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High-resolution emission inventory development and co-emission hotspot identification of air pollutants and greenhouse gases in central plains region, China

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Table S1. Emission source categorization used in this study

Category	Sector	Activity level data	Data sources
Electricity and thermal power	Thermal power generation Other electricity generation Combined heat and power Heat production and supply Biomass power generation	Coal, natural gas, biomass, waste, diesel, other fuels	Henan Provincial Department of Ecology and Environment; China Energy Statistical Yearbook
Industry	Industrial combustion	Coal, fuel oil, LPG, LNG, natural gas, coke, diesel, other fuels	Henan Provincial Department of Ecology and Environment; China Energy Statistical Yearbook
	Non-metallic product industry	Cement, ceramic, refractory, bricks, graphite, glass, lime gypsum production	Henan Provincial Department of Ecology and Environment; China Energy Statistical Yearbook
	Ferrous metal industry	Cast iron, iron making, sintered ore	
	Non-ferrous metal	Aluminum oxide, electrolytic aluminum, aluminum foil	
	Chemical raw material industry	Chemical fertilizer, coating production, pigment	
	Alcohol	Beer, liquor	
	Papermaking	Papermaking	
	Chemical fiber production	Chemical fiber production	
	Rubber and plastic production	Rubber and plastic production	
	Food industry	Meat product, soya bean oil, peanut oil, other edible oils	
	Industrial solvent	Quantity of the products	
Mobile source and oil storage and transportation	On-road mobile	Gasoline, diesel, new energy, other fuel	Henan Provincial Department of Ecology and Environment; China Transportation Statistical Yearbook
	Agricultural machunery and transport	Airport, railway locomotive, agriculture machinery, construction machinery	
	Railway		
	River transport		
	Construction machunery		
	Airplane		
	Gas station		
	Oil storage and transportation	Gasoline, diesel, natural gas	
Fugitive dust	Road dust	High speed, national road, provincial road, county road, rural road, urban road	Henan Provincial Department of Ecology and Environment; China Transportation Statistical Yearbook; Henan Statistical Yearbook
	Construction dust	Construction area	Field Survey
Resident	Residential combustion	Coal, natural gas	Henan Statistical Yearbook
	Interior straw burning	Wheat, corn, soybean, sweet potato, other straw	Henan Statistical Yearbook
	Interior wood burning	Firewood consumption	Henan Statistical Yearbook
	Residential solvent use	Population and the consumption of solvent	Henan Provincial Department of Ecology and Environment; Henan Statistical Yearbook
	Building surface coating	Consumption of coating	
	Road asphalt paving	Consumption for road asphalt	
	Corporate catering	Amount of cooker, total annual operating hours	
Agriculture	Livestock breeding	Cattle, cow, goat, sheep, sow, hog, house, donkey, mule, rabbit, poultry	Henan Statistical Yearbook
	Fertilizer use	Urea, ABC, AS, AN,	China Rural Statistical Yearbook
	Natural ammonia sources	Amount of straw composted, crop sown area	Henan Statistical Yearbook

Waste treatment	Open straw burning	Wheat, corn, soybean, sweet potato, other straw	Henan Statistical Yearbook
	Sewage treatment	Amount of sewage	Henan Statistical Yearbook
	Garbage disposal t	Amount of waste	Henan Statistical Yearbook

Table S2. Emission factors of power and heat industry

Source	Fuel type	Emission factors (kg/t-fuel)							
		SO_2	NOx	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3	N_2O
Electricity and thermal power	Coal	16*S	7.21/8.19/8.96[a]	8[a]	46[b]	12[b]	0.04[a]	0.02[c]	1.4/6.1[d]
	Natural gas	0.071[b]	4.1[a]	1.3[a]	0.24[b]	0.17[b]	0.02[a]	0.513[b]	1[d]
	Biomass	2.67[e]	1.54[e]	3.6[f]	10.28[e]	5.88[f]	5.3[b]	0.04[g]	
	Waste	2.67[e]	1.54[e]	3.6[f]	10.28[e]	5.88[f]	5.3[b]		
	Diesel	3[a]	7.4[a]	0.6[a]	0.5[a]	0.5[a]	0.13[a]		0.4[d]
	Other gas		1.35[a]	1.3[a]	0.03[a]	0.03[a]	0.02[a]		

Note: The N_2O emission factor (kg/TJ) needs to be multiplied by the NCV of fuel (see Table S3).

[a] He et al. (2018)

[b] MEPPRC (2014)

[c] Yin et al. (2010)

[d] NDRC (2011)

[e] Qi et al. (2017)

[f] U.S. EPA.

[g] Pham et al. (2008)

Table S3. Net calorific value, carbon content and carbon oxidation rate of energy

Fuel category	Net calorific value	Carbon content	Carbon oxidation rate
Coal	223.1/230.9/174.6[a]	27.5/22.0/33.6[b]	95/85/89.5[a]
Gasoline	448[a]	18.5[b]	98[a]
Diesel	433.3[a]	19.8[a]	98[a]
LPG	473.1[a]	16.9[b]	98[a]
Natural gas	3893.1[a]	15.2[b]	99[a]
fuel oil	401.9[a]	20.7[b]	98[a]
Coke	325[a]	26.6[b]	93[a]
Other coking	439.6[a]	27.4[b]	93[a]
Other coal gas	1575.8[a]	12.2[b]	99[a]
LNG	515.0[a]	15.0[b]	98[a]
Biogas	2100/2090.8		

Unit: NCV, $TJ/10^4t$ or $TJ/10^8$ m^3; CC, tons C/TJ; COF, %.

[a] DEEGP (2020)

[b] NDRC (2011)

