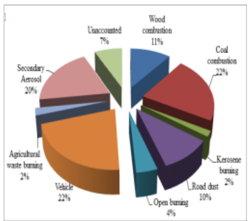
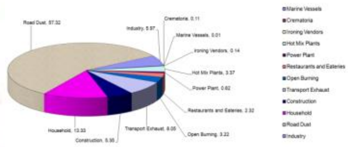
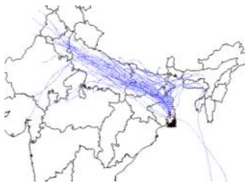
PM$_{10}$ and PM$_{2.5}$ Source Apportionment Study and Development of Emission Inventory of Twin Cities Kolkata and Howrah of West Bengal

Sponsor: West Bengal Pollution Control Board, Kolkata







CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, INDIA

December 2019

Final Report

PM_{10} and $PM_{2.5}$ Source Apportionment Study and Development of Emission Inventory of Twin Cities Kolkata and Howrah of West Bengal

Sponsor

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CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, INDIA

December 2019

Foreword

Kolkata is witnessing a long-standing problem of air pollution, primarily with particulates (PM_{10} and $PM_{2.5}$) and at a few places high levels of NO_2 and associated public health risks. In response to air quality deterioration and urge for source assessment study in the twin cities, West Bengal Pollution Control Board engaged CSIR-NEERI to execute a project on PM_{10} and $PM_{2.5}$ air quality monitoring, emission inventory and source apportionment in the twin cities of Kolkata and Howrah.

The major components of the study were (i) Ambient Air Quality (AAQ) monitoring for PM_{10} and $PM_{2.5}$ (ii) Development of Emission Inventory (iii) Receptor Modeling for source apportionment of PM_{10} and $PM_{2.5}$.

The study assessed ambient air quality status in terms of PM_{10} and $PM_{2.5}$ at twelve locations in Kolkata and Howrah. Emission inventory study along with the Receptor Modelling through CMB was undertaken and various activities viz. Biomass Combustion, Fossil Fuel Combustion, Secondary Aerosols, Road dust & Construction were accounted for their contribution to ambient air pollution in these two cities for summer and winter seasons. The study identified the major sources contributing to PM_{10} and $PM_{2.5}$ in the twin cities with a seasonal comparison of source contributions through receptor modelling. The findings of source apportionment were supported with the results of other techniques such as elemental ratio analysis, enrichment factor, emission inventory and literature survey. Long-range transport of coarse and fine particulate matter was studied through back-trajectory analysis. Such studies however, need periodic evaluation and validation due to dynamic nature of emission sources and anthropogenic activities in the city.

As per source apportionment analysis, the major sources of PM_{10} in Kolkata during summer were vehicles, road dust and secondary aerosols, whereas the major sources of $PM_{2.5}$ were vehicles, secondary aerosols and coal combustion. The major sources of PM_{10} during winter in Kolkata were secondary aerosols and wood combustion, followed by coal combustion, road dust and vehicles, whereas the major sources of $PM_{2.5}$ were secondary aerosols, vehicles followed by wood and coal combustion. In Howrah, the major sources of PM_{10} and $PM_{2.5}$ during summer were vehicles, secondary aerosols and wood combustion. During winter, the major sources of PM_{10} in Howrah were wood combustion, secondary aerosols, road dust and coal combustion, whereas the major sources of $PM_{2.5}$ were vehicles and secondary aerosols.

We would like to acknowledge the cooperation and support provided by West Bengal Pollution Control Board (WBPCB) in selection of air quality stations, industrial data collection, elemental characterization of PM through XRF and various other aspects, Kolkata and Howrah Municipal Corporations, Regional transport Offices and various other stakeholders.

Rameshwar

December, 2019
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EXECUTIVE SUMMARY

Kolkata is witnessing a long-standing problem of air pollution primarily with particulates (PM_{10} and $PM_{2.5}$) and NO_2 and associated public health risks. Population wise, Kolkata is the third largest city after Delhi and Mumbai in South Asia. Kolkata along with Howrah, is facing issues like agglomeration, congested roads and constant increase in vehicular population. Most of the studies on air quality assessment in India have been done in Delhi and comparatively a limited number of studies have been carried out on air pollution in Kolkata. Detailed source apportionment study has not been done for Kolkata. In response to air quality deterioration and urge for source assessment study in the twin cities based on the recent National Clean Air Programme (NCAP) Report, West Bengal Pollution Control Board sponsored a project on air quality monitoring, emission inventory and source apportionment in the twin cities of Kolkata and Howrah and entrusted CSIR-NEERI with the assignment of executing the project. The project titled "PM_{10} and $PM_{2.5}$ Source Apportionment (SA) Study and Development of Emission Inventory of Twin Cities Kolkata and Howrah of West Bengal" had the following objectives:

1. Monitoring of particulate matter (PM_{10} & $PM_{2.5}$) in ambient air covering the spatial and seasonal variations in Kolkata and Howrah.
2. Chemical signature analysis of collected particulate samples with the objective of receptor modeling. Analysis of collected samples for ions, elements, Polycyclic Aromatic Hydrocarbons (PAHs) and carbon fractions (organic and elemental carbon).
3. Preparation of emission inventory in Kolkata and Howrah.
4. Source apportionment through receptor modeling by using CMB8.2 during summer and winter for both PM_{10} and $PM_{2.5}$ in Kolkata and Howrah.

The study comprised of some major components viz. (i) Ambient Air Quality (AAQ) monitoring (ii) Development of Emission Inventory (iii) Receptor Modeling for source apportionment.

Sampling Locations

Sampling for PM_{10} and $PM_{2.5}$ was carried out during summer (2017) and winter (2017-18) at 12 sampling locations for at least 10 days in each season. During summer of 2017, sampling was carried out at 9 locations since permission was not available in time for 3 shortlisted locations in Howrah which were replaced by 3 other available locations that were separately monitored in summer 2018. The sampling locations were finally selected based on reconnaissance survey, historical data analysis using statistical techniques and finally ratified and facilitated by WBPCB in terms of getting required permissions from the custodians of the monitoring stations that were mostly either state or central govt. buildings or schools. **Table 1** provides the details of the sampling locations.

Ambient Air Quality

Sampling for PM_{10} and $PM_{2.5}$ was carried out with $PM_{10}/PM_{2.5}$ samplers as per the guidelines of Central Pollution Control Board. The PM_{10} and $PM_{2.5}$ samples collected on various types of filters (PTFE/ Quartz) were subjected to analysis for ions, elements, OC-EC and PAHs and select molecular markers. The following inferences have been made based on results obtained in summer and winter:

Summer

$PM_{2.5}$ was observed to be below the CPCB standard limit at all locations except on few dates at Shyambazar and Minto Park. PM_{10} exceeded the CPCB standard more frequently than $PM_{2.5}$. Analysis of chemical composition of PM revealed that in summer, ions had the highest share in ambient particulate matter followed by total carbon and elements. Contribution of molecular markers, including PAHs, has negligible contribution. $SO_4^{=}$ had highest share in both $PM_{2.5}$ and PM_{10}. OC concentration was higher than EC (>50%) in both $PM_{2.5}$ and PM_{10} at most sites except in $PM_{2.5}$ at Minto Park, suggesting the dominant presence of organics in ambient particulate matter. Mass closure analysis revealed highest contribution of ammonium sulphate (14-31%) and ammonium nitrate (3-13%) in PM_{10}.

Table 1: Summary of Sampling Sites

S.No.	Station Name	Station Classification	Observed Sources
Kolkata			
1.	Baishnabghata	Residential-Traffic	Residential Area, covered market within 500m, playground, light traffic, a few Roadside tea stall and construction sites are present nearby
2.	Minto Park	Traffic – Commercial	Flyover within 100 m, near main road with heavy traffic, residential and commercial activity with roadside food stalls within 100 m
3.	Moulali	Traffic - Commercial	Commercial, 2 petrol pumps within 100 m, vegetation (thick within 50 m), moderately heavy traffic
4.	Shyambazar	Residential-Traffic	Main road with heavy traffic within 50 m, construction activity observed, Parked vehicles, West Canal Road with occasional traffic within 10 meters, Residential (major) and commercial (few) activities prominent
5.	Dunlop	Traffic - Commercial	Beside main road with heavy traffic, construction activity observed, one or two stacks observed, parked vehicle, residential (major) and commercial (few) activities are predominant
6.	Chetla	Residential-Traffic	About 100 m from main road, small roads are there within residential settlements, slum settlement in adjacent area, mixed activity of residential and commercial
7.	Control (Haringhata/ Mohanpur)	Agricultural-Residential	No prominent source other than biomass burning by local residents and construction activity in IISER campus
Howrah			
1.	Bandhaghat	Residential-Commercial	Residential (major), minor construction (2-3 nos.), Mandir (2-3 nos.), slum (small), Feeder road in 10 m, light traffic, commercial (minor)
2.	Control (Singur)	Agricultural-Residential	Biomass burning including coal and waste observed, a few roadside eateries and tea stall nearby, the nearby road outside main gate has low but continuous vehicular movements
3.	Advanced Training Institute (Dasnagar)	Residential-Industrial	Advanced Training Institute campus, Residential area with hostels; Flanked by old industrial area of Das Nagar
4.	Akshay Shikshayatan (Howrah Maidan)	Residential-Commercial	Traffic movements in nearby roads, residential area nearby along with commercial activities
5.	Buxarah High School (Buxarah)	Residential-Traffic	Traffic movements in adjacent road, Residential area along with limited commercial activities

Contribution from matters of geological origin was 5-10%, 13-25% from organic matter, 7-9% contribution from EC of and 1-12% contribution from sea-salt in PM_{10} was observed. Organic matter (OM) contribution was generally attributed to wood/biomass burning and exhausts emissions from vehicles. Further, in Howrah, OM contribution was more than $(NH_4)_2SO_4$, suggesting organic nature of coarse particulates whereas in Kolkata, $(NH_4)_2SO_4$ contribution was higher suggesting inorganic nature of coarse particulates.

