Atmospheric Composition and the Asian Monsoon (ACAM)

The 5th ACAM workshop

8-10 June 2023, Dhaka, Bangladesh

Presentation # 07.02_Rahman

Assessment and source apportionment of potential trace elements in $PM_{2.5}$ with especial emphasis on seasonal variation in the capital city of Bangladesh

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Air Pollution in Dhaka City, Bangladesh

- **The PMs is one the major components of air pollution**, which is originate from fine particles, liquid and gaseous constituents.

- PM and dust act as **recipient of potential toxic elements (PTEs)** from different sources and makes a significant contribution into air pollution in urban environment.

- **Research interest on potential toxic metals pollution** linked with PMs has been increased in the last decades in the world.

Major reasons for air pollution

Major reasons for air pollution

Bangladesh Road Transport Authority

NUMBER OF REGISTERED MOTOR VEHICLES IN BANGLADESH (YEARWISE)

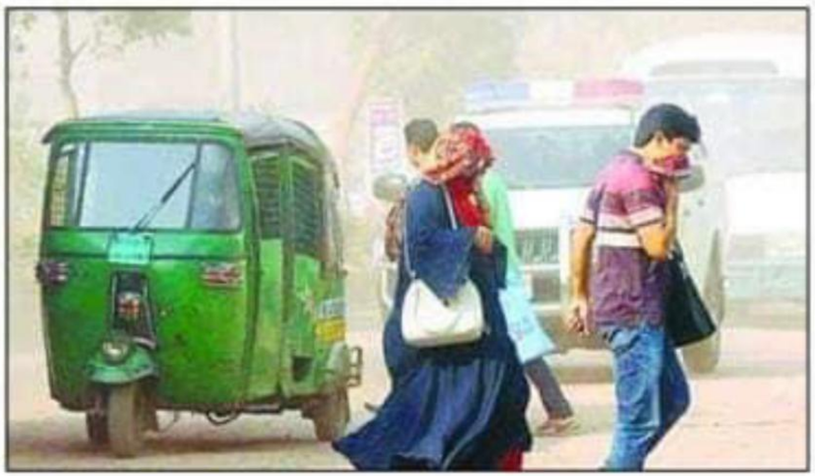
Sl. No	Type of Vehicles	Upto-2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Upto Feb/22	Grand Total
1	Ambulance	2486	218	181	240	337	472	374	493	563	665	788	755	135	**7707**
2	Auto Rickshaw	110623	20406	23528	15633	19828	18700	10656	8852	21593	29807	16724	9158	640	**306148**
3	Auto Tempo	9446	175	626	393	472	1081	1313	1592	609	224	77	25	2	**16035**
4	Bus	23385	1753	1438	1104	1486	2378	3832	3757	2755	3558	2395	1517	315	**49673**
5	Cargo Van	3363	489	282	686	605	398	1015	1413	1280	4	2	3	0	**9540**
6	Covered Van	6022	2480	1511	2347	2950	2442	3399	5201	5728	3070	2023	3800	921	**41894**
7	Delivery Van	15391	1037	802	941	1235	1779	2220	2420	2105	1523	1170	1436	216	**32275**
8	Human Hauler	4827	1151	714	385	225	1129	3443	3393	1418	509	122	52	2	**17370**
9	Jeep(Hard/Soft)	28131	2141	1575	1303	1849	3564	4869	5419	5547	5627	4911	7602	1654	**74192**
10	Microbus	62399	4037	3031	2530	4302	5177	5789	5571	4131	3682	2779	4941	1325	**109694**
11	Minibus	23070	271	246	148	257	320	459	491	436	835	620	392	72	**27617**
12	Motor Cycle	755514	116534	101895	85321	90401	229010	315089	325876	393545	401452	311016	375252	84583	**3585488**
13	Pick Up (Double/Single Cabin)	29103	10314	7530	6443	9424	9992	11220	13454	13060	11918	10498	10897	1751	**145604**
14	Private Passenger Car	207989	12942	9220	10456	14681	21029	20268	21952	18222	16779	12403	16049	3123	**385113**
15	Special Purpose Vehicle	5022	391	225	228	174	298	613	994	1334	1179	703	518	64	**11743**
16	Tanker	2606	309	188	218	350	319	380	317	527	417	304	248	57	**6240**
17	Taxicab	35122	75	170	50	372	83	43	14	159	11	8	0	2	**36109**
18	Tractor	14648	5195	3494	1885	1521	1689	2535	2777	3553	2561	2498	2567	398	**45321**
19	Truck	65889	6853	4043	4838	7939	6022	6605	10329	12644	8318	4719	5789	935	**144923**
20	Others	22332	1265	1062	1064	1580	2059	3842	5018	5973	5293	3900	4029	683	**58100**
TOTAL		**1427368**	**188036**	**161761**	**136213**	**159988**	**307941**	**397964**	**419333**	**495182**	**497432**	**377660**	**445030**	**96878**	**5110786**

The Daily Ittefaq: 2nd Sep., 2021

শিকাগো বিশ্ববিদ্যালয়ের গবেষণা

বায়ুদূষণে রাজধানীবাসীর আয়ু কমছে সাড়ে সাত বছর

সারা বিশ্বে গড়ে দুই বছর



Selected countries

Bangladesh	India	Nepal	Singapore	Pakistan	China	Bhutan
6.2 Years	5.2	4.7	3.4	2.7	2.3	2.3

*Source : *Air Quality Life Index* AFP

Air pollution alone accounts for 17.6% of the risk of death and disability in Bangladesh