Table S4. Emission factors of industry

Sources	SO_2	NOx	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3	CO_2
Industrial combustion (Coal)	16*S	4[a]	15[a]	5.4[d]	1.89[d]	0.39[d]	0.02[f]	
Industrial combustion (Fuel oil)	20*S	7.65[c]	0.6[i]	0.85[d]	0.67[d]	0.35[d]	0.13[f]	
Industrial combustion (LPG)		2.63[a]	0.36[a]	0.17[a]	0.17[a]	33[a]		
Industrial combustion (LNG)		2.63[a]	0.36[a]	0.17[a]	0.17[a]	33[a]		
Industrial combustion (Natural gas)	0.18[a]	1.76[a]	1.3[a]	0.24[a]	0.17[a]	0.18[a]	0.513[a]	
Industrial combustion (Coke)	16*S	9[j]	6.6[j]	0.29[i]	0.14[i]	0.04[i]	0.02[f]	
Industrial combustion (Diesel)	3[a]	9.62[a]	0.6[a]	0.5[a]	0.5[a]	0.12[a]	0.132[a]	
Industrial combustion (Other coking)		10.06[a]	2[a]			0.04[a]		
Industrial combustion (Other coal gas)		0.13[a]	1.3[a]	0.03[a]	0.03[a]	0.05[a]		
Industrial combustion (Other gas)		0.13[a]	1.3[a]	0.03[a]	0.03[a]	0.02[a]		
Industrial combustion (Other liquid)		10.06[a]	0.6[a]	0.62[a]	0.85[a]	0.13[a]		
Glass productions				3.07[a]	2.94[a]	0.4[a]		
Refractory	5.8[b]	4.7[c]		0.26[d]	0.11[d]	0.18[e]	0.02[f]	
Cement	3.71[a]	1.88[a]	3.71[a]	77.43[d]	28.46[d]	0.33[a]		538[g]
Graphite	18.87[a]	1.04[a]	2.83[a]	1.6[a]	2.48[a]	0.38[a]		
Ceramic	2.25[a]	5[a]		2.43[a]	0.67[a]	29.22[a]		
Bricks	0.6[a]	0.05[a]	4.04[a]	0.71[a]	0.27[a]	0.13[a]		
lime gypsum production								683[g]
Cast iron	0.14[a]	0.17[a]	15.29[a]	8.43[a]	5.27[a]			
Iron making	0.18[a]	0.21[a]		2.82[a]	1.38[a]			
Sintered ore	0.34[a]	0.55[a]	16[a]	5.81[a]	2.52[a]	0.25[a]		
Aluminum oxide				396.17[a]	297.13[a]			
Electrolytic aluminum				18.28[a]	26.51[a]			
Aluminum foil						54.5		
Chemical fertilizer				2.12[a]	1.86[a]			1[a]
Coating production						15[a]		
Pigment						81.4[a]		
Drink wine						0.25[a]		
Papermaking						3.1[a]		
Chemical fiber production						10[h]		
Rubber and plastic						10[h]		
Meat products						0.143[a]		
Soya bean oil Products						2.45[a]		
Peanut oil Production						10.35[a]		
Other edible oil production						9.26[a]		
Wood-based panel						0.5[d]		
Printing and dyeing cloth						10[d]		
Furniture surface coating						640[a]		
Motor vehicle surface coating						77.25[k]		
Equipment manufacturing						77.25[k]		
Shoemaking						479[k]		
Printing						100/750[a]		

Unit: Emission factors are expressed per ton of fuel or product unless otherwise specified. VOCs may be reported in kg/t, g/kg, or g/m³ depending on the emission source type.

[a] He et al. (2018)

[b] He et al. (2013)

[c] Tian et al. (2001)

[d] MEPPRC (2014).

[e] Bo et al. (2008)

[f] Yin (2011)

[g] NDRC (2011)

[h] Pan et al. (2015)

[i] Lu (2014)

[j] Qi et al. (2017)

[k] Yan (2016)

Table S5 Emission factors for on-road mobile source

Vehicle type	Fuel type	National Standard	SO_2	NO_x	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3	BC	OC	CH_4	N_2O
LPV (Large passenger vehicle)	Gasoline	China 0	0.02[a]	6.06	137.38	0.34	0.3	6.59	0.03[a]	0.08[a]	0.09[a]		
		China 1	0.02[a]	3.17	82.61	0.18	0.16	6.73	0.03[a]	0.05[a]	0.05[a]		
		China 2	0.02[a]	3.23	19.74	0.08	0.07	2.53	0.03[a]	0.02[a]	0.02[a]		
		China 3	0.02[a]	1.9	11.25	0.05	0.04	1.22	0.03[a]	0.01[a]	0.01[a]	3.90[b]	3.90[b]
		China 4	0.02[a]	1.08	5.98	0.05	0.04	0.72	0.03[a]	0.01[a]	0.01[a]		
		China 5	0.02[a]	0.8	5.98	0.05	0.04	0.72	0.03[a]	0.01[a]	0.01[a]		
		China 6	0.02[a]	0.8	5.98	0.05	0.04	0.72	0.03[a]	0.01[a]	0.01[a]		
	Diesel	China 0	0.14[a]	14.06	12.62	1.15	1.03	1	0.02[a]	0.76[a]	0.24[a]		
		China 1	0.14[a]	11.96	9.62	1.14	1.02	0.6	0.02[a]	0.58[a]	0.19[a]		
		China 2	0.14[a]	11.83	8.43	0.48	0.44	0.49	0.02[a]	0.58[a]	0.18[a]		
		China 3	0.14[a]	11.08	3.48	0.22	0.2	0.15	0.02[a]	0.25[a]	0.08[a]	3.90[b]	3.90[b]
		China 4	0.14[a]	9.68	1.73	0.11	0.1	0.08	0.02[a]	0.11[a]	0.04[a]		
		China 5	0.14[a]	9.68	1.73	0.11	0.1	0.08	0.02[a]	0.06[a]	0.02[a]		
		China 6	0.14[a]	14.06	12.62	1.15	1.03	1	0.02[a]	0.06[a]	0.02[a]		
	Natural gas	China 0	-	21.16	18.7	0.33	0.29	3.84	0.00[a]	0.08[a]	0.09[a]		
		China 1	-	16.8	15.14	0.18	0.16	3.2	0.00[a]	0.05[a]	0.05[a]		
		China 2	-	13.06	12.11	0.08	0.07	2.86	0.00[a]	0.02[a]	0.02[a]		
		China 3	-	9.32	6.36	0.05	0.04	1.72	0.00[a]	0.01[a]	0.01[a]	0.092[b]	0.003[b]
		China 4	-	8.64	4.67	0.02	0.02	1.19	0.00[a]	0.01[a]	0.01[a]		
		China 5	-	3.73	1.58	0.05	0.04	1.19	0.00[a]	0.01[a]	0.01[a]		
		China 6	-	3.73	1.58	0.05	0.04	1.19	0.00[a]	0.01[a]	0.01[a]		
MPV	Gasoline	China 0	0.02[a]	3.45	53.36	0.11	0.1	3.22	0.03[a]	0.03[a]	0.03[a]	3.90[b]	3.90[b]

