Research Article

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Source apportionment of soil contamination based on multivariate receptor and robust geostatistics in a typical rural–urban area, Wuhan city, middle China

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Abstract: In this study topsoil samples were collected from 57 sites of Dongxihu District which is a typical Chinese urban–rural combination area, to analyze the causes and effects of 6 heavy elements. (Ni, Pb, As, Cu, Cd, and Hg) Pollution of Enrichment factor, multivariate statistics, geostatistics were adopted to study the spatial pollution pattern and to identify the priority pollutants and regions of concern and sources of studied metals. Most importantly, the study area was creatively divided into central urban, semi-urbanized, and rural areas in accordance with the characteristics of urban development and land use. The results show that the pollution degree of potential ecological risk assessment is $Hg > Ni > Cu > As > Cd > Pb$, and semi-urban regions > city center > rural areas. Results based on the proposed integrated source identification method indicated that As was probably sourced from agricultural sources (33.99%), Pb was associated with atmospheric deposition (50.11%), Cu was related to industrial source 1 (45.97%), Cd was mainly derived from industrial source 2 (42.97%) and Hg come mainly from industrial source 3 (56.22%). The pollution in semi-urban areas in urbanization need more attention.

Keywords: urbanization process; soil, heavy metals; land use; source apportionment; Positive Matrix Factorization.

1 Introduction

Currently industrial and economic activities are increasingly concentrated in city areas in china and it have become a new focus of resource consumption and chemical emissions [1,2]. The formation of an urban–rural interlaced zone around the city is an important intermediate product during the rapid period of land urbanization development and it always show as a ring shaped with the traffic line of trunk highways, suburban railways, and urban rail transit [3]. More important, the pollution distribution in soil changes in these areas because of the complex source apportionment with the huge scale of construction and the mass human activities [4,5]. Soil pollution in the urban–rural zone has seriously affected the quality of human living environments and has restricted sustainable development [6,7].

Soil pollution evaluation in China uses various evaluation methods, such as the single factor index, Nemero index, and environmental capacity methods, based on soil quality standards to identify the land and evaluate its developmental ability [8,9]. And in China, soil environmental quality risk control standards for soil contamination is now update to GB15618-2018 (agricultural land) and GB36600-2018 (construction land). The assessment of the impact of different pollutants on human health or ecological risk become more important instead of the quality control indexes identified [10]. From the perspective of environmental toxicology and ecological effects, the potential ecological risk index method can assess the situation of various heavy metals with different harmful substances and then make a comprehensive

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analysis to recognize the pollutant source easily; such technique is often used for polluted agricultural lands, lake sediment, and urban soil evaluation [11-14]. Potential ecological risk assessment is particularly suitable for the prediction of soil pollution trends in complex areas [15-20].

Soil pollution source analysis is conducive to the evaluation of land pollution trends. Such analysis includes ratios identification, multivariate statistics, and multireceptor models. Multivariate statistical analysis, especially principal component analysis, is often used for the source analysis of missing source lists. However, such technique is restricted due to the lack of quantitative data [21-23]. The multireceptor model was first proposed in the 1960s and used for quantitative identification of atmospheric pollution sources [24-26]. Such model has been frequently applied to the study of soil heavy metal in recent years. The model can recognize pollution sources by analyzing pollution content in the receptors and then calculating the contribution rate of each source [27-32]. Positive matrix factorization (PMF) models are calculated by the source profile and contribution rate, and the fitting is preferable at low content points. However, accuracy will be reduced in the heavily polluted areas [33]. Both models are applicable to rural and urban soils, but APSC-MLR is applicable to areas with a high correlation between different pollutants. PMF adds uncertainties to resolving weighted factorization. Enabling the individual treatment of elements also reduces the demand for data connectivity [34,35]. PMF on the division of sources is more detailed and presents a precise parsing compared with APCA-MLR in the case of complex environmental pollution in towns [36,37], it has a small data requirement and aims at various characteristics, such as complex pollution sources, low pollutant concentration, and low correlation between pollutants [38,39]. Moreover, using PMF model combined with GIS can quantify potential sources contributions and the spatial distribution [40].

