Polycyclic aromatic hydrocarbons in atmospheric dust deposition from Anqing, China: pollution characteristics, sources and health risk assessment

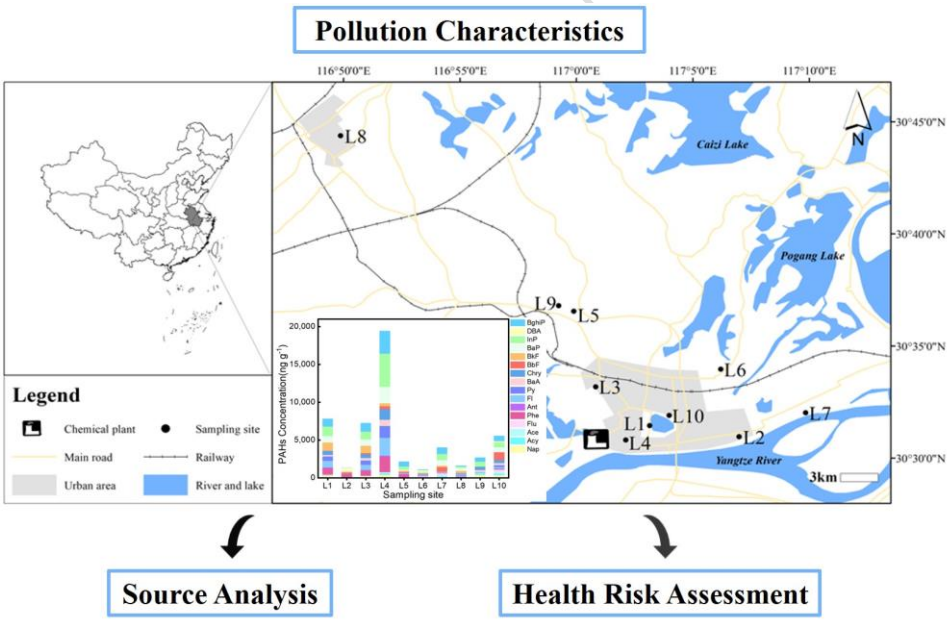
Tian Yangji, Liu Ting, Li Fasong*, Mei Xuan, Shi Jie, Fang Mengjun, Xu Bowen, Qiu Jianfeng

College of Resources and Environment, Anqing Normal University, Anqing, Anhui 246011, China

*e-mail: lifs628@163.com;

Tel.: +86-556-5306208.

Graphical abstract



Abstract

This study systematically analyzed the pollution characteristics, source apportionment, and health risks of 16 polycyclic aromatic hydrocarbons (PAHs) in atmospheric dust deposition, using Anqing City—a typical industrial city in China—as the research subject. Results indicate that the concentration range of Σ_{16}PAHs in atmospheric dust in Anqing City is 85.22 – 21,351.03 ng g^{-1}, with

an average of 5,301.21 ng g^{-1}, placing the pollution level in the lower-middle range nationally. Spatial distribution revealed significantly higher PAH concentrations in industrial clusters of Daguan District compared to other areas, indicating industrial emissions as a major point source of PAHs. The composition was dominated by high-ring (5–6 ring) PAHs (average proportion: 58.90%), indicating primary origin from high-temperature combustion processes. Integrated source apportionment using ring number distribution, characteristic ratio analysis, and positive matrix factorization (PMF) models identified fossil fuel combustion and industrial activities as the primary PAH sources. Health risk assessments revealed skin contact as the predominant exposure pathway for both adults and children, with carcinogenic risks approaching or exceeding acceptable thresholds under certain high-exposure scenarios.

Keywords: Polycyclic aromatic hydrocarbons; Atmospheric dust deposition; Health risk assessment; Anqing

1. Introduction

The presence of environmental pollutants represents a significant threat to human health. Among these pollutants, polycyclic aromatic hydrocarbons (PAHs) are of significant concern due to their toxicity, carcinogenicity, and teratogenicity(Barbosa Jr et al., 2023). PAHs constitute a diverse group of organic compounds found extensively in environmental matrices like road dust, soil, and sediments(Ma et al., 2017). In light of the pervasive presence of these compounds in the environment and their potential implications for human and ecological health, the United States Environmental Protection Agency (USEPA) has identified 16 PAHs as priority pollutants(Samburova et al., 2017).

Globally, a significant quantity of PAHs are released into the atmosphere on an annual basis, and since PAHs are mostly products of incomplete combustion, most of them primarily manifest as particulate matter, which will migrate and diffuse with the atmosphere, and finally land on the ground in the form of dust(Yang et al., 2021). In addition to direct harm to the human body, atmospheric dust

fall pollution will also produce some damage to humans and the environment through various environmental media(Kothiyal et al., 2022).

In recent years, people have gradually realised that PAHs contamination will constitute a great threat to public health, so the research on PAHs has become a hot spot. The research on PAHs in foreign countries started earlier, but the research on PAHs in China started later, and the cities that have carried out the research on PAHs in urban air are Shenzhen, Guangzhou, Tianjin, Xi'an and Beijing and other large cities(Fu et al., 2023, Jiang et al., 2023, Wu et al., 2022, Zhang et al., 2025, Li et al., 2022). Anqing, as a representative medium-sized industrial city in the Yangtze River Economic Belt, hosts a dense cluster of chemical, thermal power, steel, and building material industries(Sun et al., 2022). These sectors are characterized by intensive fossil fuel consumption and high-temperature processes, which are significant PAHs emission sources. Despite the proliferation of PAHs studies in megacities, systematic investigations in medium-sized industrial cities—particularly those with mixed industrial profiles like Anqing—remain scarce. This study aims to fill this gap by providing a comprehensive assessment of PAHs pollution characteristics, sources, and health risks in Anqing, thereby offering a scientific basis for targeted pollution control in similar urban contexts.

