Supplementary Material

PTowards Sustainable Air Quality in Coal-Heated Cities: A Case Study from Astana, Kazakhstan

Akmaral Agibayeva, Aiganym Kumisbek, Aslan Nauyryzbay, Egemen Avcu, Kuanysh Zhalgasbayev, Ferhat Karaca and Mert Guney

Table S1: Overview of $PM_{2.5}$ and $PM_{2.5-10}$ sampling periods.

		Sampling period
2021	Fall	Oct 15-Nov 5 Nov 12-Nov 25
2022	Winter	Feb 4-Feb 17 Dec 9-Dec 23
	Spring	Mar 4 Mar 18 Apr 8- Apr 22 May 20-May 31
	Summer	June 1-June 3 June 20- June 29 July 15-July 29
	Fall	Aug 23-Aug 31 Sep 1-Sep 6
2023	Winter	Jan 20-Feb 3
	Spring	Mar 30-Apr 13 May 30- May 31
	Summer	June 1-June 13

	Total by season	
	Number of samples	
	$PM_{2.5}$	**$PM_{2.5-10}$**
Fall	43	43
Winter	44	44
Spring	58	58
Summer	49	49

Table S2: Overview of snow and rainwater sampling periods.

Season	Sampling period	Number of samples
Winter	December 13, 2022; December 22, 2022; January 4, 2023; January 20, 2023; January 23, 2023; February 10, 2023 February 24, 2023	7
Spring	March 18, 2022; March 24, 2022; April 6, 2022; April 19, 2022; April 21, 2022; April 22, 2022; May 22, 2022; May 31, 2022; March 10, 2023; March 14, 2023; March 15, 2023	12
Summer	June 1, 2022; June 5, 2022; June 13, 2022; June 25, 2022; July 5, 2022; August 11, 2022	6
Fall	September 11, 2022; September 27, 2022; October 9, 2022; October 22, 2022; November 15, 2022	5

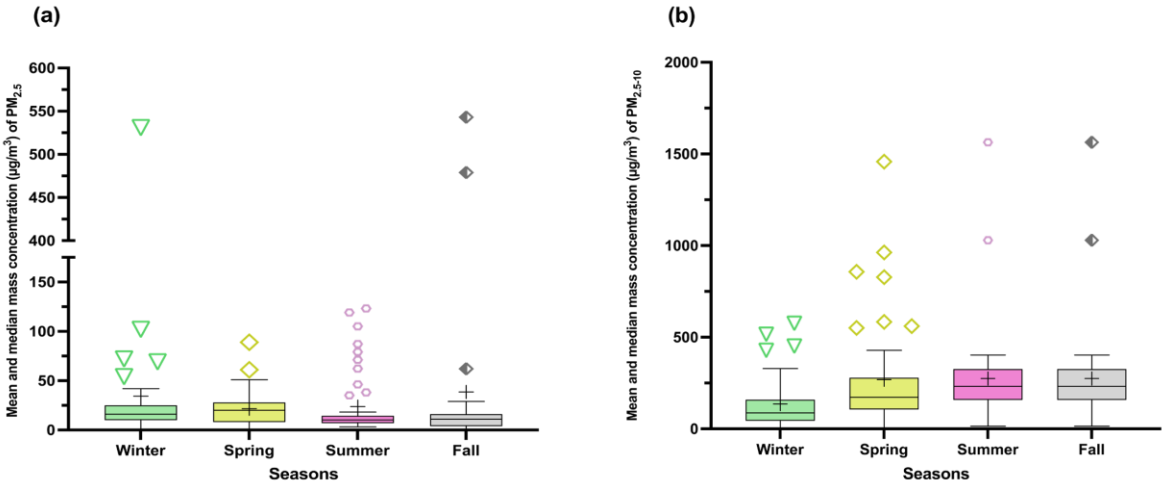


Figure S1: Mean and median mass concentration ($\mu g \cdot m^{-3}$) of (a) $PM_{2.5}$ and (b) $PM_{2.5\text{-}10}$ in four seasons.