The cost of toxic air pollution

THE BUSINESS STANDARD

Wednesday September 14, 2022

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বাংলা

ENVIRONMENT

Mohammad Ali & Kamran Siddiqui

13 February, 2020, 03:05 pm

Last modified: 13 February, 2020, 05:33 pm

Bangladesh loses $14bn a year to air pollution

THE COST OF TOXIC AIR

$38.3 million lost per day due to air pollution in Bangladesh

China bears the highest cost from fossil fuel air pollution

4.5 million die prematurely per year worldwide due to air pollution

4 million new cases of asthma in children each year linked to **NO2** pollution

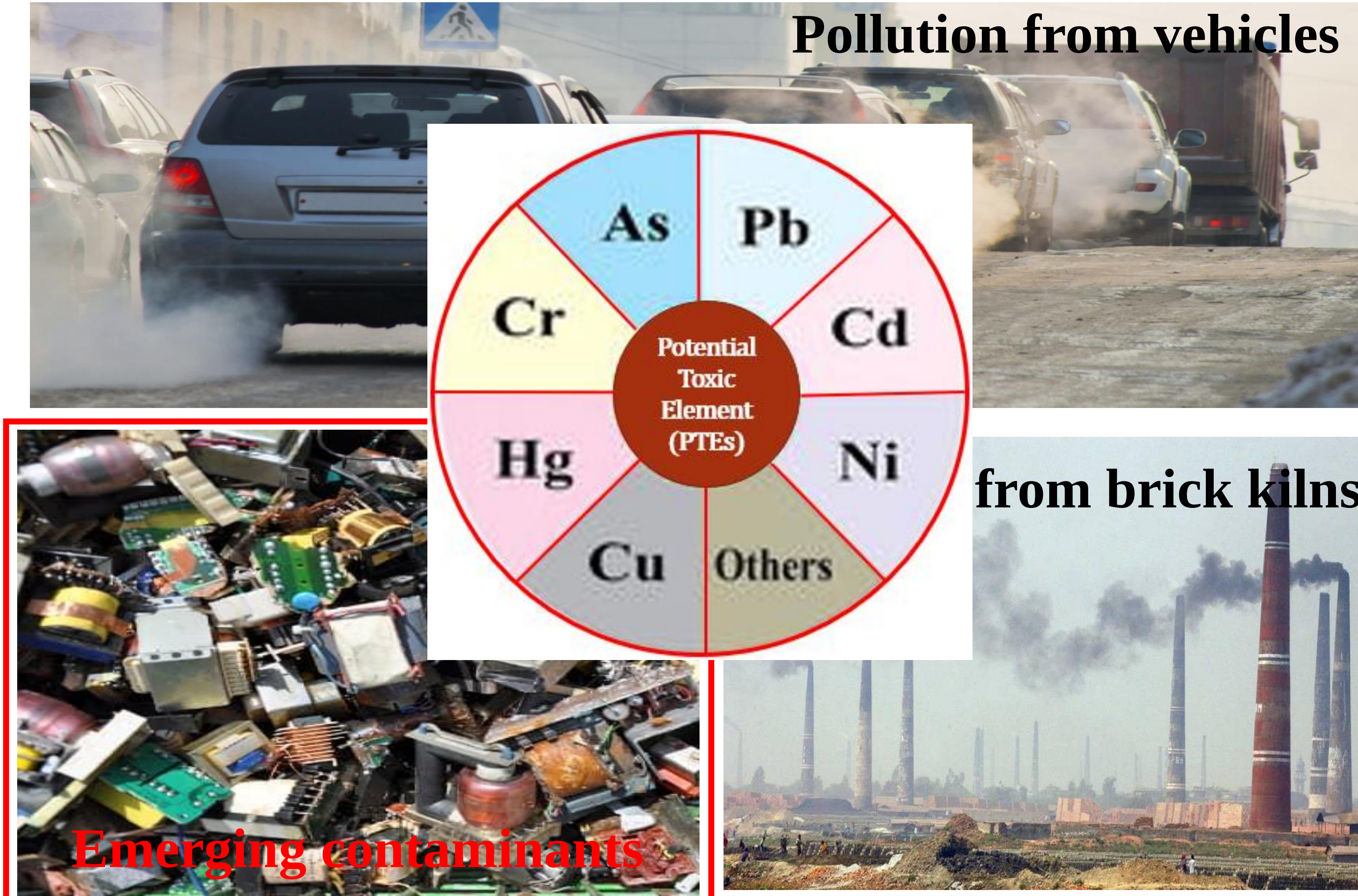
$8 billion lost worldwide due to air pollution from fossil fuels every day

	Total Cost (Million USD)	Premature Deaths (2018)
India	150,000	1,000,000
Bangladesh	**14,000**	**96,000**
Pakistan	6,100	50,000
Nepal	940	12,000
Sri Lanka	760	3,300
Afghanistan	270	3,900
Bhutan	54	240
Maldives	26	40

SOURCE: SOURCE: GREENPEACE

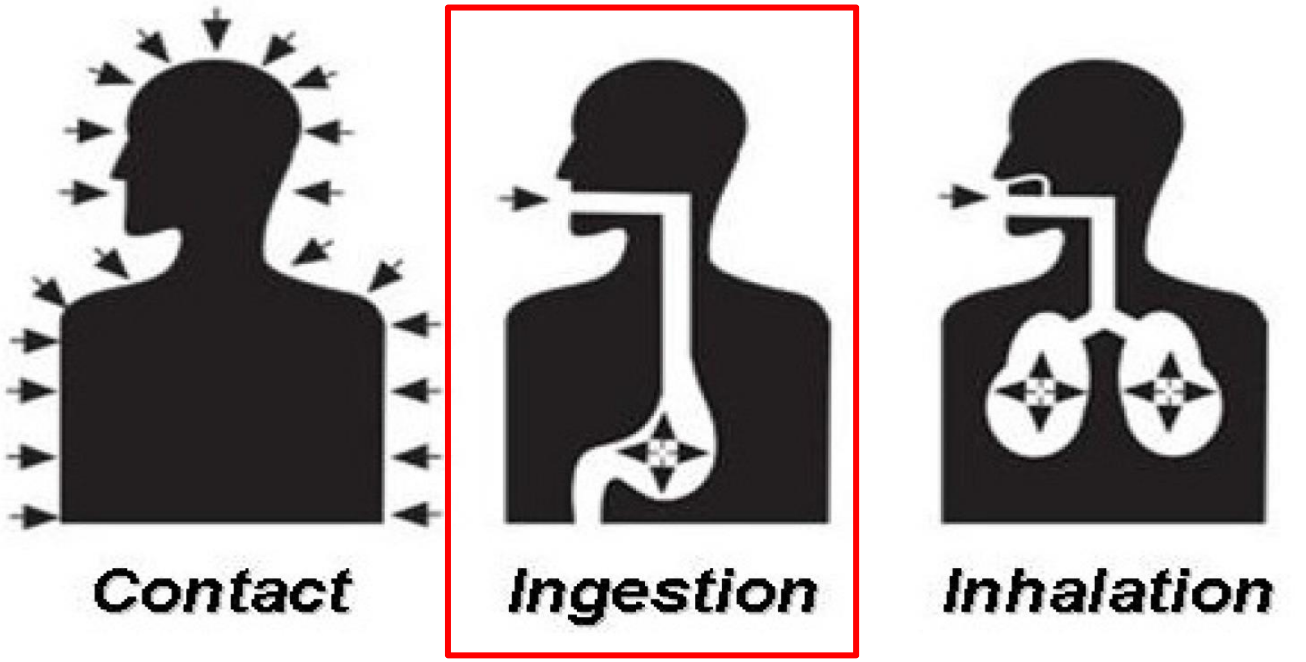
Source: Greenpeace Southeast Asia

Potential toxic elements in PMs



Exposure pathways

Contaminants (**PTEs**) in road dusts can directly pose significant human health risks through oral ingestion, particle inhalation, and dermal contact.



