Supplement of Atmos. Chem. Phys., 25, 12657–12673, 2025
https://doi.org/10.5194/acp-25-12657-2025-supplement

Atmospheric Chemistry and Physics
Open Access

Supplement of

Toxic dust emission from drought-exposed lake beds – a new air pollution threat from dried lakes

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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.

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.

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.

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 S5 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 km² (~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 km² (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 S6.

Table S1. Mass (g) of particles collected in dust aerosols for $PM_{2.5}$ and PM_{10} across three replicates ($PM_{2.5}$-1 to $PM_{2.5}$-3 and PM_{10}-1 to PM_{10}-3). Sampling sites include dry (D), transitional (T), and submerged (S) regions of Poyang Lake (PY) and Dongting Lake (DT).

EXP	PY-D1	PY-T1	PY-S1	PY-D2	PY-T2	PY-S2	DT-D1	DT-T1	DT-S1
$PM_{2.5}$-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 S2. Scenarios setting.

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

Table S3. 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 S4. 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}

Note: Only metals with available toxicity equivalency factors (TEFs) from the U.S. EPA are listed with values; "/" indicates that no TEF value is currently available.

Table S5. 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 S6. 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 Ni: 0.2 As: 0.2 V: 30 Cu: 100	OEHHA (Monserrat, 2016)

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 S7. 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 S8. 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
$PM_{2.5}$ (μg m^{-3})	**OBS**	32.33	32.33	
	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} (μg m^{-3})	**OBS**	55.28	55.28	
	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	

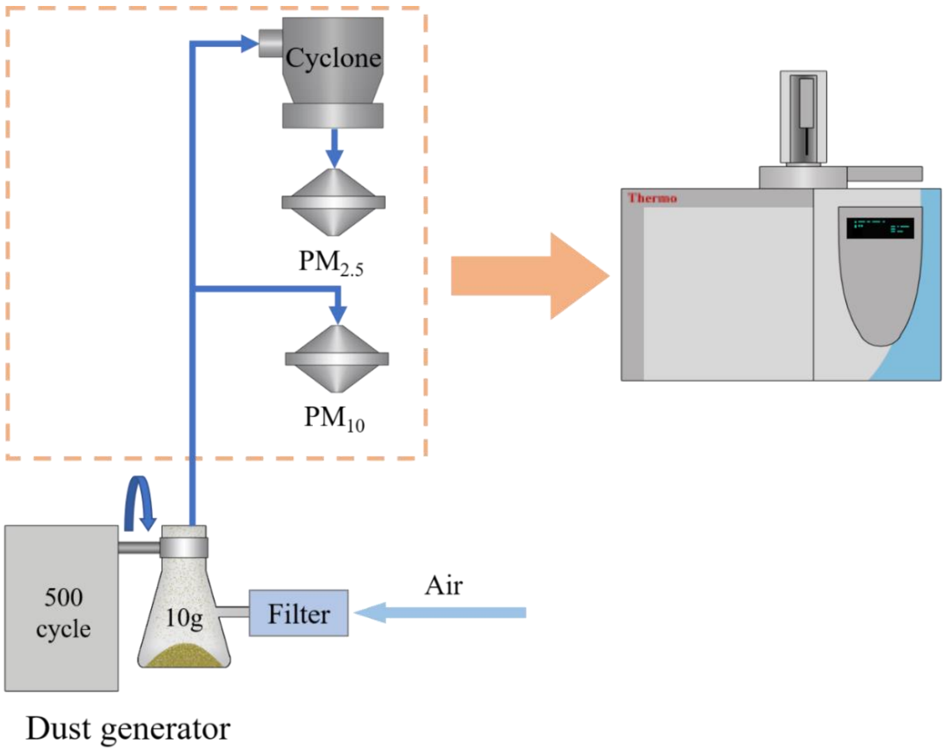

Figure S1. Experimental setup. The setup consists of four parts: a dust generation system (Shaker), a dust particle size separation system ($PM_{2.5}$ Cyclone), a dust collection system (Filter holder), and a chemical analysis instrument (GC-MS).

