Supplementary Information for

Toxic Dust Emission from Drought-Exposed Lakebeds – A New Air Pollution Threat from Dried Lakes

Qianqian Gao[#], Guochao Chen[#], Xiaohui Lu, Jianmin Chen, Hongliang Zhang* and Xiaofei Wang*

Corresponding author: xiaofeiwang@fudan.edu.cn; zhanghl@fudan.edu.cn

4 Texts

9 Tables

15 Figures

Texture S1. PAH Standards

A PAH standard mixture, referred to as PAH-Mix 16, encompasses 16 target analytes: phenanthrene (PHE), anthracene (ANA), fluoranthene (FLA), pyrene (PYR), benzo[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), dibenzo[a,h]anthracene (DBA), indeno[1,2,3-cd]pyrene (IDP), and benzo[g,h,i]perylene (BPE) dissolved in dichloromethane (1000 μg/mL). Additionally, five internal standards including D8-naphthalene, D10-acenaphthene, D10-phenanthrene, D12-chrysene, and D12-perylene in dichloromethane (1000 μg/mL) were provided by TanMo Quality Testing Technology Co., Ltd. All standards were verified with a purity of over 98%. Working solutions were prepared at concentrations of 1, 2, 5, 10, 20, 25, 50, 100, 200 and 500 ng/mL ng/mL in isooctane and stored at -10°C in a refrigerator. Each calibration level contained relevant internal standards at 100 ng/mL.

Texture S2. Temperature programmed method of PAHs

The GC-MS oven temperature was programmed as follows: starting at an initial temperature of 40 °C, held for 4 min, then increased to 160 °C at a rate of 10 °C/min and held for 1 min, followed by a ramp to 280 °C at 10 °C/min, where it was held for 4 min. Finally, the temperature was raised to 300 °C at 10 °C /min and maintained for 10 min. The total analysis duration was 45 min. Sample injections were carried out in splitless mode, using helium as the carrier gas at a constant flow rate of 1 mL/min. Five internal standards were spiked into each sample before analysis. The retention times for the PAHs were established after identifying each compound in scan mode.

Text S3. All statistics equations related to the model validation are shown below:

$$\mathbf{MB} = \frac{1}{N}\sum_{i=1}^{N}(C_m - C_o)$$

$$\mathbf{GE} = \frac{1}{N}\sum_{i=1}^{N}|C_m - C_o|$$

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(C_m - C_o)^2}{N}}$$

$$\mathbf{MFB} = \frac{1}{N}\sum_{i=1}^{N}\frac{(C_m - C_o)}{\left(\frac{C_o + C_m}{2}\right)}$$

$$\mathbf{MFE} = \frac{1}{N}\sum_{i=1}^{N}\frac{|C_m - C_o|}{\left(\frac{C_o + C_m}{2}\right)}$$

$$\mathbf{MNB} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{C_m - C_o}{C_o}\right)$$

$$\mathbf{MNE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{C_m - C_o}{C_o}\right|$$

In these equations $\boldsymbol{C_m}$ represents the model results, $\boldsymbol{C_o}$ represents the observations, and $\boldsymbol{N}$ is the number of data points, $\boldsymbol{i}$ represents a data point.

Text S4. Determination of exposure frequency in health risk assessment of Poyang Lake and Dongting Lake

To establish the parameter settings for health risk assessment formulas, this study referenced EPA reports and pertinent literature on Poyang Lake and Dongting Lake. For residents, the outdoor exposure time was defined as 8 hours per day (Ren et al., 2021; Agency), 2009). Fig. S3, Fig. S4, and Table S6 illustrate that during drought periods, the water level at Xingzi Station in Poyang Lake was defined at 7 m below, corresponding to a lake area of 600 km^2 (~4 % of the lake's area) (Fig. S3a). Based on the 15-year average from 2000 to 2014, the exposure frequency for Poyang Lake was calculated as 80 days per year. For Dongting Lake, drought conditions were defined when the lake area dropped below 700 km^2 (Fig. S3b), and timing data (Fig. S4) established an exposure frequency of 140 days per year. Additionally, the exposure duration for residents was set at 30 years, consistent with government environmental assessment guidelines (Bureau, 2009). All parameters are systematically presented in Table S7.

Table S1. The properties of different soils.

ID	Type	Color	Density (g/cm^3)	Location	Longitude	Latitude
A1	Sandy Loam	Brown	1.18826	Duchang County, Poyang Lake	116.157996 E	29.243726 N
B1	Sandy Loam	Brown	1.007	Duchang County, Poyang Lake	116.157990 E	29.243528 N
C1	Loamy Sand	Brown	1.08158	Duchang County, Poyang Lake	116.157810 E	29.242878 N
A2	Sandy Clay Loam	Yellow	0.9787	Yugan County, Poyang Lake	116.396692 E	29.053927 N
B2	Silt Clay	Black	0.92936	Yugan County, Poyang Lake	116.396182 E	29.053813 N
C2	Silt Clay Loam	Brownish Yellow	1.17544	Yugan County, Poyang Lake	116.395759 E	29.053549 N
A3	Silt Clay Loam	Brownish Yellow	1.30354	Yueyang County, Yueyang City	113.069367 E	29.338117 N
B3	Sandy Clay Loam	Brown	1.08312	Yueyang County, Yueyang City	113.064997 E	29.336263 N
C3	Silt Clay	Black	1.01874	Yueyang County, Yueyang City	113.063560 E	29.336425 N

Table S2. Mass collected in dust aerosols of $PM_{2.5}$ and PM_{10}. The unit is g.

EXP	A1	B1	C1	A2	B2	C2	A3	B3	C3
$PM_{2.5}$-1	0.0131	0.011	0.0134	0.0143	0.0118	0.0111	0.0137	0.0112	0.0123
$PM_{2.5}$-2	0.0155	0.0129	0.0151	0.0127	0.0118	0.0139	0.0131	0.0112	0.0149
$PM_{2.5}$-3	0.0163	0.0124	0.0134	0.0164	0.0145	0.0161	0.0137	0.0123	0.0129
PM_{10}-1	0.0226	0.0222	0.0214	0.0213	0.0246	0.0253	0.0229	0.0223	0.0226
PM_{10}-2	0.0288	0.0212	0.023	0.0223	0.0241	0.022	0.0225	0.0298	0.0215
PM_{10}-3	0.0227	0.0217	0.0223	0.022	0.0232	0.0276	0.0236	0.0232	0.0243

Table S3. Scenarios setting.

	description
CASE_unexposed	**2022 Meteorology with ordinary lake**
CASE_exposed	**2022 Meteorology with the exposed lakebed**

Table S4. The sixteen priority PAHs identified by the U.S. EPA, along with their abbreviations and toxic equivalency factors (TEFs) as derived from previous studies (Delistraty, 1997; Nisbet and Lagoy, 1992).

PAHs name	abbreviation	TEF	Quantitative ion
Naphthalene	NAP	0.001	128
Acenaphthylene	ANY	0.001	152
Acenaphthene	ANA	0.001	154
Fluorene	FLU	0.001	166
Phenanthrene	PHE	0.001	178
Anthracene	ANT	0.01	178
Fluoranthene	FLT	0.001	202
Pyrene	PYR	0.001	202
Benz[a]anthracene	BaA	0.1	228
Chrysene	CHR	0.01	228
Benzo(b)fluoranthene	BbF	0.1	252
Benzo(k)fluoranthene	BkF	0.1	252
Benzo(a)pyrene	BaP	1	252
Indeno[1,2,3-cd] pyrene	IPY	0.1	278
Dibenz[a,h]anthracene	DBA	1	276
Benzo[ghi]perylene	BPE	0.01	276

Table S5. Twelve selected toxic metals, along with TEFs, were estimated obtained from the U.S. EPA website (EPA).