(Medium passenger vehicle)		China 1	0.02[a]	2.13	28.51	0.07	0.06	3.29	0.03[a]	0.02[a]	0.02[a]		
		China 2	0.02[a]	1.84	18.23	0.02	0.02	1.84	0.03[a]	0.01[a]	0.01[a]		
		China 3	0.02[a]	0.59	5.9	0.01	0.01	0.52	0.03[a]	0.00[a]	0.00[a]		
		China 4	0.02[a]	0.28	3.14	0.01	0.01	0.19	0.03[a]	0.00[a]	0.00[a]		
		China 5	0.02[a]	0.21	3.14	0.01	0.01	0.19	0.03[a]	0.00[a]	0.00[a]		
		China 6	0.02[a]	0.21	3.14	0.01	0.01	0.19	0.03[a]	0.00[a]	0.00[a]		
	Diesel	China 0	0.14[a]	6.89	5	1.87	1.68	2.6	0.02[a]	0.95[a]	0.30[a]		
		China 1	0.14[a]	6.04	4.4	0.55	0.48	2.47	0.02[a]	0.27[a]	0.08[a]		
		China 2	0.14[a]	6.88	3.13	0.2	0.19	0.74	0.02[a]	0.10[a]	0.03[a]		
		China 3	0.14[a]	4.01	2.65	0.17	0.16	0.64	0.02[a]	0.09[a]	0.03[a]	3.90[b]	3.90[b]
		China 4	0.14[a]	3	1.97	0.1	0.09	0.5	0.02[a]	0.05[a]	0.02[a]		
		China 5	0.14[a]	2.55	1.97	0.05	0.04	0.5	0.02[a]	0.02[a]	0.01[a]		
		China 6	0.14[a]	2.55	1.97	0.05	0.04	0.5	0.02[a]	0.02[a]	0.01[a]		
	Natural gas	China 0	0.00[a]	0.6	9.1	0.11	0.1	1.92	0.00[a]	0.03[a]	0.03[a]		
		China 1	0.00[a]	4.8	7.57	0.07	0.06	1.6	0.00[a]	0.02[a]	0.02[a]		
		China 2	0.00[a]	4	6.06	0.02	0.02	1.43	0.00[a]	0.01[a]	0.01[a]		
		China 3	0.00[a]	2.55	3.18	0.01	0.01	0.86	0.00[a]	0.00[a]	0.00[a]	0.092[b]	0.003[b]
		China 4	0.00[a]	5.94	2.33	0.02	0.02	0.6	0.00[a]	0.00[a]	0.00[a]		
		China 5	0.00[a]	1.06	3.22	0.01	0.01	0.6	0.00[a]	0.00[a]	0.00[a]		
		China 6	0.00[a]	1.06	3.22	0.01	0.01	0.6	0.00[a]	0.00[a]	0.00[a]		
	Gasoline	China 0	0.01[a]	2.29	38.14	0.03	0.03	6.92	0.07[a]	0.01[a]	0.01[a]		
SPV (Small passenger vehicle)		China 1	0.01[a]	0.48	15.47	0.03	0.03	1.8	0.07[a]	0.01[a]	0.01[a]		
		China 2	0.01[a]	0.54	3.49	0.01	0.01	1.59	0.07[a]	0.00[a]	0.00[a]	3.90[b]	3.90[b]
		China 3	0.01[a]	0.18	1.99	0.01	0.01	0.64	0.07[a]	0.00[a]	0.00		
		China 4	0.01[a]	0.04	0.95	0.00	0.00	0.32	0.07[a]	0.00[a]	0.00[a]		

		China 5	0.00[a]	0.03	0.64	0.00	0.00	0.08	0.07[a]	0.00[a]	0.00[a]		
		China 6	0.00[a]	0.03	0.64	0.00	0.00	0.08	0.07[a]	0.00[a]	0.00[a]		
MV (Mini passenger vehicle)	Gasoline	China 0	0.01[a]	2.29	38.14	0.03	0.03	6.92	0.07[a]	0.01[a]	0.01[a]	3.90[b]	3.90[b]
		China 1	0.01[a]	0.48	15.47	0.03	0.03	1.8	0.07[a]	0.01[a]	0.01[a]		
		China 2	0.01[a]	0.54	3.49	0.01	0.01	1.59	0.07[a]	0.00[a]	0.00[a]		
		China 3	0.01[a]	0.18	1.99	0.01	0.01	0.64	0.07[a]	0.00[a]	0.00[a]		
		China 4	0.01[a]	0.04	0.95	0	0	0.32	0.07[a]	0.00[a]	0.00[a]		
		China 5	0.01[a]	0.03	0.64	0	0	0.08	0.07[a]	0.00[a]	0.00[a]		
		China 6	0.01[a]	0.03	0.64	0	0	0.08	0.07[a]	0.00[a]	0.00[a]		
HDT (Heavy-duty truck)	Diesel	China 0	0.14[a]	17.42	17.4	1.53	1.39	7.1	0.02[a]	0.78[a]	0.25[a]	3.90[b]	3.90[b]
		China 1	0.14[a]	12.09	7.41	0.73	0.65	1.56	0.02[a]	0.38[a]	0.11[a]		
		China 2	0.14[a]	9.59	3.42	0.65	0.58	0.9	0.02[a]	0.33[a]	0.10[a]		
		China 3	0.14[a]	9.48	3.49	0.3	0.26	0.44	0.02[a]	0.15[a]	0.04[a]		
		China 4	0.14[a]	6.22	2.35	0.12	0.11	0.17	0.02[a]	0.06[a]	0.02[a]		
		China 5	0.14[a]	5.29	2.35	0.02	0.02	0.17	0.02[a]	0.02[a]	0.00[a]		
		China 6	0.14[a]	5.29	2.35	0.02	0.02	0.17	0.02[a]	0.02[a]	0.00[a]		
MDT (Medium-duty truck)	Gasoline	China 0	0.02[a]	6.82	170.14	0.34	0.3	8.49	0.03[a]	0.08[a]	0.09[a]	3.90[b]	3.90[b]
		China 1	0.02[a]	3.56	100.84	0.18	0.16	8.67	0.03[a]	0.05[a]	0.05[a]		
		China 2	0.02[a]	3.67	27.67	0.08	0.07	3.86	0.03[a]	0.02[a]	0.02[a]		
		China 3	0.02[a]	2.14	14.61	0.05	0.04	1.93	0.03[a]	0.01[a]	0.01[a]		
		China 4	0.02[a]	1.26	7.13	0.05	0.04	0.97	0.03[a]	0.01[a]	0.01[a]		
		China 5	0.02[a]	0.94	7.13	0.05	0.04	0.97	0.03[a]	0.01[a]	0.01[a]		
		China 6	0.02[a]	0.94	7.13	0.05	0.04	0.97	0.03[a]	0.01[a]	0.01[a]		
	Diesel	China 0	0.14[a]	13.59	15.42	1.53	1.39	6.19	0.02[a]	0.78[a]	0.25[a]	3.90[b]	3.90[b]
		China 1	0.14[a]	9.43	5.42	1.06	0.96	2.8	0.02[a]	0.54[a]	0.17[a]		
		China 2	0.14[a]	7.52	5.13	0.35	0.31	0.74	0.02[a]	0.18[a]	0.06[a]		