In $PM_{2.5}$, unidentified mass was observed to be lower as compared to PM_{10}. The contribution of $(NH_4)_2SO_4$ and organic matter were high, followed by non-crustal mass. High contribution of $(NH_4)_2SO_4$ suggested inorganic nature of fine particulates in Kolkata and Howrah. Contribution of particulate matter of geological origin was 4-11%, whereas sea-salt and NH_4NO_3 contribution were negligible. Contribution of SOC to OC was observed to be ~28%.

Winter

During winter, average of both PM_{10} and $PM_{2.5}$ concentration was observed to be ~2-4 times above CPCB prescribed standards. At control sites (Singur and Harighata), average PM_{10} and $PM_{2.5}$ concentrations were 1.5 and ~2 times above the CPCB prescribed standards. The $PM_{2.5}/PM_{10}$ ratio (0.32–0.99) showed wide temporal variations, indicating variations in source-wise emissions. Howrah Maidan was one exceptional site where along with high concentrations of PM_{10} and $PM_{2.5}$, dispersion in daily average PM_{10} and $PM_{2.5}$ concentrations were highest amongst all.

Particulate Matter (PM) at some stations in Kolkata and Howrah were observed to be exceeding National Ambient Air Quality Standards (NAAQS) in winter; cases of this were more than summer in terms of daily average values. The mean $PM_{2.5}/PM_{10}$ ratios (>0.5) were higher in winter at all the sites as compared to summer 2017, which means that there was an increase in combustion activities in winter.

Chemical compostion analysis revealed that carbon and ionic fractions dominated ambient particulate matter at all sites. Amongst ions, $SO_4^{=}$, Br^- and NH_4^+ were predominant while amongst elements (all including alkali and alkaline earth metals), crustal species such as Ca and Fe dominated others. Mass closure analysis revealed that the unidentified mass contribution was highest at Haringhata, Howrah Maidan, Badhaghat, Minto Park, Dunlop, Shyam Bazar and Singur for PM_{10} and at Minto Park, Dunlop, Moulali, Baishnabghata and ATI Dasnagar for $PM_{2.5}$. Amongst the identified mass, organic matter contribution was highest at 12-33% followed by EC and ammonium sulphate. Geological matter and sea-salt contribution were ~1-8%. Secondary organic carbon (SOC) was also estimated, which showed its contribution to OC as ~24%. For $PM_{2.5}$, the unidentified mass was lower as compared to PM_{10}. Contribution of organic matter, elemental carbon and ammonium sulphate were high followed by sea-salt and geological matter. Non-crustal matter contribution ranged from 1-5%. Contribution of SOC to OC was observed to be ~40%.

Emission Inventory

Emission inventory estimates were prepared for the city of Kolkata (KMC Area) and Howrah (HMC Area) by identifying sector-wise major and minor sources of PM_{10} and $PM_{2.5}$, their respective activity data i.e. fuel type, fuel usage rate, total fuel usage, human population and number of sectors like hotels and restaurants, households, crematoria, ironing vendors, vehicles (with types, vintage, numbers, mileage etc.), numbers of ferries operating on Hooghly river and also numbers or quantity of other relevant units in operation. For emission inventory estimates, 2016 has been considered to be the base year.

Estimated total emission load for PM_{10} was 12480.4 MT/year and for $PM_{2.5}$, it was 4054.2 MT/year in Kolkata (KMC area). The share of various sectors on total city (KMC area) emission load is presented in **Fig. 1** and **Fig. 2** for PM_{10} and $PM_{2.5}$, respectively.

Emissions from select types of industries and manufacturing units in Kolkata are presented in **Table 3.** Industries/ manufacturing units classified as Producer Gas Plant was found to be the largest emitter of PM_{10} and $PM_{2.5}$ followed by Jute Processing, Bakeries, Ferrous and non-ferrous units' and so on.

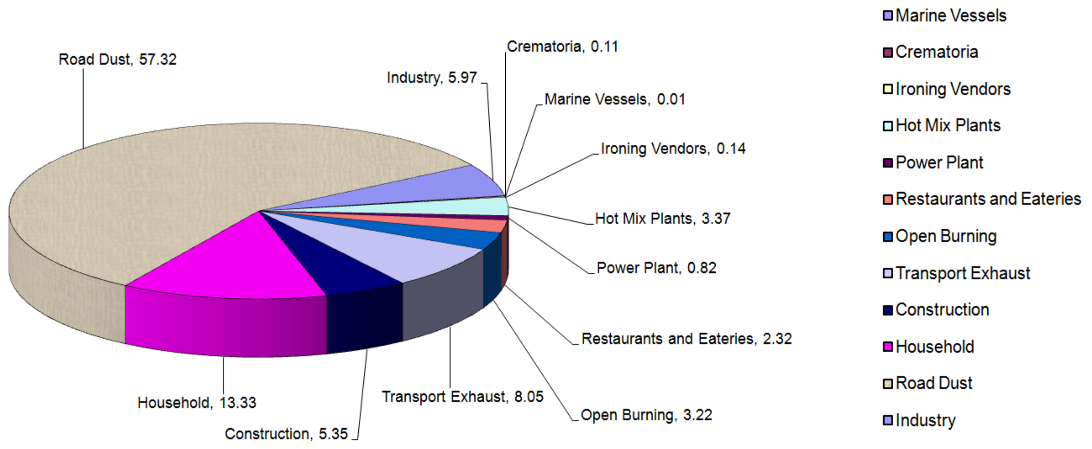


Fig. 1: Share (%) of Sectors in PM_{10} Emission Load in Kolkata (KMC)

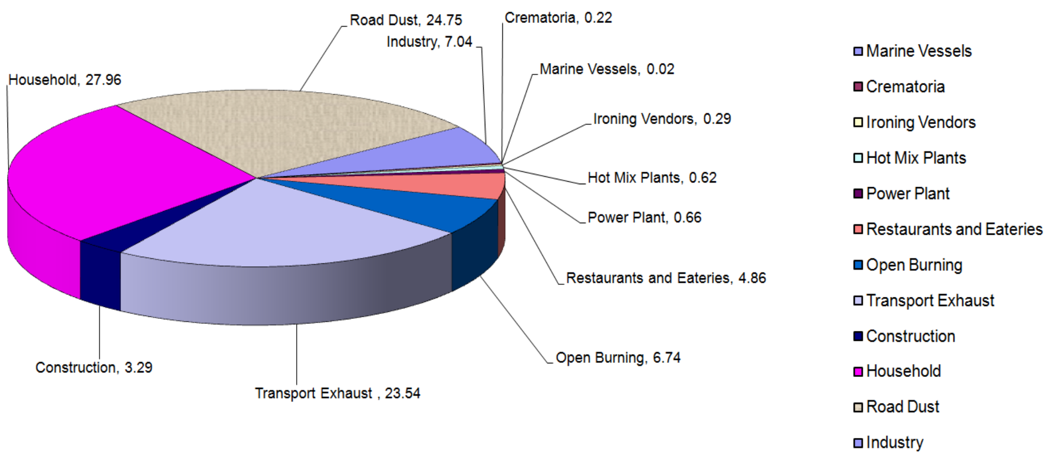


Fig. 2: Share (%) of Sectors in $PM_{2.5}$ Emission Load in Kolkata (KMC)

Emission from transport sector was sub-divided into emissions from various categories of vehicles as presented in **Table 4.** Goods Carriers (including 3-wheeler Goods Carriers) were found to be the highest emitter of PM_{10} and $PM_{2.5}$ on account of their substantial numbers and much higher emission factors than motor cars or two-wheelers, which had more numbers over Goods Carriers (treated under LCV category, except 3-W Goods Carriers). It was followed by emissions from buses and 2-wheelers and so on. The share of Goods Carriers in total PM_{10} and $PM_{2.5}$ emissions were about 49% and 49.5%, respectively **(Fig. 3-4)**.

