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# Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China

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**Abstract**

Though there are many studies of heavy metal contaminations of urban dusts in developed countries, little attention has been paid to this kind of study in developing countries, including China. Therefore, a series of investigations were performed to provide heavy metal signatures of urban dusts and to evaluate potential sources in Xi'an, Shaanxi Province. Sixty-five samples of urban dusts were collected in Xi'an. Then Ag, Cr, Cu, Mn, Pb and Zn concentrations were determined by using atomic absorption spectrophotometry, and As, Hg and Sb concentrations by atomic fluorescence spectroscopy. The results indicate that, in comparison with Chinese soil, urban dusts in Xi'an have elevated metal concentrations as a whole, except those of arsenic and manganese. These concentration levels are comparable to those in other studies. Correlation coefficient analysis, principal component analysis (PCA) and cluster analysis (CA) were performed and three main sources with corresponding cluster elements were identified: (1) Ag and Hg have commercial and domestic sources; (2) Cr, Cu, Pb, Sb and Zn are mainly derived from industrial sources, combined with traffic sources as well for Pb and Zn; (3) As and Mn come mainly from soil sources, and As also has an industrial source. Based on PCA and CA analyses, manganese was selected as the reference element, and heavy metal enrichment factors (Efs) were calculated, which in turn further confirms the source identification. Also, Efs give an insight of human influence degree of urban dusts.



*Keywords:* Heavy metals; Principal component analysis; Cluster analysis; Enrichment factor; Xi'an

## 1. Introduction

Of the three materials, soil, sediment and dust, which originate primarily from the earth's crust, dust is the most pervasive and important factor affecting human health and well-being.

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Components and quantity of urban dusts are environmental pollution indicators, especially in big cities. Interest in the levels of contaminants associated with urban dusts has risen in the last decades, particularly in the concentration and distribution of lead (Jones and Mcdonald, 1983; Von Schirnding and Fuggle, 1996; Chatterjee and Banerjee, 1999) and other elemental concentrations, such as copper, zinc and cadmium, and their source identification (Ferguson and Kim, 1991; Nagerotte and Day, 1998). Moreover, it has been established that populations exposed to these elements develop alterations in their nervous system functions, with neurophysiological consequences constituting a severe health hazard (US EPA, 1986; Chatterjee et al., 1993; Olivero and Solano, 1998). Many studies throughout the world have identified the sources of these contaminants in urban dusts as those associated with vehicular traffic, industrial and commercial areas (Day et al., 1975; Thornton, 1990; Al-Chalabi and Hawker, 1997) as well as weathering or building facades, and have in fact recognized urban dusts as a significant pollution source itself (Akhter and Madany, 1993). Soils represent another major source making up the dust that settles on city surface.

Though there are numerous studies of heavy metal contamination of urban dusts in developed countries, little information is available on heavy metals of urban dusts in developing countries (Banerjee, 2003), including China. Also, in developed countries, most of these studies of heavy metal contamination in urban dusts focused on lead, copper, and zinc (Charlesworth et al., 2003). Little attention has been paid to other trace elements, such as arsenic, mercury, antimony, chromium, manganese, silver, etc.

The objectives of this study were (1) to determine average concentrations of nine heavy metals (Ag, As, Cr, Cu, Hg, Mn, Pb, Sb and Zn) in urban dusts in Xi'an; (2) to identify their natural or anthropogenic sources by using principal component analysis and cluster analysis; and (3) to gauge the degree of anthropogenic influence on heavy metal contamination in urban dusts. Multivariate statistical method was utilized throughout the study.

## 2. Materials and methodologies

### 2.1. Location of the research

Xi'an, the central city of Shaanxi Province that covers a large part of the Loess Plateau of China, is one of the biggest tourist cities in China, with a population of over 3.8 million. The city is located in a semi-arid zone, where the major sources for Asian dust lie in (Zhang et al., 1997, 2001), with the annual mean air temperature being 13.0–13.4°C, while the annual rainfall is 558–750mm (XAGW). Due to the city being surrounded by mountains, inversion weather is occurs frequently and this may prevent dusts from migrating, which has an adverse influence on the local environment.