In this study, atmospheric dust deposition samples were collected from 10 different areas in Anqing City. The samples were extracted and concentrated using ultrasonic extraction before being quantitatively analysed for PAHs using gas chromatography-mass spectrometry (GC-MS). The primary objectives of this paper are to: (1) reveal the concentration and compositional characteristics of PAHs in atmospheric dust deposition in Anqing City; (2) identify the main origins of PAHs in atmospheric dust deposition; (3) assess the human health hazards associated with PAHs in atmospheric dust deposition.

2. Materials and Methods

2.1. Study area and sampling

In the last few years, the Anqing area of China has been designated a hub for chemical-based industries, boasting over 400 chemical companies, including Anqing Petrochemical and numerous others(Sun et al., 2022). With the concomitant increase in population and rapid economic growth, the issue of environmental pollution has become increasingly salient. In this study, 10 dust samples were gathered from diverse sites in Anqing City, with the sampling points distributed across the primary urban areas of Anqing City and Huaining County (Figure 1), covering industrial, commercial, residential, and suburban areas. During sampling, approximately 5 grams of dust is collected from outdoor window sills, etc., using a brush impregnated with acetone solution according to a strict procedure, and placed in a polythene sample bag labelled with the appropriate collection site. Subsequent to collection, the samples are returned to the laboratory to remove impurities, sieved through a 0.15 mm screen and stored at low temperatures.

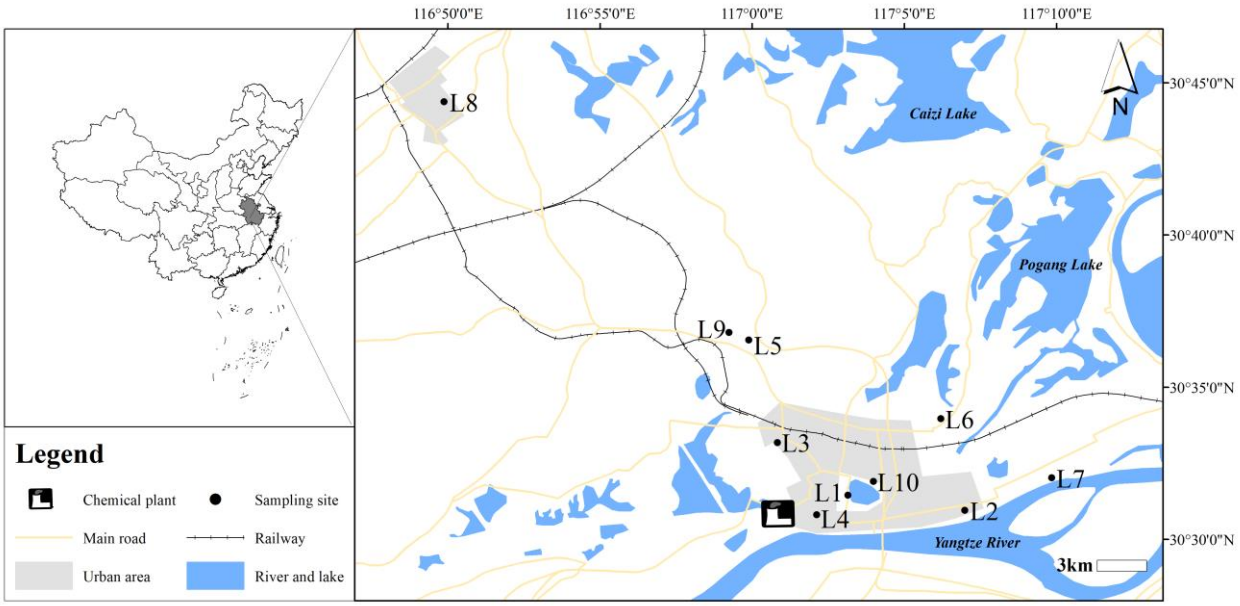


Figure 1. Schematic diagram of atmospheric dust deposition sampling points

2.2. Analysis of PAHs in atmospheric dust deposition

The study analyzed the sixteen priority PAHs as identified by the USEPA, which include naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluoranthene (Fl), phenanthrene (Phe), anthracene (Ant), fluorene (Flu), pyrene (Py), benzo[a]anthracene (BaA), chrysene (Chry), benzo[a]pyrene (BaP), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), indeno[1,2,3-

cd]pyrene (InP), dibenzo[a,h]anthracene (DBA), and benzo[g,h,i]perylene (BghiP). Ultrasonic extraction method (USA EPA 3550B) was used. About 2 g of sediment was weighed, 2 g of copper powder was added, and the extract was extracted by ultrasonication with 15 mL of 1:1 (V:V) n-hexane/acetone solution for 30 min, centrifuged and transfer the supernatant, and the above ultrasonication was repeated for 2 times and the temperature was controlled to be below 40 ℃. The extracts were combined, rotary evaporated to 2 mL, and the extracts were passed through a chromatography column (1 cm anhydrous sodium sulfate, 6 cm 3% deactivated alumina, and 12 cm 3% deactivated silica gel from top to bottom). The column was pre-eluted with 15 mL of n-hexane, the hexane eluent was discarded, and then eluted with 70 mL of a (3:7 dichloromethane/n-hexane) mixture, all of which was received. The received solution was rotary evaporated and fixed to 1.0 mL with n-hexane, and stored at low temperature for measurement. The analysis of PAHs was conducted utilizing a GC-MS (Agilent 5975C/7890A) with ionization in electron impact (EI) mode, and data acquisition took place under the selective ion monitoring (SIM) mode.