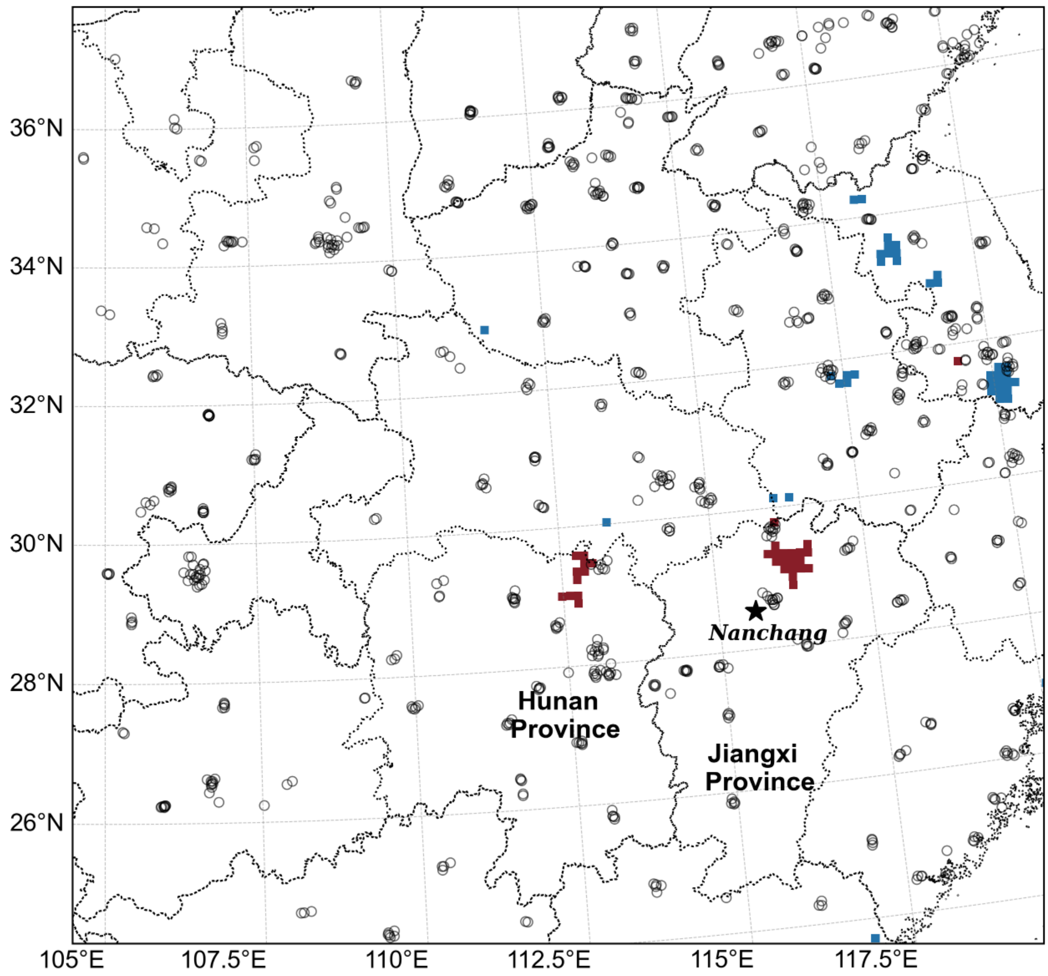

Figure S2. Study area setting. Grid cells in the plot of blue are ordinary lakes, and those in red are the exposed lakebeds detected by sentinel-2. Nanchang near Poyang Lake is marked. Hollow circles indicate observation sites.

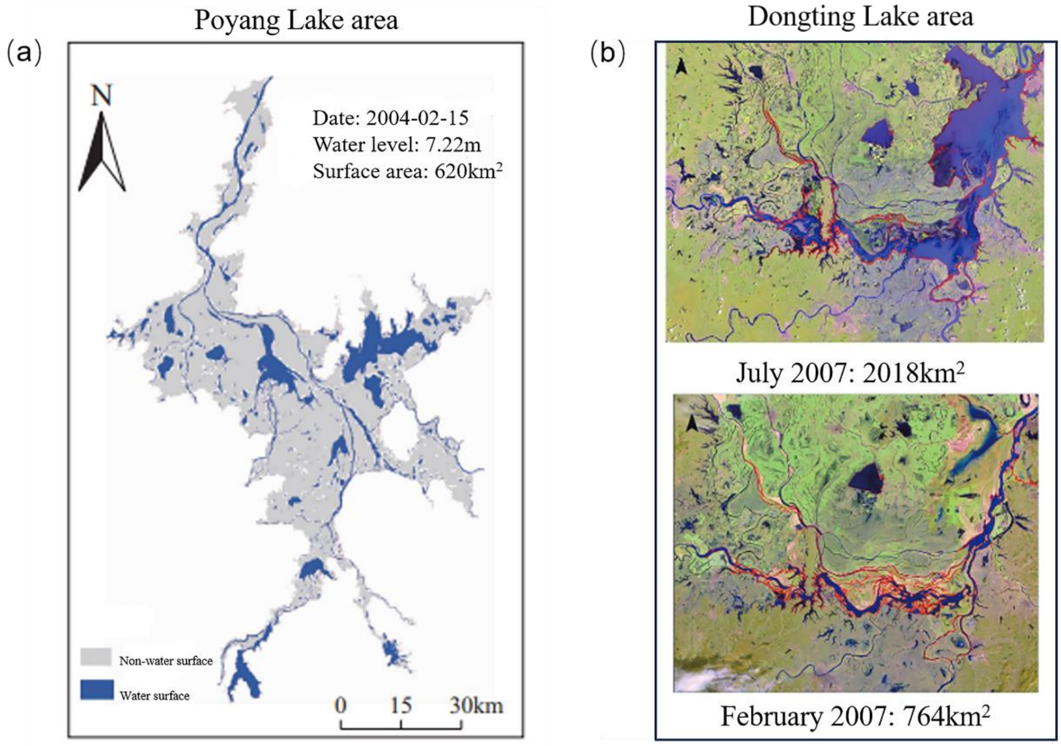

Figure S3. Lake area of Poyang and Dongting lakes. Water surface area of Poyang Lake (a) and Dongting Lake (b) during drought periods. Data were obtained from these studies (Liu et al., 2022; Li et al., 2013).