Table 3: PM_{10} and $PM_{2.5}$ emissions (MT/y) from Select Categories of Industries having the major share in fuel consumption in Kolkata (KMC area)

Industry Type	**PM_{10} (MT/y)**	**$PM_{2.5}$ (MT/Y)**
Producer gas plant/coal gasification	531.06	144.04
Jute Processing	22.47	12.39
Bakery	21.41	14.56
Ferrous and non-ferrous	14.03	8.93
Basic Chemicals	13.56	9.04
Milk and Milk products	12.72	8.48
Synthetic detergents and soaps	4.14	1.08
Non-alcoholic beverage	3.67	2.45
Hotels	3.49	2.82
Ceramic	1.83	1.69
Dyeing and bleaching	0.65	0.44
Gold and Silver-Smiths	0.57	0.15
Lube oils, grease and petroleum products	0.47	0.31
Pickling and Electroplating	0.40	0.29
Rubber goods	0.28	0.19
Rolling Mill	0.25	0.17
Food and food processing	0.02	0.02
Pd-acid battery Manufacturing	0.01	0.01

Table 4: Comparative Scenario of PM_{10} and $PM_{2.5}$ Emissions (MT/y) from Select Types of Vehicles in Kolkata (KMC)

PM_{10} (MT/y)					
Buses + Omni Buses	**Motor Car (personal)+ Motor Cab (commercial) [Petrol + Diesel]**	**Goods Carrier (Incl. 3-W)**	**Passenger 3-Wheelers**	**2-Wheelers**	**Others**
102.298	25.948	214.113	36.014	46.751	7.583
$PM_{2.5}$ (MT/y)					
97.183	24.651	203.407	34.213	44.413	7.204

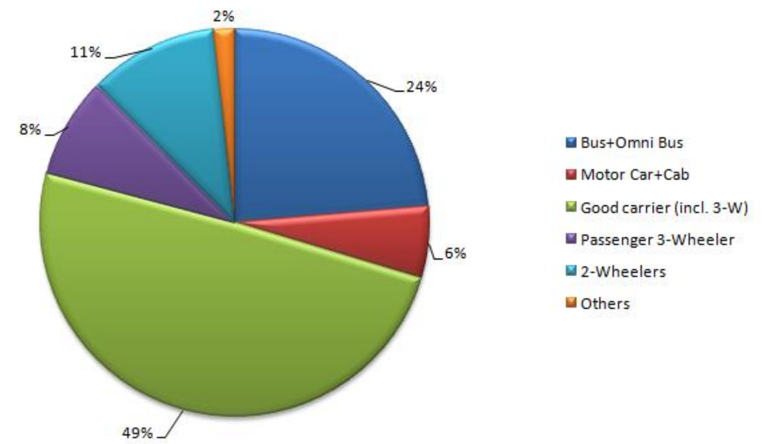


Fig. 3: Share (%) of Types of Vehicles in PM_{10} Emissions in Kolkata (KMC)

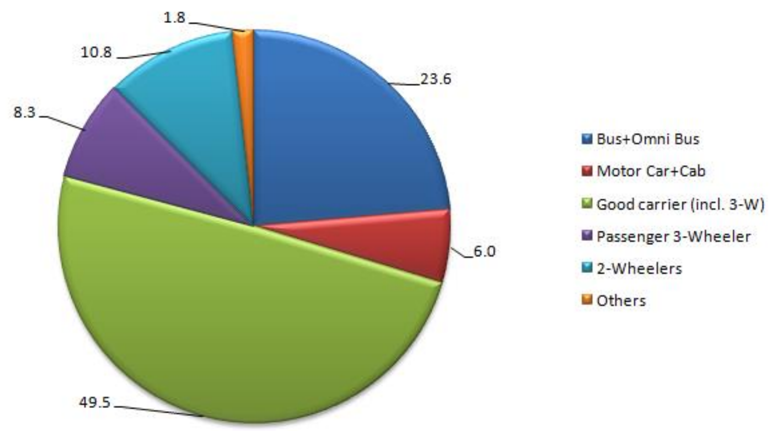


Fig. 4: Share (%) of Types of Vehicles in $PM_{2.5}$ Emissions in Kolkata (KMC)

On the other hand, estimated total emission load for PM_{10} was 10622.3 MT/year and for $PM_{2.5}$, it is 2785.0 MT/year in Howrah (HMC area). The percent share of various sectors in total emission load in Howrah is plotted in **Fig. 5** and **Fig. 6** for PM_{10} and $PM_{2.5}$, respectively.

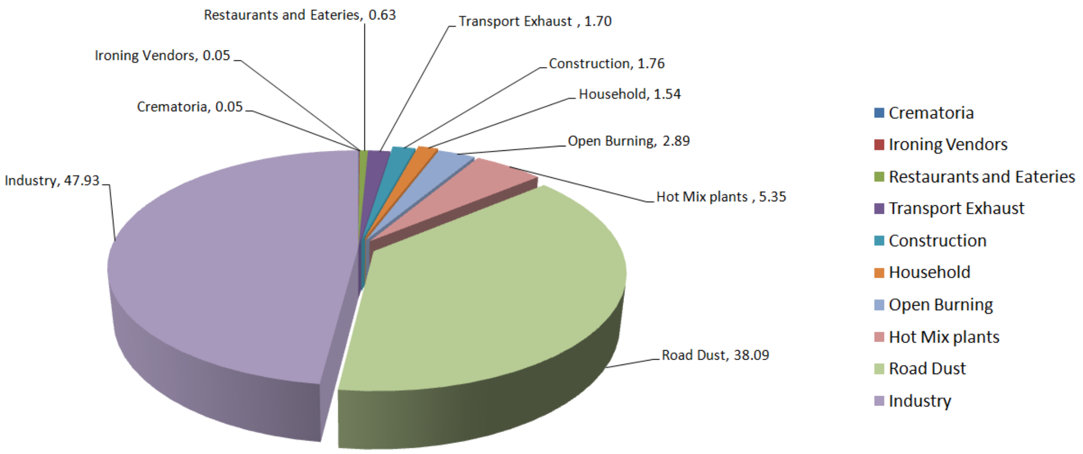


Fig. 5: Share (%) of Sectors in PM_{10} Emission Load in Howrah (HMC)

Apart from developing sectoral emission inventory estimates, intra-sectoral emission inventory was also prepared for industrial sector, based on intra-sectoral fuel usage estimates extracted from consent to operate database. Emissions from select types of industries and manufacturing units in Howrah are presented in **Table 5.** Industries/ manufacturing units classified as Foundries was found to be the largest emitter of PM_{10} and $PM_{2.5}$ followed by Rolling mills, Ferrous and non-ferrous, Textile and yarn, Jute processing units and so on.

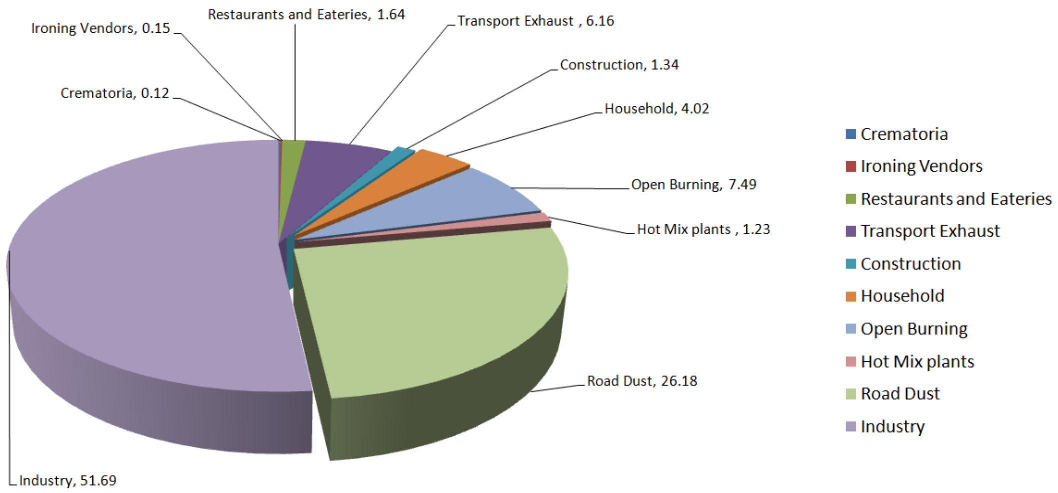


Fig. 6: Share (%) of Sectors in $PM_{2.5}$ Emission Load in Howrah (HMC)

Table 5: PM_{10} and $PM_{2.5}$ emissions (MT/y) from select categories of industries having the major share in fuel consumption in Howrah (HMC area)

Industry Type	**PM_{10} (MT/y)**	**$PM_{2.5}$ (MT/y)**
Foundry	2715.4	708.7
Rolling Mill	621.8	188.8
Ferrous/Non-ferrous	175.2	49.5
Textile/Yarn	132.8	34.8
Jute processing	101.0	68.7
Gas fired boiler	98.2	31.0
Steel and Steel products	93.6	25.3
Pickling/Electroplating	81.5	24.2
Pulp and Paper	21.8	14.8
Al Smelter/Al-Cu extraction	18.7	10.5
Engineering and fabrication	10.6	6.9
Heat treatment (Oil fired)	2.5	1.7
Bakery	2.2	1.5
Railway Locomotives	0.7	0.4

Emission from transport sector was sub-divided into emissions from select categories of registered vehicles (within 15 years of registration) as presented in **Table 6**. Goods Carriers (including 3-wheeler Goods Carriers) were found to be the most prominent emitter of PM_{10} and $PM_{2.5}$ on account of their high numbers and high emission factor. It was followed by emissions from buses and 2-wheelers and so on. The share of Goods Carriers in total PM_{10} and $PM_{2.5}$ emissions were about 67% **(Fig. 7-8)**.

