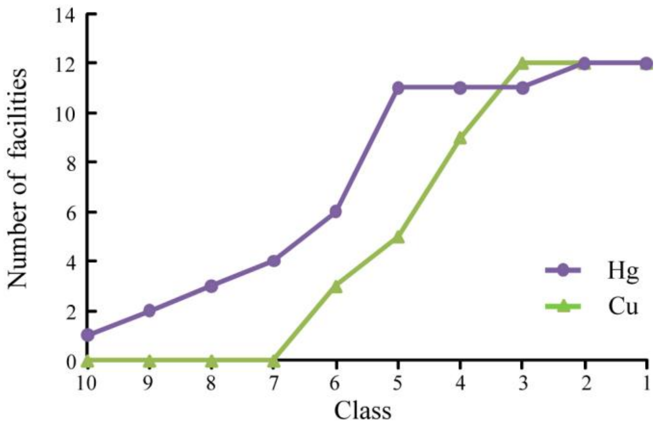

Fig. 7. Plot of number of agricultural facilities in Yicheng area within the same rank of Hg and Cu concentration contour showing a positive spatial correlation between location of agricultural facilities and Hg concentrations but an anti-correlation between the location of agricultural facilities and Cu concentrations.

5. Conclusions

This study focuses on the geochemistry of heavy metal contaminated soils from the Daxing and Yicheng areas, both of which are located close to the city of Hefei, in Anhui Province, China. Multifractal modelling and the resulting multifractal parameters indicate that the soils from the Daxing area have stronger multifractality for Cu, Pb, Zn, Cd and As than soils from the Yicheng area, although the latter have relatively strong multifractality for Hg. The ordering of values for the multifractal parameters $\Delta\alpha$, $\Delta f(\alpha)$ and $\tau''(1)$ indicate the degree of multifractality for the geochemical data for soils within the Daxing area descends as follows: Pb>Cd>As>Zn>Hg>Cu, whereas the overall order in soils within the Yicheng area descends as follows: Hg>Zn>As>Cd>Pb>Cu. In addition, Cu concentrations in soils in the Yicheng area may still have their original (i.e. natural) distribution and may not have been influenced by human activities. These data indicate that the industrial activity concentrated in the Daxing area generates multi-element heavy metal soil contamination whereas the agricultural activity concentrated in the Yicheng area generates Hg-dominated heavy metal soil contamination. The latter is important, as Hg contamination can cause serious health issues (e.g. Minamata disease) and the soils in this area may well require remediation, especially as Hg can be concentrated up the food chain and the Yicheng area is heavily agricultural, indicating that this activity may both be concentrating Hg as well as contaminating soils in this area.

The initial results presented here indicate that multifractal modeling and the associated generation of multifractal parameters can efficiently reflect the multifractality caused by industrial and agricultural activities in the Daxing and Yicheng areas, respectively. This in turn indicates that multifractal modeling can be a useful approach in the evaluation of heavy metal pollution in soils and the identification of major sources of heavy metal contamination.

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