Metals toxicity in human health

- Pb: It causes neurodevelopment in children, memory loss
- Cd: toxic effects on the kidney, classified as a human carcinogen
- Zn: Long term zinc toxicity can suppress the immune system. It damages kidney and stomach
- Hg: Mental retardation, blindness, neurological deficits, and mercury poisoning can result in death
- Cu: It damages liver and kidney
- Cr: It increases risk of respiratory system cancers
- Mn: It causes permanent neurological disorder
- Ni: It has adverse health effect --induced toxicity & carcinogenicity
- As: Long-term exposure to As can cause different types of cancer

No. of cancer deaths and new cases in the world as estimated for 2000[1] and predicted for 2021[2]

Year	Region	New cases (millions)	Deaths (millions)
2000	More developed countries	4.7	2.6
	Less developed countries	5.4	3.6
	All countries	10.1	6.2
2020	More developed countries	6.0	3.5
	Less developed countries	9.3	6.3
	All countries	15.3	9.8

[1] *Asian Pacific Journal of Cancer Prevention (2002)*

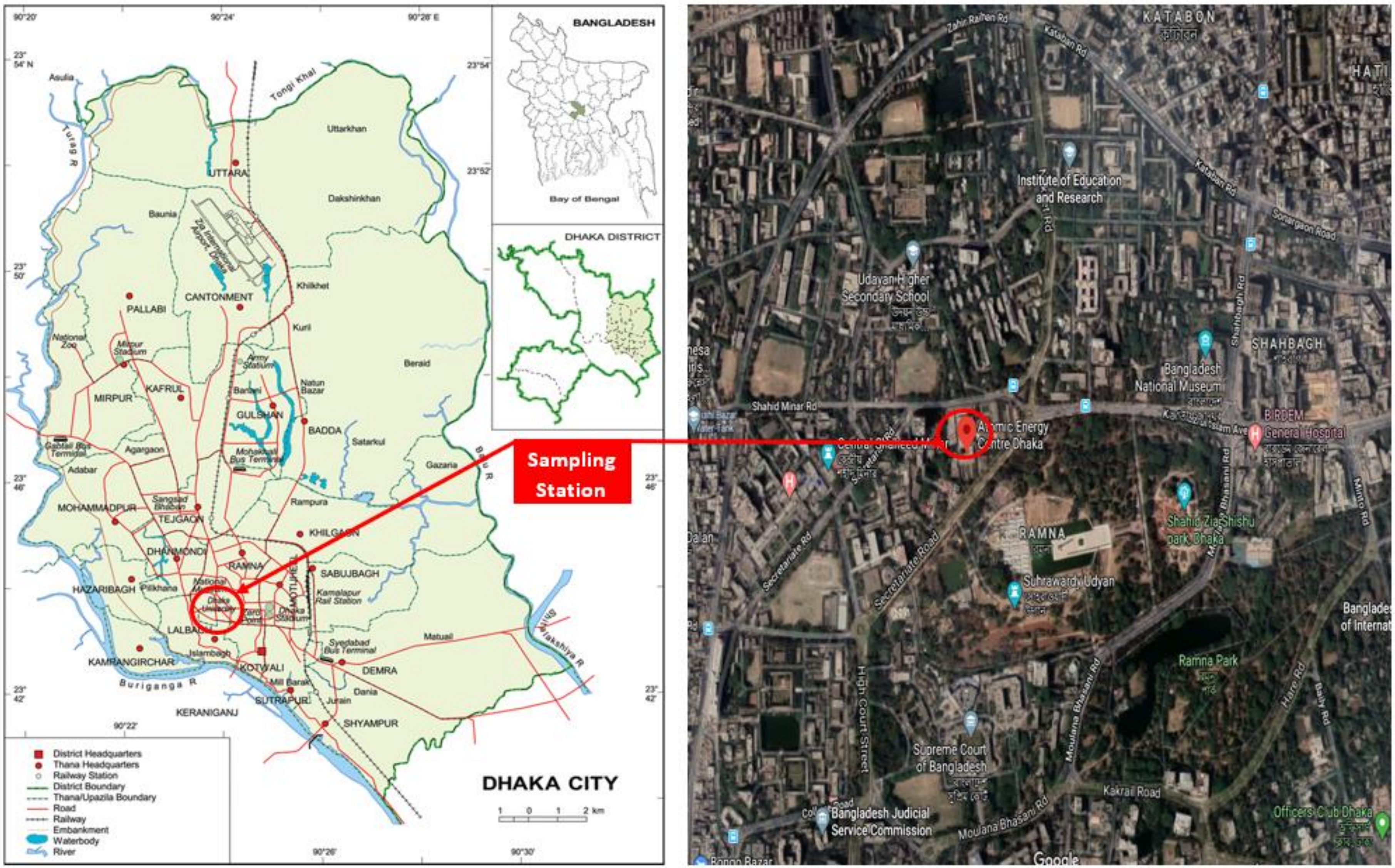
[2] *WHO*, 2021

Study Area

Atomic Energy Centre, Dhaka

Study Area

Atomic Energy Centre, Dhaka



Sample Collection

- ❑ **Sampling period:** 24 hr
- ❑ **Filter Type:** Nucleopore polycarbonate membrane filters
- ❑ **Diameter:** 47 mm
- ❑ **Air flow rate:** 17 L/min
- ❑ **Total sample:** 96 in a year (twice a week)

Bangladesh has a subtropical monsoon climate and **considering the monsoon and metrological condition** in Bangladesh, the year is divided into four seasons:

(i) Pre-monsoon (March to May)
(ii) Monsoon (June to September),
(iii) Post-monsoon (October to November) and
(iv) Winter (December to February).

Chemical analysis of PM sample

6 digits balance (MT5, Metler, Japan) uses for PM mass concentration measurement

EEL-type smoke stain reflectometer (Diffusion Systems Ltd., Model 43D, UK) uses for BC measurement

The static charge accumulated on the filters was eliminated using a U-shaped electrostatic charge eliminator (STATICMASTER; Amstat Industries).

Chemical analysis of PM sample

Elemental analysis in PM2.5 samples using EDXRF (Thermo, USA)

National Institute of Standards & Technology

Certificate of Analysis

Standard Reference Material® 2783

Air Particulate on Filter Media

This Standard Reference Material (SRM) is an air particulate sample reduced in particle size to simulate $PM_{2.5}$ air particulate matter (particles with an aerodynamic equivalent diameter of 2.5 µm) and deposited on a polycarbonate filter membrane. It is primarily intended for use in the evaluation and calibration of methods of analysis for common and toxic elements contained in various fractions of airborne particulate matter collected on filter media. A unit of SRM 2783 includes two loaded filters and two blank filters.

Certified Values: The certified values for elemental content of the SRM, expressed as mass of element deposited on the filter membrane, are provided in Table 1. A NIST certified value is a value for which NIST has the highest confidence in its accuracy in that all known or suspected sources of bias have been investigated or taken into account [1]. The certified values for all elements are based on results of NIST methods and results from collaborating laboratories using independent and complementary analytical methods.