Table 6: Comparative Scenario of PM_{10} and $PM_{2.5}$ Emissions (MT/y) from Select Types of Vehicles in Howrah (HMC) [registered in between 2004-2018]

PM_{10} (MT/year)					
Buses + Omni Buses	**Motor Car (personal)+ Motor Cab (commercial) [Petrol + Diesel]**	**Goods Carrier (Incl. 3-W)**	**Passenger 3-Wheelers**	**2-Wheelers**	**Others**
24.0	2.7	120.9	2.3	30.0	0.6
$PM_{2.5}$ (MT/year)					
22.8	2.6	114.9	1.3	28.5	1.4

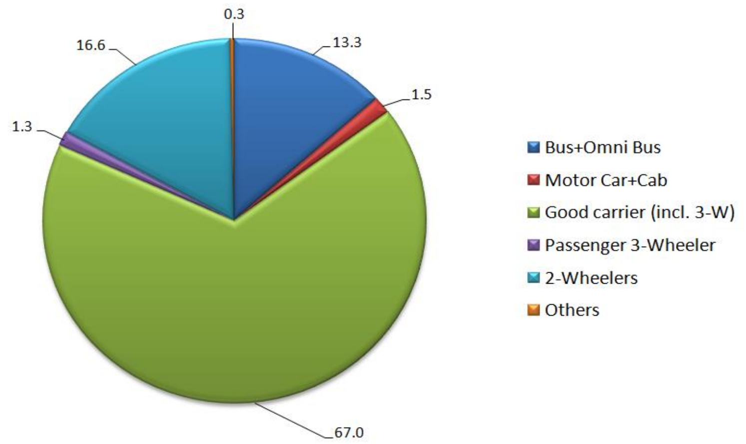


Fig. 7: Share (%) of Various Categories of Registered Vehicles in PM_{10} Emissions in Howrah (HMC)

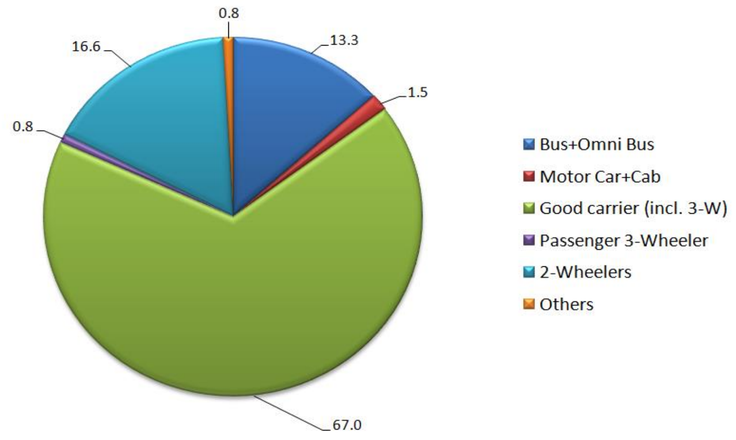


Fig. 8: Share (%) of Various Categories of Registered Vehicles in $PM_{2.5}$ Emissions in Howrah (HMC)

Receptor Modeling

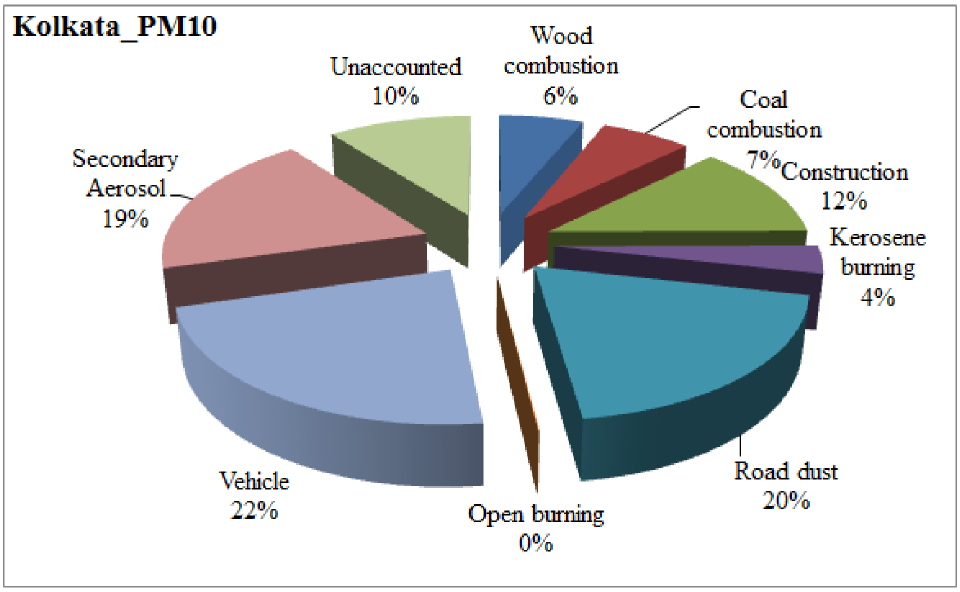
PM_{10} and $PM_{2.5}$ along with the chemical composition at various sites during summer and winter were subjected to analysis by chemical mass balance (CMB) model. The output of model depicted contribution of each source to particulate matter at a given monitoring station.

Summer

Fig. 9 and **Fig. 10** depict the overall results of the CMB model for Kolkata and Howrah during summer for PM_{10} and $PM_{2.5}$, respectively.

Kolkata: PM_{10} is contributed significantly by vehicles (22%), road dust (20%) followed by secondary inorganic aerosols (19%). The contribution of domestic and commercial combustion activities to PM_{10} is 16% followed by construction activity (12%). $PM_{2.5}$ is contributed significantly by domestic and commercial combustion activities (35%), vehicles (22%) and slightly by road dust (10%) and open burning (6%). The secondary aerosol contribution is observed to be 20%. The unaccounted PM_{10} and $PM_{2.5}$ mass is 10.4% and 7.5%, respectively. Secondary ammonium sulphate contribution can be observed to be 11-24% for PM_{10} and 10-21% for $PM_{2.5}$ in mass closure analysis. Ammonium nitrate contribution is observed to be 3-10% for PM_{10} and 0.1-1% for $PM_{2.5}$. The sea salt contribution is observed to be in the range 1-9% and 0-1% for PM_{10} and $PM_{2.5}$, respectively. From back-trajectory analysis, the source regions were identified to be in the SSW direction for air masses associated with PM_{10} concentration, whereas for air masses associated with $PM_{2.5}$ concentration, the contribution of source regions in SSW direction is quite less.

Howrah: PM_{10} is contributed significantly by domestic and commercial combustion activities (30%) followed by vehicles (21%), road dust (20%) and secondary aerosols (20%). Construction and open burning also contribute to PM_{10} (11% and 9%, respectively) in Howrah. $PM_{2.5}$ is contributed significantly by domestic and commercial combustion (27%), secondary aerosols (28%) and vehicles (20%). Open burning contribution (16%) is observed to be higher for $PM_{2.5}$ in Howrah as compared to Kolkata. Road dust contribution is observed to be 10% of $PM_{2.5}$ mass. The unaccounted mass is 0.4% and -1.5% for PM_{10} and $PM_{2.5}$, respectively. The mass closure analysis showed that in Howrah, the secondary ammonium sulphate contribution to PM_{10} and $PM_{2.5}$ mass is 11-18% and 10-21%, respectively. Ammonium nitrate contribution is observed to be in the range 3-3.8% and 0.3-0.4% for PM_{10} and $PM_{2.5}$, respectively. The sea salt contribution is observed to be in the range 1-3% and 0% for PM_{10} and $PM_{2.5}$, respectively.