		China 3	0.14[a]	7.44	2.61	0.21	0.19	0.35	0.02[a]	0.11[a]	0.03[a]		
		China 4	0.14[a]	4.87	1.77	0.09	0.08	0.14	0.02[a]	0.05[a]	0.02[a]		
		China 5	0.14[a]	4.14	1.77	0.02	0.02	0.14	0.02[a]	0.01[a]	0.00[a]		
		China 6	0.14[a]	4.14	1.77	0.02	0.02	0.14	0.02[a]	0.01[a]	0.00[a]		
LDT (Light-duty truck)	Gasoline	China 0	0.01[a]	3.88	65.23	0.11	0.1	4.16	0.06[a]	0.03[a]	0.03[a]		
		China 1	0.01[a]	2.4	34.81	0.07	0.06	4.25	0.06[a]	0.02[a]	0.02[a]		
		China 2	0.01[a]	2.1	25.55	0.02	0.02	2.83	0.06[a]	0.01[a]	0.01[a]		
		China 3	0.01[a]	0.66	7.65	0.01	0.01	0.86	0.06[a]	0.00[a]	0.00[a]	3.90[b]	3.90[b]
		China 4	0.01[a]	0.32	3.76	0.01	0.01	0.29	0.06[a]	0.00[a]	0.00[a]		
		China 5	0.01[a]	0.24	3.76	0.01	0.01	0.29	0.06[a]	0.00[a]	0.00[a]		
		China 6	0.01[a]	0.24	3.76	0.01	0.01	0.29	0.06[a]	0.00[a]	0.00[a]		
	Diesel	China 0	0.05[a]	8.56	4.23	0.47	0.43	2.61	0.00[a]	0.24[a]	0.08[a]		
		China 1	0.05[a]	7.06	5.4	0.29	0.27	2.54	0.00[a]	0.15[a]	0.05[a]		
		China 2	0.05[a]	6.78	3.6	0.31	0.28	1.63	0.00[a]	0.16[a]	0.05[a]		
		China 3	0.05[a]	4.53	2.37	0.14	0.13	0.46	0.00[a]	0.07[a]	0.02[a]	3.90[b]	3.90[b]
		China 4	0.05[a]	2.97	1.59	0.04	0.04	0.18	0.00[a]	0.02[a]	0.01[a]		
		China 5	0.05[a]	2.52	1.59	0.01	0.01	0.18	0.00[a]	0.01[a]	0.00[a]		
		China 6	0.05[a]	2.52	1.59	0.01	0.01	0.18	0.00[a]	0.01[a]	0.00[a]		
MT (Mini truck)	Gasoline	China 0	0.01[a]	3.88	65.23	0.11	0.1	4.16	0.06[a]	0.03[a]	0.03[a]		
		China 1	0.01[a]	2.4	34.81	0.07	0.06	4.25	0.06[a]	0.02[a]	0.02[a]		
		China 2	0.01[a]	2.1	25.55	0.02	0.02	2.83	0.06[a]	0.01[a]	0.01[a]		
		China 3	0.01[a]	0.66	7.65	0.01	0.01	0.86	0.06	0.00	0.00	3.90[b]	3.90[b]
		China 4	0.01[a]	0.32	3.76	0.01	0.01	0.29	0.06	0.00	0.00		
		China 5	0.01[a]	0.24	3.76	0.01	0.01	0.29	0.06[a]	0.00[a]	0.00[a]		
		China 6	0.01[a]	0.24	3.76	0.01	0.01	0.29	0.06[a]	0.00[a]	0.00[a]		
	Diesel	China 0	0.05[a]	8.56	4.23	0.47	0.43	2.61	0.00[a]	0.24[a]	0.08[a]	3.90[b]	3.90[b]

		China 1	0.05[a]	7.06	5.4	0.29	0.27	2.54	0.00[a]	0.15[a]	0.05[a]		
		China 2	0.05[a]	6.78	3.6	0.31	0.28	1.63	0.00[a]	0.16[a]	0.05[a]		
		China 3	0.05[a]	4.53	2.37	0.14	0.13	0.46	0.00[a]	0.07[a]	0.02[a]		
		China 4	0.05[a]	2.97	1.59	0.04	0.04	0.18	0.00[a]	0.02[a]	0.01[a]		
		China 5	0.05[a]	2.52	1.59	0.01	0.01	0.18	0.00[a]	0.01[a]	0.00[a]		
		China 6	0.05[a]	2.52	1.59	0.01	0.01	0.18	0.00[a]	0.01[a]	0.00[a]		
NM (Normal motorcycle)	Gasoline	China 0	0.00[a]	0.14	18.32	0.03	0.03	2.70	0.01[a]	0.01[a]	0.01[a]	3.90[b]	3.90[b]
		China 1	0.00[a]	0.16	11.27	0.02	0.02	1.21	0.01[a]	0.01[a]	0.01[a]		
		China 2	0.00[a]	0.18	2.89	0.01	0.01	0.65	0.01[a]	0.00[a]	0.00[a]		
		China 3	0.00[a]	0.12	1.43	0.00	0.00	0.28	0.01[a]	0.00[a]	0.00[a]		
LM (Light motorcycle)	Gasoline	China 0	0.00[a]	0.13	12.38	0.03	0.03	7.26	0.01[a]	0.01[a]	0.01[a]	3.90[b]	3.90[b]
		China 1	0.00[a]	0.12	5.26	0.02	0.02	2.63	0.01[a]	0.01[a]	0.01[a]		
		China 2	0.00[a]	0.13	2.21	0.01	0.01	2.02	0.01[a]	0.00[a]	0.00[a]		
		China 3	0.00[a]	0.08	1.06	0.00	0.00	1.18	0.01[a]	0.00[a]	0.00[a]		
LST (Low-speed truck)	Diesel	China 0	0.05[a]	6.04	7.50	0.26	0.25	2.10	0.00[a]	0.14[a]	0.04[a]	3.90[b]	3.90[b]
		China 1	0.05[a]	5.93	4.35	0.23	0.22	1.85	0.00[a]	0.12[a]	0.04[a]		
		China 2	0.05[a]	3.90	2.87	0.13	0.12	1.17	0.00[a]	0.07[a]	0.02[a]		
Bus	Gasoline	China 2	0.02[a]	0.02	19.68	0.08	0.07	2.47	0.03[a]	0.02[a]	0.02[a]	3.90[b]	3.90[b]
		China 3	0.02[a]	1.93	11.22	0.05	0.04	1.19	0.03[a]	0.01[a]	0.01[a]		
		China 4	0.02[a]	1.09	5.96	0.05	0.04	0.70	0.03[a]	0.01[a]	0.01[a]		
		China 5	0.02[a]	0.81	5.96	0.05	0.04	0.70	0.03[a]	0.01[a]	0.01[a]		
	Diesel	China 2	0.14[a]	14.72	12.07	1.27	1.14	0.76	0.02[a]	0.65[a]	0.21[a]	3.90[b]	3.90[b]
		China 3	0.14[a]	14.56	10.58	0.54	0.49	0.62	0.02[a]	0.28[a]	0.09[a]		
		China 4	0.14[a]	13.96	4.52	0.24	0.21	0.18	0.02[a]	0.12[a]	0.04[a]		
		China 5	0.14[a]	12.19	2.25	0.12	0.11	0.10	0.02	0.06[a]	0.02[a]		
	Natural gas	China 2	0.00[a]	13.06	12.11	0.08	0.07	2.86	0.00[a]	0.02[a]	0.02[a]	0.092[b]	0.003[b]

		China 3	0.00[a]	9.32	6.36	0.05	0.04	1.72	0.00[a]	0.01[a]	0.01[a]		
		China 4	0.00[a]	6.52	4.67	0.05	0.04	1.19	0.00[a]	0.01[a]	0.01[a]		
		China 5	0.00[a]	3.73	4.57	0.05	0.04	1.19	0.00[a]	0.01[a]	0.01[a]		
Taxi	Gasoline	China 3	0.01[a]	0.31	4.89	0.01	0.01	0.70	0.07[a]	0.00[a]	0.00[a]	3.90[b]	3.90[b]
		China 4	0.05[a]	0.90	0.18	0.03	0.03	0.02	0.00[a]	0.02[a]	0.01[a]		
	Diesel	China 3	0.05[a]	1.24	0.22	0.05	0.04	0.04	0.00[a]	0.02[a]	0.01[a]	3.90[b]	3.90[b]
		China 4	0.01[a]	0.26	4.39	0.00	0.00	0.48	0.07[a]	0.00[a]	0.00[a]		
	Natural gas	China 3	0.00[a]	0.06	0.84	0.01	0.01	0.12	0.00[a]	0.00[a]	0.00[a]	0.092[b]	0.092[b]
		China 4	0.00[a]	0.04	0.54	0.00	0.00	0.07	0.00[a]	0.00[a]	0.00[a]		

Unit: g/km; kgCH_4/TJ; kgN_2O/TJ; Notice: The emission factors for NOx, CO, PM_{10}, $PM_{2.5}$ and VOCs are based on corrections made using parameters such as temperature and wind speed to the local emission factors.