Since the 1950s, Xi'an has been gradually developing into an important industrial city in China, in which the major industries are heavy metal industry, textile industry and chemical industry. As shown in Fig. 1, the heavy metal industry is mainly located in the western part of city outside the second ring road, the textile industry is east of Chan River, and the chemical industry is in different areas generally outside the second ring road. Due to the rapid urbanization in the last two decades, the trade industry and roads have achieved a remarkable development. Apart from the downtown areas located in the inner ring road, the previous agricultural areas located in the north of Xi'an outside the inner ring road and some other major areas have developed into integrated-use areas with high residential density and different kinds of markets. Furthermore, it was estimated that over 300 thousand motor vehicles in the city in 2003.

### 2.2. Sampling and analysis

A series of investigations were conducted during May of 1998, 1999 and 2001. A total of 65 samples were collected, the sampling grid shown in Fig. 1. Samples were collected by using a clean plastic dustpan and a brush (Akhter and Madany, 1993), each one from a 1-$m^2$ area measured by a ruler.

All the samples were dried in an oven at 40 °C for 2 days. The dried samples were passed though a 1-mm plastic sieve to remove large plant roots and gravel-sized materials, and then ground and homo-

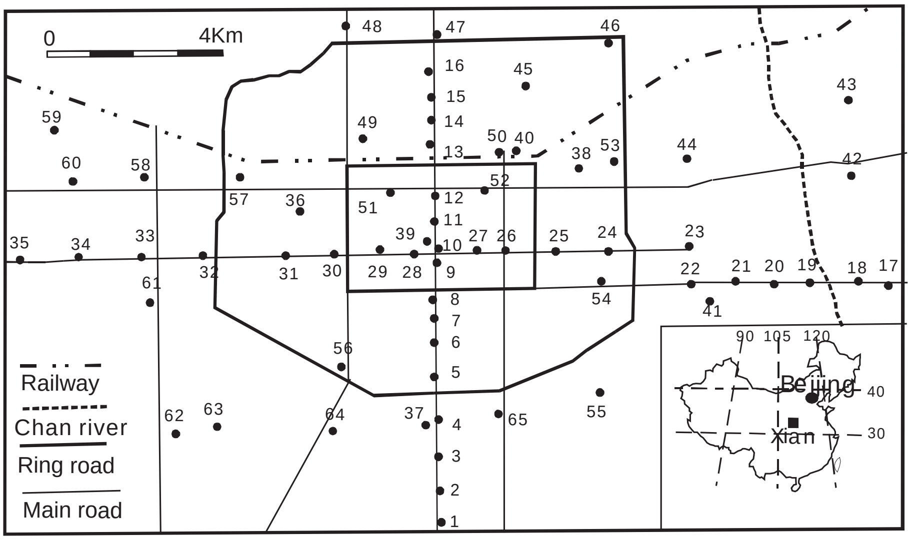


Fig. 1. Sample location of urban dusts in Xi'an.

genized with a polypropylene mortar and sieved though a 200 mesh sieve (airborne diameter 66 um).

A small portion of each sample (1 g) was collected and placed in a polypropylene vessel, adding 20 ml mixture of 10:1:10:1 HF, $H_2SO_4$, HNO and $HClO_4$. The solution was heated on an open hot plate for about 4 h until white fumes were given off, and then the residue was redissolved in a plastic bottle with 10 ml HCL (1:1) and was diluted to 50 ml with deionized water. Concentrations of Cu, Pb, Zn, Cr, Ag and Mn were determined by using a Vario 6 atomic absorption spectrophotometer (CGL, 1987). Another small portion of each sample (0.5 g) was digested with $HNO_3/H_2SO_4$ and total mercury, arsenic and antimony were analyzed by cold vapor atomic spectrometry (CVAFS), according to CGL (1987), similar to Levine and Fernando (2002). Blank samples, standard samples and duplicated samples were simultaneously performed in the two analyses as quality control.

### 2.3. Descriptive analysis and correlation coefficient

Descriptive data analysis, including mean, standard deviation (SD), minimum and maximum concentrations, skewness, variation coefficient etc., was carried out. Together with SD, variation coefficient (VC), which is SD/mean, was used to reflect the degree of discrete distribution of different metal element concentrations, and to indicate indirectly the activeness of the selected element in the examined environment. Skewness was also utilized to reflect different distributions of the metals. In addition, correlation coefficients were calculated to determine relationships among different metals.