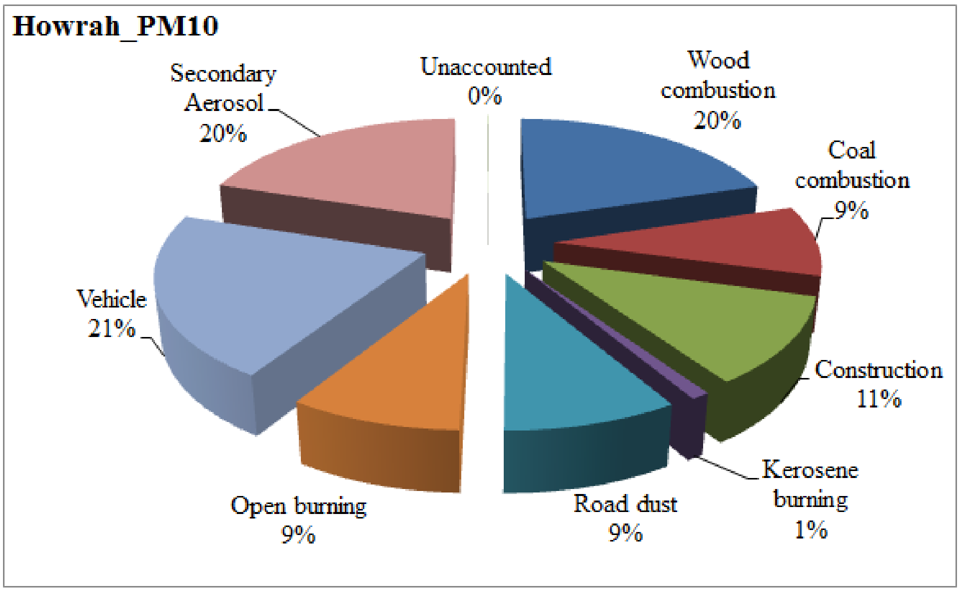


Fig. 9: Overall % Contribution of Various Sources to PM_{10} in Kolkata and Howrah: Summer

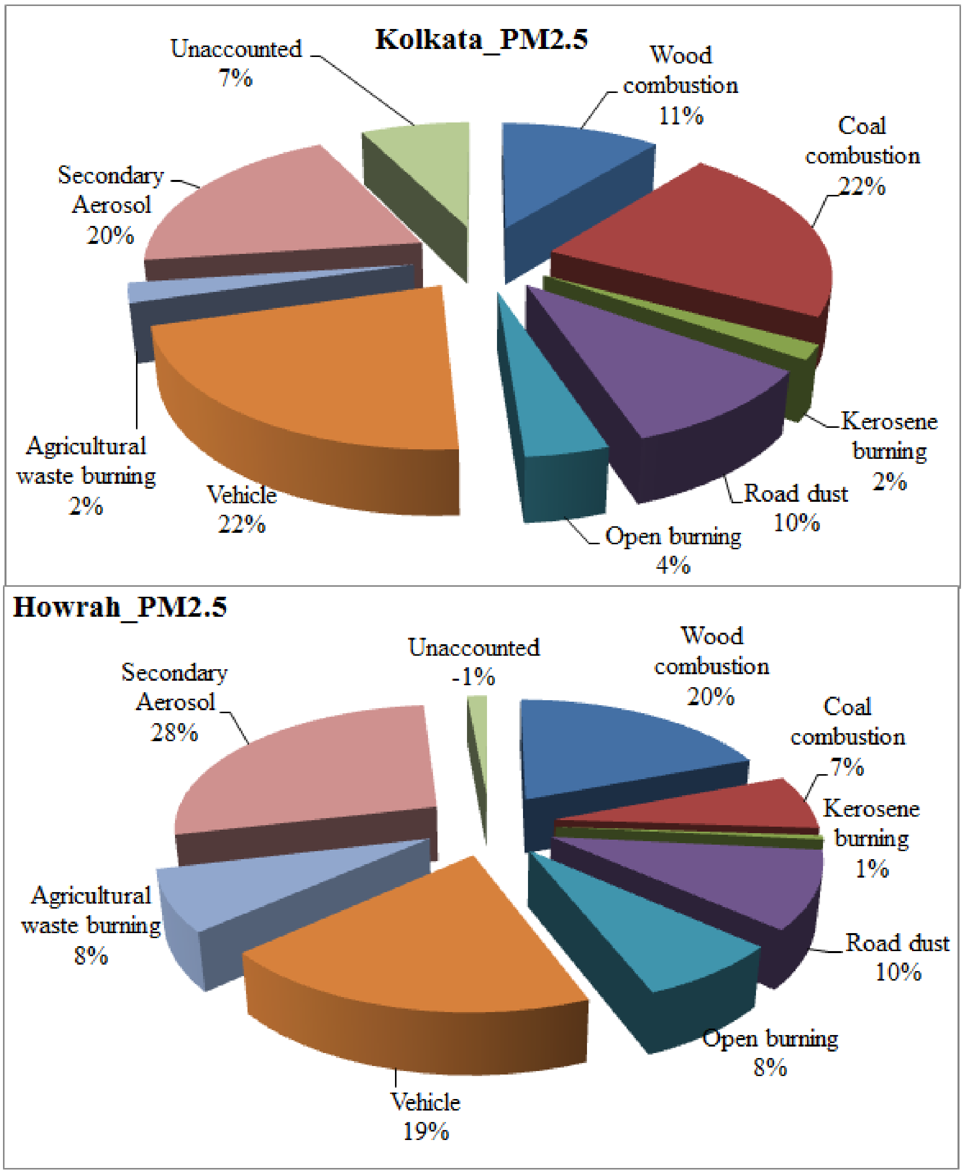


Fig. 10: Overall % Contribution of Various Sources to $PM_{2.5}$ in Kolkata and Howrah: Summer

Based on the above analysis undertaken for summer 2017, it can be inferred that the major source contributing to PM_{10} in Kolkata is road dust followed by vehicles, secondary aerosols and combustion activities. $PM_{2.5}$ is majorly contributed by combustion activities, vehicles and secondary aerosols. In Howrah, the major source contributing to both PM_{10} and $PM_{2.5}$ is combustion activities. $PM_{2.5}$ is also contributed majorly by secondary aerosols in Howrah.

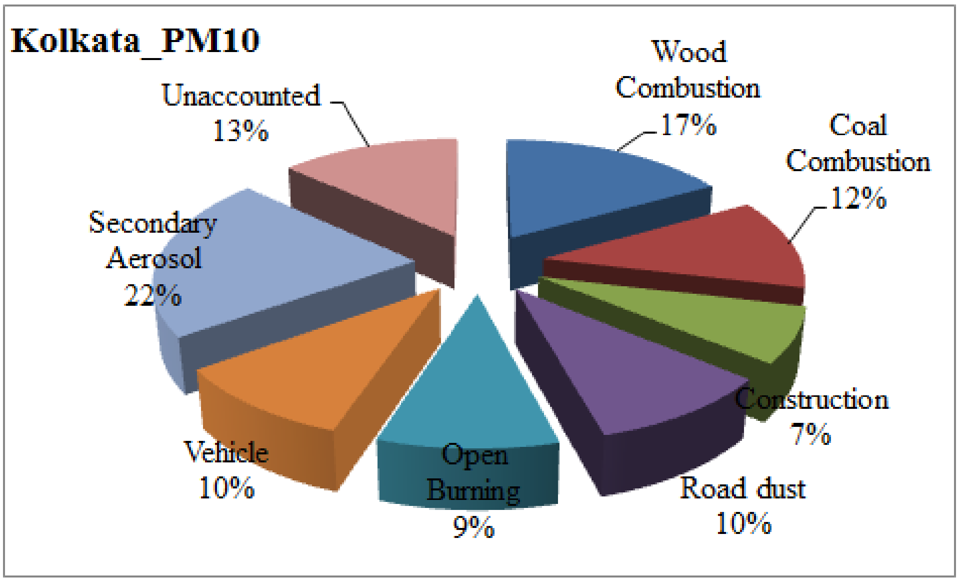
Winter

Fig. 11 and **Fig. 12** depict the overall results of the CMB model for Kolkata and Howrah during winter for PM_{10} and $PM_{2.5}$, respectively.

Kolkata: $PM_{2.5}$ is contributed significantly by vehicular activities (25%) after secondary aerosols (32%) and moderately by wood combustion (15%) and coal combustion (9%). The unaccounted $PM_{2.5}$ mass is 13%. Secondary ammonium sulphate and ammonium nitrate contribution can be observed to be 32% for $PM_{2.5}$ whereas in mass closure analysis, the contribution of both the compounds was ~15%. OM and EC contribution based on the mass closure analysis were ~23% and 20%, respectively. From back-trajectory analysis, the air masses associated with the high and moderate PM_{10} and $PM_{2.5}$ concentration were observed to be originated in the NNW direction.

Howrah: Vehicular contribution to $PM_{2.5}$ is observed to be 31% in Howrah. Coal and wood combustion share is 11% each, whereas secondary aerosol contribution is 27%. The unidentified mass is 12%. Back-trajectory analysis revealed that the air masses associated with high and moderate PM contributions have originated from NNW direction.

Comparing the results for both winter and summer, it is observed that for $PM_{2.5}$, biomass burning contribution has slightly increased in winter in Kolkata. In Howrah, biomass burning contribution has decreased in winter. Fossil fuel burning has decreased considerably in Kolkata during winter as compared to summer. In Howrah the fossil fuel burning has increased significantly. Road dust (& construction) contribution has also reduced during winter for $PM_{2.5}$ and taken over by secondary aerosol contribution. For PM_{10}, biomass combustion has considerably increased in Kolkata during winter. In Howrah, it is almost similar during summer and winter. Fossil fuel combustion in winter has slightly reduced in Kolkata and Howrah. Road dust (& construction) contribution has reduced in Kolkata. In Howrah, there is as such no significant difference between the two seasons.