2.3. Health risk assessment

The toxicity of PAHs present in atmospheric dust deposition is determined by means of the toxicity equivalency factor (TEF) of these compounds(Zhang et al., 2022). The most toxic PAH-BaP had a TEF value of 1, and the TEF values for the other PAHs were derived by comparing their carcinogenicity levels with those of BaP(Škrbić et al., 2019). CS denotes the total concentration of PAH congeners calculated using the TEF method (Equation (1))(Wang et al., 2011). Each PAH congener's concentration is denoted by C_n (m^3 kg^{-1}), and the corresponding TEF for each PAH is denoted by TEF_n (Table 2).

$$CS=\sum(C_n\times TEF_n) \quad (1)$$

The incremental lifetime cancer risk (ILCR) associated with exposure to PAHs was determined based on previous research(Wu et al., 2020). The ILCRs for dermal contact, inhalation, and ingestion were quantified for each area dust sample in Anqing according to the following Equation (2) - (5):

$$ILCR_{Ingestion}=\frac{CS\times\left(CSF_{Ingestion}\times\sqrt[3]{BW/70}\right)\times IR_{Ingestion}\times EF\times ED}{BW\times AT\times 10^{6}} \quad (2)$$

$$ILCR_{Inhalation}=\frac{CS\times\left(CSF_{Inhalation}\times\sqrt[3]{BW/70}\right)\times IR_{Inhalation}\times EF\times ED}{BW\times AT\times PEF} \quad (3)$$

$$ILCR_{Dermal}=\frac{CS\times\left(CSF_{Dermal}\times\sqrt[3]{BW/70}\right)\times SA\times AF\times ABS\times EF\times ED}{BW\times AT\times 10^{6}} \quad (4)$$

$$CR=ILCR_{Ingestion}+ILCR_{Inhalation}+ILCR_{Dermal} \quad (5)$$

To minimise computational uncertainty, a Monte Carlo simulation (Oracle Crystal Ball, USA) was employed. This simulation was based on parameters from previous researchs (Kong et al., 2025, Tarafdar and Sinha, 2019)(Table 1) research and comprised 20,000 iterations.

Table 1. Exposure parameters for probabilistic risk assessment.

Exposure variable	Distribution types[a]	Adult	Child	Unit
Averaging life span (AT)	Point	70×365=25,550	70×365=25,550	day
Body weight (BW)	Normal	[52.10, 6.50]	[16.30, 2.40]	kg
Dermal exposure area (SA)	Lognormal	[4,619.11, 1.77]	[4,619.11, 1.77]	cm^2
Dermal adherence factor (AF)	Lognormal	[0.04, 3.41]	[0.04, 3.41]	mg cm^{-2}
Dermal adsorption fraction (ABS)	Lognormal	[0.13, 1.26]	[0.13, 1.26]	unitless
Exposure duration (ED)	Uniform	[0, 24]	[0, 6]	year
Exposure frequency (EF)	Triangular	345 [180, 365]	345 [180, 365]	day $year^{-1}$
Ingestion rate ($IR_{ingestion}$)	Point	100	200	mg day^{-1}
Inhalation rate ($IR_{inhalation}$)	Lognormal	[13.9, 1.07]	[7.19, 1.62]	m^3 day^{-1}
Particle emission factor (PEF)	Point	1.36×10^9	1.36×10^9	m^3 kg^{-1}
Ingestion carcinogenic slope factor ($CSF_{Ingestion}$)	Lognormal	[7.30, 1.15]	[7.30, 1.15]	mg kg^{-1} day^{-1}
Inhalation carcinogenic slope factor ($CSF_{Inhalation}$)	Lognormal	[3.14, 1.80]	[3.14, 1.80]	mg kg^{-1} day^{-1}
Dermal carcinogenic slope factor (CSF_{Dermal})	Point	25	25	mg kg^{-1} day^{-1}

[a] For normal, point, uniform and lognormal distributions, the values in parentheses represent the arithmetic mean and standard deviation, the fixed values, the minimum and maximum, and the geometric mean and geometric standard deviation, respectively.

2.4. Positive matrix factorization (PMF)

Source apportionment was performed using the US EPA PMF 5.0 model. The model decomposes the original data matrix X (n samples × m species) into factor contributions (G) and factor profiles (F), minimizing the objective function Q:

$$X=G\times F+E \tag{6}$$

$$Q=\sum_{i=1}^{n}\sum_{j=1}^{m}\left(\frac{e_{ij}}{u_{ij}}\right)^2 \tag{7}$$

where E is the residual matrix and u_{ij} is the uncertainty of species j in sample i.

Uncertainties (u_{ij}) were calculated following(Guo et al., 2025b):

$$u_{ij}=\begin{cases}0.2\times C_{ij}+\dfrac{MDL}{3}, \text{ if } C_{ij}\leqslant MDL\\ 0.1\times C_{ij}+\dfrac{MDL}{3}, \text{ if } C_{ij}>MDL\end{cases} \tag{8}$$

where C_{ij} is the concentration and MDL is the method detection limit.

Model robustness was evaluated using multiple criteria. The optimal number of factors (three) was determined by examining the change in Q (Q_{robust}/Q_{true}) with increasing factor numbers, ensuring physical interpretability of profiles. Bootstrap analysis (100 runs) was performed to assess factor stability and uncertainty. Key goodness-of-fit metrics, including the coefficient of determination (R^2) between observed and modeled concentrations for key species, are reported to validate model performance.