### 2.4. Multivariate analysis

Principal component analysis (PCA) and cluster analysis (CA) are the most common multivariate statistical methods used in environmental studies (Miranda et al., 1996; Díaz et al., 2002). For our study, SPSS for Windows, version 11.5 (SPSS Inc, USA), was utilized for the multivariate statistical analysis, and for descriptive and correlation analyses.

PCA is widely used to reduce data (Loska and Wiechuła, 2003) and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables. If large differences exist in the standard deviations of variables, PCA results will vary considerably depending on whether the covariance or correlation matrix is used (Farnham et al., 2003). The concentrations of the heavy metals evaluated in this study vary by different orders of magnitude. PCA was therefore applied to the correlation matrix for this study, and each variable is normalized to unit variance and therefore contributes equally.

To make the results more easily interpretable, the PCA with VARIMAX normalized rotation was also applied, which can maximize the variances of the factor loadings across variables for each factor. Factor loadings > 0.71 are typically regarded as excellent and < 0.32 very poor (Nowak, 1998; García et al., 2004). In this study, all principal factors extracted from the variables were retained with eigenvalues > 1.0, as suggested by the Kaiser criterion (Kaiser, 1960).

When PCA with VARIMAX normalized rotation was performed, each PC score contains information on all of the metal elements combined into a single number, while the loadings indicate the relative contribution each element makes to that score. The PC loadings were plotted and the plot was inspected for similarities observed as clusters in the PC loading plot.

Cluster analysis (CA) was performed to further classify elements of different sources on the basis of the similarities of their chemical properties. Hierarchical cluster analysis, used in this study, assisted in identifying relatively homogeneous groups of variables, using an algorithm that starts with each variable in a separate cluster and combines clusters until only one is left. As the variables have large differences in scaling, standardization was performed before computing proximities, which can be done automatically by the hierarchical cluster analysis procedure. A dendrogram was constructed to assess the cohesiveness of the clusters formed, in which correlations among elements can readily be seen. The CA is complementary to PCA.

### 2.5. Enrichment factor

The enrichment factor (EF) can be utilized to differentiate between the metals originating from human activities and those from natural procedure, and to assess the degree of anthropogenic influence. One such technique that have often been applied is normalization of a tested element against a reference one. Here a question arose about which element can be chosen as a reference element. A reference element is often a conservative one, such as the most commonly used elements: Al, Fe, Me, Mn, Sc, Ti etc. (Quevauviller et al., 1989; Isakson et al., 1997; Lee et al., 1998; Reimann and de Caritat, 2000; Bergamaschi et al., 2002; Hernandez et al., 2003; Conrad and Chisholm-Brause, 2004; Mishra et al., 2004). Therefore, Mn is expected to be a conservative element and may be chosen as the reference element. Previous to calculating the EFs, the PCA and CA were performed to ascertain whether Mn is a conservative element.

If the analytical results confirm that Mn is a conservative element, the value of the enrichment factor was calculated by the modified formula suggested by Buat-Menard and Chesselet (1979):

$$EF = [C_n f(\text{sample})/C_{\text{ref}}(\text{sample})] / [B_n(\text{baseline})/B_{\text{ref}}(\text{baseline})]$$

where $C_n$(sample) is the concentration of the examined element in urban dusts, $C_{\text{ref}}$(sample) is the concentration of the reference element in urban dusts, $B_n$(baseline)is the content of the examined element in China soils (here China background values were selected as the baseline), $B_{\text{ref}}$(baseline) is the content of the reference element in China soils.