[a] zhang. (2025)

[b] IPCC. (2006)

Table S6. Emission factors for Oil storage and transportation

Sources	VOCs	CH_4
Mobile source and oil storage and transportation (Oil storage)		
Gasoline station		
Gasoline	3.24[a]	
Diesel	0.08[a]	
Oil storage		
Gasoline	0.16[a]	
Diesel	0.05[a]	
Crude oil	0.12 [a]	7.53[b]
Mobile source and oil storage and transportation (Oil transportation)		
Gasoline	1.6[a]	
Diesel	0.05[a]	
Natural gas	2.6[a]	

Unit: g/kg; g/t

[a] He et al. (2018)

[b] MEPPRC (2024)

Table S7. Emission factors of Resident source

Source type		Emission factor (kg/t)								
		SO_2	NOx	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3	CH_4	N_2O
Residential combustion	Coal	18.5[h]	1.88[h]	75[i]	9.52[h]	7.35[h]	1.8[h]	0.9[h]		
	Natural gas	0.18[f]	1.76[j]	1.3[a]	0.24[k]	0.1[k]	0.18[h]	0.32[h]		
Interior straw burning	Rice	0.48[a]	0.31[a]	67[a]	6.68[a]	6.4[a]	8.4[a]	0.52[a]	2.8[g]	0.13[g]
	Corn	1.33[a]	1.86[d]	56.60	7.39	6.87	7.34	0.37[b]	2.8[g]	0.13[g]
	Wheat	0.04[b]	1.19[d]	171.70	8.86	8.24	13.74[e]	1.3[c]	2.8[g]	0.13[g]
	Others	0.27[d]	2.49[d]	85.20	7.69	7.15	7.97[f]	1.3[b]	2.8[g]	0.13[g]
Interior wood burning		0.40[a]	1.19[e]	75.93[f]	6.16[b]	3.24[a]	3.13[a]	1.3[a]	2.4[g]	0.08[g]
Domesticate solvent (City)								0.5[l]		
Domesticate solvent (Rura)								0.1l		
Pesticide use								568/562/576/382/568/355.8[a]		
Cooking								3.5[m]		
Building interior wall (waterborne coating)								120[a]		
Building exterior wall (solvent coating)								360[a]		
Road asphalt paving								353[a]		
Catering					8[a]	6.4[a]	5.6[a]			

Unit: g/kg.

Note: In interior biogas burning, the CH_4 and N_2O emission factor (kg/TJ) needs to be multiplied by the NCV of fuel (see Table S3).

[a] He et al. (2018)

[b] Li et al. (2007)

[c] Andreae and Merlet (2001)

[d] Cao et al. (2011)

[e] Wang et al. (2009)

[f] Lu (2014)

[g] NDRC (2011)

[h] MEPPRC (2014)

[i] Wang et al. (2005)

[j] Yin et al. (2010)

[k] He et al. (2013)

[l] Wang (2006)

[m] Pan et al. (2015)

Table S8. Emission factors for waste treatment source

Sources	PM_{10}	$PM_{2.5}$	VOCs	NH_3	CO_2	CH_4	N_2O
Sewage treatment			0.0011[a]	0.003[b]		0.099[c]	0.005[c]
Waste treatment							
Waste incineration			0.74[a]	0.21[a]			
Landfill			0.74[a]	1.275[a]			
Garbage composting			0.23[a]	0.56[a]			

Unit: kg/t, g/m^3, kg/year/people, t/MWh.

[a] MEPPRC (2014).

[b] Wei (2009)

[c] NDRC (2011)

Table S9. The key parameters used in emission calculation

	L_0	OX	Nex	$Frac_{gas}$	N_E
Landfill	0.043[a]	0.1[a]			
Sewage treatment					369.045[a]
livestock and poultry farms				40/25/45/48[a]	
Non-dairy milk			40[b]		
milk			60[b]		
poultry			0.6[b]		
sheep			12[b]		
pig			16[b]		
other			40[b]		

Unit： 10^4t CH_4/10^4t waste; kg N/ head/year; %; kg N

[a] MEPPRC (2024)

[b] NDRC (2011)

Table S10. N_2O emission factors for agricultural source

	EF_i	EF_1
livestock and poultry farms		0.01[a]
Liquid storage	0.005[a]	
solid storage	0.02[a]	
grazing/free-range	0.02[a]	
composting	0.01[a]	
other	0.005[a]	

Unit:kg N_2O-N/kg N; kg/ head

[a] MEPPRC (2024)

Table S11. Temporal allocation profile and reference for difference source

Category	Subcategory	Temporal allocation	profile reference
Electricity and thermal power	Power plant	Thermal power generation	National Bureau of Statistics of China
Industry	Industrial combustion	Industrial Boiler Output	National Bureau of Statistics of China
	Non-metallic mineral industry	Product yield	
	Ferrous metals industry		
	Nonferrous metals industry		
	Chemical raw material industry		
	Alcohol		
	Papermaking		
	Chemical fiber production		
	Rubber and plastic production		
	Food industry		
	Industrial solvent use	Consumption of industrial solvent	Local investigation
Mobile source and oil storage and transportation	On-road mobile sources	Traffic flow	Henan Provincial Department of transportation
	Non-road mobile source	Airports' passenger flow, agricultural busy production and operation, railway transport data	
	Oil storage and transportation	Average	
Fugitive dust	Road dust	Rainfall information, traffic flow	Henan Provincial Department of transportation, national Bureau of Statistics of China
	Construction dust	Construction area	
	Soil dust	Average	
	Yard dust	Yard area	
Resident	Residential combustion	Natural gas variation	National Bureau of Statistics of China
	Interior straw burning	Average	
	Interior wood burning	Average	
	Residential solvent use	Average	

Agriculture	Building surface coating	Completed area of residential	Local investigation
	Road asphalt paving	Consumption of asphalt	
	Catering	Restaurant hours business hours	
	Livestock	Average	
	Fertilizer application	Consumption of fertilizer	
	Natural ammonia sources	Average	
	Farming land	Consumption of fertilizer, farming time	
	Open straw burning	Monthly fire points	https://firms.modaps.eosdis.nasa.gov
Waste treatment	Sewage treatment	Average	
	Garbage disposal	Average	