2.5.Quality assurance/quality control

To ensure the representativeness, accuracy, and comparability of the data, stringent quality control measures were implemented. Results for reagent blanks, laboratory blanks, and recovery experiments fell within acceptable ranges. Each PAH working standard curve exhibited good linearity with correlation coefficients (R^2) $\geqslant$ 0.995. No PAHs were detected in reagent blanks. Laboratory blanks showed only trace amounts of Nap and Phe (below 3% of actual sample levels), with final concentrations adjusted by corresponding blank subtraction. The method's minimum detection limits ranged from 0.20 to 1.20 ng g^{-1}. Except for the relatively low recovery rate of highly volatile

naphthalene (65.8%), recovery rates for other compounds ranged from 76 to 110%, with relative standard deviations < 8.0%. PAH concentrations in the measured dust were not corrected for recovery.

3. Results and Discussion

3.1. Distribution of PAHs content in dust

In this study, the contents of PAHs in dust samples from 10 sampling sites in urban areas of Anqing were counted. Table 2 lists the TEF, mean, median and range of 16 PAHs in the dust samples from the 10 sampling points.

153 **Table 2.** Distribution of PAHs in dust samples from different areas of Anqing city.

Congeners	TEF	Mean(ng g^{-1})	Median(ng g^{-1})	Concentration(ng g^{-1})
Nap	0.001	175.016	127.96	0 - 409.51
Acy	0.001	98.229	42.12	0 - 232.7
Ace	0.001	46.33	19.475	0 - 157.06
Flu	0.001	93.833	28.16	0 - 365.27
Phe	0.001	482.271	273.635	17.11 – 2,005.35
Ant	0.01	38.783	14.335	1.75 - 194.64
Fl	0.001	453.363	116.385	1.64 – 2,343.66
Py	0.001	323.667	80.505	0.96 – 1,567.34
BaA	0.1	211.601	138.275	15.57 - 815.77
Chry	0.01	365.861	266.145	28.29 – 1,408.7
BbF	0.1	245.095	122.935	0 - 998.03
BkF	0.1	334.646	170.54	0 – 1,077.93
BaP	1	616.714	525.87	0 – 2,177.43
InP	0.1	943.586	652.815	7.49 – 4,378.85
DBA	1	59.467	0	0 - 226.64
BghiP	0.01	812.849	679.085	12.41 – 2,992.15
$\sum_{16}$PAHs	—	5,301.21	3,258.29	85.22 – 21,351.03

154 As shown in Table 2, the concentration of $\sum_{16}$PAHs ranged from 85.22 - 21,351.03 ng g^{-1}, with a
155 mean concentration of 5301.21 ng g^{-1} and a median concentration of 3,258.29 ng g^{-1}; of these, InP
156 had the highest concentration, with a mean concentration of 943.59 ng g^{-1}, followed by BghiP and
157 BaP; Ant had the lowest concentration with an average of 38.79 ng g^{-1}, while Ace and DBA also had
158 relatively low concentrations, detected in only 3 sampling sites. The minimum concentrations of the
159 2-ring PAHs (Nap, Acy, Ace, Flu) were all 0. This may be due to the fact that most of the 2-ring

PAHs are mainly present in the gas-phase and are volatile, and therefore their content in the particles may be below the detection limit.

Combined with Figure 2 we can clearly see the degree of contamination at each sampling point: L4>L1>L3>L10>L7>L9>L5>L8>L2>L6. It can be seen that the most serious pollution in the urban area of Anqing is Daguan District, Daguan District, there are Sinopec Anqing Petrochemical Company, Anqing Changhong Chemical Co., Ltd, Anqing Yicheng Chemical Technology Co., Ltd, Anqing Jingyi Fine Chemical Co., Ltd, and other chemical enterprises, and these chemical enterprises are very likely to be an important reason for the more serious pollution of PAHs in this area.

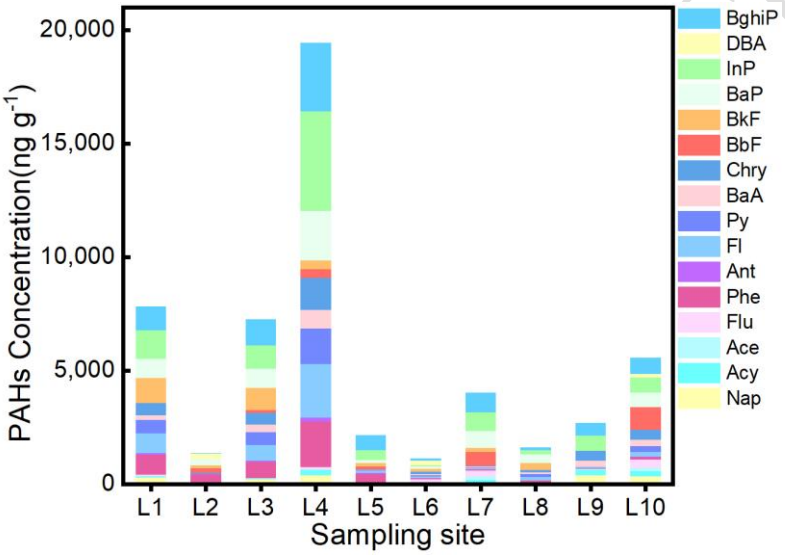


Figure 2. Distribution of PAHs in dust samples from different areas of Anqing city

Compared with other cities and countries, the levels of PAHs in atmospheric dust deposition in Anqing were significantly lower than those in Tianjin (average concentration of 7,990 ng g^{-1})(Yu et al., 2014), Canada (average concentration of 24,700 ng g^{-1})(Gill et al., 2020), Laiwu (average concentration of 10,892 ng g^{-1})(Wei et al., 2021), and Shenzhen (average concentration of 29,920 ng g^{-1})(Liu et al., 2016). The difference with Hubei Province (average concentration of 4,430 ng g^{-1}) is small(Zhang et al., 2016). It is not difficult to see that the average level of PAHs in atmospheric dust deposition in Anqing is lower than that in some large cities in China, which may be due to the high population density, motor vehicle emissions and fossil energy demand in large cities, and thus the

PAHs content in dust in large cities is much higher than that in small and medium-sized cities like Anqing.