Heavy metals	TEF
Fe	
Mg	
Mn	
Ba	
Ti	
V	
Cu	
Zn	
Cr	1
Ni	3.1×10^{-3}
As	5.12×10^{-2}
Pb	1.43×10^{-4}

Table S6. The drought duration in recent years according to water level records from Xingzi station of Poyang Lake (Qi et al., 2019).

	Drought duration/d					
Year	<5.5 m	5.5~6 m	6~7 m	7~8 m	8~9 m	9~10 m
2003	0	1	31	54	83	118
2004	31	61	83	118	175	190
2005	0	0	34	71	95	152
2006	0	6	83	139	184	229
2007	20	61	100	145	195	222
2008	9	42	86	109	127	159
2009	0	55	123	141	167	188
2010	0	13	57	88	122	142
2011	0	0	70	181	239	264
2012	0	9	19	59	104	134
2013	3	16	69	122	148	188
2014	4	52	69	90	144	169
1951-1999 average	3.4	12.7	42.7	73.5	100	126.4
2000-2014 average	4.5	18.9	56.6	97.8	136	169.5

Table S7. Summary of key parameter values used in assessing health risks from inhalation exposure to heavy metals in PM_{10}.

Parameter	Definition	Unit	Value	Reference
ET	Exposure time	hours×day^{-1}	8	USEPA, 2009(Agency), 2009)
EF	Exposure frequency	days×year^{-1}	140 for Dongting Lake; 80 for Poyang Lake	These studies(Qi et al., 2019; Huang et al., 2012)
ED	Exposure duration	year	30	USEPA, 2009(Agency), 2009)
AT	Averaging time	hour	ED×365×24 (for non-carcinogenic risk)	USEPA, 2009(Agency), 2009)
			70×365×24 (for carcinogenic risk)	
RfC	Reference concentration	μg×m^{-3}	Cr (VI)*: 1.0×10^{-7}	USEPA, 2020(Agency), 2020)
			Mn: 5.0×10^{-8} Co: 6.0×10^{-9} Ni: 1.4×10^{-8} As: 1.5×10^{-8} Cd: 1.0×10^{-8} Ba: 5.0×10^{-7} V: 1.0×10^{-7} BaPeq: 2.0×10^{-3}	
IUR	Inhalation unit risk	(μg×m^{-3})$^{-1}$	Cr (VI)*: 8.4×10^{-2}	USEPA, 2020(Agency), 2020)
			Co: 9.0×10^{-3} Mn: 0 Ba: 0 V: 0 Ni: 2.4×10^{-4} As: 4.3×10^{-3} Cd: 1.8×10^{-3} Pb: 8.0×10^{-5}	
			BaP_{eq}: 8.0×10^{-2}	WHO(Organization, 2000)
AV	Acute dose-response Value	μg×m^{-3}	Cr (III)**: 0.48 Mn: 0.17	OEHHA(Monserrat, 2016)

	Ni: 0.2
	As: 0.2
	V: 30
	Cu: 100

Note:

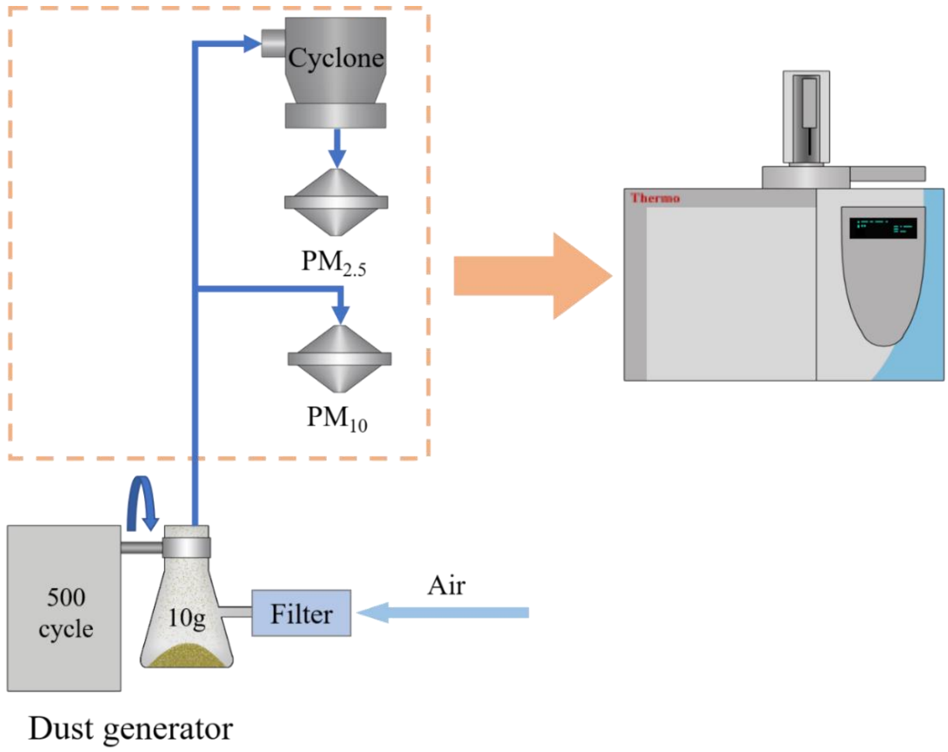
— Only the total Cr content was determined in this study. Given that the ratio of Cr (VI) to Cr (III) in the atmosphere has been reported as approximately 1:6 (Wu et al., 2020; Ramírez et al., 2020; Liu et al., 2018; Huang et al., 2018), the Cr (VI) content was estimated to be one-seventh of the total Cr content for the purpose of assessing chronic non-carcinogenic and carcinogenic risks. And Cr (III) content was estimated to be six-seventh of the total Cr content for assessing short-term non-carcinogenic risks.

Table S8. Meteorology performance in 2022 October (OBS is mean observation; PRE is mean prediction; MB is mean bias; GE is gross error; RMSE is root mean square error). The benchmarks are suggested by Emery et al. (2001)). The values that do not meet the criteria are denoted in bold. The related equations are shown in Text S3.