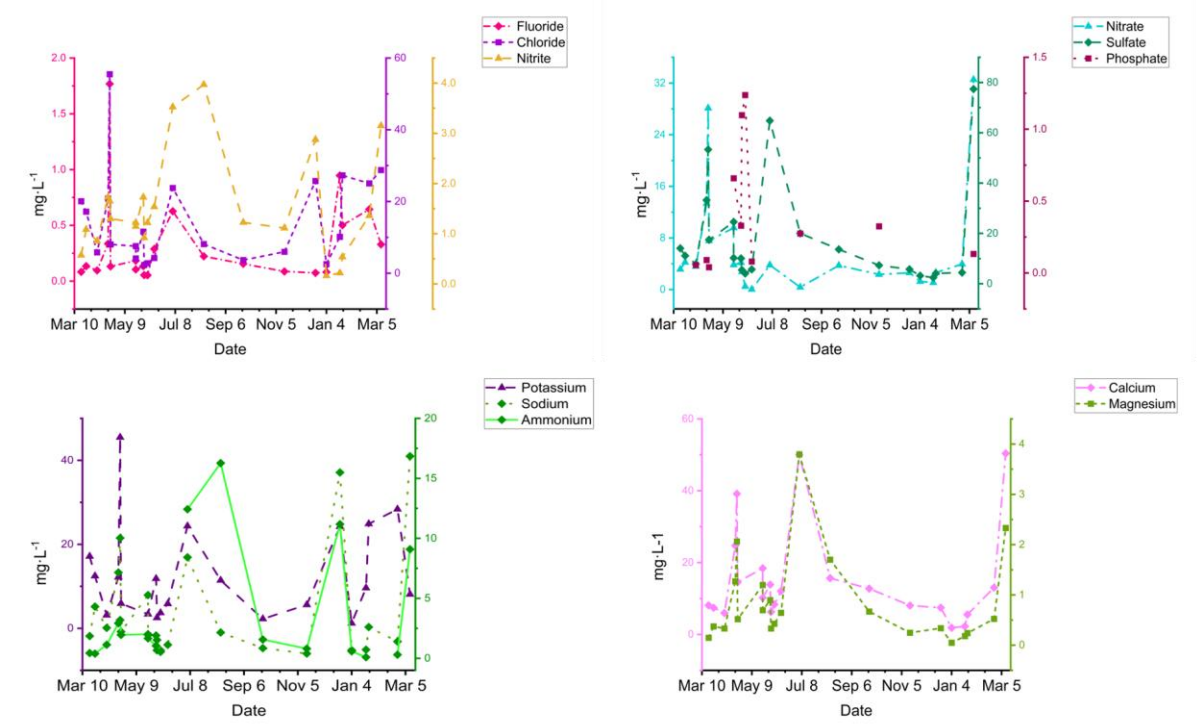


Figure S2: Concentrations of water-soluble ions ($mg \cdot L^{-1}$) (F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, K^+, Na^+, NH_4^+, Ca^{2+}, Mg^{2+}) in snow and rainwater samples by date collected in Astana from March 2022 to March 2023.