EFs can give an insight into differentiating an anthropogenic source from a natural origin. EFs close to 1 point to a crustal origin while those greater than 10 are considered to have a non-crustal source (Nolting et al., 1999). Further, EFs can also assist the determination of the degree of metal contamination. Five contamination categories are recognized on the basis of the enrichment factor (Sutherland, 2000; Loska and Wiechuła, 2003) (Table 1):

Table 1
Contamination categories based on EF values

| | |
|---|---|
| EF<2 | Deficiency to minimal enrichment |
| EF=2–5 | Moderate enrichment |
| EF=5–20 | Significant enrichment |
| EF=20–40 | Very high enrichment |
| EF>40 | Extremely high enrichment |

## 3. Results and discussion

### 3.1. Heavy metal concentrations

Descriptive statistics of heavy metal concentrations of urban dusts in Xi’an, as well as background values

Table 2
Heavy metal concentrations of urban dusts in Xi'an (mg/kg)

| Element | Range | Mean | Median | SD | VC | Skewness | Reference value[a] | Trigger[b] |
|---|---|---|---|---|---|---|---|---|
| Ag | 0.17–7.79 | 0.84 | 0.51 | 1.12 | 1.33 | 4.51 | 0.132 | NL |
| As | 5.95–20 | 10.62 | 9.78 | 3.46 | 0.32 | 0.94 | 11.2 | 10 |
| Cr | 28–853 | 167.28 | 65.00 | 195.69 | 1.17 | 1.74 | 61.0 | 600 |
| Cu | 20–1071 | 94.98 | 72.40 | 130.18 | 1.37 | 6.86 | 22.6 | 130 |
| Hg | 0.108–5.212 | 0.638 | 0.429 | 0.723 | 1.13 | 4.42 | 0.065 | 1 |
| Mn | 414–1318 | 687 | 700 | 192 | 0.27 | 0.59 | 583 | NL |
| Pb | 29–3060 | 230.52 | 131.00 | 431.02 | 1.87 | 5.34 | 26 | 500 |
| Sb | 0.63–59.85 | 5.41 | 3.69 | 7.37 | 1.36 | 6.48 | 1.21 | NL |
| Zn | 80–2112 | 421.46 | 295.00 | 456.03 | 1.08 | 3.00 | 74.2 | 300 |

NL—not limited. VC—SD/mean.
[a] CNEMC (1990).
[b] ICRCL (1983).

of Chinese soils, (CNEMC, 1990) which are considered to be the reference values, and the trigger values (ICRCL, 1983) are presented in Table 2. The mean concentrations of Ag, AS, Cr, Cu, Hg, Mn, Pb, Sb and Zn are 0.84, 10.62, 167.28, 94.98, 0.64, 687.00, 230.52, 5.41 and 421.46 mg/kg, respectively. These concentration levels are comparable to those in other studies (Kim et al., 1998; Chatterjee and Banerjee, 1999; Charlesworth et al., 2003), especially for Cu, Pb and Zn, whose information is more available. Each heavy metal shows a wide range of values, except Mn and As. Compared with background values of Chinese soils, the heavy metal mean concentrations of urban dusts in Xi'an are much higher, except As and Mn, which renders them distinct from the other elements. Hg mean concentration in urban dusts is nearly 100 times higher than the reference value. The values of the mean concentrations in urban dusts divided by the corresponding reference value decrease in the order of Hg>Ag>Pb>Zn>Sb>Cu>Cr, among which even the mean concentration of the lowest element, Cr, is nearly 2.7 times higher than the reference value. In contrast, Mn and As mean concentrations are approximately the same as their reference values. This suggests that Mn and As may have mainly a natural source, while the other elements may come mainly from human sources.

Skewness values indicate that only Mn and As approach a normal distribution, the other metal elements being positively skewed towards the lower concentrations, as can also be confirmed by the fact that the median concentrations of these metals are much lower than their mean concentration. It seems that, based on their variation coefficients (VCs), the examined elements can be classified into two groups:

Table 3
Pearson's correlation matrix for the metal concentrations

| | Ag | As | Cr | Cu | Hg | Mn | Pb | Sb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Ag | | 0.138 | 0.027 | 0.006 | 0.000 | 0.638 | 0.127 | 0.731 | 0.128 |
| As | 0.186 | | 0.008 | 0.012 | 0.305 | 0.002 | 0.000 | 0.933 | 0.000 |
| Cr | 0.247* | 0.325** | | 0.051 | 0.050 | 0.000 | 0.010 | 0.121 | 0.001 |
| Cu | 0.336** | 0.309* | 0.234 | | 0.968 | 0.011 | 0.279 | 0.974 | 0.000 |
| Hg | 0.679** | 0.129 | 0.244* | 0.005 | | 0.029 | 0.245 | 0.368 | 0.840 |
| Mn | −0.059 | −0.385** | −0.493** | 0.313* | −0.272* | | 0.251 | 0.856 | 0.716 |
| Pb | 0.191 | 0.474** | 0.318* | 0.136 | 0.146 | −0.144 | | 0.899 | 0.000 |
| Sb | −0.044 | 0.011 | −0.194 | 0.004 | 0.114 | 0.023 | −0.016 | | 0.882 |
| Zn | 0.191 | 0.489** | 0.402** | 0.491** | −0.026 | 0.046 | 0.501** | −0.019 | |