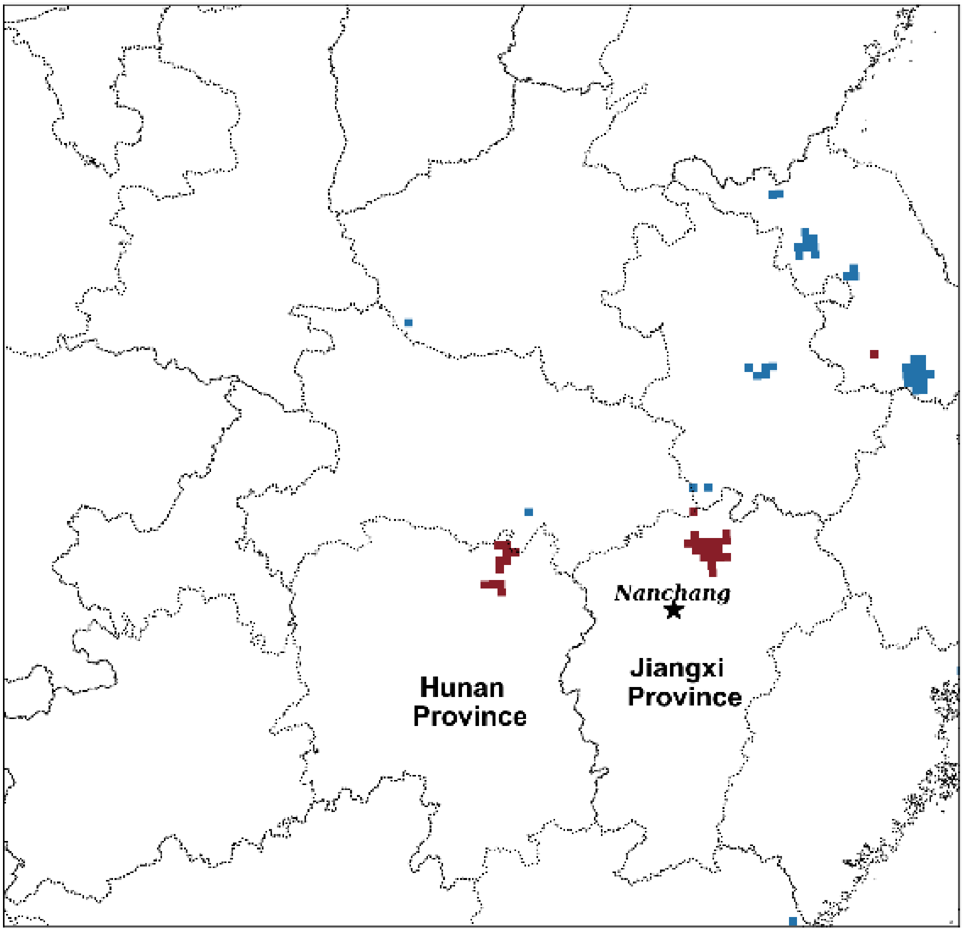
		CASE_unexposed (12km)	**CASE-exposed (12km)**	**Criteria**
T2 (K)	**OBS**	290.2	290.2	
	PRE	290.3	290.3	
	MB	0.05	0.04	≤ ±0.5
	GE	**2.11**	**2.11**	≤ 2.0
	RMSE	2.82	2.82	
WS (m s^{-1})	**OBS**	3.21	3.21	
	PRE	4.22	4.23	
	MB	**1.01**	**1.02**	≤ ±0.5
	GE	1.60	1.61	≤ 2.0
	RMSE	**2.09**	**2.10**	≤ 2.0
WD (°)	**OBS**	134.3	134.3	
	PRE	113.6	113.7	
	MB	-7.39	-7.34	≤ ±10
	GE	**37.49**	**37.42**	≤ 30
	RMSE	53.78	53.64	
RH (%)	**OBS**	66.7	66.7	
	PRE	57.9	57.8	
	MB	-8.83	-8.92	
	GE	13.82	13.85	
	RMSE	18.37	18.40	

Table S9. Model performance on $PM_{2.5}$ and PM_{10} in 2022 October. (MNB is mean normalized bias; MNE is mean normalized error; MFB is mean fractional bias; MFE is mean fractional error). The performance criteria for PM are suggested by this study (Boylan and Russell, 2006).

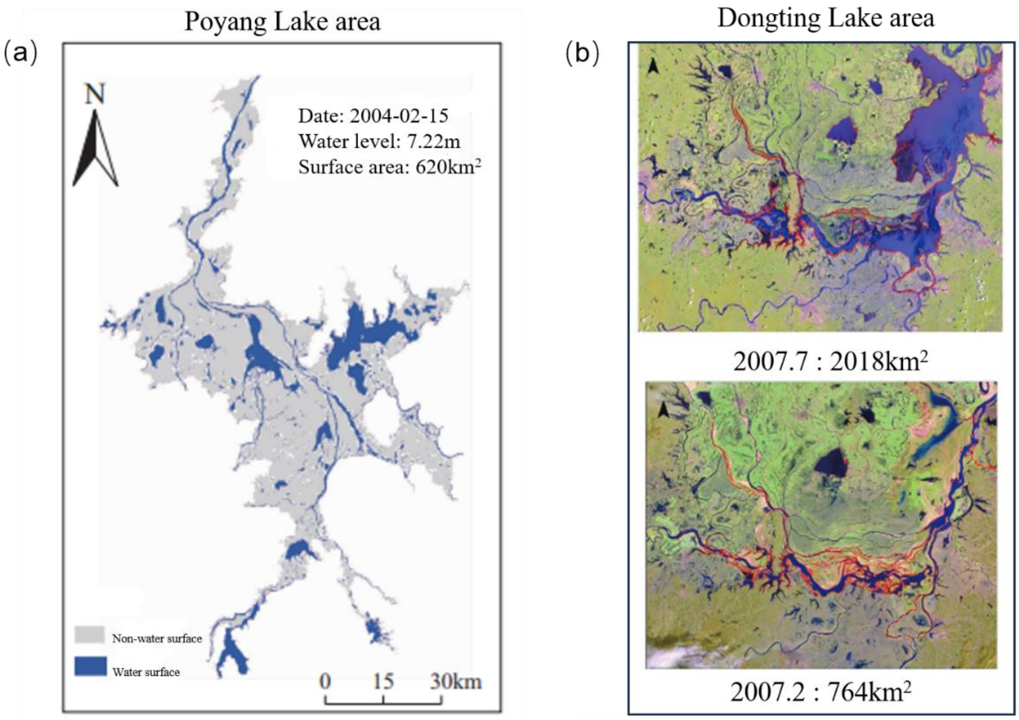
		CASE_unexposed (12 km)	CASE_exposed (12 km)	Criteria
$PM_{2.5}$	**OBS**	32.33	32.33	
(μg m^{-3})	**PRE**	42.35	42.08	
	MNB	0.60	0.60	
	MNE	1.00	1.00	
	MFB	8%	8%	≤ ±60%
	MFE	65%	65%	≤ 75%
	RMSE	38.22	37.96	
PM_{10}	**OBS**	55.28	55.28	
(μg m^{-3})	**PRE**	46.82	48.07	
	MNB	0.03	0.06	
	MNE	0.65	0.65	
	MFB	-27%	-24%	≤ ±60%
	MFE	64%	62%	≤ 75%
	RMSE	43.65	42.94	