Attribute	Ca_ppm	Cl_ppm	F_ppm	K_ppm	Mg_ppm	Na_ppm	NH4_ppm	NO2_ppm	NO3_ppm	PO4_ppm	SO4_ppm	sum_anions	sum_cations
Ca_ppm	1.00	0.59	0.45	0.40	0.93	0.68	0.53	0.66	0.75	-0.19	0.98	0.81	0.94
Cl_ppm	0.59	1.00	0.75	0.92	0.46	0.66	0.24	0.29	0.67	-0.41	0.58	0.81	0.73
F_ppm	0.45	0.75	1.00	0.76	0.41	0.26	0.04	0.06	0.50	-0.32	0.42	0.64	0.51
K_ppm	0.40	0.92	0.76	1.00	0.37	0.43	0.23	0.26	0.35	-0.37	0.34	0.71	0.60
Mg_ppm	0.93	0.46	0.41	0.37	1.00	0.55	0.67	0.75	0.51	-0.15	0.89	0.72	0.90
Na_ppm	0.68	0.66	0.26	0.43	0.55	1.00	0.58	0.61	0.70	-0.29	0.71	0.62	0.80
NH4_ppm	0.53	0.24	0.04	0.23	0.67	0.58	1.00	0.93	0.18	-0.10	0.53	0.49	0.70
NO2_ppm	0.66	0.29	0.06	0.26	0.75	0.61	0.93	1.00	0.28	-0.05	0.61	0.59	0.77
NO3_ppm	0.75	0.67	0.50	0.35	0.51	0.70	0.18	0.28	1.00	-0.19	0.80	0.72	0.69
PO4_ppm	-0.19	-0.41	-0.32	-0.37	-0.15	-0.29	-0.10	-0.05	-0.19	1.00	-0.22	-0.33	-0.27
SO4_ppm	0.98	0.58	0.42	0.34	0.89	0.71	0.53	0.61	0.80	-0.22	1.00	0.78	0.91
sum_anions	0.81	0.81	0.64	0.71	0.72	0.62	0.49	0.59	0.72	-0.33	0.78	1.00	0.87
sum_cations	0.94	0.73	0.51	0.60	0.90	0.80	0.70	0.77	0.69	-0.27	0.91	0.87	1.00

Figure S3: Pearson correlation matrix of measured concentrations of soluble fractions as well as total sums of all anions (including HCO_3^-) and cations (including H^+).

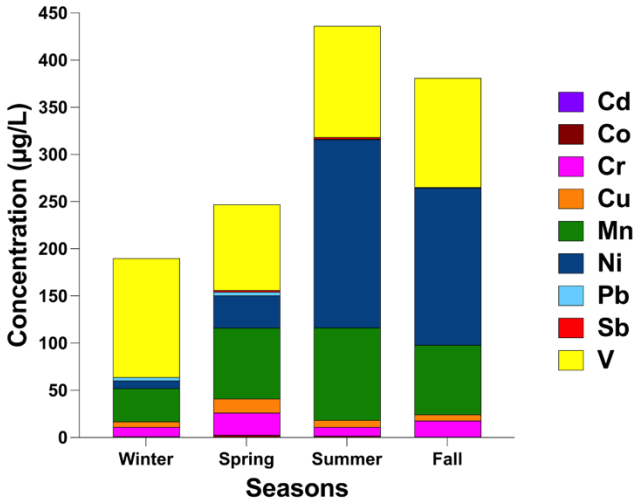


Figure S4: Average concentration of PTEs ($\mu g \cdot L^{-1}$) (Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, and V) in precipitation in four seasons.