Although this study's sample size is sufficient for a preliminary spatial assessment, it may limit the statistical robustness and spatial representativeness of the findings, particularly in heterogeneous urban environments. This limitation has been identified as a constraint of the study, and caution should be exercised when interpreting the results in relation to city-wide extrapolation. It should be noted that this study did not account for seasonal variations or meteorological influences, which may affect the deposition patterns and source contributions of PAHs. Future research should incorporate multi-seasonal sampling and atmospheric dispersion modelling to improve temporal representativeness.

3.2. Source analysis of PAHs in dust

3.2.1. Comparison of ring numbers of PAHs in dust

The distribution of PAHs with different ring numbers in the 10 dust samples collected in this experiment is shown in Figure 3, and the PAHs in the studied area are mainly 5-ring and 4-ring, followed by 3-ring. The other 16 PAHs can be divided into three groups according to their ring numbers: low molecular weight (2-3 ring, LMW), middle molecular weight (4 ring, MMW) and high molecular weight (5-6 rings, HMW) to discriminate their different sources of contamination. In general, LMW PAHs primarily originate from crude oil contamination and the combustion of materials such as wood and coal at temperatures below moderate levels(Zhang et al., 2020). MWM PAHs mainly stem from fuel combustion, while HWM PAHs primarily result from the high-temperature combustion of fossil fuels. The proportion of LMW PAHs in the dust samples in the studied area ranged from 11.30 - 32.95%, with a mean value of 20.32%, the proportion of MMW PAHs ranged from 3.43 - 31.59%, with a mean value of 20.78%, and the proportion of HMW PAHs ranged from 44.83 - 79.42%, with a mean value of 58.90%. This indicates that PAHs in atmospheric dust deposition in Anqing City primarily originate from high-temperature combustion processes, such as coal combustion and motor vehicle exhaust emissions.

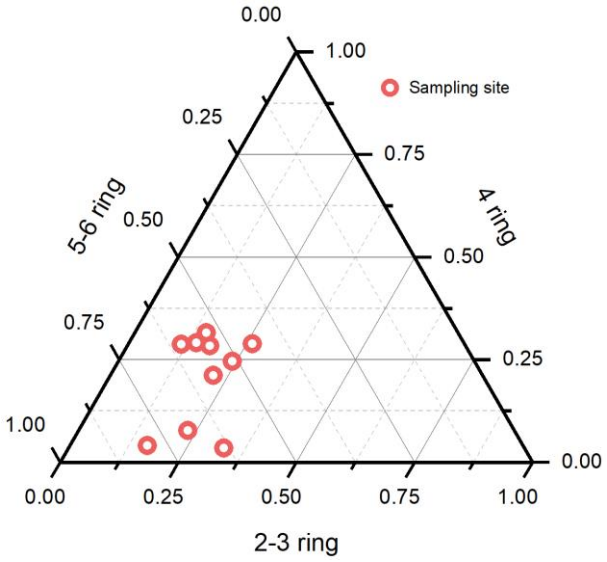


Figure 3. Ternary plot showing comparative contribution of 2–3 ring, 4 ring and 5–6 ring PAHs in samples

3.2.2. Characteristic ratio method of PAHs in dust

In order to gain a more detailed understanding of the emission origins of PAHs in atmospheric dust deposition, a diagnostic comparison of PAHs was performed, the results of which are shown in Figure 4(Li et al., 2017). The majority of the samples exhibited Fl/(Fl + Py) ratios greater than 0.5, suggesting a mixture of fuel combustion sources(Han et al., 2021). The ratios of BaA/(BaA + Chry) and InP/(InP + BghiP) both exceeded 0.2, indicating that the primary origins of PAHs in atmospheric dust deposition were emissions from coal, wood, fuel combustion, and vehicular exhaust(Wang et al., 2022). The predominance of PAHs at most road atmospheric samples, as indicated by ratios of Phe/(Phe + Ant) > 0.7, was attributed to fossil fuel combustion(Zhang et al., 2024).