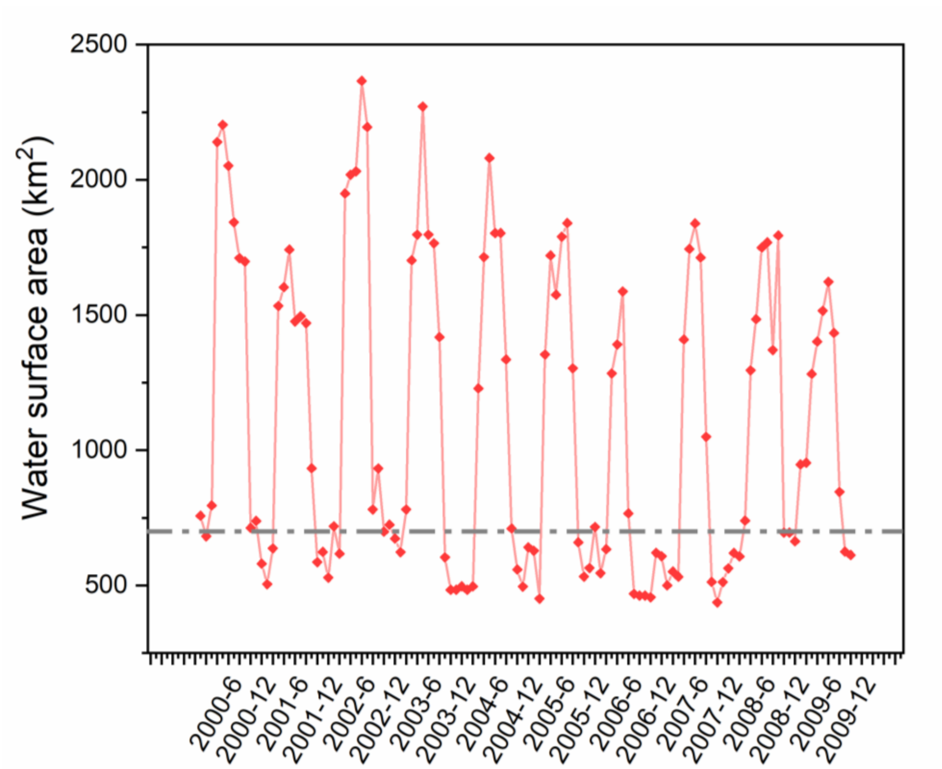

Figure S4. Variations of water area in the Dongting Lake. Data observed by Terra/MODIS between March 2000 and December 2009. The gray dotted line at 700 km^2 indicates the drought conditions in Dongting Lake. Between 2000 and 2009, the average duration of drought conditions was 140 days per year (Huang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

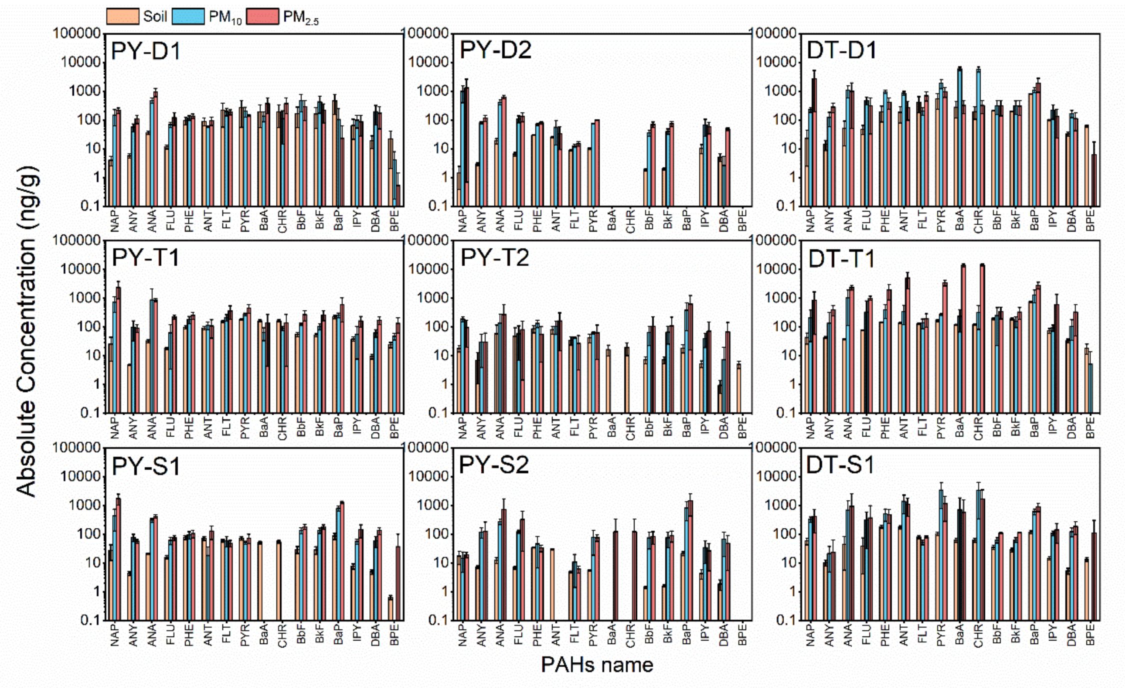

Figure S5. Comparison of the absolute concentrations of heavy metals between natural soil samples and dust aerosols. PY-D1, PY-T1, PY-S1, PY-D2, PY-T2 and PY-S2 were obtained in Poyang Lake, and DT-D1, DT-T1 and DT-S1 were obtained in Dong ting Lake. PY-D1, PY-D2 and DT-D1 are regions typically dry and exposed year-round. PY-T1, PY-T2 and DT-T1 are transitional zones that fluctuate between submerged and dry states. PY-S1, PY-S2 and DT-S1 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.