Reference Values: The reference values for elemental content, expressed as mass of element deposited on the filter membrane, are provided in Table 2. Reference values for selected elements in blank filters are provide in Table 4. Reference values are noncertified values that are the best estimate of the true value; however, the values do not meet the NIST criteria for certification and are provided with associated uncertainties that may reflect only measurement precision, may not include all sources of uncertainty, or may reflect a lack of sufficient statistical agreement among multiple analytical methods [1].

Information Values: Supplementary information values for average deposit area and mass loading per loaded filter are provided in Table 3. Information values for blank filters are provided in Table 5. An information value is considered to be a value that will be of use to the SRM user, but insufficient information is available to assess the uncertainty associated with the value.

Expiration of Certification: The certification of **SRM 2783** is valid, within the measurement uncertainty specified, until **01 September 2021**, provided the SRM is handled and stored in accordance with the instructions given in this certificate (see "Instructions for Handling, Storage, and Use"). This certification is nullified if the SRM is damaged, contaminated, or otherwise modified.

Maintenance of SRM Certification: NIST will monitor this SRM over the period of its certification. If substantive technical changes occur that affect the certification before the expiration of this certificate, NIST will notify the purchaser. Registration (see attached sheet) will facilitate notification.

This SRM has been developed in cooperation with the International Atomic Energy Agency (IAEA) Laboratories, Seibersdorf, Austria and collaborating laboratories in several countries.

The material was prepared by R. Oflaz and R.L. Zeisler of the NIST Analytical Chemistry Division. The coordination of the technical measurements leading to certification was performed by R.L. Zeisler.

Stephen A. Wise, Chief
Analytical Chemistry Division

Gaithersburg, MD 20899
Certificate Issue Date: 13 December 2011
Certificate Revision History on Last Page

Robert L. Watters, Jr. Chief
Measurement Services Division

PM and BC conc. with season variation

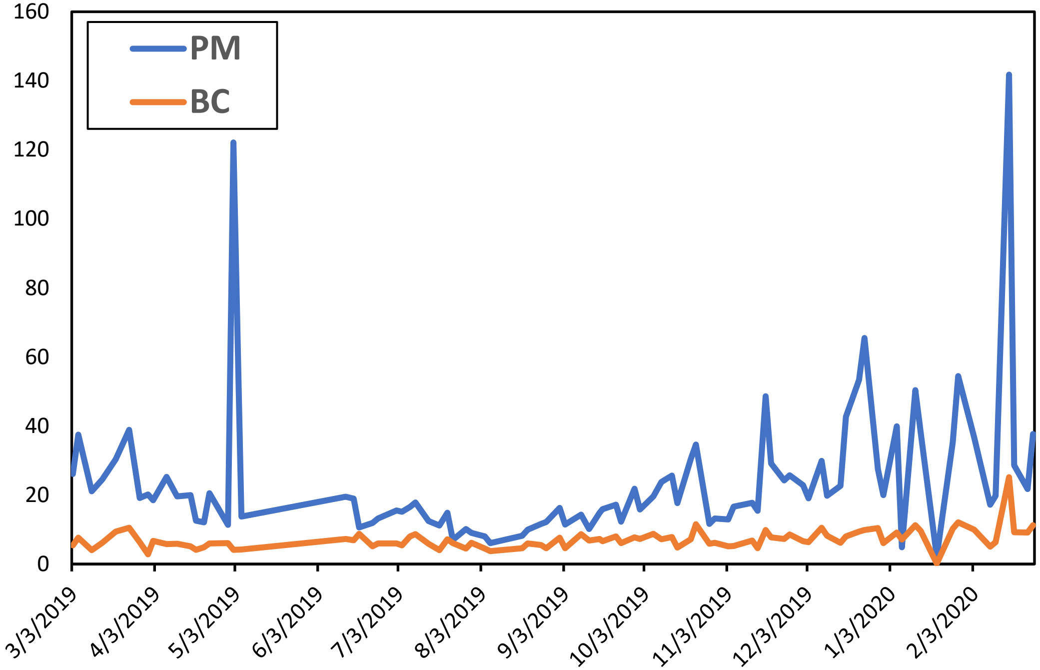
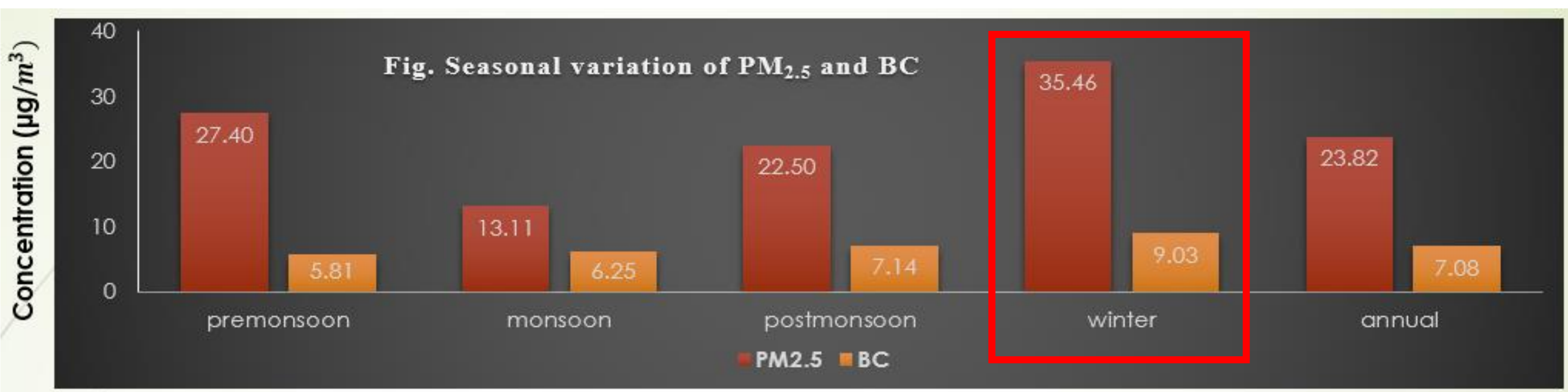


Fig. 2. Time series variations in PM2.5 and BC mass conc.