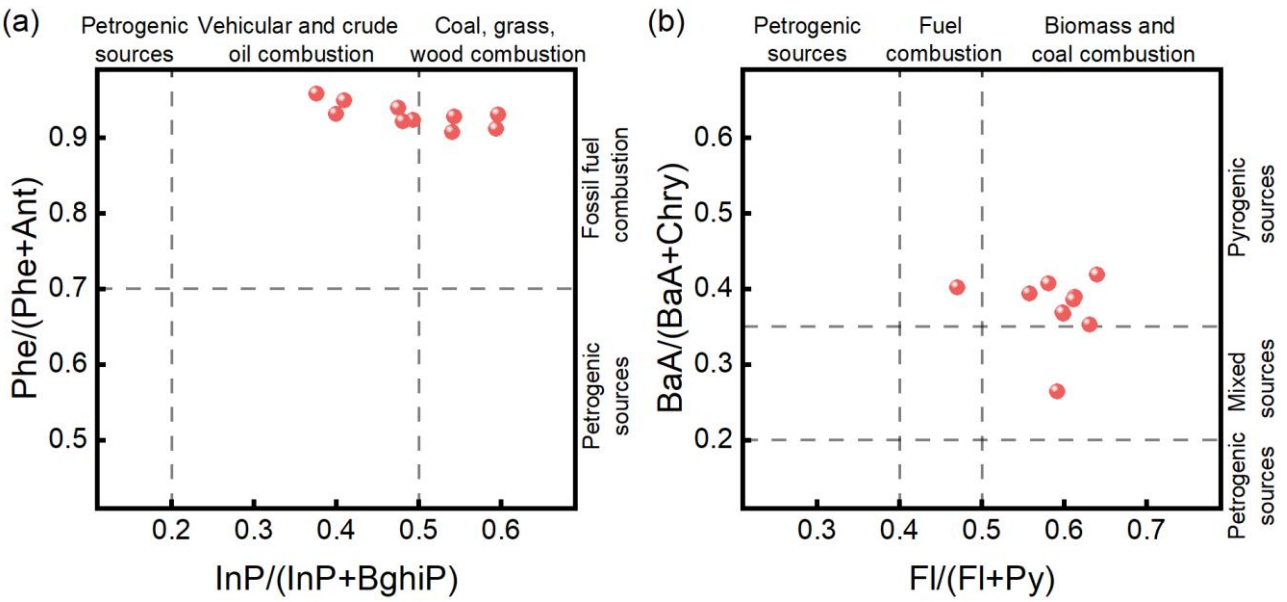


Figure 4. Characteristic ratios of PAHs in dust in different areas of Anqing City

In summary, the PAHs in atmospheric dust deposition in Anqing City primarily originate from a combination of pollution sources, including fossil fuel combustion, coal combustion, and motor vehicle emissions. The pollution source structure was similar across all sampling sites, with no significant spatial variation observed.

3.2.3. PMF of PAHs in dust

To identify the primary sources of PAHs in atmospheric dust deposition, this study employed a positive matrix factorization model for source apportionment of 16 PAHs. Based on model goodness-of-fit and factor independence, three factors were ultimately determined as the optimal solution. The loadings of PAHs across each factor and their contributions to total concentration are shown in Figure 5.

Factor 1 explained 30.66% of the total PAH concentration, primarily contributed by high-molecular-weight PAHs such as BkF (81.65%), BaP (46.77%), and InP (21.77%). These compounds are typically associated with high-temperature combustion processes, particularly coal combustion and industrial high-temperature operations(Wang et al., 2025). Additionally, medium-ring PAHs like Phe, Fla, and Pyr constitute a significant proportion within this factor, further supporting its combustion-derived characteristics. Thus, factor 1 is identified as originating from coal and industrial combustion sources.

Factor 2 contributed 15.49% of the total concentration, primarily loaded onto low-ring PAHs such as Acy (75.75%), Ace (86.07%), and BaA (40.11%). These compounds are frequently associated with incomplete combustion of biomass or volatilization of petroleum substances(Guo et al., 2025a). Notably, Acy and Ace are widely recognized as tracers of biomass combustion. Therefore, factor 2 is classified as a biomass and petroleum volatiles source.

Factor 3 is the largest contributing source, accounting for 53.85% of total PAH concentration. It primarily includes medium-to-low ring PAHs such as Flu (100%), Phe (65.20%), Fl (71.84%), and Py (71.94%). These compounds are commonly found in transportation emissions, particularly gasoline vehicle exhaust(Ma et al., 2025). Additionally, InP and BghiP constitute a significant proportion within this factor, further supporting its association with motor vehicle emissions. Consequently, factor 3 is identified as a transportation emission source.

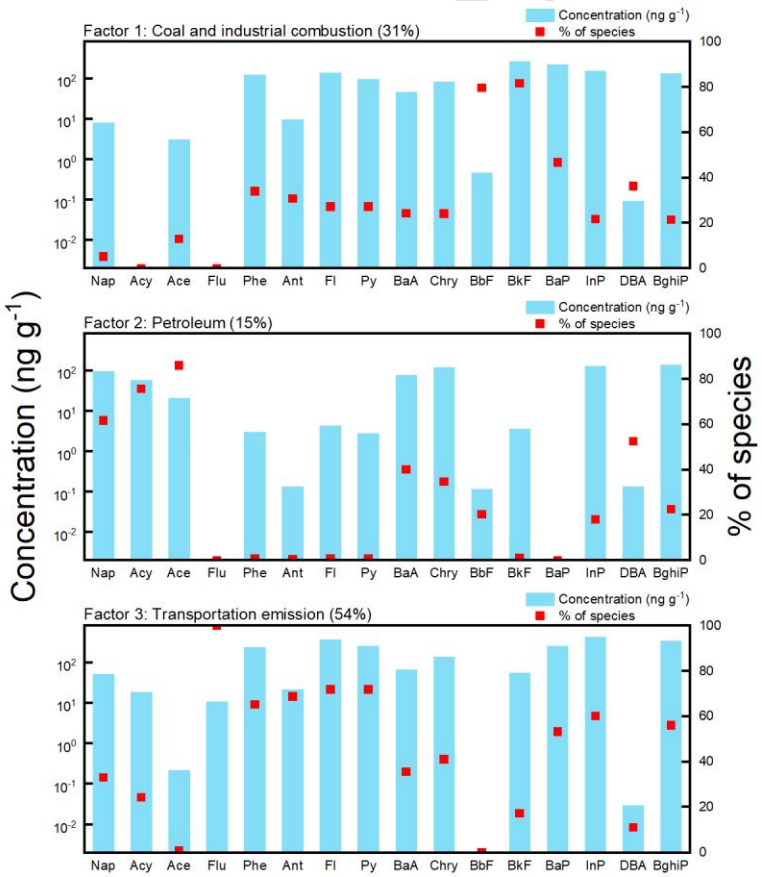


Figure 5. Analysis of sources of PAHs based on PMF

The contribution order of the three sources to total PAHs was: traffic emissions (53.85%) > coal and industrial combustion (30.66%) > biomass and petroleum volatiles (15.49%). Coal and industrial

combustion contributed more than in Shanghai (14.7 %)(Feng et al., 2022) but less than in Anshan (32.6 %)(Wang et al., 2020). This source profile aligns with Anqing's status as an industrial city with growing vehicular activity. Comparing with other Chinese cities, the contribution of traffic sources here (53.85%) is higher than in some heavily industrial cities where coal combustion dominates, highlighting the need for targeted vehicular emission controls alongside industrial regulations.