In recent cases, most of the research areas that have been done in typical agriculture, mining or industrial areas with a single or significant using, but rarely attended to semi-urbanized areas with complex land using [41-44]. Dongxihu District is a new urban-rural interlaced zone in Wuhan. In this district cultivated land accounts for 44.59%, and construction land accounts for 19.05%, of which industrial land accounts for more than half of construction land. There are 169 industrial parks and more than 150 logistics companies. Over the past few decades, construction land has increased by 9.2%, the city has expanded rapidly. The original industrial zone has been demolished to build residential and public facilities, and

some rural land has been built as factories, the land use changes frequently. This work aims to (1) divide the land into central urban, semi-urbanized, and rural areas according to the characteristics of land using; (2) analysis of pollution degree in different urbanization areas in the process of urbanization by Potential ecological risk assessment; (3) analysis the geographical distribution characteristics of pollutants by GIS; (4) identify the pollution sources and contribution of major pollution elements based on PMF, identify the exploration of source spatial distribution by PMF and GIS. The ultimate goal is to understand the law of pollution in the process of urbanization, and to put forward reasonable suggestions for the planning and using of land for urbanization in rural areas.

2 Materials and methods

2.1 Study area, sample collection and chemical analysis

The Dongxihu District is affiliated with Wuhan City, Hubei Province, has a total area of 499.71 km² (Figure 1). The area is now regarded as a typical urban-rural interlaced zone in Wuhan. The grid distribution and expert layout are combined to follow the 8 × 8 km grid for farmland soil and 2 × 2 km grid for other regions on the basis of the recent land use information in Dongxihu District, pollution source survey, water system distribution, and other data. With regard to large-scale traffic trunks, we add points to each distance, including 50 km. We increase the amount of points of the industrial and animal husbandry pollution sources according to the rules of adding points. Thereafter, we correct the amounts based on the natural and social environmental data and site survey results. As shown in Figure 1, 57 sampling sites were set by the grid combined with an expert site-placement method. At each sampling site, a quincunx sampling method was adopted to select the topsoil (0–20 cm). then the soil screening by 2mm sieves were accurately dried by airing, classified, numbered, sealed, and made ready for use. pH, Cd, Hg, As, Pb, total Cr, Cu, Ni, and Zn of soil were determined according to GB15618-2018 and GB36600-2018 by CTI (Centre Testing International), Hg, As of soil were determined by Cold atomic absorption spectrophotometry, according to HJ 680-2013. Cu, Zn, Ni, Pb, Cd were determined by ICP according to USEPA3052:1996, USEPA6010D:2014. Reagent blanks, analytical duplicates, and standard reference materials (GBW07429 and GBW07317) were used for the quality assurance and quality control [45, 46].

Figure 1: Location, land use types, and sample points of the Dongxihu District.

Table 1: Risk value and risk degree interval.

E_f^i	Pollution Level Description	PER	Pollution Level Description
$E_f^i < 40$	Slight ecological risk	$PER < 150$	Slight ecological risk
$40 \leq E_f^i < 80$	Medium ecological risk	$150 \leq PER < 300$	Medium ecological risk
$80 \leq E_f^i < 160$	Strong ecological risk	$300 \leq PER < 600$	Strong ecological risk
$160 \leq E_f^i < 320$	Very strong ecological risk	$PER \geq 600$	Very strong ecological risk
$E_f^i \geq 320$	Extremely strong ecological risk		