The left lower part is correlation coefficient; the right upper part is significant level.
* $P<0.05$ (2-tailed).
** $P<0.01$ (2-tailed).

Table 4
Rotated component matrix for data of Xi'an urban dusts (PCA loadings>0.4 are shown in bold)

| Element | Component | | | | Communities |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Ag | 0.14 | **0.90** | 0.20 | −0.09 | 0.88 |
| As | **0.81** | 0.08 | −0.12 | 0.05 | 0.68 |
| Cr | **0.57** | 0.30 | −0.24 | **−0.46** | 0.68 |
| Cu | **0.42** | 0.20 | **0.73** | −0.10 | 0.76 |
| Hg | 0.03 | **0.91** | −0.20 | 0.11 | 0.88 |
| Mn | −0.33 | −0.18 | **0.85** | 0.12 | 0.87 |
| Pb | **0.73** | 0.07 | −0.03 | 0.04 | 0.55 |
| Sb | 0.06 | 0.06 | −0.02 | **0.94** | 0.89 |
| Zn | **0.79** | −0.01 | 0.37 | **−0.79** | 0.78 |
| Initial Eigenvalue | 2.46 | 1.81 | 1.55 | 1.14 | |
| Percent of variance | 27.34 | 20.12 | 17.21 | 12.69 | |
| Cumulative percent | 27.34 | 47.46 | 64.66 | 77.35 | |

Mn and As, whose VCs are lower than 0.4; and the other metals whose VCs are higher than 1.0. One would expect those elements dominated by a natural source to have low VCs, while the VCs of elements affected by anthropogenic sources to be quite high. This is especially the case for urban dusts, for they have undergone erosion and aeolian transport before ultimate deposition and have therefore been fully mixed.

### 3.2. Correlation coefficient analysis

Pearson's correlation coefficients of heavy metal elements in urban dusts in Xi'an are summarized in Table 3. From Table 2, Cr, Cu, Pb and Zn are significantly positively correlated, which may suggest a common origin, while Ag and Hg form another group based on their positive correlation. As is also positively correlated to Cr, Pb and Zn, indicating that apart from a natural source, it may also be influenced by traffic and industrial activities. Mn is negatively correlated with the other metals, reflecting different sources of Mn and of other elements, including As, though both of them may originate mainly from soils.

### 3.3. Multivariate analysis results

#### 3.3.1. Principal component analysis

PCA was applied to assist in the identification of sources of pollutants. Table 4 displays the factor loadings with a VARIMAX rotation, as well as the eigenvalues. A 3-D plot of the PCA loadings is presented in Fig. 2, and the relationships among the nine heavy metals are readily seen. Just as expected,

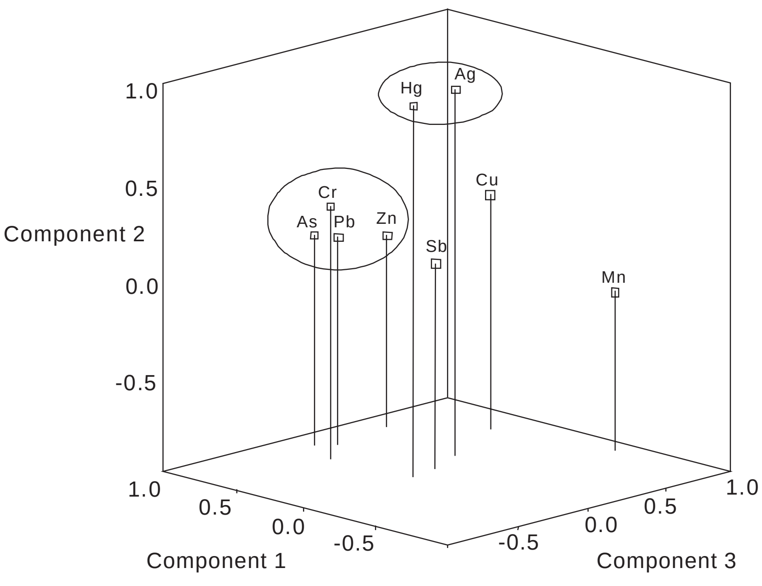


Fig. 2. PCA loading 3-D plot (PC1 vs. PC2 vs. PC3) for 9 heavy metals.