3.3. Health risk assessment of PAHs

This study employed Monte Carlo simulations to assess the ILCR of PAHs in atmospheric dust deposition for adults and children(Bharali et al., 2025). Overall, dermal contact and oral ingestion represent the predominant exposure pathways, while inhalation risks are negligible.

As shown in the ILCR probability distribution in Figure 6, both adults and children exhibit significantly right-skewed risk distributions for skin contact and oral ingestion, with pronounced high-risk "tails." Notably, in the skin contact pathway, the rightmost tail of the distribution curve approaches or even exceeds 1×10^{-4}, indicating that skin contact may pose unacceptable carcinogenic risks under extreme exposure scenarios(Sun et al., 2025).

Although the median and mean ILCR values for skin contact are below 10^{-4}, the high-end quantiles (e.g., 95th percentile or higher) suggest that for a portion of highly exposed individuals (approximately 5% or less), the carcinogenic risk via this route may have reached levels warranting intervention. This finding aligns with the high contribution of the AF in sensitivity analyses, indicating that individual behavioral variations and uncertainties in exposure levels are key drivers of the high-risk tail.

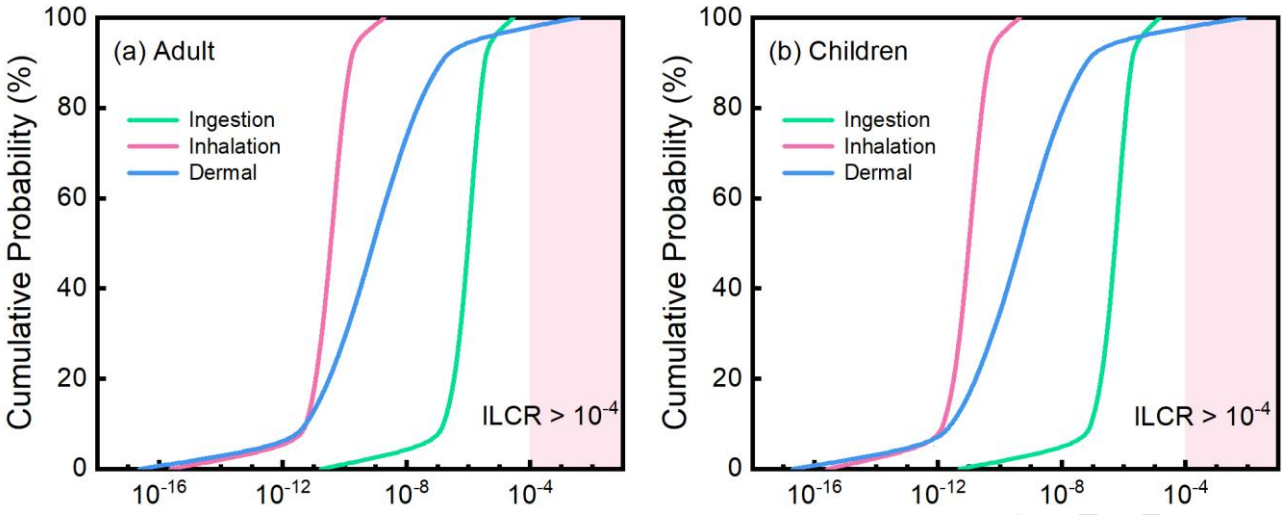


Figure 6. Probability distribution for carcinogenic risks of PAHs for (a) adults and (b) children

As shown in Figure 7, ED and BaP equivalent toxicity concentration (CS) are the most sensitive parameters across all exposure pathways. For the dermal exposure pathway, the AF is also a critical influencing factor(Khalili et al., 2021). This indicates that, in addition to controlling the toxic equivalent concentration of dust, reducing the frequency of skin contact with dust and the amount of dust adhering to the skin—particularly through protective measures in high-risk environments such as frequent ground activities and cleaning operations—is especially crucial for controlling the high tail risk associated with the dermal pathway.

In summary, although the average carcinogenic risk from PAHs in indoor dust is generally manageable, skin contact exposure under extreme conditions may pose unacceptable health risks (ILCR > 10^{-4}). This finding underscores that risk assessment and management should prioritize high-risk populations and extreme exposure scenarios, beyond merely monitoring average risk levels. This underscores that, in addition to reducing environmental PAHs concentrations, behavioral and exposure mitigation measures—such as improved hygiene practices, use of protective gear for outdoor workers, and reducing children's direct contact with dust—are crucial for managing population risk, especially for vulnerable subgroups.