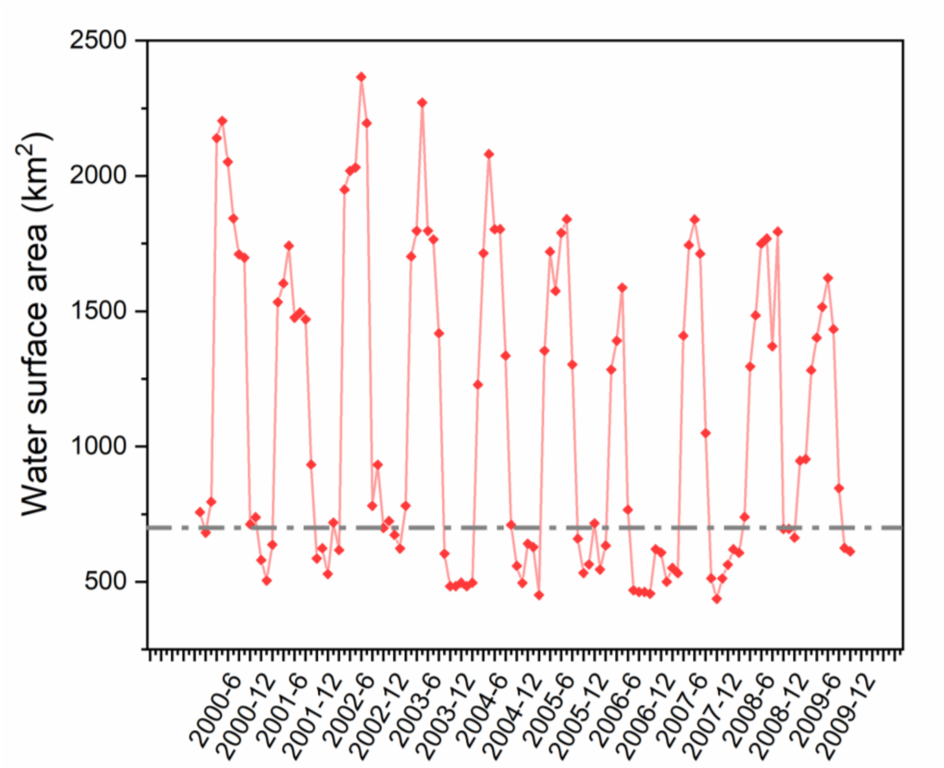
Supplementary Figure S1. Experimental setup. The setup consists of four parts: a dust generation system (Shaker), a dust particle size separation system ($PM_{2.5}$ Cyclone), a dust collection system (Filter holder), and a chemical analysis instrument (GC-MS).



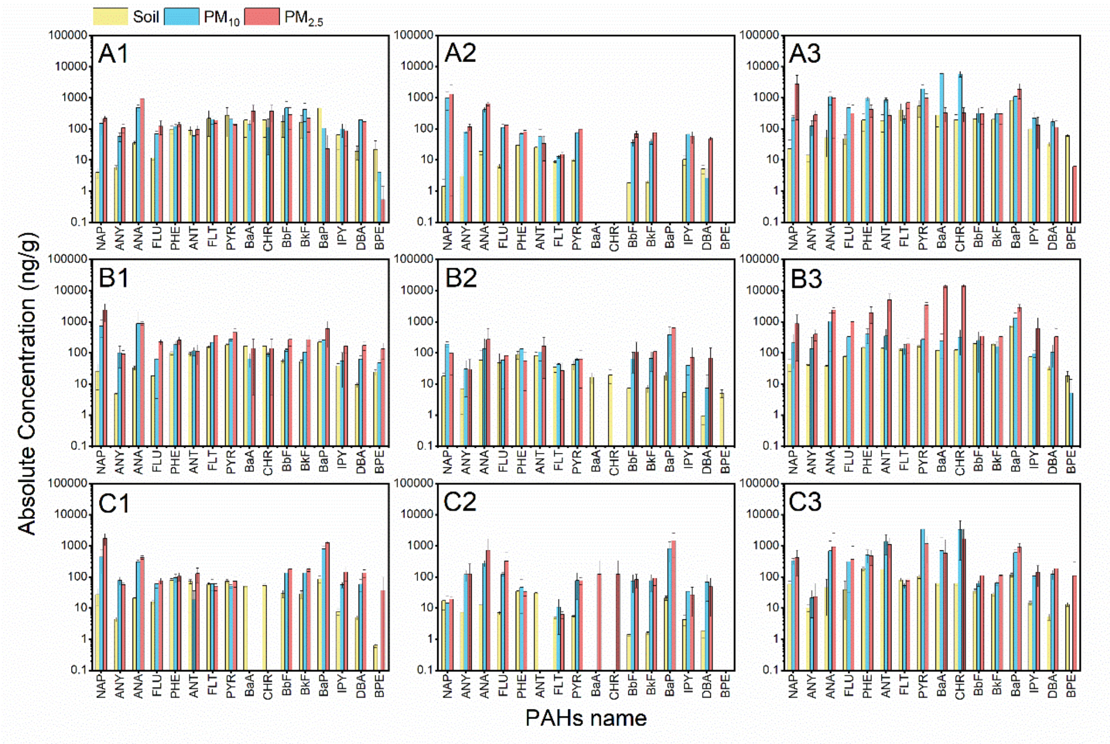
Supplementary Figure S2. Study area setting. Grid cells of blue are ordinary lakes, and those in red are the exposed lakebeds detected by sentinel-2. Nanchang near Poyang Lake is marked.



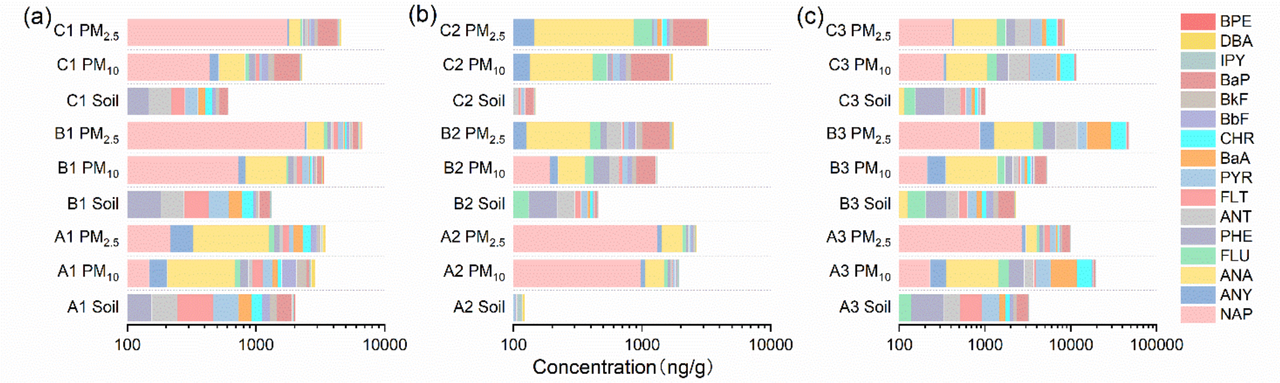
Supplementary Figure S3. Lake area of Poyang and Dongting lakes. Water surface area of Poyang Lake (a) and Dongting Lake (b) during drought periods. Date were obtained from these studies (Liu et al., 2022; Li et al., 2013).



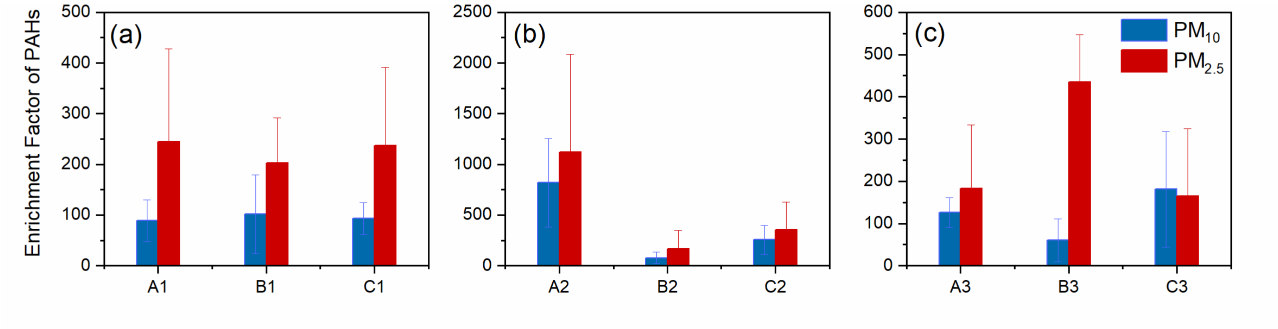
Supplementary Figure S4. Variations of water area in the Dongting Lake. Data observed by Terra/MODIS between March 2000 and December 2009. The gray dotted line at 700 km^2 indicates the drought conditions in Dongting Lake. Between 2000 and 2009, the average duration of drought conditions was 140 days per year (Huang et al., 2012).