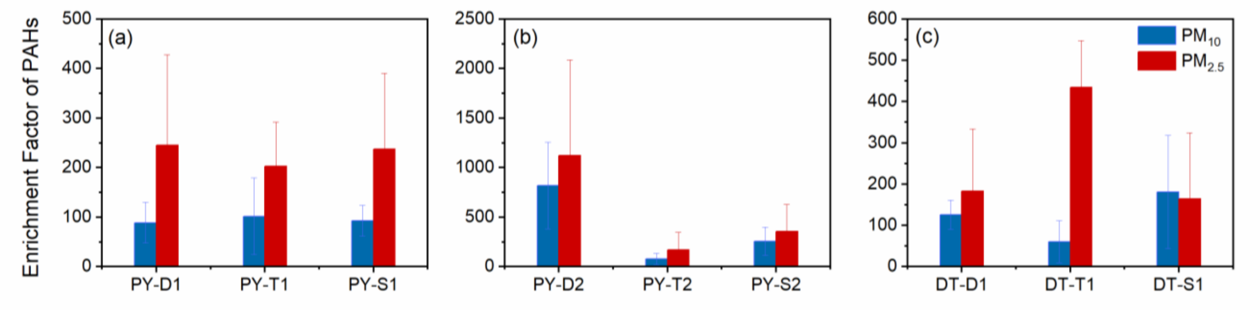

Figure S6. Total enrichment factors of PAHs in dust aerosols from soils. PY-D1, PY-D2 and DT-D1 are regions typically dry and exposed year-round. PY-T1, PY-T2 and DT-T1 are transitional zones that fluctuate between submerged and dry states. PY-S1, PY-S1, PY-S2 and DT-S1 are areas usually underwater but sometimes exposed due to extreme drought.