2.2 Potential ecological risk assessment

Hakanson proposed the potential ecological risk index, which combines heavy metal properties based on sedimentology [47]. Such index is generally used to evaluate the metal contamination degree in soil [48-50]. The calculation formula is shown as follows:

$$C_f^i = \frac{C_i}{C_n^i}, \quad C_d = \sum_{i=1}^N C_f^i, \quad (1)$$

$$E_f^i = T_f^i * C_f^i, \quad PER = \sum_{i=1}^N E_f^i, \quad (2)$$

where C_i is the concentration measurement of a certain heavy metal element, C_n^i is the local soil background value of the element, C_f^i is the pollution factor of the metal, C_d is the sum of pollution factor of individual metals, E_f^i is the potential ecological risk index of a single metal element, and T_f^i is the toxicity response factor of each heavy metal. Xu et al. [41] reported that the obtained toxicity response factors of six heavy metals are as follows: As (10), Hg (40), Cu (5), Ni (5), Pb (5), and Cd (30). PER is the sum of the potential comprehensive ecological risk index. Table 1 shows the calculated risk range.

2.3 Positive Matrix Factorization

PMF was first proposed by Paatero [35,36]. This approach is a method for the quantitative analysis of pollution sources via receptor model mathematical methods using sample composition or fingerprints. The minimum iterative square algorithm decomposes the original matrix, E_{ik} , into two factor matrices, namely, A_{ij} and B_{jk} , and residual matrix, ε_{ik} . The basic equation is as follows [25,26]:

$$E_{ik} = \sum_{j=1}^p A_{ij} B_{jk} + \varepsilon_{jk} \quad (i = 1, 2, \dots, m, k = 1, 2, \dots, n) \quad (3)$$

where E_{ik} is the concentration of the k th heavy metal contaminant in the i th sample; A_{ij} is the i th sample contributing to the j th source, such as the source sharing ratio matrix; B_{jk} is the k th contaminant in the contribution concentration of the j th source, such as the source component spectrum matrix; and ε_{jk} is the random error. The PMF model is based on the weighted least squares method for finite and iterative calculations. Matrix E_{ik} is continuously decomposed to obtain optimal matrices G and F . The optimization goal is to minimize the objective function Q . Such function is defined as follows:

$$Q = \sum_{j=1}^m \sum_{k=1}^n \left(\frac{\varepsilon_{jk}}{\sigma_{jk}} \right)^2 \quad (4)$$

where σ_{jk} denotes E_{ik} uncertainty. During the operation, the uncertainty data are calculated as follows: When the heavy metal concentration is less than or equal to the corresponding method detection limit (MDL), the uncertainty value is:

$$Unc = 5/6 \times MDL \quad (5)$$

When the heavy metal concentration is more than the corresponding MDL , the uncertainty value is:

$$Unc = \sqrt{(\sigma \times c)^2 + (MDL)^2} \quad (6)$$

where σ is the relative standard deviation, c is the element concentration, and MDL is the method detection limit.

Ethical approval: The conducted research is not related to either human or animal use.

Figure 2: Areas of different urbanization processes.

3 Results and discussion

3.1 Field investigation and region division

The Dongxihu District has a suburban development pattern in the typical urbanization process. The urban–rural interlaced land is mainly distributed in the southwest, near the 107 National Highway and the expressway to the northwest and in the ring between the traditional agricultural production team, Hankou District, and the main market towns. The used suburban land has been subordinated to the Dongxihu production brigade. The land with a number of artificially constructed ditches for irrigation was originally used for vegetable and rice fields, but at present, is used for industrial, logistics distribution centers, residential buildings that only a small portion is utilized for agriculture.

The period of land use change and enterprise emergence is accompanied with pollution problems. The pollution sources are illustrated on the basis of the general survey and on-site investigations of industrial pollution sources in the Dongxihu District (Figure 1). The