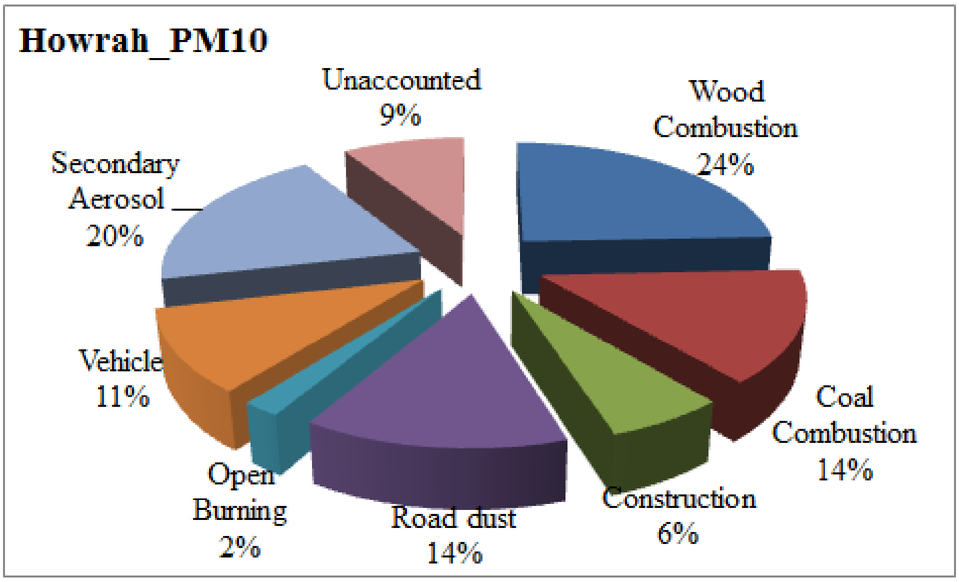


Fig. 11: Overall % Contribution of Various Sources to PM_{10} in Kolkata and Howrah: Winter

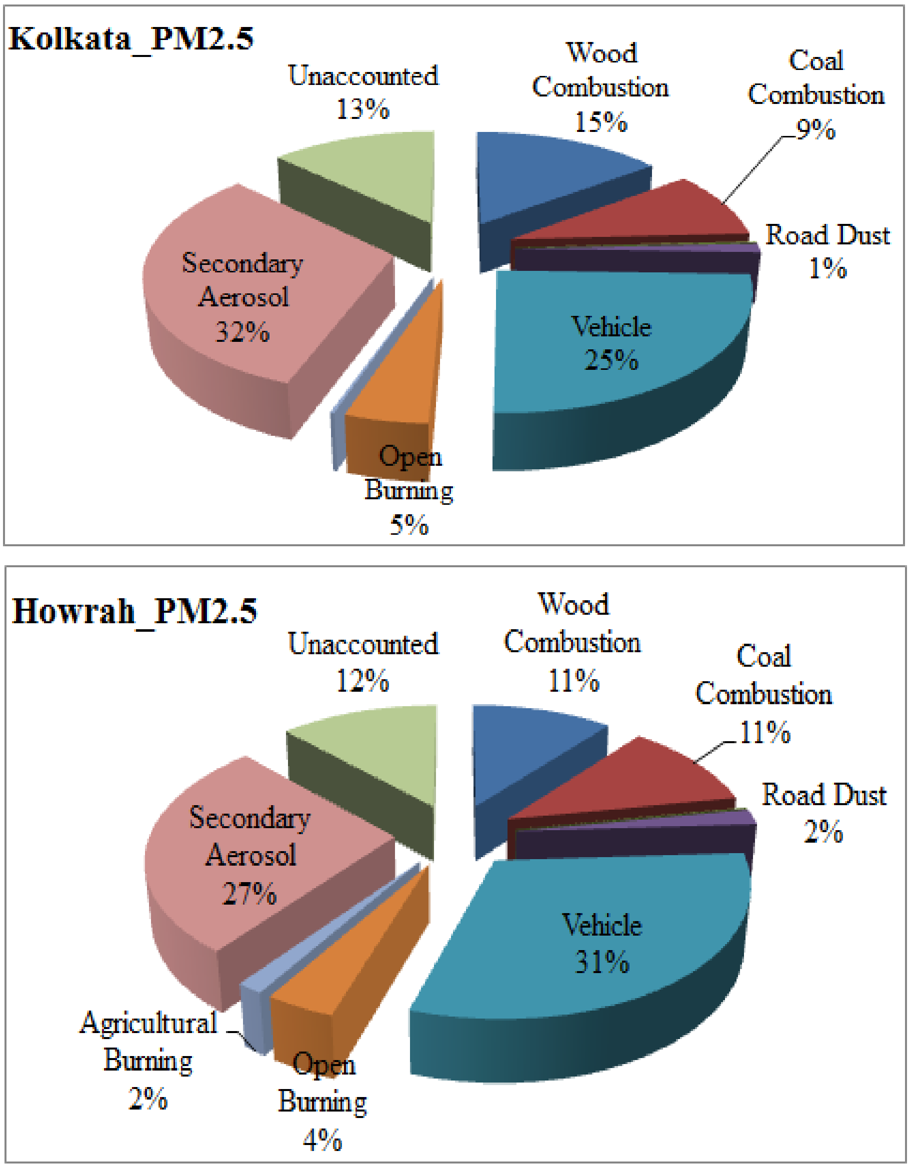


Fig. 12: Overall % Contribution of Various Sources to $PM_{2.5}$ in Kolkata and Howrah: Winter

Chapter 1

Introduction

1.1 Introduction

Indian cities are persistently facing problems related to air pollution notwithstanding implementation of the Air (Prevention and Control of Pollution) Act (1981), other related environmental acts and various policy instruments in the country. Particulate matter ($PM_{2.5}$ and PM_{10}) is the major air pollutants that pose challenges for its mitigation and control. Particulate matter (PM) pollution issue in India is different from other countries as ambient PM concentrations observed are frequently higher in India due to abundance of geological dust in air. The USEPA, EU and WHO standards are quite stringent as compared to the standards stipulated by Central Pollution Control Board (CPCB). Standards stipulated by USEPA and WHO are 15, and 10 $\mu g\ m^{-3}$ for annual and 35 and 25 $\mu g\ m^{-3}$ for 24h average $PM_{2.5}$ concentration whereas CPCB stipulated standards for annual and 24h average $PM_{2.5}$ are 40 and 60 $\mu g\ m^{-3}$, respectively. Except USEPA standard for 24 hourly PM_{10}, all the standards prescribed by CPCB are lenient as compared to most other countries/ international agencies.

Due to background dust pollution, ambient PM concentrations in India are observed to be very high. As far as Indian cities are concerned, enforcement of various instruments to control particulate air pollution looks less than adequate. Delhi has become one of the examples, where despite commencement and implementation of several control measures such as Graded Response Action Plan (GRAP), PM concentration levels in winter every year reaches alarming levels. Although meteorology plays an important role in aggravating air pollution, steep increase in population, migration from rural areas, modern household consumption patterns, increase in vehicular population and improper solid waste management are few of the other driving factors causing high levels of ambient particulates in many urban locales in India.

One of the large metropolitan areas of India, Kolkata, is also witnessing air pollution problem and associated health risks that take worst forms in winter. Population wise, Kolkata is the third largest city after Delhi and Mumbai in India. Densely populated Kolkata along with adjacent Howrah are gateways to north-east (NE) India and are facing issues like agglomeration, congested narrow roads, increase in vehicular population and regular flow of inbound and outbound population. Automobiles contribute significantly to PM, the other major sources being the construction activity, solid waste burning and firing of smoking fuels in commercial eateries etc. At present only one Thermal Power Plant is operating in KMC area, in addition to chemical, metallurgical, ferrous, non-ferrous, rubber, engineering and food industries. Lack of maintenance of vehicles, congestion at traffic intersection points, road encroachment by pavement dwellers and street hawkers, illegal car parking led to emissions of huge amount of automobile-related pollutants in the city (Roy Chowdhury, 2015). In Howrah, which is mainly an industrial city, industrial emissions along with traffic, solid waste burning and construction activities are significant.

West Bengal Pollution Control Board (WBPCB) has been carrying out ambient air quality monitoring at various locations in West Bengal over last two decades. As per WBPCB data collected during 2012-2018 in Kolkata and Howrah, SO_2 concentration was always observed to be below the stipulated ambient air quality standard prescribed by Central Pollution Control Board (CPCB) at all the monitoring sites. NO_2 concentrations exceeded the CPCB standard at about 15% occasions while PM_{10} exceeded the standards at about 70% occasions in Kolkata. This shows that both the cities have a problem of high ambient PM pollution. As per the study undertaken by CSIR-NEERI for various cities in India during 2012-2015 (NEERI, 2012-2015) and based on WBPCB data, Kolkata ranked 2nd in terms of PM pollution (**Fig. 1.1**). The annual average PM concentration has exceeded the CPCB standard of 60 µg m^{-3} stipulated for PM_{10} over 2012-2015, indicating to the severity of air pollution by particulate matter.