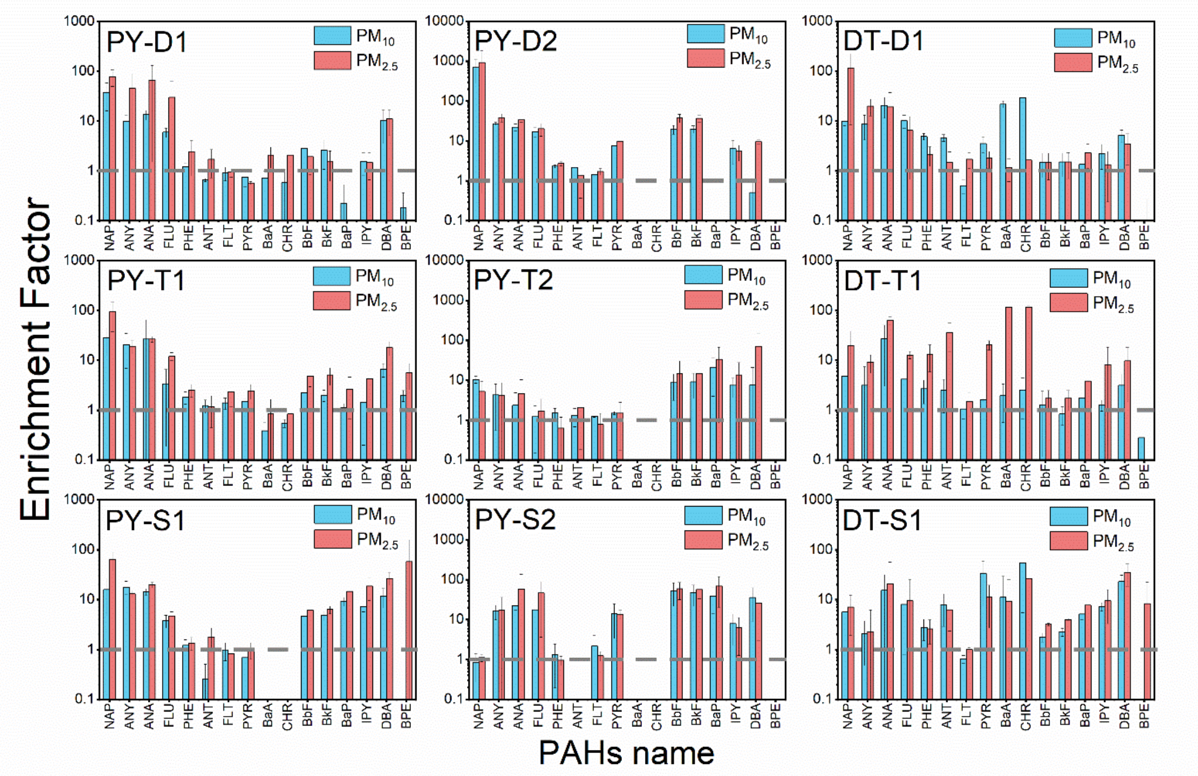

Figure S7. Enrichment factors of individual PAH in dust aerosols from soils. Red represents $PM_{2.5}$ and blue represents PM_{10}. The grey dotted line represents the EF as 1. PY-D1, PY-T1, PY-S1, PY-D2, PY-T2 and PY-S2 were obtained in Poyang Lake, and DT-D1, DT-T1 and DT-S1 were obtained in Dong ting Lake. PY-D1, PY-D2 and DT-D1 are regions typically dry and exposed year-round. PY-T1, PY-T2 and DT-T1 are transitional zones that fluctuate between submerged and dry states. PY-S1, PY-S2, and DT-S1 are areas usually underwater but sometimes exposed due to extreme drought. The whiskers on the bars represent the standard deviations of triplicates.

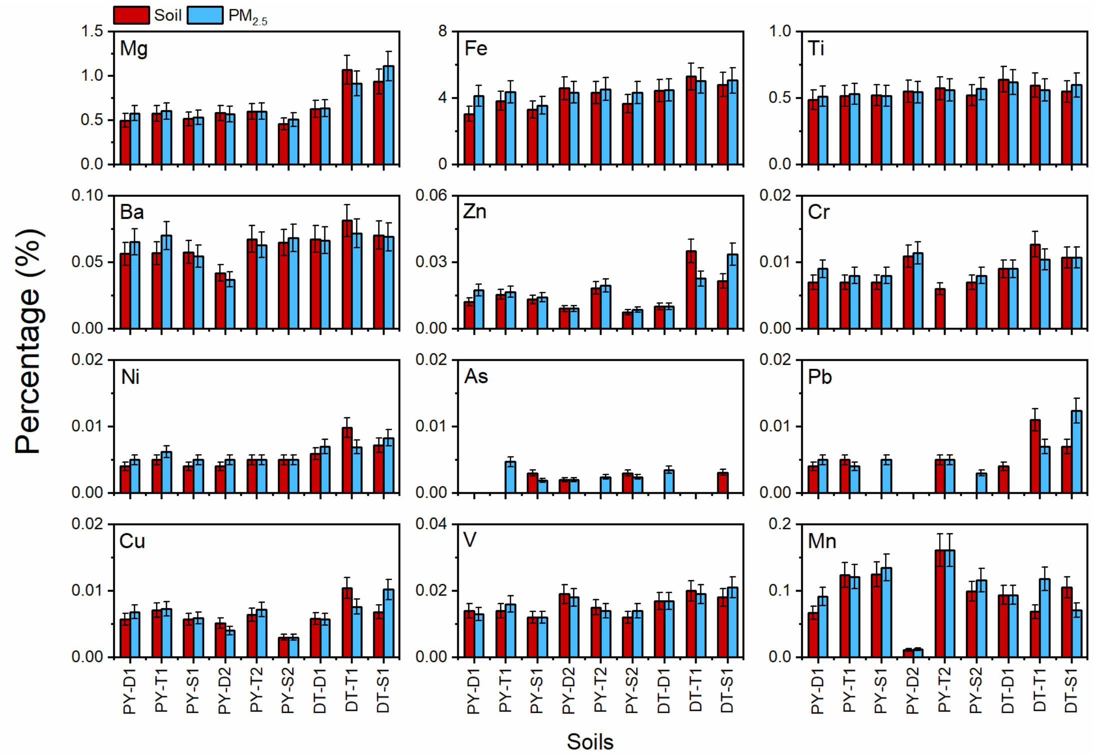

Figure S8. Comparison of the absolute concentrations of heavy metals between natural soil samples and dust aerosols. PY-D1, PY-T1, PY-S1, PY-D2, PY-T2 and PY-S2 were obtained in Poyang Lake, and DT-D1, DT-T1 and DT-S1 were obtained in Dong ting Lake. PY-D1, PY-D2 and DT-D1 are regions typically dry and exposed year-round. PY-T1, PY-T2 and DT-T1 are transitional zones that fluctuate between submerged and dry states. PY-S1, PY-S2 and DT-S1 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.