four main types of sources are industrial pollution, traffic and logistics pollution. Industrial sources are mainly distributed in the Zoumaling–Xingou area, the U-shaped dispersions in the Baiquan–Xiaohe area in the Zoumaling, Xingou, and Jinyinhu districts, and the Jin River near Wuxiao Expressway. The boundary between the factory and the residential area is obscured, and it is mostly mixed and distributed. The industrial type includes food package processing, glass-ceramics production, electrical/electronic processing and chemicals. The main emissions are wastewater to Han River with organic matter and highly concentrated suspended solids and waste gas containing particulate matter including heavy metal, sulfur dioxide, and chloride. A small number of heavy industrial enterprises are located in the northern bank of the Jinyin Lake (Jinhe Chemical Corporation) and Jinyintan (Yangtze Bus). The traffic pollution sources mainly come from many types of roads in the urban–rural junction area. The overall road network density in the east is considerably higher than that in the west. Expressways, elevated railways, and rural roads are mixed. Dust in logistics parks is prominent due to large-scale vehicles that frequently appear poor

road conditions, and automobile exhaust emissions. In addition, these pollutants will enter agricultural land with irrigation, rainwater runoff and atmospheric settlement, causing pollution of agricultural land.

Dongxihu is a typical urban–rural integration zone from traditional agricultural areas to new industrial ones. Dividing the area can analyze the pollution situation of each area separately, so as to make corresponding evaluations and develop solutions for different areas. According to the land planning documents and field visits, we divided the land of Dongxihu District into urban area, semi-urban area and rural area as Figure 2 shows. Most of the urban area is a kind of construction land in the planning, and most of the uses are urban green space, residential and commercial center, where in the middle and east of the district. The semi-urbanized area is mostly planned for second-class construction land, mixed with farmland, industrial land, residential areas and logistics parks, where in the southwest part of the district. Most of the rural areas are planned agricultural land, mainly used for undeveloped land and farmland. There are scattered towns and highway viaducts. The rural areas are located in the northwest and northeast of the studied district.

3.2 Contents of soil pollution elements Evaluation of pollution degree

3.2.1 pH

The descriptive statistics of pH and six metals of topsoil were shown in Figure 3. Soil pH in the Dongxihu District generally ranges from 7 to 8. The pH values of the rural areas, semi-urbanized area, central city, and entire area are 7.00, 7.74, 7.77, and 7.60, respectively. The pH of the town regions is evidently lower than those of the semi-urbanized and central city areas, which have high data dispersion. The Dongxihu District used to be a traditional agricultural area, and several sampling points were affected by long-term agricultural production, thereby resulting in pH drop [38]. The soil pH of Dongxihu is high in the southeast and low in the northwest. The pH value is consistent with the development situation, including agriculture in the northwest and urbanization in the southeast.

3.2.2 Descriptive statistics

The concentration of all metal in the entire area is smaller than the risk screening value, only except As in Baiquan town, which is slightly exceeds the screening value of the first type of construction land. And the average

Figure 3: pH of different soil types.

concentration of As, Cu, Ni are lower than the local background value (1990), while As, Hg, Pb are several times higher in some special sample plots that affected by nearby pollution sources. Fei et al. (2019) also find that As and Pb concentration levels are high in Shanghai [51]. Several differences are observed in the variation coefficient of different heavy metals. This condition is mainly due to the differences in the types of heavy metals emitted by the source [52, 53].

3.2.3 Potential ecological risks

The risk index of each element is calculated in accordance with the PER. The average risk index values of the elements are 40.43 (Hg) > 14.2 (Ni) > 12.3 (Cu) > 10.00 (As) > 3.53 (Cd) > 3.43 (Pb). In general, Dongxihu District, the average ecological risk of soil is small, the soil quality is generally good as Table 3 and Figure 3 shows. But minority area has high risk values for one or two elements such as Hg (169.5) which has a high level of ecological hazard and Cd (49.41) which is a medium ecological hazard level. The SD or Variance differences values of As, Cu, and Pb containments are less marked, the distribution of them at all points in the entire region is relatively uniform. By contrast, Hg, Ni and Cd have significant limited pollution point which has connection to point source pollution. Through the above analysis, we need to pay attention to urban mercury pollution in urban land use.

The potential ecological risk index of different land use types and the spatial distribution of the total ecological risk are shown in Figs. 4 and 5. The ecological

Table 2: Statistics of heavy metal concentration.