Table S12. Spatial allocation profile and reference for difference source

Category	Subcategory	Spatial allocation	Profile reference
Electricity and thermal power	Power plant	Longitude and latitude	
Industry	Industrial combustion	Longitude and latitude	
	Non-metallic mineral industry	The latitude and longitude of industrial plants	
	Ferrous metals industry		
	Nonferrous metals industry		
	Chemical raw material industry		
	Alcohol		
	Papermaking		
	Chemical fiber production		
	Rubber and plastic production		
	Food industry		
	Industrial solvent use	The latitude and longitude of industrial plants	National Earth System Science Data Sharing Infrastructure (Google Maps)
Mobile source and oil storage and transportation	On-road mobile sources	Road	
	Non-road mobile source	Cultivated fields, population, railway, longitude and latitude of airport	
	Oil storage and transportation	Latitude and longitude，Population	
Fugitive dust	Road dust	Road	
	Construction dust	Construction area	
	Soil dust	Soil area	
	Yard dust	Longitude and latitude	
Resident	Residential combustion	Population	
	Interior straw burning	Rural residential	
	Interior wood burning	Rural residential	
	Residential solvent use	Population	
	Building surface coating	Population	
	Road asphalt paving	Road	

	Catering	Population, latitude and longitude
Agriculture	Livestock	Rural residential
	Fertilizer application	Arable land
	Natural ammonia sources	Rural residential
	Farming land	Arable land
	Open straw burning	Arable land
Waste treatment	Sewage treatment	Latitude and longitude
	Garbage disposal	Latitude and longitude

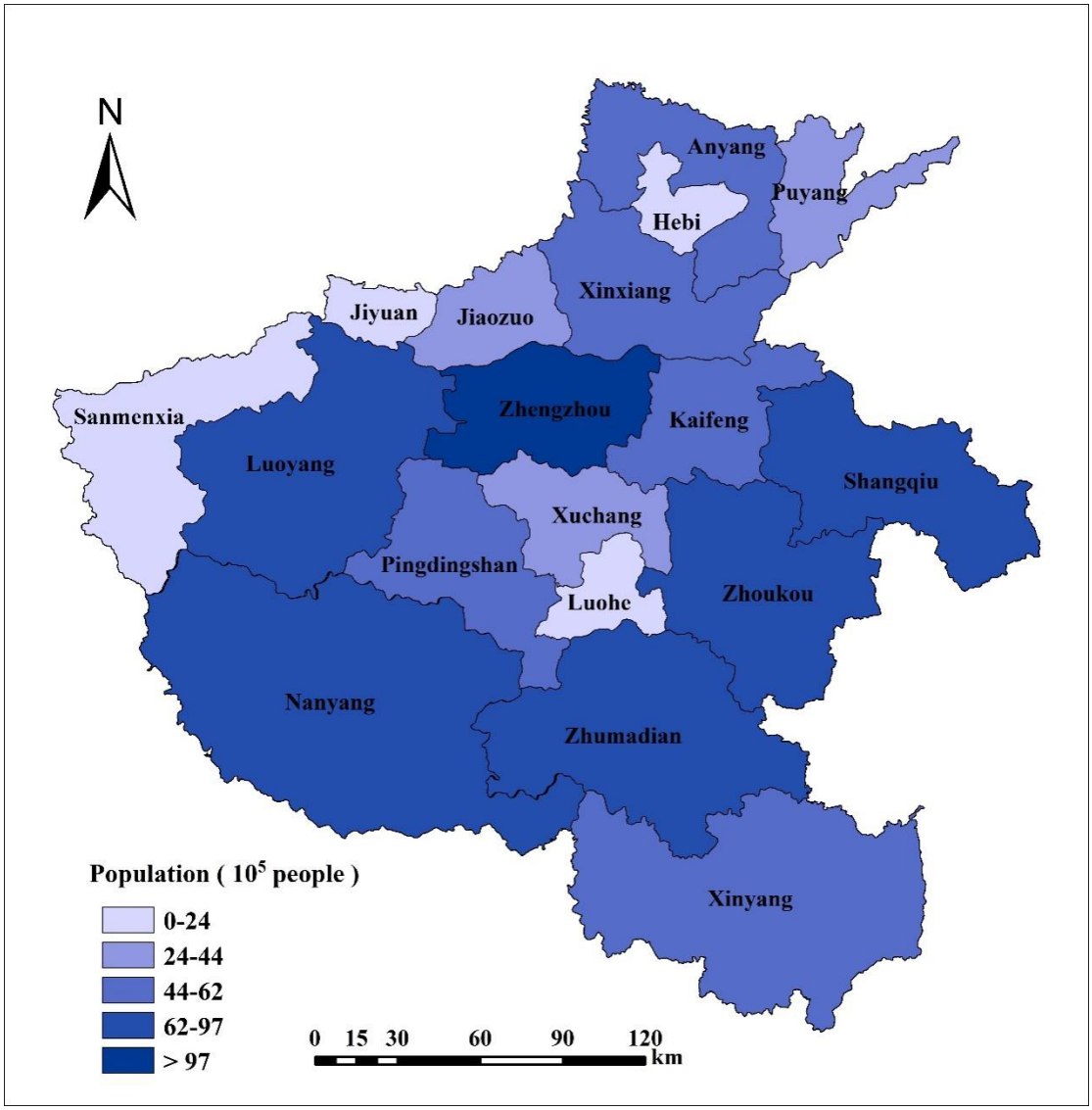


Figure S1. Spatial distribution of population in Henan Province.