As a result of increasing particulate pollution, several policy initiatives have been placed under consideration and even implemented in Kolkata. But considering the presence of ambient particulate matter concentration higher than the national standard, a detailed study with quantification of contributing sources to ambient particulate pollution in the twin cities was required. Any air pollution control strategy or management policy relies heavily on the basic understanding of various contributing sources prevalent in the area. Although the sources of air pollution in an area can usually be identified by thorough reconnaissance survey, crucial information on actual contribution of each source to air pollution can be estimated by emission inventory, air quality monitoring, chemical signature analysis of collected dust and application of select mathematical models. Further, it has been observed that most of the studies on air quality assessment in India have been done in Delhi and comparatively limited number of studies have been carried out on air pollution in Kolkata. Detailed source apportionment study has not been done for Kolkata's air pollution. It was therefore required to conduct a comprehensive study to identify the predominant sources of air pollution in Kolkata and Howrah so that proactive and robust measures with an integrated approach could be taken to tackle and curb particulate pollution.

In response to air quality deterioration and urge for source assessment study in the twin cities, West Bengal Pollution Control Board initiated the study on air quality monitoring, emission inventory and source apportionment study in twin cities of Kolkata and Howrah and entrusted CSIR-NEERI with the execution of the project.

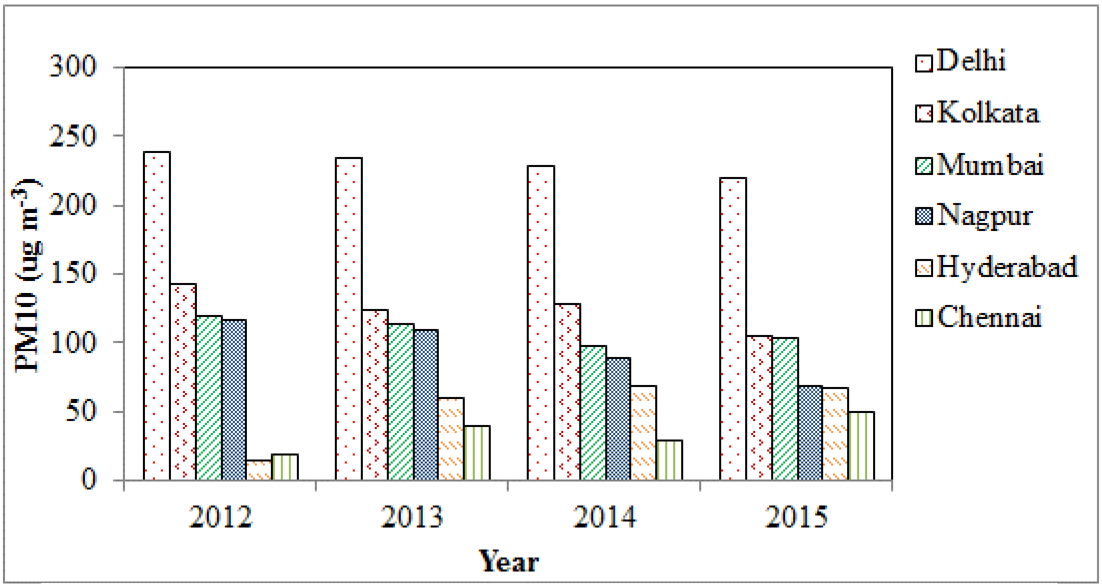


Fig. 1.1: Particulate Matter (µg m^{-3}) in Various Cities during 2012-2015 (Source: WBPCB and NEERI Reports, 2012-2015)

1.2 Background Information and Pre-requisites

- Ambient PM pollution is observed to be substantial, often breaching NAAQS in the twin cities of Kolkata and Howrah in West Bengal.
- To delineate an effective management plan and adaptation of control options, it is important to understand the sources of PM pollution in the area.
- There are various sources of PM pollution viz. paved roads, construction, traffic, solid waste burning, coal combustion, biomass burning etc. in Kolkata and Howrah. In addition to these sources, transported dust, which may be natural or anthropogenic in nature, may also contribute to the dust pollution in both the cities. It is essential to identify local and regional contributions to ambient PM pollution.
- Due to complexity and multiplicity involved in the sources contributing to ambient PM, it is essential to quantify contribution of sources for further actions.

1.3 Objectives and Scope of the Study

This study aimed to undertake PM_{10} and $PM_{2.5}$ Source Apportionment (SA) Study and Development of Emission Inventory of Twin Cities of Kolkata and Howrah in West Bengal with the following objectives:

1. Monitoring of particulate matter (PM_{10} and $PM_{2.5}$) in ambient air covering the spatial and seasonal variations in Kolkata and Howrah.
   - Sampling of Particulate Matter (PM_{10} and $PM_{2.5}$) using speciation and equivalent samplers at selected 12 sites.
   - Sampling (frequency - 24 hrs) for 10 days at each location for 2 seasons.
2. Chemical signature analysis of collected particulate samples with the objective of receptor modeling.
   - Analysis of collected samples for ions, elements, Polycyclic Aromatic Hydrocarbons (PAHs) and carbon fractions (organic and elemental carbon).
3. Preparation of emission inventory in Kolkata and Howrah.
   - To collect information on PM_{10} and $PM_{2.5}$ emission sources (through emission inventory) within the study area from the primary surveys and secondary data.
4. Source apportionment through receptor modeling by using CMB8.2 during summer and winter for both PM_{10} and $PM_{2.5}$ in Kolkata and Howrah.
   - Application of CMB8.2 using CPCB-ARAI (CPCB, 2009) and CPCB-IITB (Sethi and Patil, 2008) source profiles.

1.4 Methodology

A comprehensive air quality management plan usually has three basic requirements i.e., ambient air quality monitoring, development of emission inventory and source apportionment analysis. In this study, guideline document of CPCB on air quality monitoring, emission inventory and source apportionment study in Indian cities is referred to for the purpose (CPCB, 2011). The detailed methodology followed is given below:

- Sampling of PM_{10} and $PM_{2.5}$ on select filters (PTFE/ Quartz) by using speciation samplers, FRM samplers and other PM_{10}/$PM_{2.5}$ samplers (or fine particulate samplers) at 12 locations in twin cities. The details of site selection, sampling methods and findings have been given in relevant chapter.
- Sampling (24 hrs.) for at least 10 days in each season.
- Calculation of PM emission load for different sources based on the primary surveys or using secondary data, based on the activities in and around the study area. Emission factors of USEPA, CPCB, ARAI or other credible agencies have been used. The details are given in relevant chapter.
- Analysis of collected samples was undertaken for relevant ions, elements, select PAHs and carbon fractions (organic and elemental carbon). The XRF facility of WBPCB has been utilized for elemental analysis. Molecular marker and other markers analyses have been undertaken in-house at CSIR-NEERI.
- Calculation of PM emission load for different sources based on primary surveys around and secondary data on activities in and around the study area.
- Source apportionment analysis was undertaken by CMB8.2 receptor model based on the data obtained from chemical analysis and already established source profiles.
- Source profiles generated by CPCB-ARAI, Pune and CPCB-IITB, Mumbai have been used for modeling towards source apportionment.

1.5 Earlier Studies on Air Quality Monitoring, Emission Inventory and Source Apportionment in the Area

A few studies have been carried out in past on air quality monitoring, emission inventory and source apportionment of PM in the study area. Georgia Institute of Technology carried out source apportionment studies between March 2001 and January 2002 in Kolkata for $PM_{2.5}$. Average $PM_{2.5}$ concentration was observed to be 108 μg m^{-3}. WBPCB has been operating a large air quality monitoring network since 2000. **Table 1.1** summarizes the major findings of the source contribution assessment studies. In addition to the above studies, CSIR-NEERI carries out ambient air quality monitoring study at three locations in Kolkata as a part of National Ambient Air Quality Monitoring Programme sponsored by Central Pollution Control Board (CPCB). CSIR-NEERI maintains manual stations and monitors PM_{10}, SO_2, NO_2, NH_3, H_2S at three stations namely Kasba, Lalbazar and Cossipore (104 measurements in a year) while measurements on O_3, CO and $PM_{2.5}$ are undertaken for Kasba station only.