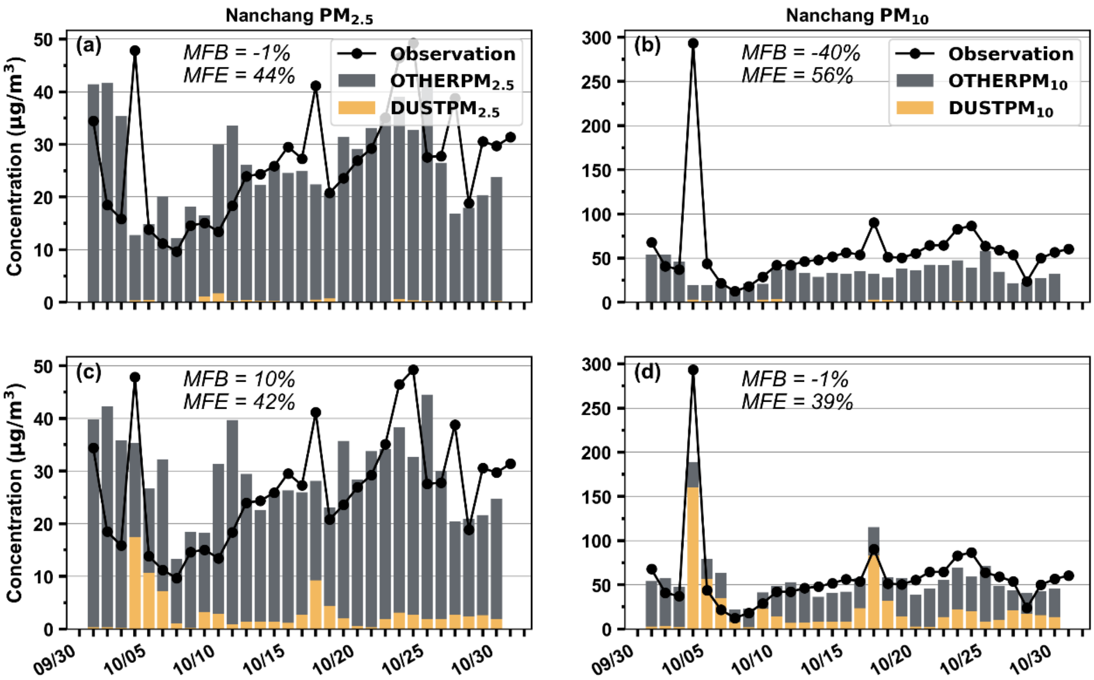

Figure S9. Time series of PM concentrations in Nanchang. Upper panels display the CASE_unexposed (a) $PM_{2.5}$ and (b) PM_{10} concentration in Nanchang from October 1 to 30 2022. Bottom panels display the CASE_exposed (c) $PM_{2.5}$ and (d) PM_{10} concentration in Nanchang from October 1 to 30 2022. (MFB: mean fractional bias; MFE: mean fractional error).

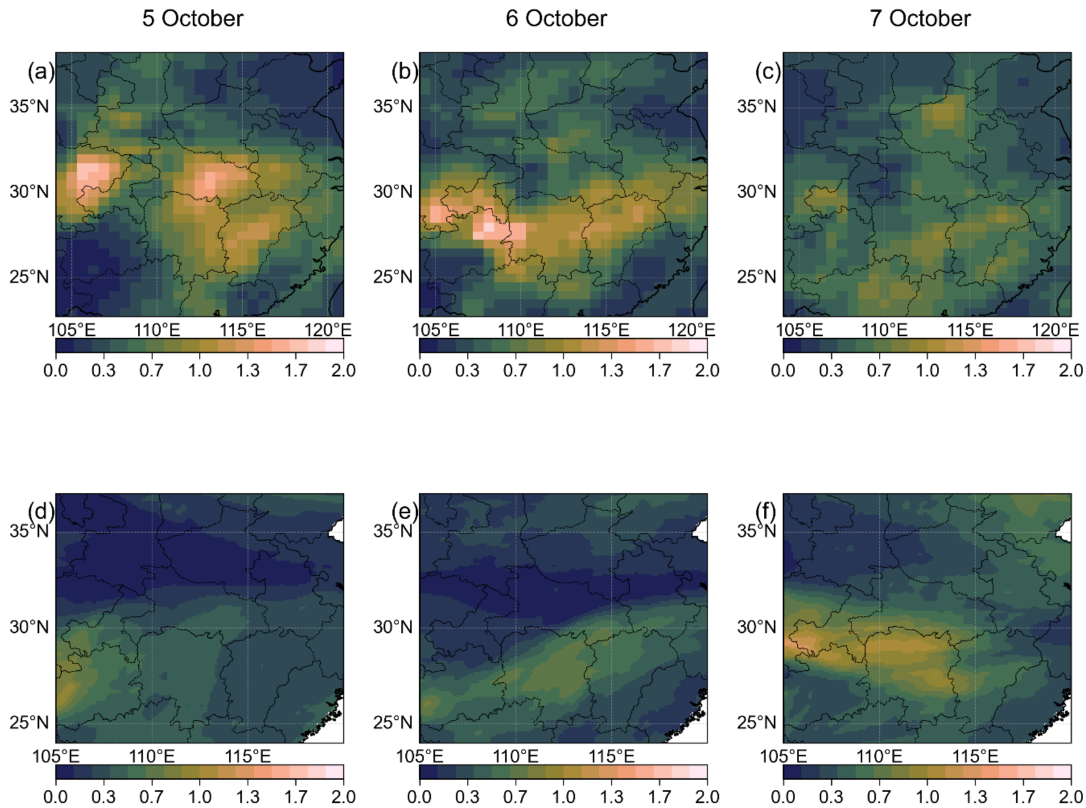

Figure S10. Spatial distribution of AOD from MERRA-2 reanalysis (a-c) and CMAQ (CASE_exposed scenario) (d-f), during 5–7 October 2022.