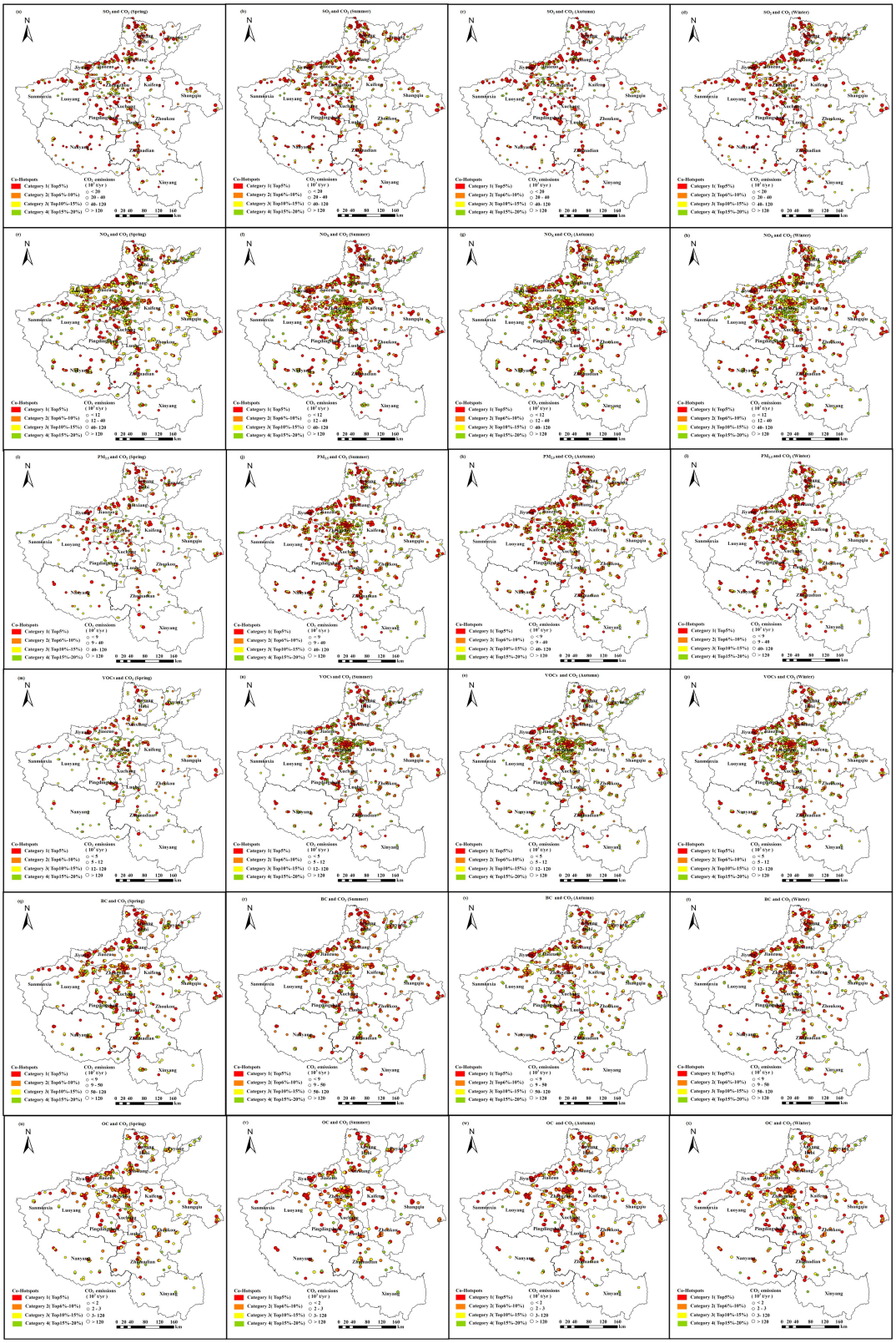


Figure S2. Seasonal spatial maps of the co-hotspots of (a-d) SO_2 and CO_2, (e-h) NO_X and CO_2, (i-l) $PM_{2.5}$ and CO_2, (m-p) VOCs and CO_2, (q-t) BC and CO_2, and (u-x) OC and CO_2 from spring to winter.

Sect. S1 Spatial pattern comparison and attribution of discrepancies between the 3×3 km emission inventory and CHAP concentration data.

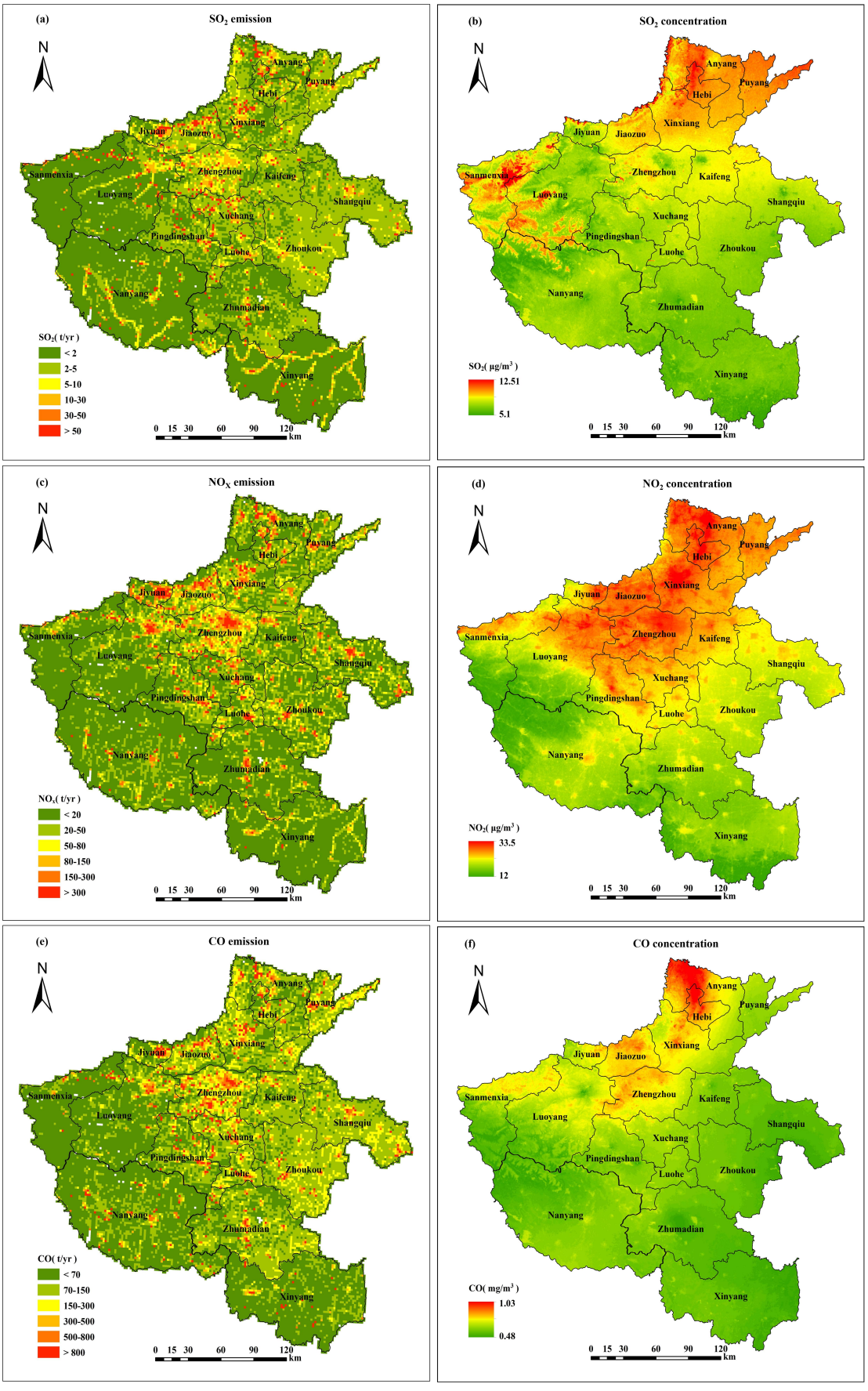
To verify the rationality of the 2022 provincial-level 3 km × 3 km grid emission inventory constructed in Henan Province in terms of spatial distribution, we conducted a systematic spatial comparison analysis with the CHAP (China High-Resolution Air Pollutants) concentration dataset at the same period with a resolution of 1 km × 1 km. Figure S3 shows the spatial comparison of the concentrations (a, c, e, and g) and emissions (b, d, f, and h) of four pollutants: SO_2, NO_X, CO, and $PM_{2.5}$. The specific analysis is as follows.