Parameter	$PM_{2.5}$	BC	$BC/PM_{2.5}$
Average (μg/m³)	32.7	7.62	0.23
Minimum (μg/m³)	5.27	2.10	0.40
Maximum (μg/m³)	106	17.7	0.17
Stdev (μg/m³)	18.7	3.93	0.21
25% Percentile	18.9	4.31	0.23
Median (μg/m³)	30.4	6.77	0.22
75% Percentile	43.7	10.4	0.24
VC (Coefficient of Variance)	0.57	0.52	0.91
GM (Geometric Mean, μg/m³)	27.8	6.63	0.24
%RSD (Relative Standard Deviation)	57.0	51.6	0.91
Reference value			
BNAAQS, 2005 (μg/m³)	15		
WHO, 2004 (μg/m³)	10		



PM and BC conc. with season variation

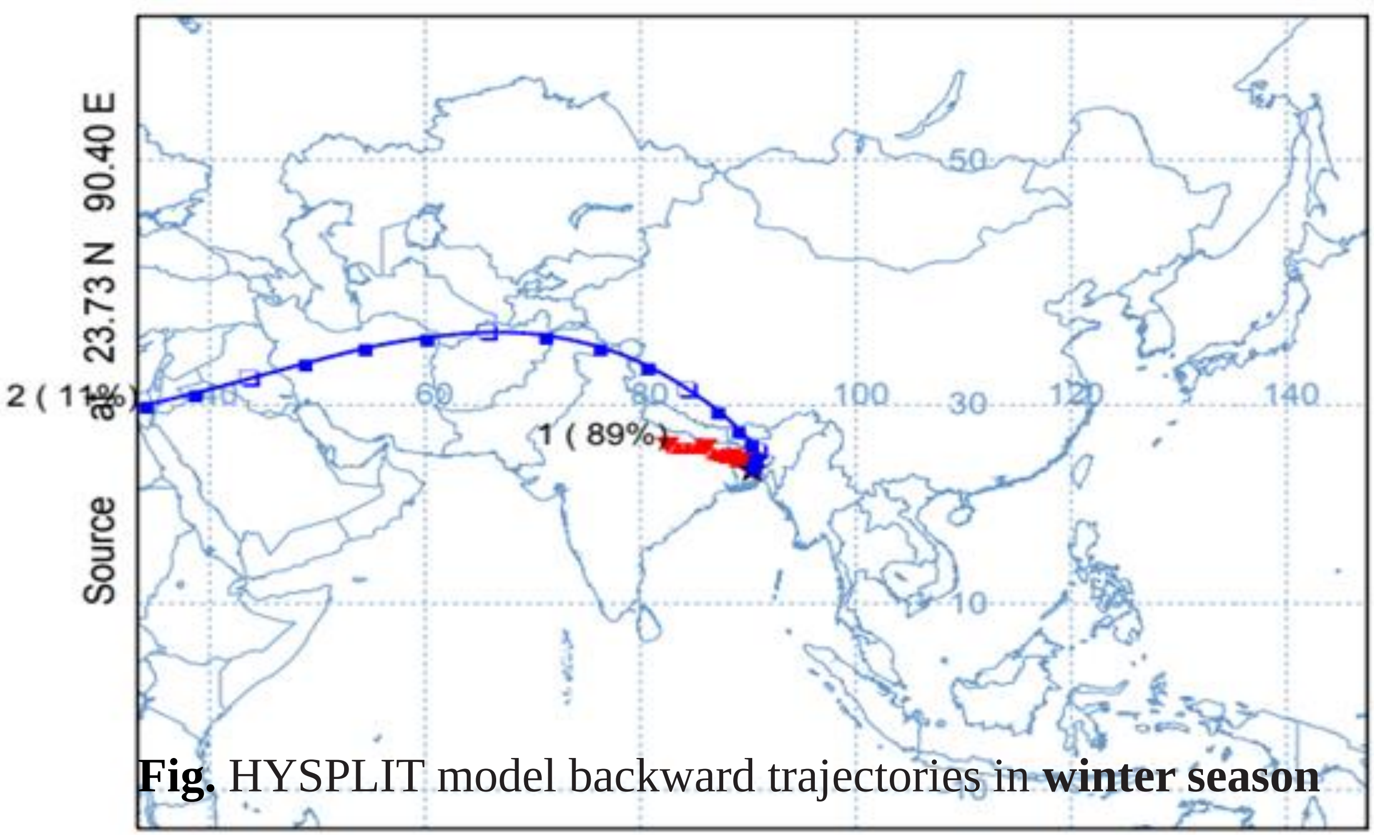


Fig. HYSPLIT model backward trajectories in **winter season**

During winter, wind blows from the **north and northwest**, and may transport PM including BC air masses; which were mainly originated from the Himalayas (**accounted for 89%)** with a small portion coming from northwest direction (accounted for 11%).

Descriptive statistics for chemical (ng/m^3) analysis in $PM_{2.5}$ samples in 4 different seasons

	Winter (Dec to Feb)			Pre-Monsoon (Mar to May)			Monsoon (Jun to Sep)			Post-Monsoon (Oct to Nov)			**Whole year** (Jan to Dec)		
	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	**Average**	Max
PM2.5	21637	52552	105536	19082	36757	70555	5269	17775	52333	16684	28360	52349	5269	**32731**	105536
BC	4756	10522	15424	3535	6478	15111	2096	4411	9633	3611	10338	17661	2096	**7616**	17661
Na	<DL	421	714	<DL	367	628	227	402	1098	239	327	607	<DL	**381**	1098
Mg	<DL	103	224	3.97	49.1	217	<DL	15	59.9	<DL	14.4	45.7	<DL	**44.6**	224
K	192	581	1043	78.2	467	1566	61.3	176	286	120	311	630	61.3	**370**	1566
Ca	119	399	873	61.1	229	674	43.9	118	249	89	218	491	43.9	**232**	873
Al	44.7	381	773	31.1	194	812	39	66.7	151	46.3	92	246	31.1	**176**	812
Si	182	785	2292	177	785	2395	170	286	680	226	389	734	170	**545**	2395
Fe	142	389	675	73.5	260	654	59.6	168	296	120	255	523	59.6	**260**	675
Ti	<DL	37.51	63.74	4.72	23.5	53.2	2.74	10.5	20.5	9.33	21.6	42.4	<DL	**22.1**	63.7
Cl	<DL	117	494	<DL	132	329	<DL	206	631	<DL	229	631	<DL	**171**	631
Br	<DL	52.2	110	<DL	39.3	61.8	16.9	31.1	81	<DL	32.8	75.2	<DL	**38**	110
S	538	1680	3564	290	1733	3936	248	675	1344	393	783	1410	248	**1188**	3936
V	<DL	5.41	12.84	<DL	8.68	22.9	<DL	13	32.5	<DL	6.15	14.7	<DL	**9.3**	32.5
Cr	4.9	8.62	13.5	2.51	6.41	23.4	3.99	6.33	15.9	4.89	11.1	21.1	2.51	**7.91**	23.4
Mn	5.07	12.3	24.4	6.3	17.1	37.2	2.06	12	31.7	4.76	15.6	33.4	2.06	**14.1**	37.2
Ni	<DL	6.28	13	<DL	8.56	13.3	<DL	10.5	18	<DL	7.18	15.2	<DL	**8.18**	18
Cu	<DL	11.8	30.8	<DL	11.6	34.3	5.28	11.9	22.9	6.55	11.1	22.2	<DL	**11.6**	34.3
Zn	50.3	166	541	85.7	510	1334	48.6	731	1652	60.2	348	1185	48.6	**463**	1652
Pb	5.03	101	214	<DL	88	397	3.04	155	498	15.3	161	503	3.59	**131**	503

* **Crustal elements** such as Mg, Al, Si, Ca, Na, K, Ti and Fe contributed ~50% to total elements