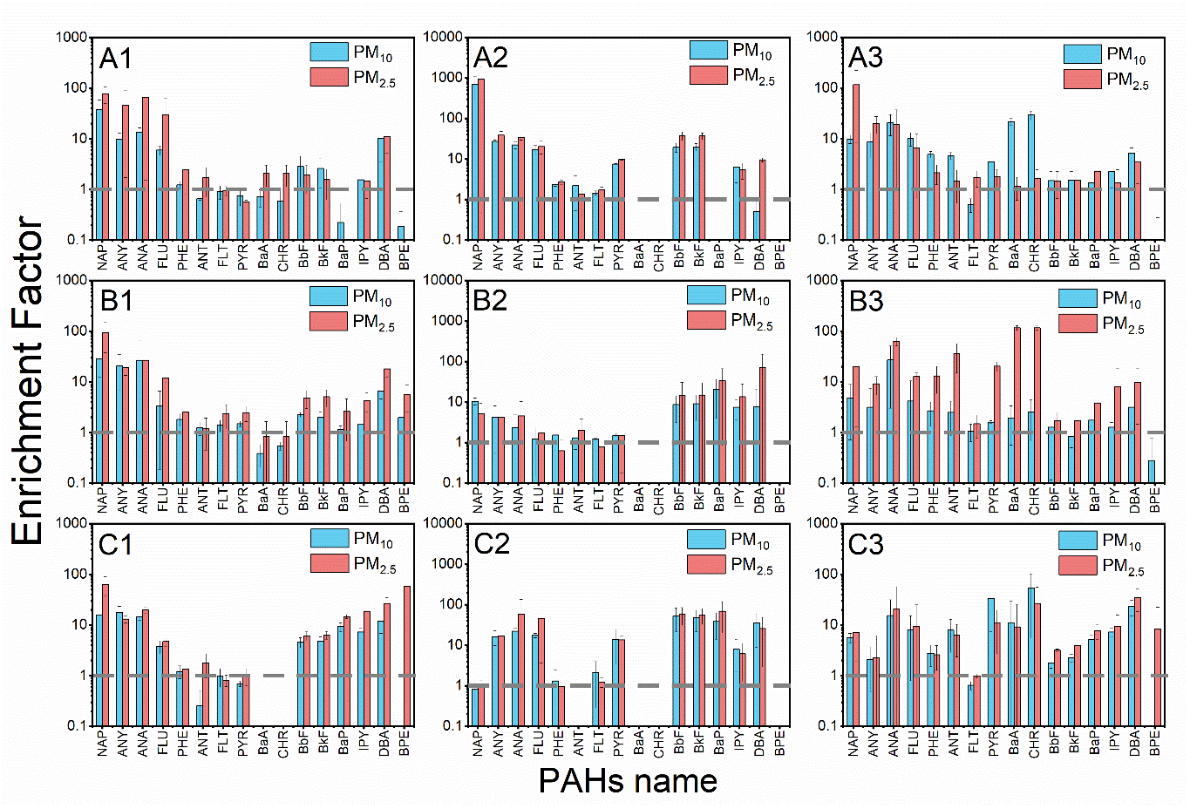
Supplementary Figure S5. Comparison of the absolute concentrations of heavy metals between natural soil samples and dust aerosols. A1, B1, C1, A2, B2 and C2 were obtained in Poyang Lake, and A3, B3 and C3 were obtained in Dong ting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.



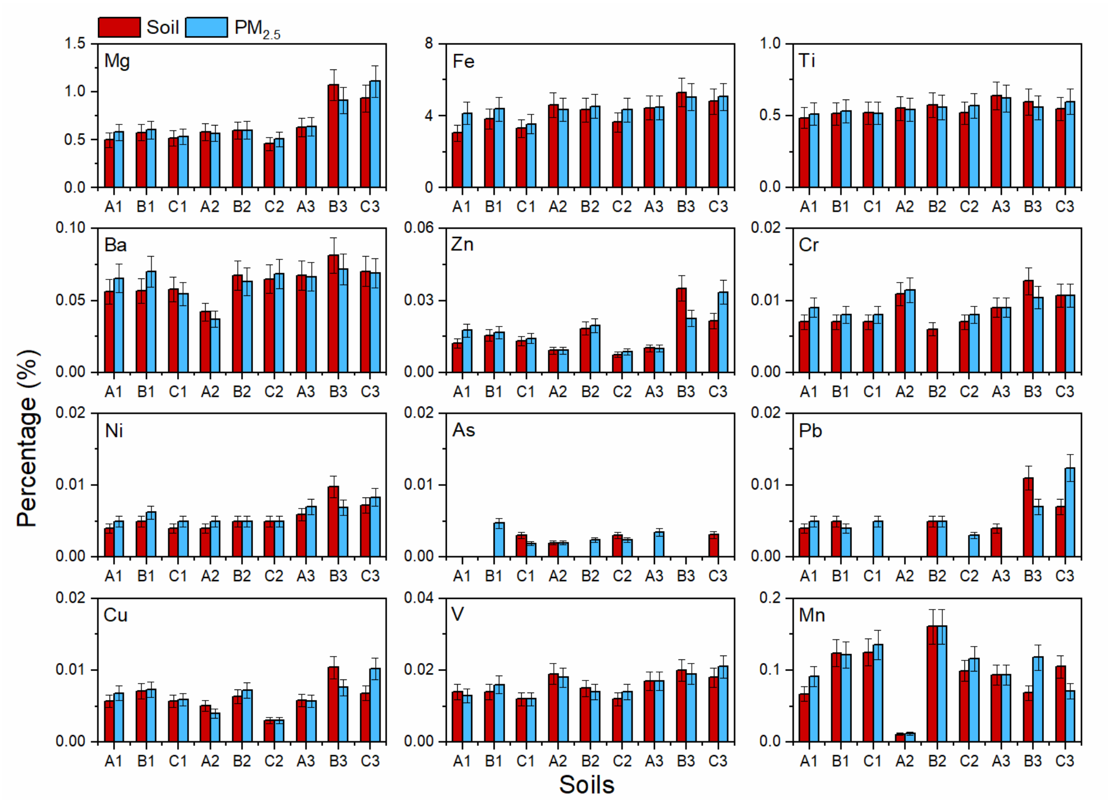
Supplementary Figure S6. Comparison of individual PAH concentrations in soil, dust-PM_{10} and dust-$PM_{2.5}$. A-B were sampled in Poyang Lake and C was sampled in Dongting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought.