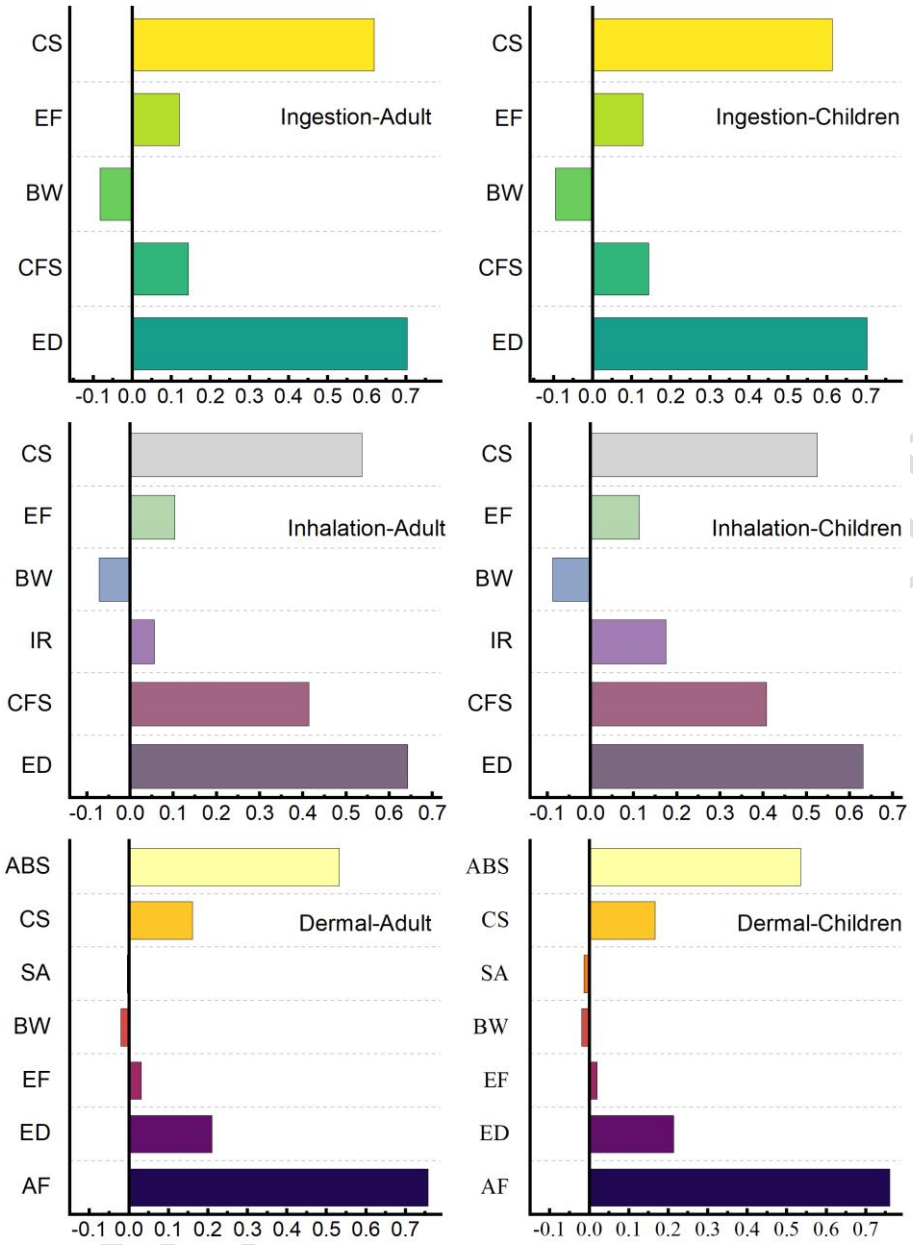


Figure 7. Sensitivity analysis of ILCR for PAHs

4. Conclusions

This study systematically examined the pollution levels, composition profiles, sources, and health risks of 16 priority PAHs in atmospheric dust deposition across different functional zones in Anqing City, China. The concentration range of Σ_{16}PAHs in atmospheric dust in Anqing City was relatively wide (85.22 – 21,351.03 ng g^{-1}), with an average concentration of 5,301.21 ng g^{-1}, indicating a pollution level in the lower-middle range nationally. Spatial distribution revealed significantly higher concentrations in industrial clusters like Daguan District (L1, L3, L4) compared to other areas, indicating local industrial emissions as a major point source of PAHs. Composition analysis showed

high-ring (5–6 ring) PAHs dominated (average 58.90%), revealing that PAHs in the study area primarily originate from high-temperature combustion processes. Comprehensive source apportionment using ring number distribution, characteristic ratio method, and PMF models yielded mutually corroborating results, confirming that Anqing's PAH pollution stems from a hybrid contamination pattern involving fossil fuel combustion and industrial activities. Probabilistic health risk assessment was conducted using a Monte Carlo simulation-based ILCR model. Results indicate that for the general population of Anqing City, the overall carcinogenic risk from PAH exposure via particulate matter deposition is at an acceptable level. Skin contact is the primary exposure pathway, with its high-risk tail (e.g., 95th percentile) approaching or reaching 10^{-4}, warranting attention. Children's total risk is slightly higher than adults', which is associated with their behavioral patterns (frequent hand-to-mouth contact).

5. Environmental implications

The findings underscore that in industrial cities like Anqing, control strategies must adopt a multi-target approach. Prioritizing traffic emission reductions (e.g., upgrading vehicle fleets, promoting EVs) is essential, given its dominant contribution. Simultaneously, stringent controls on industrial and coal combustion emissions are needed, especially in identified hotspot areas like Daguan District. Public health measures should focus on reducing dermal exposure for high-risk groups (children, outdoor workers). This study establishes a critical baseline and a methodological framework (integrating PMF and probabilistic risk assessment) that can be applied to other industrial cities for evidence-based environmental management.

Acknowledgements

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Conflict of Interest

The authors declare no conflict of interest.

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