* **Sulfur (S)** was the most abundant element (29.2%), **S containing fuel like diesel**

* **Zn** was the 3rd abundant element (after S and Si) accounting for 11.4% of TEC conc. in PM

* **Pb** - about 56% of paints purchased from China contain Pb equal to or larger 600 ppm; Coal combustion emission is another major source of Pb contamination in air mass

Chemical analysis of PM sample

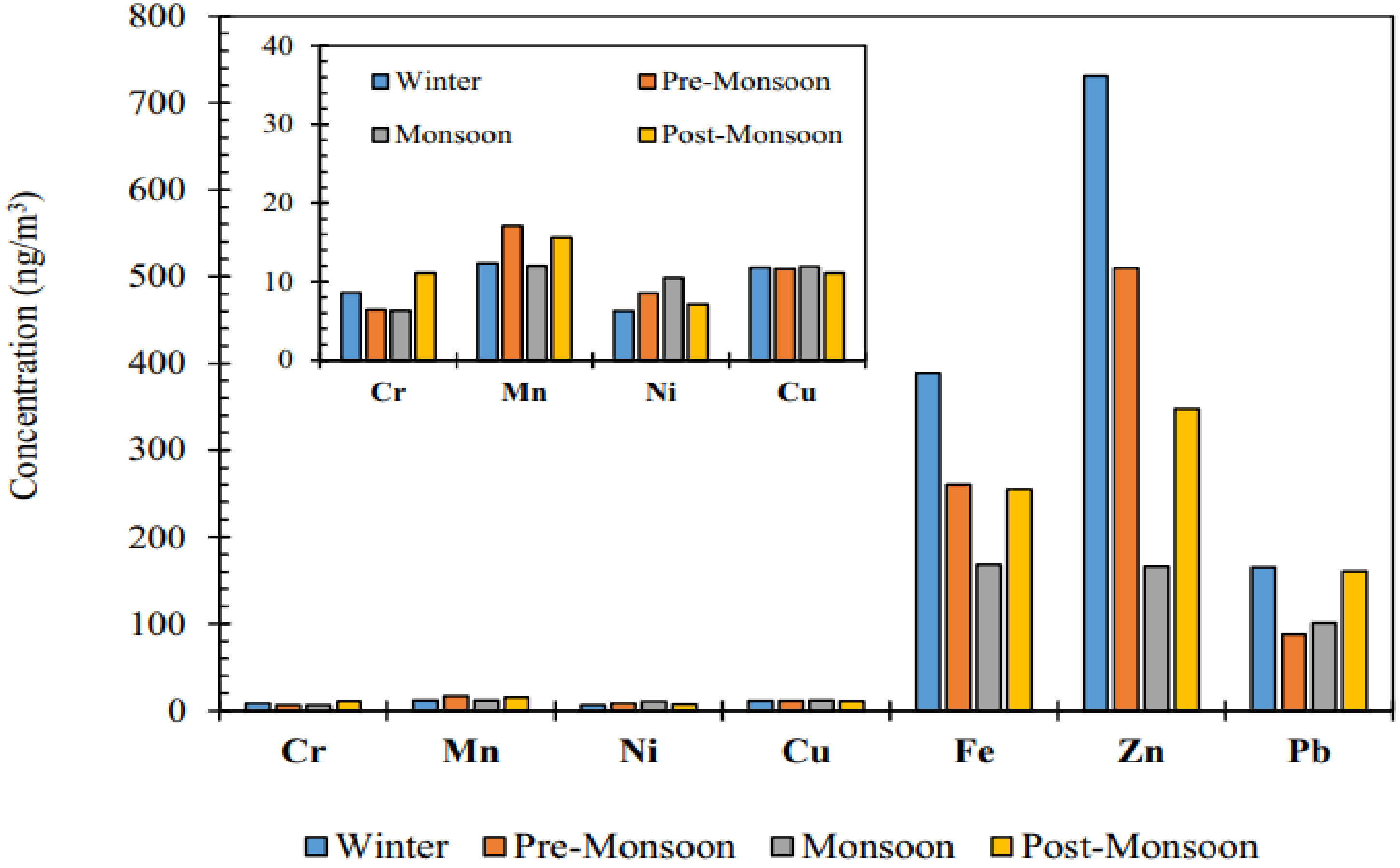


Fig. Heavy metal concentration in PM mass for four different seasons in the study area.

Pollution level of PTEs in $PM_{2.5}$ Sample

Enrichment factor (EF)

$$EF = \frac{[C_x/C_{ref}]_{Sample}}{[B_x/B_{ref}]_{Background}}$$

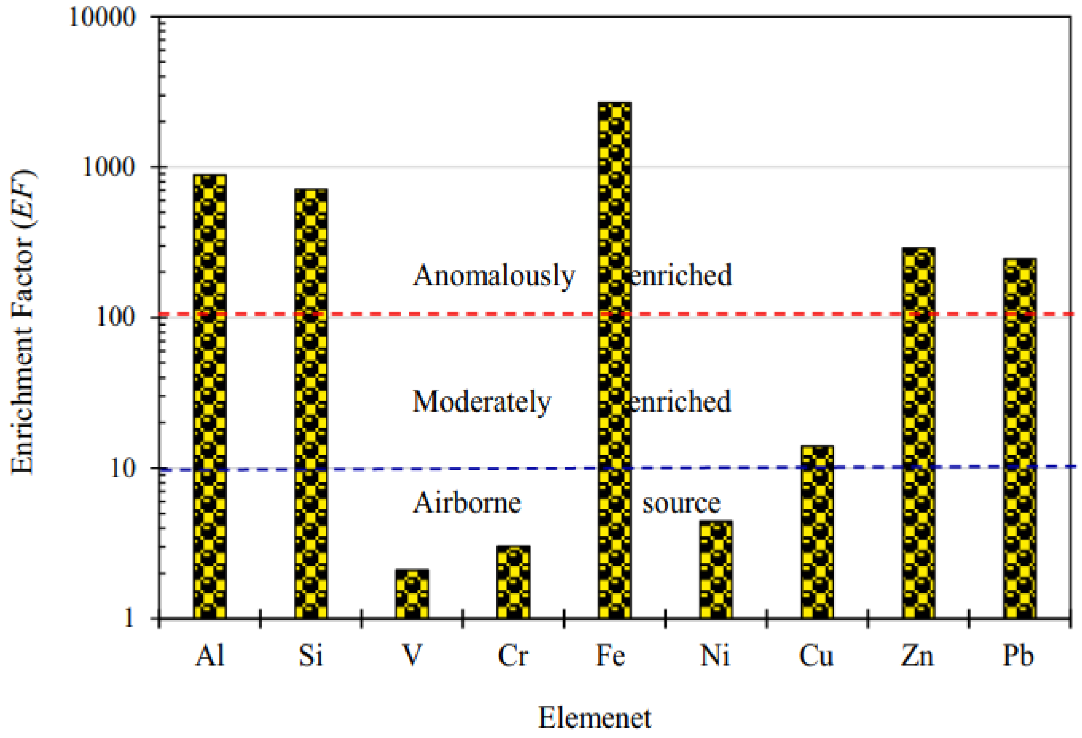


Fig. 5. Enrichment factor (EF) for Al, Si, V, Cr, Fe, Ni, Cu, Zn and Pb in PM2.5 samples.