four factors were obtained, accounting for 77.35% of the total variance. Factor 1 is dominated by As, Cr, Cu, Pb and Zn, accounting for 27.34% of the total variance. In this case, the Cr and Cu loadings (0.569 and 0.42, respectively) are not as high as the loadings of the other elements of the group, which may, therefore, imply a quasi-independent behavior within the group. Factor 2, dominated by Ag and Hg, accounts for 20.11% of the total variance. Factor 3 is dominated by Mn and Cu, accounting for 17.20% of the total variance. From Fig. 2, Mn and Cu separated by a large distance in the 3-D PCA loading plot, which may suggest that the two elements are poorly correlated and have different sources. Factor 4 is dominated by Cr, Sb and Zn, accounting for 12.69% of the total variance, while Cr and Zn are negatively correlated with Sb.

#### 3.3.2. Cluster analysis

A CA was applied to the standardized bulk concentration data using War's method, with Euclidian distances as the criterion for forming clusters of elements. In general, this form of CA is regarded as very efficient, although it tends to create small clusters. Fig. 3 displays four clusters: (1) Ag–Hg; (2) Cu–Sb–Pb; (3) Zn–Cr; (4) Mn–As. It is observed, however, that clusters 2 and 3 join together at a relatively higher level implying perhaps a common source, while the long distance between As and Mn in cluster 4 may suggest that this cluster can be further divided into two subclusters.

### 3.4. Source identification

From the descriptive statistical analysis, the skewness and variation coefficient (VC) analysis have created an impression that Mn and As may have different sources from other elements. Compared with background values of Chinese soils, Ag, Cr, Cu, Pb, Sb and Zn have extremely elevated concentrations in urban dusts of Xi'an, which suggests anthropogenic sources of these elements, while As and Mn have concentrations approximating to their corresponding background values, indicating a natural origin.

PCA and CA analyses are consistent with these interpretations. The group of As and Mn is remarkably different from the other elements in terms of Euclidian distances in CA, which implies a different origin from the other elements and gives additional credence to the previous analysis, though Mn is correlated with Cu in PCA analysis. In addition, as was expected, some detailed understanding of source identification can be obtained from the PCA and CA analyses. A strong correlation between Hg and Ag in both analyses is an indicator of the common source or sources of the two elements. Cr, Cu, Pb and Zn are also correlated in both analyses, suggesting another common sources. Sb, although poorly correlated with other elements in PCA analysis, may have a common source with Cu, suggested by its strong correlation with Cu in CA analysis. As is correlated with Cr, Cu, Pb and Zn in PCA analysis, but separated from all of the other elements in CA analysis, except Mn, which

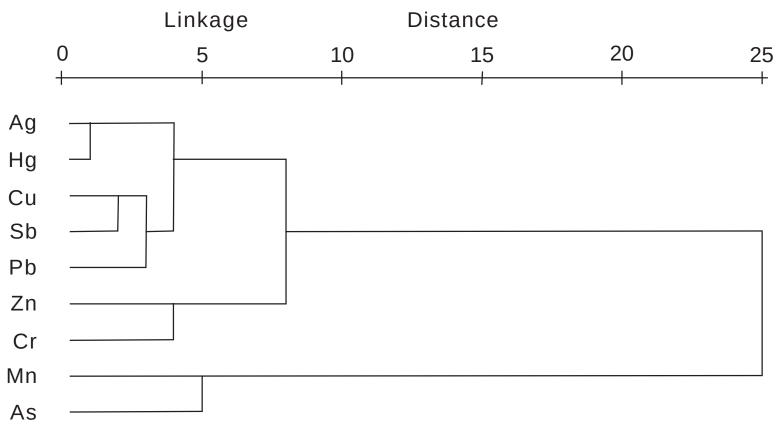


Fig. 3. Hierarchical dendogram for 9 elements obtained by War's hierarchical clustering method (the distances reflect the degree of correlation between different elements).

indicates perhaps a mixed source (natural and anthropogenic) of arsenic. For this metal, natural emissions normally exceed anthropogenic sources.