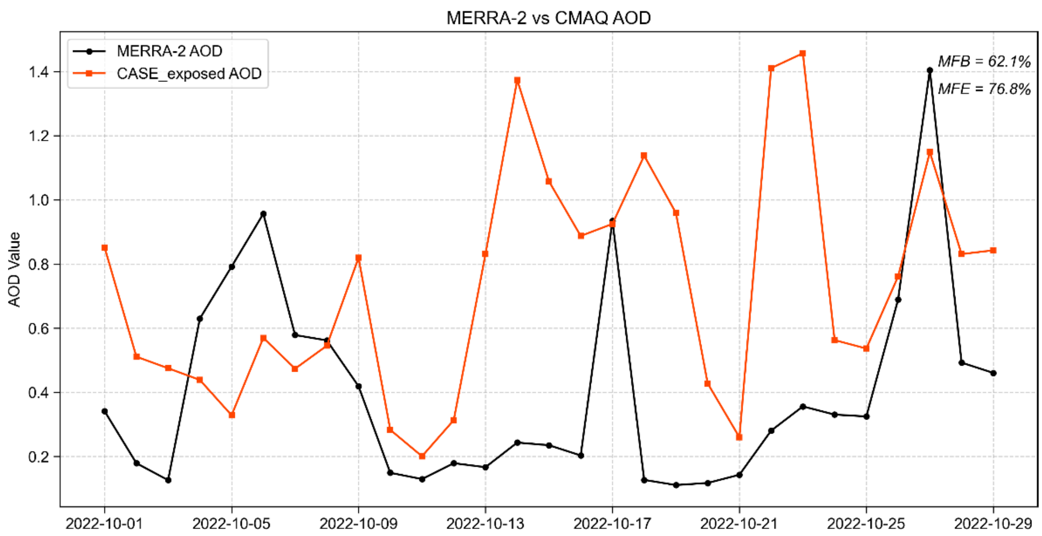

Figure S11. Time series of AOD at a grid point near Nanchang (29.3°N, 115.8°E) from MERRA-2 reanalysis and CMAQ (CASE_exposed scenario).

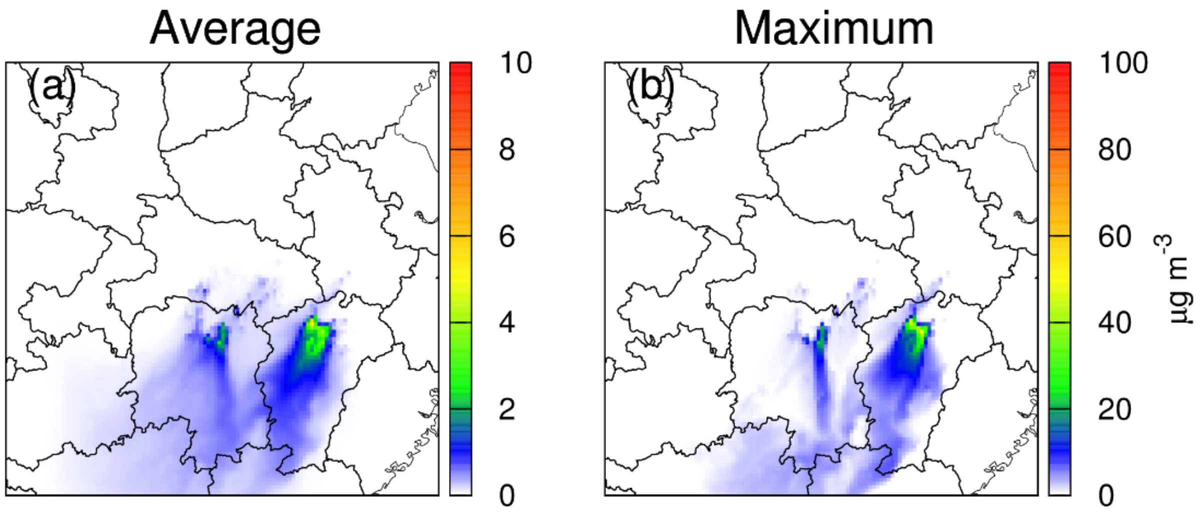

Figure S12. Spatial distribution of predicted monthly average and maximum daily concentrations of lakebed dust $PM_{2.5}$. Lakebed dust $PM_{2.5}$ for (a) monthly average and (b) maximum daily concentrations.