Source Identification for PTEs in $PM_{2.5}$ Samples

Table . Spearman correlation matrix of all the variables measured in atmospheric samples

	Na	Mg	Al	Si	S	K	Ca	Ti	Fe	Cu	Zn	Br	Pb	Cr	V	Mn	$PM_{2.5}$	BC	Cl	Ni
Na	1																			
Mg	0.36	1																		
Al	0.35	0.71	1																	
Si	0.19	0.50	0.77	1																
S	0.36	0.62	0.75	0.75	1															
K	0.26	0.56	0.82	0.76	0.86	1														
Ca	0.18	0.53	0.90	0.75	0.67	0.82	1													
Ti	0.25	0.47	0.83	0.71	0.73	0.85	0.90	1												
Fe	0.25	0.48	0.88	0.76	0.67	0.81	0.94	0.88	1											
Cu	0.27	0.08	0.25	0.21	0.20	0.24	0.27	0.25	0.45	1										
Zn	0.11	-0.09	-0.22	-0.08	-0.03	-0.17	-0.23	-0.24	-0.05	0.38	1									
Br	0.70	0.05	0.19	0.06	0.21	0.21	0.10	0.22	0.16	0.19	0.03	1								
Pb	0.03	-0.32	-0.30	-0.27	-0.16	-0.14	-0.25	-0.17	-0.14	0.26	0.39	0.22	1							
Cr	0.14	0.05	0.45	0.39	0.20	0.38	0.51	0.48	0.58	0.33	-0.15	0.13	0.04	1						
V	-0.06	-0.06	-0.21	-0.04	-0.02	-0.19	-0.25	-0.28	-0.10	0.30	0.74	-0.18	0.24	-0.25	1					
Mn	0.25	0.19	0.35	0.41	0.47	0.47	0.36	0.39	0.51	0.46	0.45	0.20	0.23	0.19	0.43	1				
$PM_{2.5}$	0.05	0.35	0.51	0.46	0.52	0.61	0.54	0.55	0.48	0.03	-0.21	0.13	-0.26	0.24	-0.22	0.13	1			
BC	0.13	0.25	0.58	0.46	0.50	0.75	0.65	0.68	0.67	0.33	-0.17	0.26	0.09	0.53	-0.25	0.42	0.49	1		
Cl	-0.02	-0.12	-0.08	-0.04	-0.28	-0.24	-0.11	-0.19	-0.05	0.04	0.28	-0.08	-0.03	0.12	0.11	-0.06	-0.20	-0.28	1	
Ni	0.10	-0.04	-0.06	0.02	-0.09	-0.11	-0.13	-0.14	-0.11	-0.15	0.24	0.18	-0.02	-0.14	-0.02	-0.06	-0.05	-0.11	0.18	1

Shaded correlation coefficients are statistically significant at $p < 0.05$.

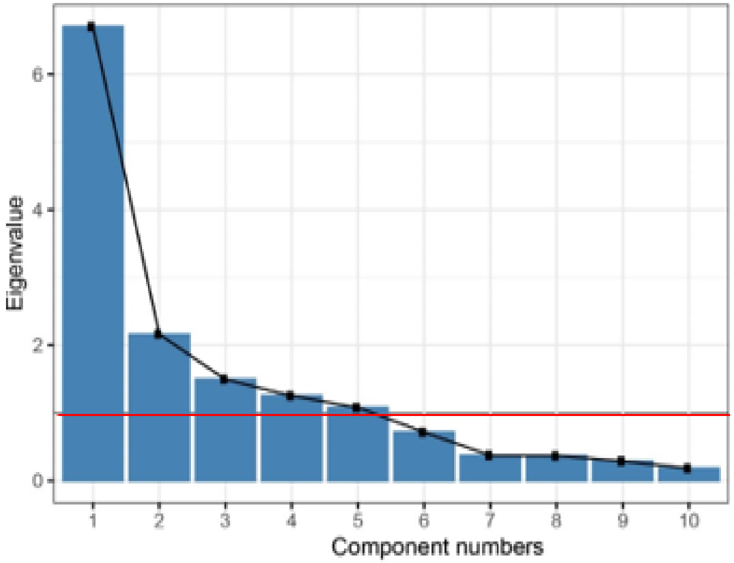
- Good correlations ($r = 0.47$–0.94, $p < 0.05$) among the marker elements **of crustal origin** (Al, Ti, Fe, Si, Ca, K and Mg). It implies that they may have originated from **wind-blown soil and road dust**.
- **Zn was well correlated with V** ($r = 0.74$, $p < 0.05$) and with **Pb** ($r = 0.39$, $p < 0.05$) -indication of traffic sources.
- A good correlation between Na and Br ($r = 0.70$, $r < 0.05$) -indicates their origin from **sea salts.**
- BC and K ($r = 0.75$, $p < 0.0001$) -biomass burning