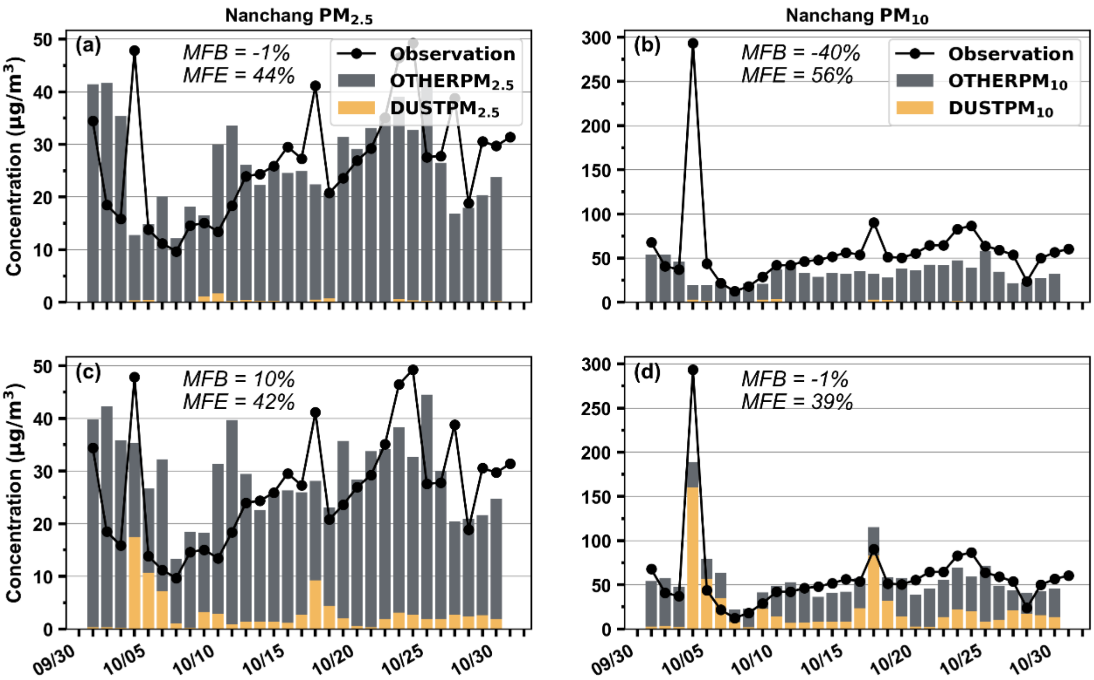
Supplementary Figure S7. Total enrichment factors of PAHs in dust aerosols from soils. A-B were sampled in Poyang Lake and C was sampled in Dongting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought.



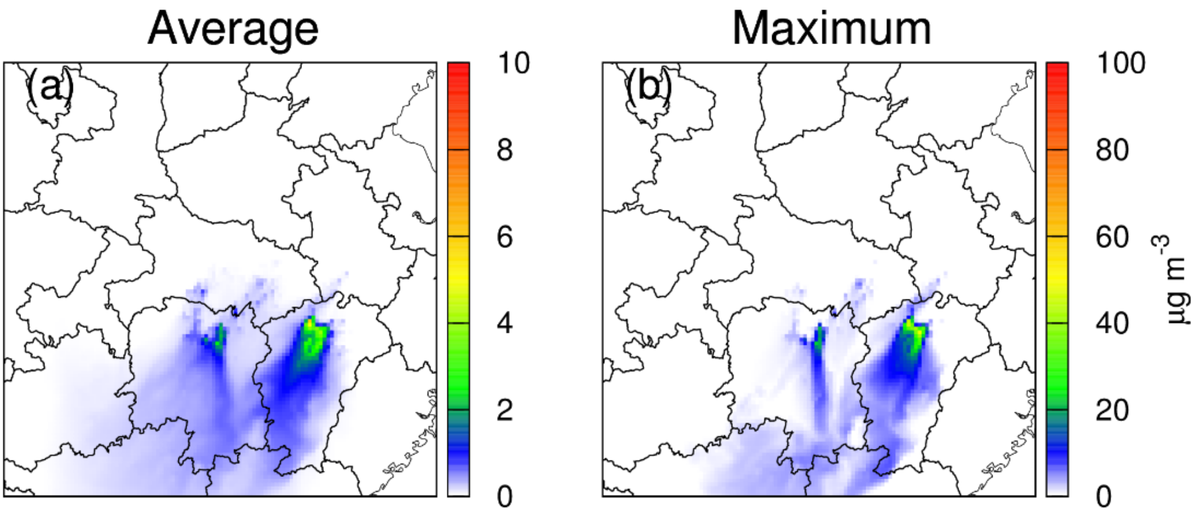
Supplementary Figure S8. Enrichment factors of individual PAH in dust aerosols from soils. Red represents $PM_{2.5}$ and blue represents PM_{10}.The grey dotted line represents the EF as 1. A1, B1, C1, A2, B2 and C2 were obtained in Poyang Lake, and A3, B3 and C3 were obtained in Dong ting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.



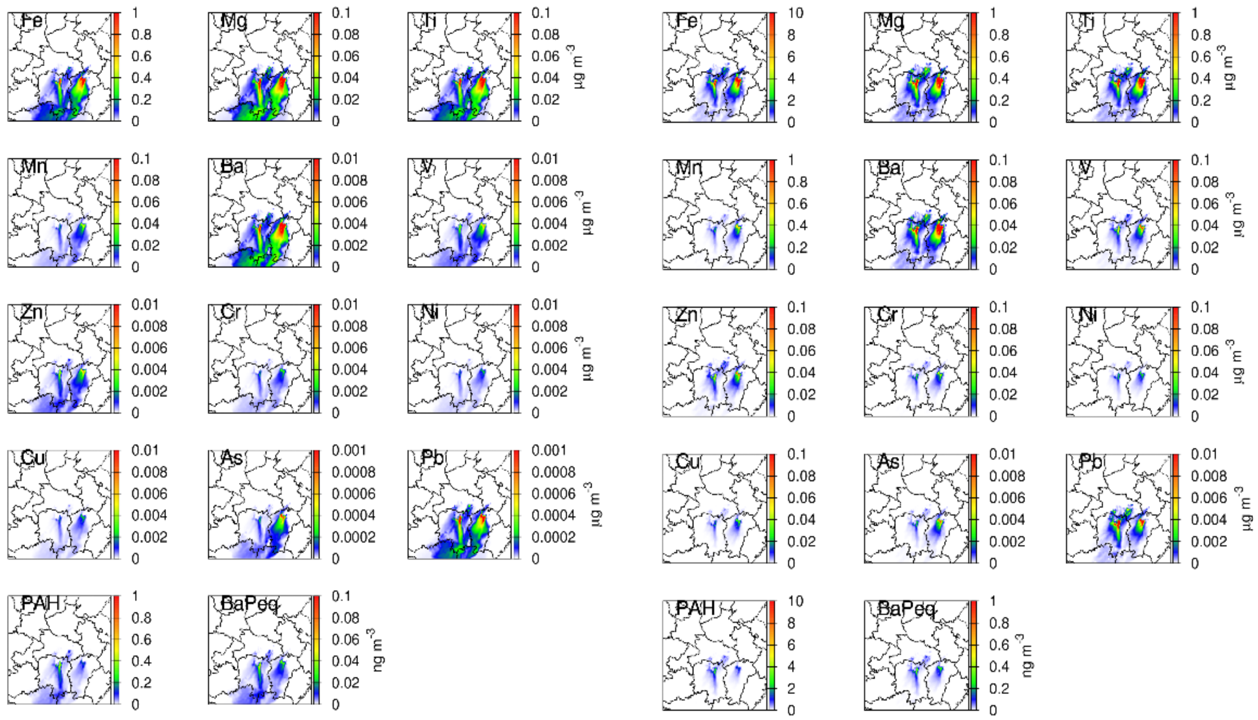
Supplementary Figure S9. Heavy metal composition of soil and $PM_{2.5}$ determined by XRF Spectroscopy. A1, B1, C1, A2, B2 and C2 were obtained in Poyang Lake, and A3, B3 and C3 were obtained in Dong ting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates. The whiskers on the bars represent the standard deviations of triplicates.