Project	Min.	Max.	Avg.	SD	Variance	CV	Bias	Peaks	Local Background Value
As	6.81	21	11.58	2.79	7.77	0.24	1.12	2.02	12.3
Hg	0.04	0.34	0.08	0.05	0.002	0.58	3.67	17.08	0.08
Cu	13.3	70.7	29.48	9.60	92.10	0.32	1.99	6.44	30.7
Ni	14.2	44.8	31.33	6.71	45.15	0.21	−0.05	−0.52	37.3
Pb	18.8	73.3	27.40	7.61	57.99	0.28	4.03	23.37	26.7
Cd	0.02	0.28	0.17	0.08	0.006	0.44	−0.32	−1.20	0.17

Table 3: Statistics of the risk index.

Project	Full Distance	Min.	Max.	Avg.	SD	Variance
As	12.26	5.89	18.15	10.00	2.41	5.80
Hg	151.50	18.00	169.50	40.43	23.36	545.57
Cu	9.99	2.31	12.30	5.13	1.67	2.79
Ni	30.60	14.20	44.80	31.33	6.72	45.15
Pb	9.94	3.43	13.37	4.99	1.39	1.93
Cd	45.89	3.53	49.41	30.53	13.48	181.62
PER	215.64	70.36	286.01	122.42	35.27	1244.10

risk values of the rural, semi-urbanized, and central urban areas are $313.3 > 249.3 > 262.9$, respectively, and the mean value of the entire district land is 275.5. The risk of the semi-urbanized area is considerably higher than others. This phenomenon might affect by high development in this area with destructive human activities such as low vegetation coverage, frequent logistics, and industrial or large vehicles activities [54]. The risk of the rural region is higher than that of the central urban area. The farmland area located in the northwestern part of the rural area is susceptible to a certain degree of heavy metal enrichment due to various factors, such as sustainable modern agricultural irrigation, pesticides, fertilizers [44], and concentrated in the first-level construction of mainly residential areas near the Jinyin Lake. While in the central urban area, large-scale vehicles and heavy industries are few, and the environmental quality is high. The individual high-value points are observed in the semi-urbanized and central urban areas such as Hg are affected by point source pollution near the sample site. In general, the degree of ecological risk from high to low are concentrated in the semi-urbanized areas especial in Xingou and Zoumaling development zone, the rural area which has modernized agriculture, and then the central urban areas such as Jinyinhu residential area, a well-governed and relatively

mature community. The pollution generated during the period of land urbanization development of suburban land is noticeable. According to the above research, we must pay attention to semi-urban areas pollution and implement supervision in urbanization construction.

3.3 Spatial distribution of soil heavy metals

The six heavy metals are subjected to logarithmic quantization and then Kolmogorov–Smirnov test are used to obtain the Sig value. The inverse distance weighing method is used for Cd and Hg (sig less than 0.05), and the Kriging method is used for the other related metals to show the spatial distribution of heavy metals (Figure 5). The six heavy metal contents, except for the pure point source, exhibit a high value in the southwest and a low value in the northeast. Cu (70.7 mg/kg) and Pb (73.3 mg/kg) show high values in the Jinyintan industrial area. Cd manifests the maximum value (0.28 mg/kg) in the Xingou and Jinyintan areas. The minimum concentration in the Baiquan area is 0.02 mg/kg. As concentration shows high distribution in the southwestern region with plaque-shape and low distribution around the Jinyin Lake. Ni exhibits a maximum value of 44.8 mg/kg in the farmland around

Figure 4: PER value from different soil types.

the 107 National Highway in the northwest. Hg presents a high concentration near Baiquan and the Sino-French Friendship Bridge.

In accordance with the spatial distribution, the high concentrations of As are scattered in various regions in the west, and the concentrations are lower in the east. The eastern region is a mature urbanized region, and the western region is a rural and semi-urbanized region. The high concentrations of Ni, Cd and Hg are both scattered in various regions in the southwest region. This area is a typical semi-urban area. Cu and Pb have high value in the southwest region, but the highest point is in the northeast corner, which is the urban area but has a few factories such as Yangtze Bus. Accordingly, the pollution caused by the heavy metal are seriously polluted in the semi-urbanized areas but not in the urban areas. The Dongxihu District has formed evident pollution belts in the urbanization process.