Source Identification for PTEs in $PM_{2.5}$ Samples

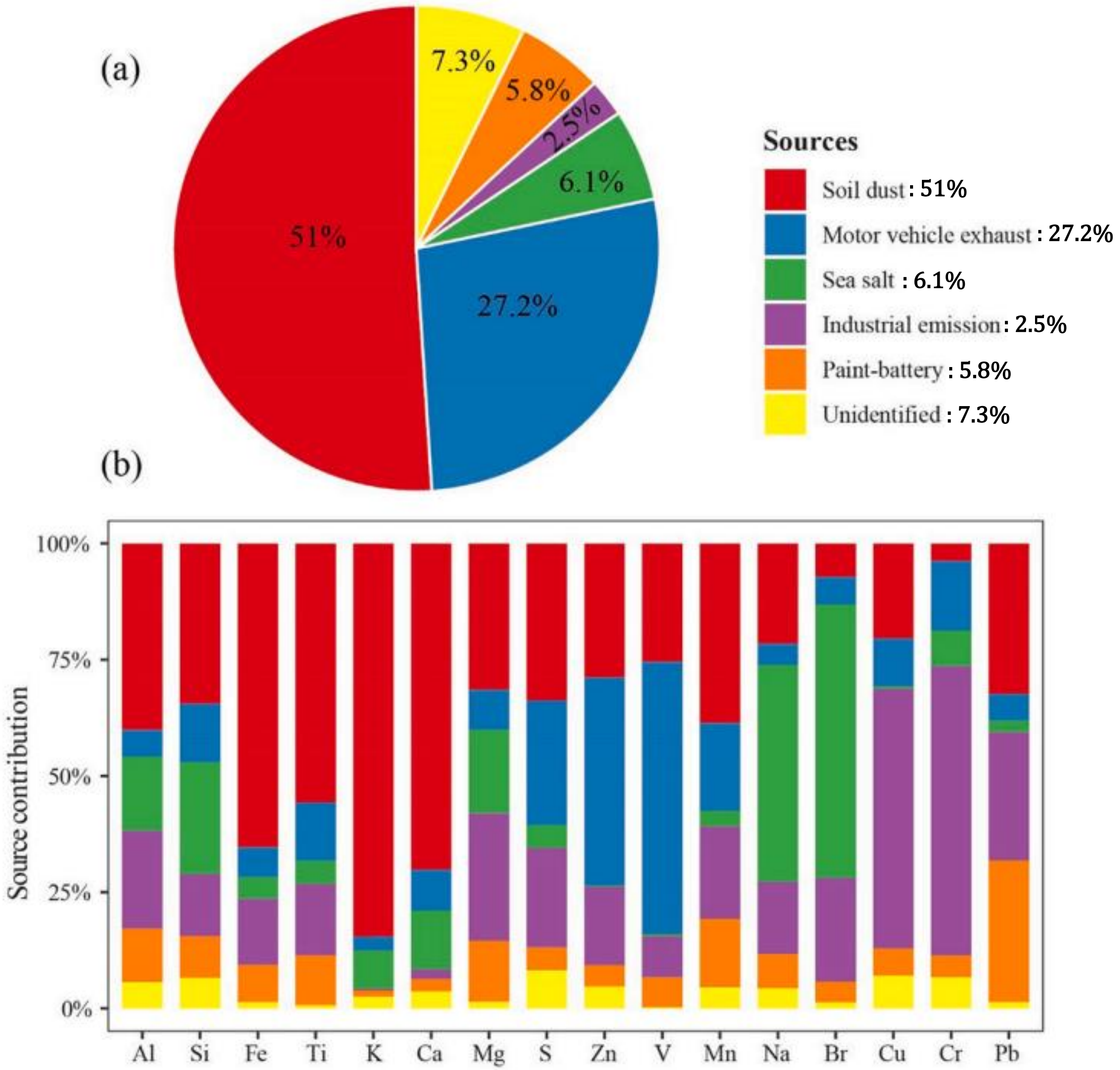
Principal components analysis (PCA) with varimax rotation.

Elements	PC1	PC2	PC3	PC4	PC5
Al	**0.88**	-0.13	0.16	0.07	-0.31
Si	**0.84**	0.04	-0.18	0.16	-0.20
Fe	**0.92**	0.01	0.02	0.30	0.01
Ti	**0.90**	-0.19	0.07	0.10	0.11
K	**0.95**	-0.03	0.01	0.09	-0.01
Ca	**0.91**	-0.14	-0.05	0.22	-0.09
Mg	**0.64**	0.05	0.23	-0.13	-0.59
S	0.16	**0.88**	0.09	-0.05	-0.13
Zn	-0.09	**0.89**	0.02	0.06	0.18
V	-0.09	**0.90**	-0.15	-0.02	-0.01
Mn	0.58	**0.59**	0.09	0.07	0.33
Na	0.00	0.01	**0.91**	0.26	-0.10
Br	0.07	-0.10	**0.90**	-0.03	0.22
Cu	0.14	0.34	0.20	**0.80**	-0.06
Cr	0.34	-0.26	0.06	**0.76**	0.20
Pb	-0.16	0.30	0.22	0.05	**0.80**
Eigen value	6.57	2.34	1.89	1.51	1.40
% Variance	41.0%	14.6%	11.8%	9.5%	8.8%
Cumulative %	41.0%	55.7%	67.5%	76.9%	85.7%

Fig Scree plot of the characteristic roots of principal component analysis



Source identification of PTEs in PM2.5 using PCA-APCA-MLR Receptor Model



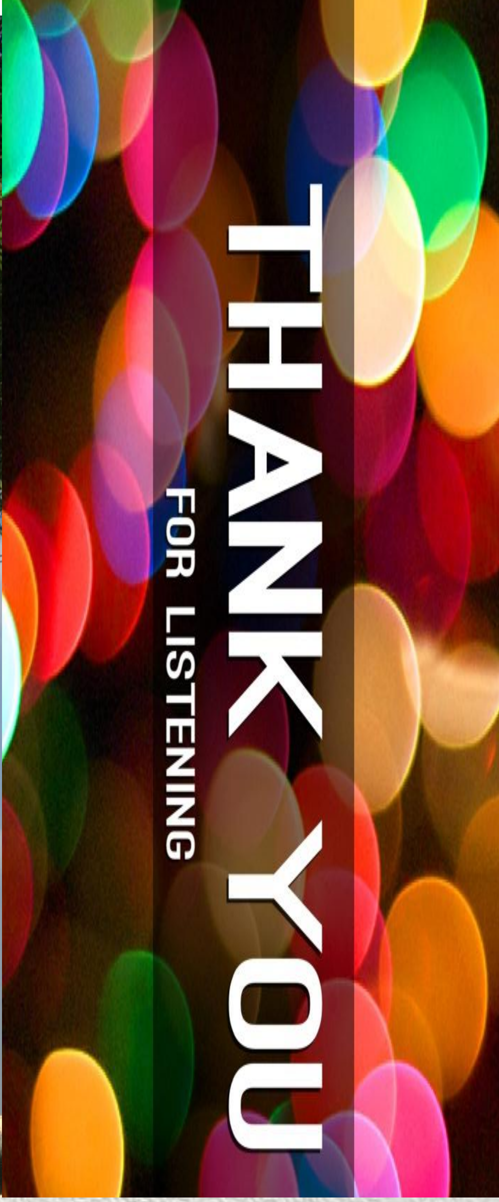
Conclusion

- The annual average $PM_{2.5}$ concentration in Dhaka City was higher than the recommended values set by WHO, EPA and BAAQS.
- The variability of $PM_{2.5}$ mass, BC and total metal concentrations were seasonally influenced with their highest amount in winter and the lowest in monsoon.
- Total 18 elements accounted for 12.4% of $PM_{2.5}$ mass, while 7.9% of $PM_{2.5}$ was made up of the elements: Na, Al, S, K and Zn.
- The analysis of enrichment factor (EF) suggested the anthropogenic air pollution in Dhaka City.
- Five possible pollution sources: soil dust (51%), motor vehicle exhaust (27.2%), sea salt (6.1%), industrial emission (2.5%) and paint-battery (5.8%) were identified using APCS-MLR receptor model.

Recommendations

- Reduce emission from motor vehicles and industries
- Reduce fly ash from coal burning in brick kilns
- Proper management of motor’s battery, tires, engine parts
- Properly recycle and management of electronics devices
- Follow up building construction and management rules
- More plantation should be continuing in all empty places
- More and continuous study needed on air pollution

Acknowledgement



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