Based on PCA and CA, three main sources with corresponding cluster elements can be identified: (1) Ag and Hg have commercial and domestic sources; (2) Cr, Cu, Pb, Sb and Zn are mainly derived from industrial sources, combined with traffic sources as well for Pb and Zn; (3) As and Mn come mainly from soil sources, and As also has an industrial source. These results will be discussed in detail below.

The first group elements Ag and Hg, which both had the highest mean concentrations among the examined elements in comparison with the reference elements, comprised the second factor extracted by PCA. Ag, widely used for ornaments in people's daily life, must come mainly from the erosion of silver ornaments in commercial areas. Mercury is also present as an unintended contaminant in a wide variety of commercial products such as thermometers, blood pressure gauges, solvents, clinical reagents and laboratory chemicals (US EPA, 1986). And it was reported (ASMA, 2000) that significant amounts of mercury were consistently found in strictly domestic wastewater in various parts of the country.

The second group elements consists of Cr–Cu–Pb–Sb–Zn. All these elements show high mean concentrations, compared with the reference elements. This group of elements has been identified as those associated with heavy metal and chemical industry in many studies (Nasiman, 1996; Mokrzycki et al., 2003), as is also true of urban dusts in Xi'an. For example, cement-derived fugitive dusts, which come from the cement plant in the west of Xi'an (sample 61), contain high levels of heavy metals, especially Cr Cu, Pb and Zn. And these dusts can influence long-range areas because these particles, with their diameters of less than 100 um, are easily resuspended (Miguel et al., 1999; Han et al., 2003).

This group can be further subdivided into two subclusters: Pb and Zn are significantly correlated, as can be shown from their correlation coefficient, and have a traffic source, coupled with industrial sources; while Cr, Cu and Sb may originate mainly from industrial sources. High Pb concentrations in street dusts have been recognized for a long period as linked mainly to traffic activities due to the utilization of leaded gasoline (Day et al., 1975; Miguel et al., 1997). Additionally, traffic activities are also a significant contribution to Zn. According to Jiries et al. (2001), Zn may be derived from the mechanical abrasion of vehicles, so the local high background value of Zn in Xi'an may therefore be related, in part, to traffic movements. Zn compounds have been employed extensively as antioxidants (e.g., zinc carboxylate complexes and zinc sulphonates) and as detergent/dispersant improvers for lubricating oils (Miguel et al., 1997). It has been reported (Ellis and Revitt, 1982) that tire wear contributes significantly to Zn of urban dusts.

The third group of elements consists of As and Mn. They are obviously separated from the other elements in CA, and the long distance between them and other elements may suggest a mainly non-anthropogenic source. Skewness shows that As and Mn concentrations approach normal distributions, with means close to their reference values, which further supports the conclusion that they have mainly natural sources. As is significantly correlated with Cr, Pb and Zn in PCA, though separated with other element in CA, which may suggests a less significant industrial source. As and Mn are poorly correlated in PCA and correlation coefficient analysis, suggesting perhaps different soil sources between the two elements. Therefore, this cluster perhaps can be divided into two subclusters.

### 3.5. Enrichment factor analysis

The analyses mentioned above confirm that Mn is a conservative element in the studied environment. EFs of different elements, therefore, were calculated, and the results display in Fig. 4, which shows the distribution of each element's EF. It is clear from Fig. 4 that all the elements, except arsenic, have a mean EFs higher than 3. Arsenic has an EF close to unity, further confirming its mainly natural source. On the other hand, other elements, with maximum EFs much higher than 10, were considered to originate mainly from anthropogenic sources (Liu et al., 2003). It seems, therefore, that EFs can also be an effective tool to differentiate a natural origin from anthropogenic sources in this study.