Supplementary Figure S10. Time series of PM concentrations in Nanchang. Upper panels display the CASE_unexposed (a) $PM_{2.5}$ and (b) PM_{10} concentration in Nanchang from October 1 to 30 2022. Bottom panels display the CASE_exposed (c) $PM_{2.5}$ and (d) PM_{10} concentration in Nanchang from October 1 to 30 2022. (MFB: mean fractional bias; MFE: mean fractional error).



Supplementary Figure S11. Spatial distribution of predicted monthly average and maximum daily concentrations of lakebed dust $PM_{2.5}$. Lakebed dust $PM_{2.5}$ for (a) monthly average and (b) maximum daily concentrations.

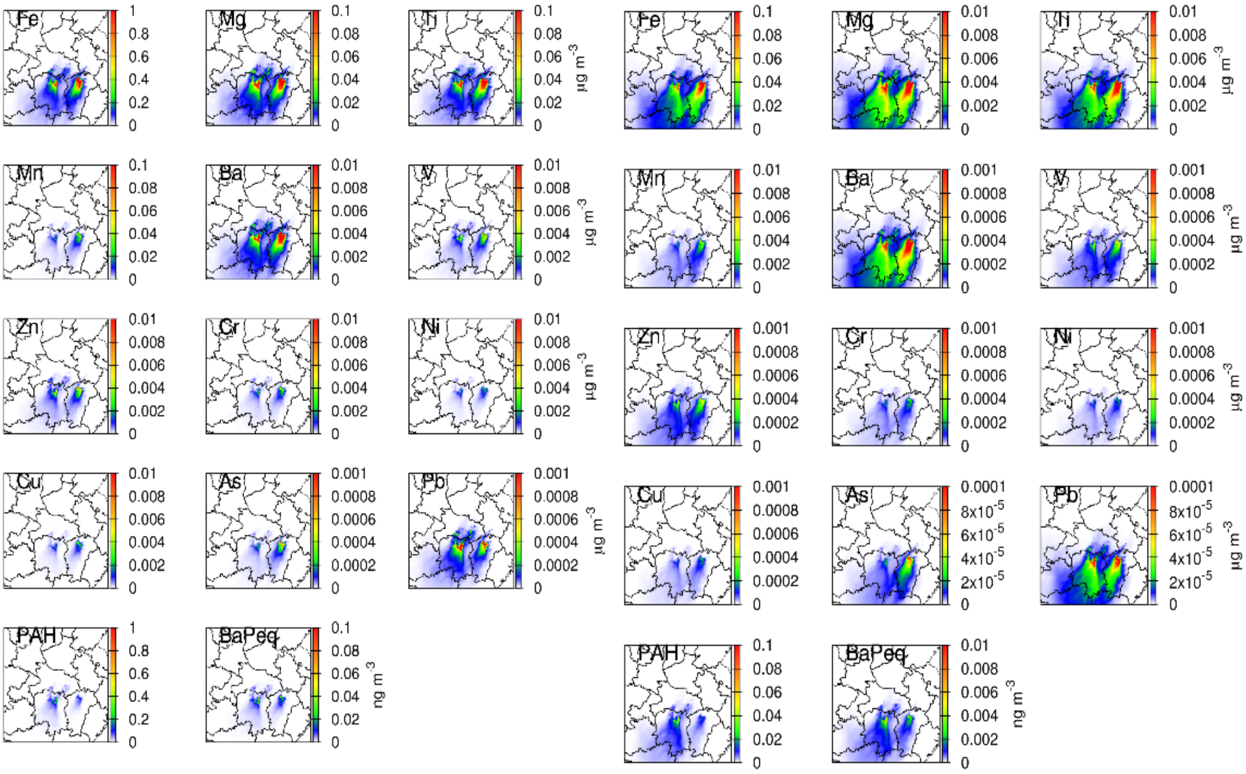


187

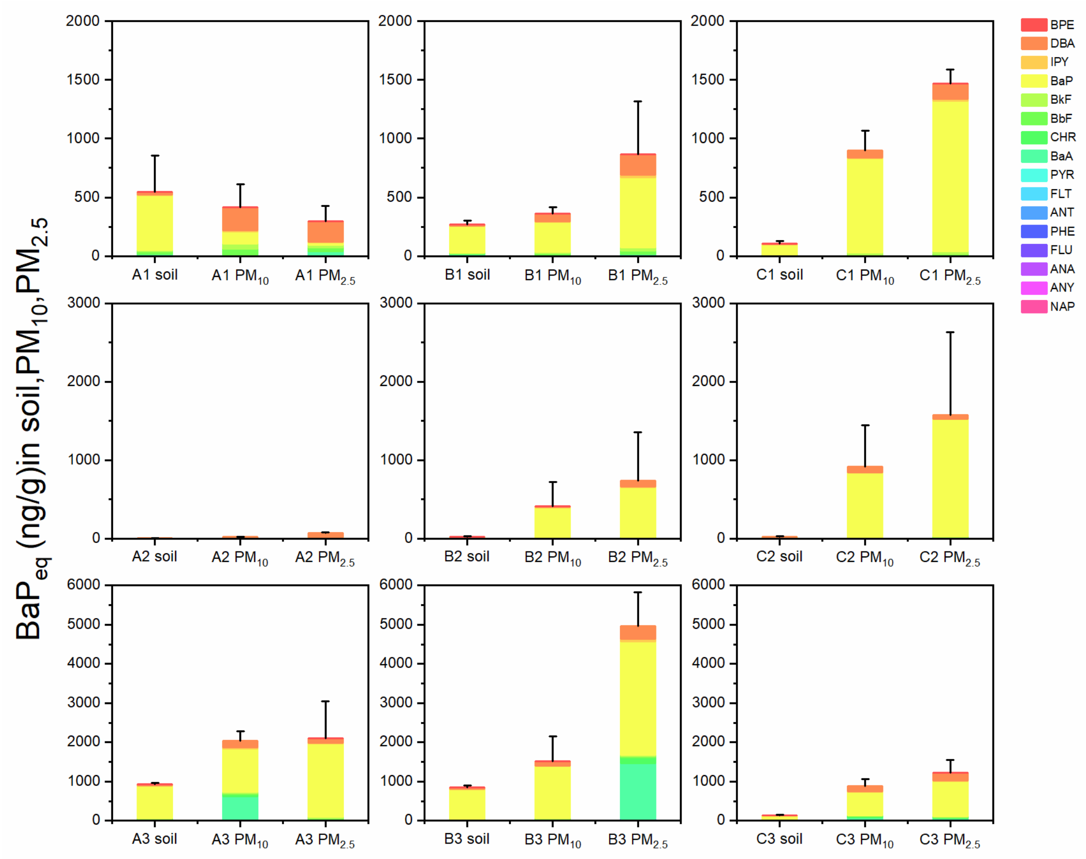
188 **Supplementary Figure S12.** Maximum daily HM and PAH concentration of lakebed dust PM.