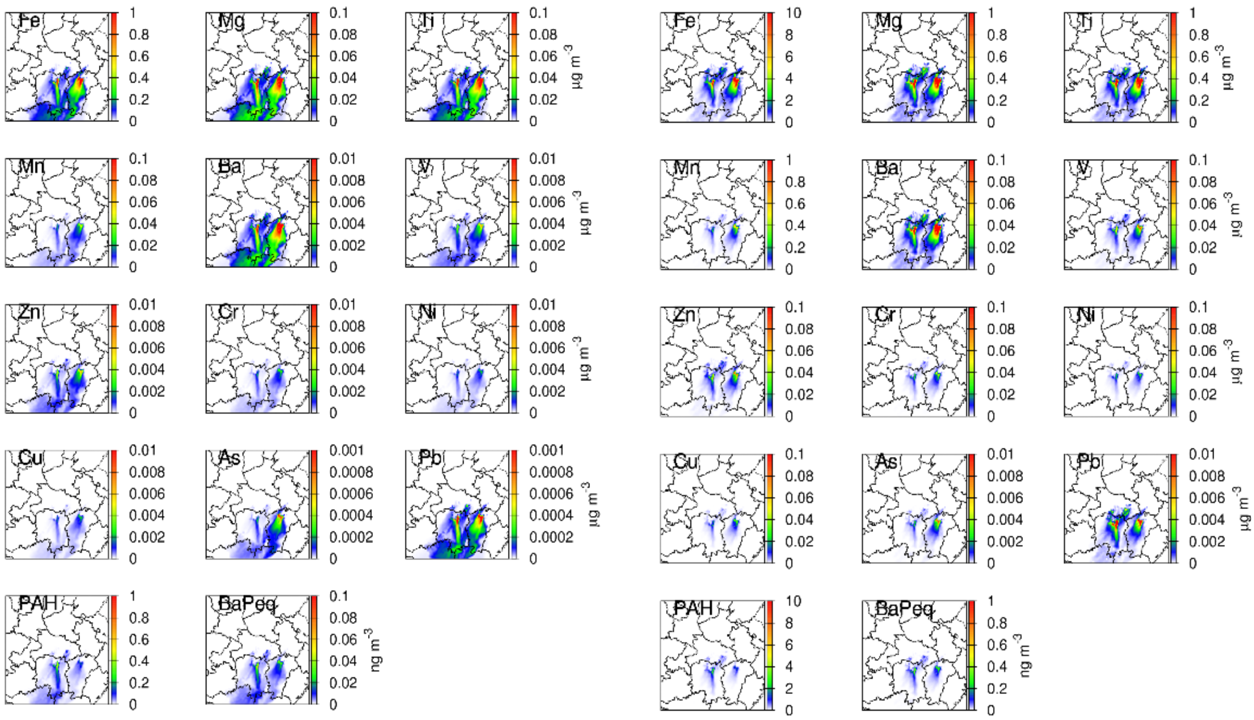

Figure S13. Maximum daily HM and PAH concentration of lakebed dust PM. Concentrations for (left) $PM_{2.5}$ and (right) PM_{10}.

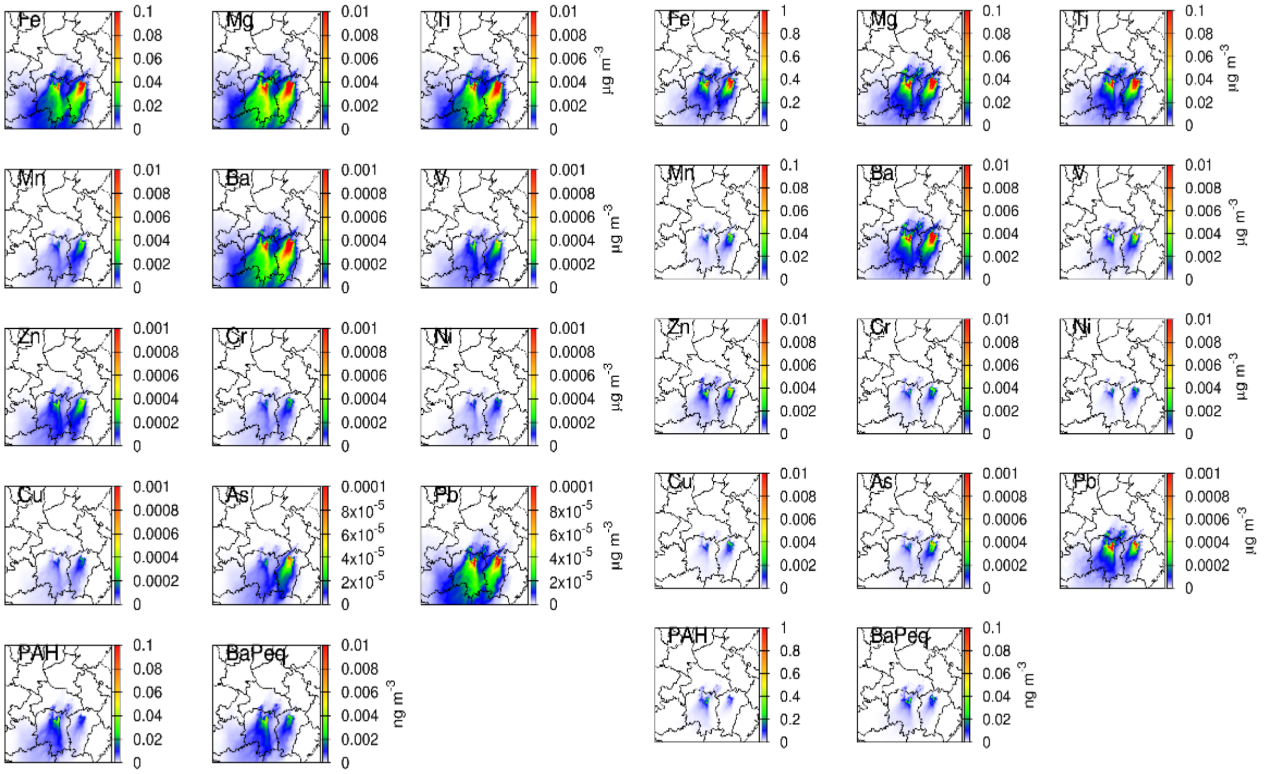

Figure S14. Monthly average HM and PAH concentration of lakebed dust PM. Concentrations for (left) $PM_{2.5}$ and (right) PM_{10}.

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