The mean EFs decrease in the order of Hg>Pb>Ag>Zn>Sb>Cu>Cr>As, which can also be seen as

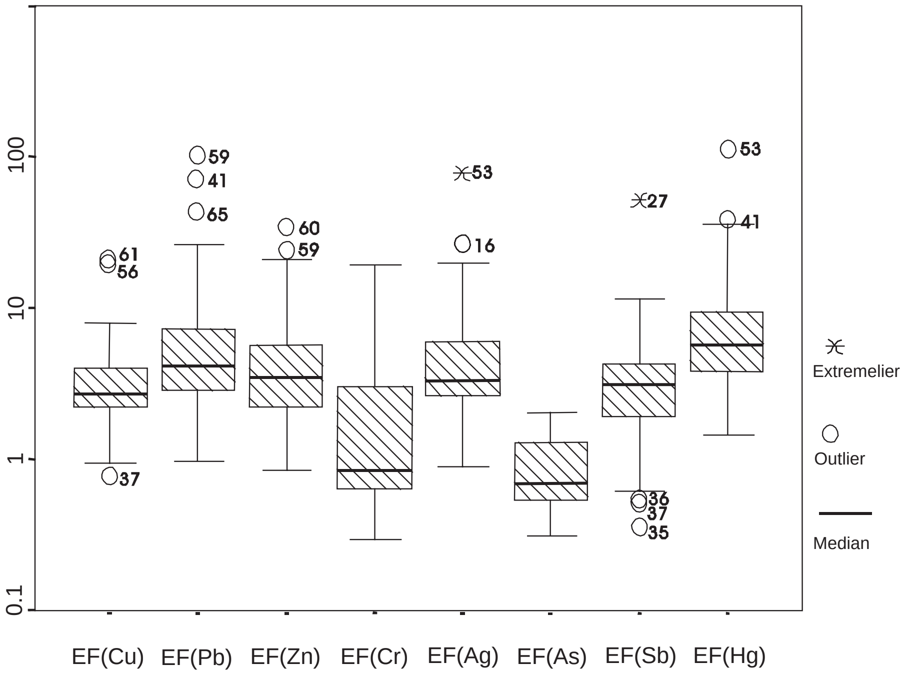


Fig. 4. Boxplot of enrichment factors for metals in the urban dusts of Xi'an city (all of the EFs were log normalized. Then the boxplot basically divides the normalized EFs into quartiles. The dark line inside the box represents the median; the boxes mark the 25th and 75th percentiles; the horizontal line outside the box, as is also called whisker, mark the values that extend 1.5 times the width of the box; points outside the whisker are called outlier; extremelier marks these points which are more than 3 times the width of the box).

the decreasing order of their overall contamination degrees of urban dusts in Xi'an. Ag, Hg, Pb and Zn have mean EFs higher than 5, which mean significant contamination; while Cr, Cu and Sb,, with their mean EFs between 2 and 5, were classified as moderately contaminated. The maximum EFs may reflect the degree to which local pollution affects each metal. The maximum EFs of Ag, Hg, Pb and Sb are higher than 50, indicating extremely high contamination of local dusts. The maximum EF of Zn is 33.96, which means very high contamination, while Cu and Cr have maximum EFs close to 20, indicating significant to very high contamination. The EF of As was very low and ranged 0.31–2.04, reflecting the lack of contamination with arsenic.

## 4. Conclusions

The application of multivariate statistical techniques combined with element concentration analysis and correlation analysis has been proved to be an effective tool for source identification of heavy metals in Xi'an dusts. Firstly, based on the comparison of heavy metal concentrations of urban dusts and background values of Chinese soils, the examined elements were classified into two main groups according to their sources: natural and anthropogenic. Then, PCA and CA analyses, coupled with correlation analysis, were used to gain additional insight into the origins of different elements in urban dusts. Three main sources for these studied elements, as well as some subdivided sources, were thereby identified. Mn and As are attributed to an main origin in soils. Furthermore, As is also associated with a less significant industrial source. Cu, Pb, Zn, Cr and Sb originate mainly from industrial sources, and Pb and Zn have traffic sources as well. Hg and Ag are mainly associated with commercial and domestic sources.

The EF analysis confirms these results. On the basis of the EF of each element, the urban dusts were classified as significantly contaminated with Hg, Pb, Ag and Zn, moderately contaminated with Cu, Cr and Sb and not contaminated with As.

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