Figure 5: Spatial distribution of the total ecological risk index of the Dongxihu District.

Figure 6: Spatial distribution of heavy metal concentration in the Dongxihu District (mg/kg).

3.4 Source apportionment by PMF model

In accordance with the PMF, the number of iterations is determined to be 20 times, and the number of factors is between four and seven. The most suitable number of factors was selected by judging the minimum and stable Q value, and finally six factors were optimal numbers (Figure 7).

The main contributing elements of Factor 1 are As, Pb, and Ni, which account for 33.98%, 31.5%, and 14.95%, and the other artificial sources have little effect. The average concentration of As and Ni are lower than the background value of soil but the max concentration

of As and Pb are much higher in some points (Table 2). Pesticides or herbicides used to agriculture were consisted by inorganic As and Pb compounds such as calcium arsenate, lead arsenate, sodium arsenate, livestock manure and fertilizers [55]. Factor 1 is mainly combined with agricultural source.

Factor 3 has high loadings of Pb (40.36%) and Cd (50.11%) and the containments of Pb are higher than Soil background value. Element Pb was a mainly marker of vehicle emission and atmosphere deposition [41,56]. The similar results were found in other studies [42,57]. Thus, the fact3 or was determined to be vehicle emission and atmosphere deposition. Factor 3 is atmospheric

Figure 7: Contribution of various factors in the soil pollution of Dongxihu.

deposition. The contribution rate of each element of Factor 5 is relatively average, it is a natural source.

Factor 2 consisted predominantly of Cu (45.97%), Ni (21.66%) and Pb (21.2%), the fourth factor was weighted primarily on Hg (40.36%) and Ni (42.97%) and the six factors, was dominated by Hg (56.21%). Hg was usually considered to originate from industrial sewage, industrial fumes and fossil fuel combustion [58]. Cu, Ni, and Cr always caused by industrial emissions [28]. According to

our field investigation, industries in the Dongxihu District mainly include the Electronics, steel structure processing, and automobile parts production, smelting and rust prevention are the main sources of heavy metal pollution from these industries. And the rust prevention process is prone to producing a large amount of wastewater, exhaust gas, and waste residue containing Cu, Ni, and Cd. So, the factors 2, 4, and 6 are industrial sources.

Figure 8: Fingerprint of each element contributing to pollution source factors.

The Fingerprint of each element contributing to pollution source factors shows the relationship between metal and source (Figure 8). In combination with the variation characteristics shows before, the Objects affected by prominent anthropogenic sources are Hg, Cd, and Cu because high contribution or no contribution emerges of certain factors. While the Contribution of various factors of Ni, As, and Pb is relatively average. As was affected both by agricultural and natural source. The industrial sources (1, 2, 3) are the main sources of Hg, Ni, and Cu. Factor 2 is the Cu emission. Ni Factor 4 is the emissions of Ni and Cd. Although the representative industries of two sources are similar, the emission sites and contents are different, thereby resulting in the variation in the correlation between different elements. Accordingly, the sources are resolved into two. Factor 6 mainly refers to Hg emission, which is different from that of Factors 2 and 4. The contribution rate of Factor 6 for other elements is low, and that of Hg reaches 56.21%. In the Dongxihu District, motor vehicle emissions are ubiquitous due to the dense road network. The dominant source of Pb and Cd is vehicle emission and atmosphere deposition [19-21].