Figure S3 shows that the high SO_2 emission areas (a) are located near major point sources in cities such as Anyang, Xinxiang, and Jiaozuo, exhibiting significant spatial overlap with the high-concentration zones (b). This indicates that the emission inventory used in this study effectively captures the primary local emission sources. However, the spatial extent of the high-concentration regions (b) is broader than that of the high-emission areas (a), particularly evident in the western Henan region, including Sanmenxia and Luoyang. This is primarily due to the region's proximity to the industrial areas of Shaanxi and Shanxi provinces located upwind. During autumn and winter, prevailing westerly or northwesterly winds place western Henan downwind of these pollution sources, making it a key receptor area for interprovincial pollutant transport. Furthermore, the local mountainous and basin topography hinders the dispersion of pollutants, leading to the accumulation of both transported and locally emitted SO_2, thereby elevating observed concentrations.

The spatial patterns of high NO_X emissions (c) and high NO_X concentrations (d) are highly consistent, with both concentrated in the densely industrialized and populated regions of central and northern Henan, particularly around Zhengzhou, Luoyang, Anyang, Xinxiang, and Jiaozuo. This agreement validates the accuracy of the 3×3 km gridded emission inventory in identifying and locating major anthropogenic sources. Nevertheless, the high-concentration zones exhibit a wider spatial extent and greater continuity compared to the emission hotspots. This expansion is a natural consequence of atmospheric diffusion, regional transport, and active chemical transformation processes. It should be emphasized that the gridded emission inventory precisely characterizes the initial location and magnitude of surface emissions but does not inherently account for subsequent atmospheric dispersion, transport, or chemical reactions.

High CO emission areas (e) and high CO concentration zones (f) show strong macro-scale spatial correspondence, especially along the northern Henan industrial corridor and in major urban centers such as Zhengzhou and Luoyang. Although regions such as Nanyang, Zhumadian, Zhoukou, and Shangqiu exhibit relatively high emissions, their observed pollutant concentrations remain at moderate to low levels. This phenomenon can be attributed to three primary factors: First, these areas are located in the flat and open expanse of the Huang-Huai-Hai Plain, which facilitates the dispersion of air pollutants. Second, the emissions in these regions are predominantly derived from low-level area sources such as residential coal combustion and transportation, which tend to disperse more easily under favorable meteorological conditions and thus make limited contributions to peak ground-level concentrations.

Primary $PM_{2.5}$ emission hotspots (g) are highly concentrated in the industrial and urban centers of central and northern Henan, including Zhengzhou, Anyang, and Jiaozuo, accurately reflecting the spatial distribution of local anthropogenic emission sources. In contrast, the concentration-based high-value zones (h) display a distinct "areal" pattern, with extensive and continuous high-concentration regions extending beyond the core emission areas to cover most of northern and eastern Henan, as well as broader surrounding regions. This spatial divergence between "grid-resolved emissions" and "areal pollution" arises mainly from two factors: first, secondary chemical formation processes convert gaseous precursors such as SO_2 and NO_X into substantial amounts of secondary particulate matter at the regional scale, effectively smoothing and expanding the localized peaks associated with primary emissions; second, northern Henan lies downstream of the Beijing-Tianjin-Hebei and surrounding regions' pollution transport corridor. Under specific synoptic conditions, the prevailing northerly winds during autumn and winter facilitate the convergence of pollutants transported from upstream provinces with local emissions and secondary aerosol products, resulting in pronounced pollutant accumulation and a regionalized pollution pattern across northern Henan and its downwind areas.


(a)
SO2 emission
N
Anyang
Puyang
Hebi
Xinxiang
Jiyuan
Jiaozuo
Sanmenxia
Zhengzhou
Kaifeng
Luoyang
Shangqiu
Xuchang
Pingdingshan
Luohe
Zhoukou
Nanyang
Zhumadian
Xinyang
SO2(t/yr)
< 2
2-5
5-10
10-30
30-50
> 50
0 15 30 60 90 120
km
(b)
SO2 concentration
SO2(μg/m3)
12.51
5.1
(c)
NOX emission
NOX(t/yr)
< 20
20-50
50-80
80-150
150-300
> 300
(d)
NO2 concentration
NO2(μg/m3)
33.5
12
(e)
CO emission
CO(t/yr)
< 70
70-150
150-300
300-500
500-800
> 800
(f)
CO concentration
CO(mg/m3)
1.03
0.48

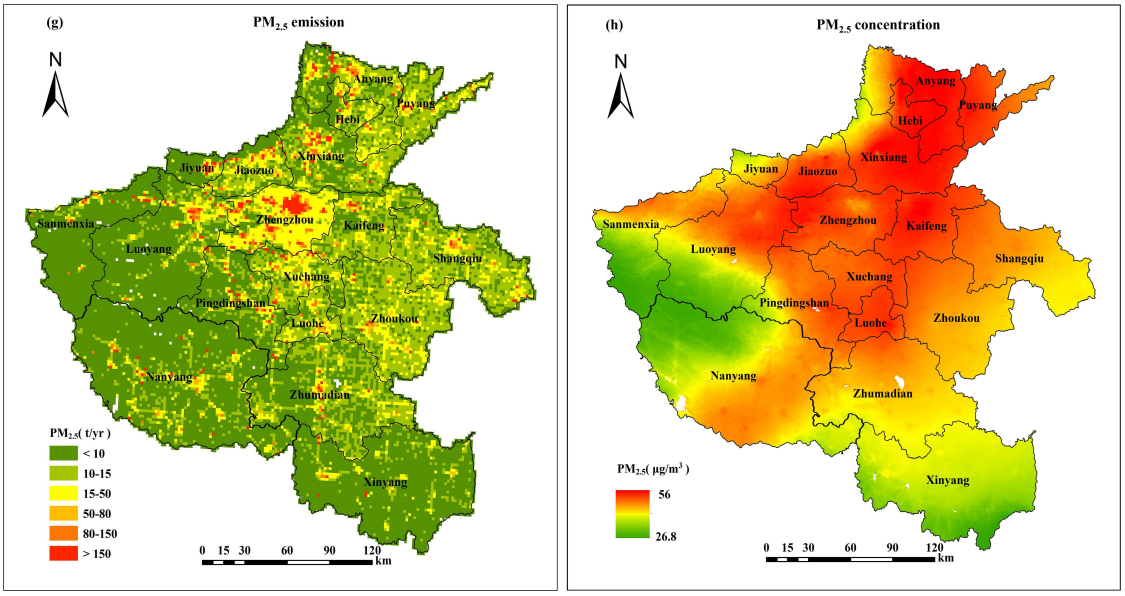


Figure S3. Side-by-side comparison of spatial distributions between 3 km × 3 km gridded emissions inventory (a, c, e, and g) and CHAP-derived (b, d, f, and h) concentrations for SO_2, NO_X, CO, and $PM_{2.5}$ in Henan Province, 2022.

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