189 Concentrations for (left) $PM_{2.5}$ and (right) PM_{10}.

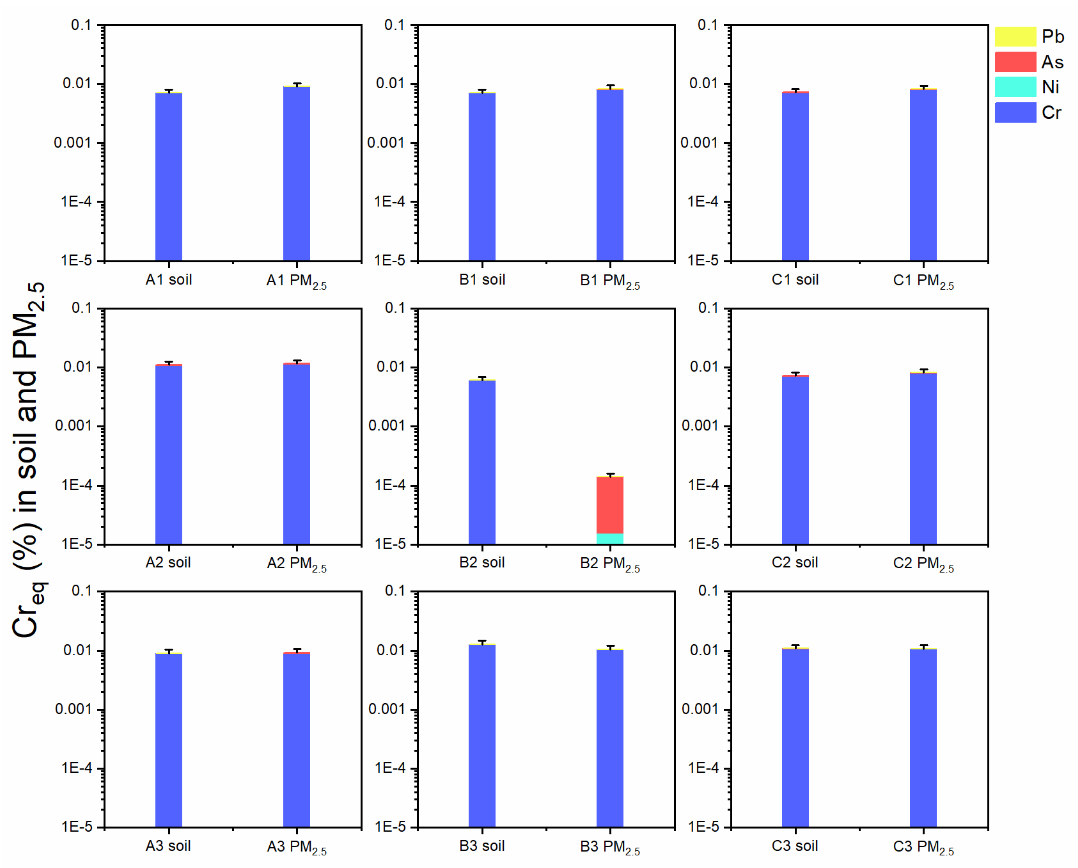
190



Supplementary Figure S13. Monthly average HM and PAH concentration of lakebed dust PM. Concentrations for (left) $PM_{2.5}$ and (right) PM_{10}.



Supplementary Figure S14. Comparison of toxic equivalent carcinogenic potency of PAHs (BaP$_{eq}$) in soil, dust-PM$_{10}$ and dust-PM$_{2.5}$ sampled in Dongting Lake. A1, B1, C1, A2, B2 and C2 were obtained in Poyang Lake, and A3, B3 and C3 were obtained in Dong ting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.



Supplementary Figure S15. Comparison of the Toxic metals (Cr_{eq}) between natural soil samples and dust aerosols in Poyang and Dongting Lakes. A1, B1, C1, A2, B2 and C2 were obtained in Poyang Lake, and A3, B3 and C3 were obtained in Dong ting Lake. A1, A2, and A3 are regions typically dry and exposed year-round. B1, B2, and B3 are transitional zones that fluctuate between submerged and dry states. C1, C2, and C3 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.

References

Agency, U. U. S. E. P.: Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment), 13-24, 2009.

Agency, U. U. S. E. P.: Regional Screening Levels (RSLs) - Resident Ambient Air Table (TR=1E-06, HQ=1), pp. 1-6, 2020.

Boylan, J. W. and Russell, A. G.: PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models, Atmospheric Environment, 40, 4946-4959, https://doi.org/10.1016/j.atmosenv.2005.09.087, 2006.

Bureau, B. M.: Environmental Site Assessment Guide (DB11T-656-2009), 2009.

Delistraty, D.: Toxic equivalency factor approach for risk assessment of polycyclic aromatic hydrocarbons, Toxicological & Environmental Chemistry, 64, 81-108, 1997.

Emery, C., Tai, E., and Yarwood, G.: Enhanced meteorological modeling and performance evaluation for two Texas ozone episodes, Prepared for the Texas natural resource conservation commission, by ENVIRON International Corporation, 2001.

EPA, U.: Regional Screening Levels (RSLs) - Generic Tables., https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables,

Huang, R.J., Cheng, R., Jing, M., Yang, L., Li, Y., Chen, Q., Chen, Y., Yan, J., Lin, C., and Wu, Y.: Source-specific health risk analysis on particulate trace elements: coal combustion and traffic emission as major contributors in wintertime Beijing, Environmental science & technology, 52, 10967-10974, 2018.

Huang, S., Li, J., and Xu, M.: Water surface variations monitoring and flood hazard analysis in Dongting Lake area using long-term Terra/MODIS data time series, Natural hazards, 62, 93-100, 2012.

Li, P., Feng, Z. M., Jing, L. G., Liu, Y., Hu, J. W., and Zhu, J.P.: Natural water surface of Poyang Lake monitoring based on remote sensing and the relationship with water level, Journal of Natural Resources, 28, 1556-1568, 2013.

Liu, J., Chen, Y., Chao, S., Cao, H., Zhang, A., and Yang, Y.: Emission control priority of PM2. 5-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective, Science of the total environment, 644, 20-30, 2018.

Liu, L., Chen, Z., and Ji, M.: Dongting Lake Area Change Monitoring Based on Sentinel-2 Satellite Data, Geospatial Information, 7, 57-60, 2022.

Monserrat, L.: OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary., OEHHA, 2016.

Nisbet, I. C. and Lagoy, P. K.: Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs), Regulatory toxicology and pharmacology, 16, 290-300, 1992.

Organization, W. H.: Air quality guidelines for Europe, World Health Organization. Regional Office for Europe2000.

Qi, S. H., Zhang, X.X., Jiang, F., and Wang, P.: Research on the causes for hydrological drought trendin Poyang Lake, Journal of Natural Resources, 34, 168-178, 2019.

Ramírez, O., De La Campa, A. M. S., Sánchez-Rodas, D., and de la Rosa, J. D.: Hazardous trace elements in thoracic fraction of airborne particulate matter: Assessment of temporal variations, sources, and health risks in a megacity, Science of the Total Environment, 710, 136344, 2020.

Ren, Y. X., Luo, Q., Zhuo, S. J., Hu, Y. A., Shen, G. F., Cheng, H. F., and Tao, S.: Bioaccessibility and public health risk of heavy Metal(loid)s in the airborne particulate matter of four cities in northern China, Chemosphere, 277, 10.1016/j.chemosphere.2021.130312, 2021.

Wu, S. P., Cai, M. J., Xu, C., Zhang, N., Zhou, J. B., Yan, J. P., Schwab, J. J., and Yuan, C. S.: Chemical nature of PM2. 5 and PM10 in the coastal urban Xiamen, China: Insights into the impacts of shipping emissions and health risk, Atmospheric Environment, 227, 117383, 2020.