The Spatial distribution characteristics of various pollution sources were show in Figure 9. In general, the soil utilization situation in the southwestern part of the Dongxihu District is complicated in accordance with the contribution of each factor. Four pollution sources simultaneously contribute. Pollution sources in the northeast and southeast, which are undeveloped and mature urban areas with fewer industries, respectively, are few. A typical area undergoing urbanization is in the

southwestern part of the district. The main contribution of natural sources is in a less developed area in the northeastern part of the Dongxihu District; this finding is consistent with facts. Most soil in the southwest has been developed and back filled. The backfill soil is mixed with the original one, and the various influences of human activities reduce the intensity of As and other elements in natural sources. Results of the preliminary investigation show that a certain overlap exists between the Dongxihu road network and the industrial area that can produce heavy metals. The industrial area (food package processing, glass-ceramics production, electrical/electronic processing and chemicals) is concentrated in Xingou, Zoumaling, and Jinyintan. The logistics distribution center is concentrated in Wujiashan and Zoumaling. Factor 1 is mainly concentrated in the northwestern farmland, showing plaque distribution, which is consistent with agricultural source characteristics. Factor 3 is atmospheric deposition and closely related with the road density and distribution of the logistics area [24,32]. The Jinyintan industrial park, which emission is complicated, has highly contributes to atmospheric sources. Factor 2, 4, 6 are different kind of industry, that Factor 2 in the Dongxihu District is mainly discharged in the Jinyintan industrial area. Factor 4 is the discharge of the Xingou and Zoumaling industrial areas. Jinyintan mainly discharges Cu and Ni, whereas Xingou emits Ni and Cd. The contribution of each point in Factor 6 is close to the distribution of Hg elements. This finding verifies that Factor 6 is mainly caused by Hg pollution. Hg pollution is slight in most parts of the Dongxihu District, and the individual points present

Figure 9: Spatial distribution characteristics of various pollution sources.

high values. The southern extreme high point is located between the railway freight yard and the mixed industrial area. The area is mainly industrial and has few other uses. If the impact of the backfill soil is excluded, then the enterprises with high Hg emissions may exist in the industrial area. The high values in the north cover the entire town of Baiquan, which has fewer industries and is a gathering place for many people. Factor 6 presents great contribution and may be caused by residual soil in the relocated industry. HgCl has been used as a catalyst for the production of some chemical products. The area near high value of factor 6 was old chemical plants, which

might cause soils to act as a reservoir for Hg over time [59–61]. According to the above research, in the treatment of soil pollution, according to the different pollution sources and key contributions in different regions, control the pollutants that make major contributions.

4 Conclusion

The soil pH of the Dongxihu District is high in the southeast and low in the northwest. The overall pollution is low while only Hg and Pb are higher than the soil

background value. The ecological risk of the entire region is also low, its ecological risk comes from the contribution of Hg. Most metals have relative high concentration value in the semi-urbanized areas, low concentration value in central urban city. The Dongxihu District has formed evident pollution belts during the urbanization process. Elements Cu, Hg, and Pb have evident pollution sources and large geographical differences. As and other elements are distributed in plaques, and no evident pollution source can be found. Six pollution sources, including natural, agricultural, atmospheric deposition, and industrial sources 1, 2, and 3, are obtained after PMF analysis. The main contributions of natural, atmospheric deposition, industrial sources 1, 2, and 3 are As, Pb, Cu, Cd, and Hg, accounting for 33.987%, 50.106%, 45.972%, 42.971%, and 56.218%, respectively. The pollution source is characterized by the urban–rural interlaced zone in which the agricultural and natural sources are distributed in the southwestern and northeastern regions, respectively. The high concentration of atmospheric deposition source is in the combination zone between the agricultural land and the second type of construction land. Industrial sources 2 and 3 are concentrated in the urban–rural integration zone in the southwest. Industrial source 1 and atmospheric deposition sources are concentrated in the urban–rural interlaced zone in the northeast. In urban development planning, combining PMF, GIS, and PER can more accurately find the pollution source, its main contribution and source location, and assess its pollution degree. In addition, we need to pay special attention to semi-urbanized areas and pay attention to the personalized connection between pollution sources and pollutant types. We need to discuss and set control targets for different pollution sources.

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