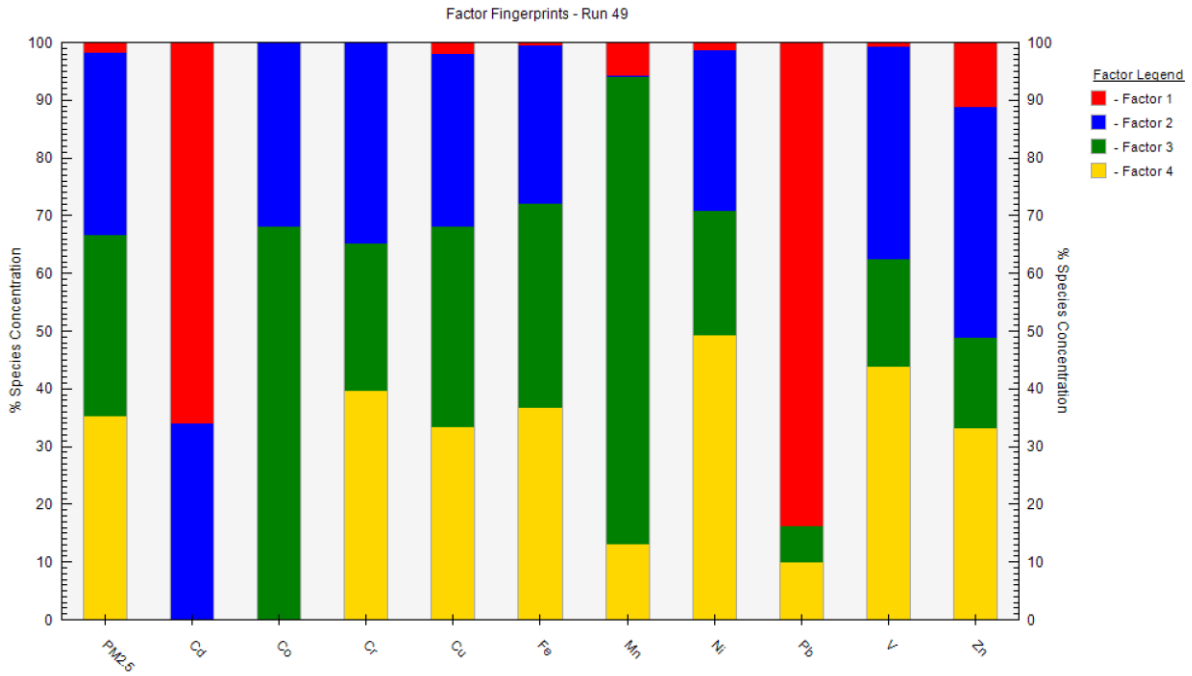


Figure S5: PMF factor fingerprints for the four-factor solution in Astana.

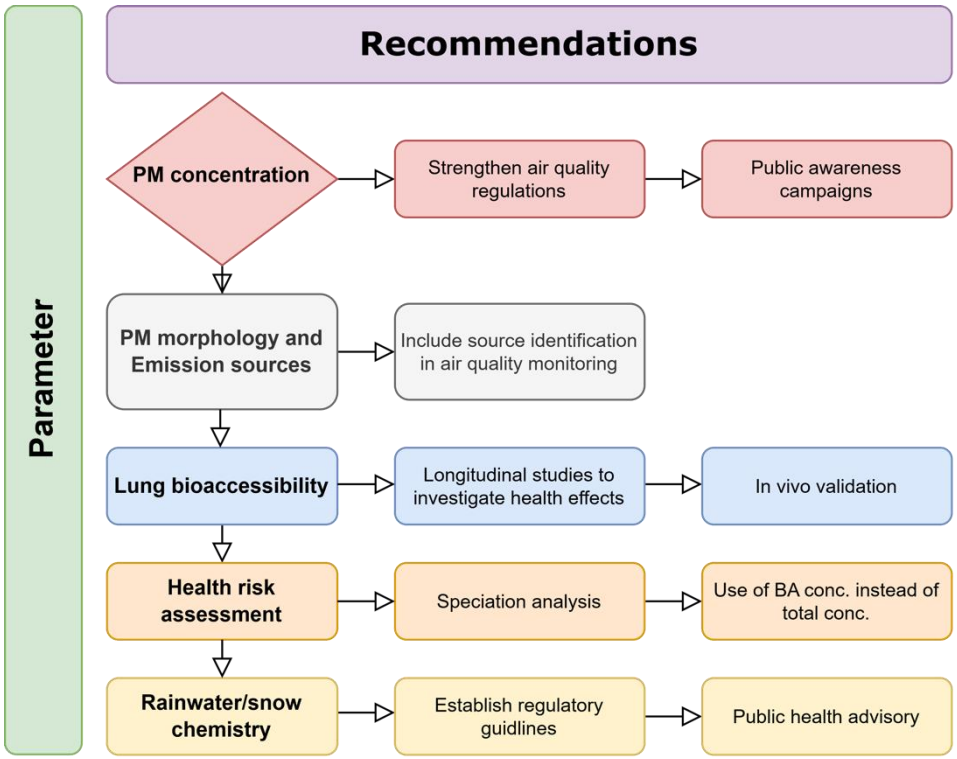


Figure S6: Key analyzed parameters and corresponding recommendations for air quality management.