Table 1.1: Source Contribution Assessment of PM in Kolkata Carried out in Past Studies

Reference	**Pollutant**	**Method**	**Site**	**Source Contributions (%)**									
				Traf	RD/ SD	Coal	BB	Ind	FB /SW	SeA	SS	Mix	TD
Gupta et al. (2007)	PM_{10}	CMB	R I	 47	21 1	42 34	1 	 1	7 				
	TSP	CMB	R I	15/7	17/19 16/36	37 17			17				
Jain et al. (2019)	PM_{10}	PMF UNMIX PCA	U	18 22 32[1]	15 22 24		21 24 20[2]	15		25 32* 7	6 17[3]		
Karar et al. (2006)	PM_{10}	FA	R I	23,15 23	14 45			 20, 16	32				
Chowd-hary et al. (2007)	$PM_{2.5}$ Winter Summer	CMB	R	44 34	3 1	4 11	13 14			21 25			
Kar et al.	PM	FA	U					36				42	

(2010)													
Das et al. (2015)	PM_{10} $PM_{2.5}$	PCA	M	 30		17 16		32 37				36	
Chatterjee et al. (2012)	$PM_{2.5}$	PCA, HYSPLI-T	CR	38 17			27[2]			11	 36		18 22
ADB (2005)	RPM $PM_{2.5}$	EI CMB EI	-	18 22 49	61 60 15	1.2 4.2	6 10.1	8.5 17	2.1[^] 19[^]	 4.7			
ADB (2005)[+]	$PM_{2.5}$ RPM	CMB	-	48 21	15 60	6 4	23 10			13 5			

[*]Include SS, [1]include secondary sulphate, [2]includes coal combustion, [3]includes industrial contribution, FA-factor analysis, PCA-Principal Component Analysis, Mix- mixed source representing traffic and industrial emissions, [^]includes other area sources, [+] based on Georgia Institute of Technology study, EI-emission inventory, CR- commercial cum residential site, R-residential site, I-industrial site, M-many sites, U-urban site, Traf-traffic, BB- biomass burning or wood burning, Coal – coal combustion, FD- field burning or agricultural waste burning, SW- solid waste burning or open burning, Ind-industrial contribution, RD-road dust, SD-soil dust, SeA-secondary aerosol, SS-sea salt, TD-transported dust

West Bengal Pollution Control Board (WBPCB) monitors criteria pollutants viz. PM_{10}, $PM_{2.5}$, SO_2, NO_2, in their manually operated stations at Tollygunge, Hyde Road, Beliaghata, Minto Park, Moulali, Ultadanga, Baishnabghata, Salt Lake, Paribesh Bhawan, Dunlop Bridge, Shyambazar, Gariahat, Picnic Garden, Topsia, Mominpore, Rajarhat, and Behala Chowrasta (twice a week, as per the GoI notification) whereas it maintains two automatic air quality monitoring stations at Victoria Memorial and Rabindra Bharati University in Kolkata. As per the latest NAAQS issued in 2009, twelve parameters are monitored by WBPCB at Shyambazar and Behala Chowrasta till 2018. In Howrah, WBPCB monitors the criteria pollutants manually at HMC, Ghusuri, Bandhaghat and Bator and one automatic air quality monitoring station at Ghusuri. WBPCB publishes results of manual stations on their website and also reports *real time* NAQI online for the three automatic stations along with graphical representation of actual values. Very recently, WBPCB has installed five numbers of new automatic air quality monitoring stations at The Administrative Training Institute (ATI) in Salt Lake, Rabindra Sarobar, Birla Institute of Technological Museum (BITM), Indian

Association of Cultivation of Science (IACS) in Jadavpur and Fort William and two in Howrah at Padmapukur Water Works and Belur. These stations are also connected with National Air Quality Index portal.

1.6 Secondary AAQ Data Analysis

WBPCB carries out AAQ monitoring at various sites in Kolkata and Howrah. PM_{10}, $PM_{2.5}$, SO_2 and NO_2 are the major pollutants monitored, with a frequency of twice a week @ 8h for PM_{10} and $PM_{2.5}$ and 4h for SO_2 and NO_2. Air Quality Monitoring data has been obtained from WBPCB for 2012-2018 for secondary data analysis. **Fig. 1.2a** shows the PM_{10} concentration averaged over 2012-2018 at different sites. It can be observed that PM_{10} at all the locations exceeded the National Ambient Air Quality Standard of 60 $\mu g\ m^{-3}$ stipulated for annual average concentration. Further analysis using air quality index is carried out to understand the nature of variations. Air quality index (AQI) as provided by CPCB is calculated using the three parameters. **Fig.1.2b** shows frequency distribution of AQI as per data obtained from WBPCB for 2012-2018. It can be observed that AQI is mostly in the ‘Good’, ‘Satisfactory’ and ‘Moderate’ categories, with lesser instances of ‘poor’ category. The details of AQI are given in http://www.cpcb.nic.in/AQI_new.php. The index categories are given in **Table 1.2**.

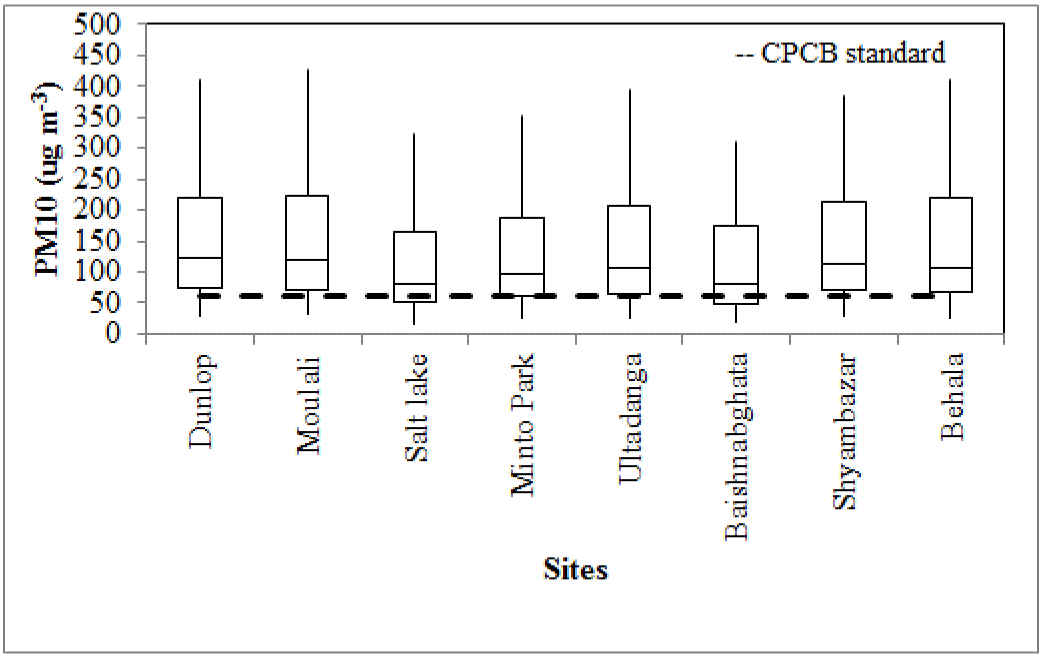


Fig. 1.2a: PM_{10} at Different Sites in the Study Area during 2012-2018
(Data Source : WBPCB)

Further, the monthly variations at some of the stations in Kolkata are also analyzed based on the data monitored by WBPCB. For this PM_{10} concentration data during 2012-2018 is considered. **Fig. 1.2c** shows the average monthly variations. It can be observed that PM_{10} was exceeding CPCB standard (stipulated for 24h average concentration) in winter.

Table 1.2: AQI Categories and Their Interpretation

AQI	AQI Category	Health Impact
0-50	Good	Minimal impact
51-100	Satisfactory	Minor breathing discomfort to sensitive people
101-200	Moderately Polluted	Breathing discomfort to the people with lung, heart disease, children and older adults
201-300	Poor	Breathing discomfort to people on prolonged exposure
301-400	Very Poor	Respiratory illness to the people on prolonged exposure
401-500	Severe	Respiratory effects even on healthy people

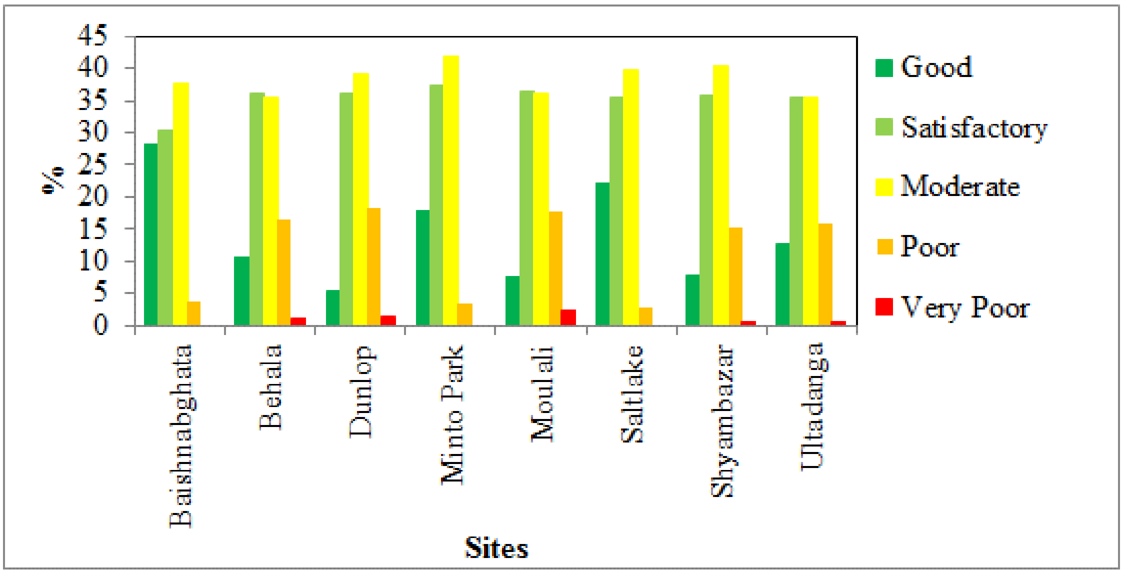


Fig. 1.2b: Frequency Distribution of Air Quality Index (Data Source : WBPCB)

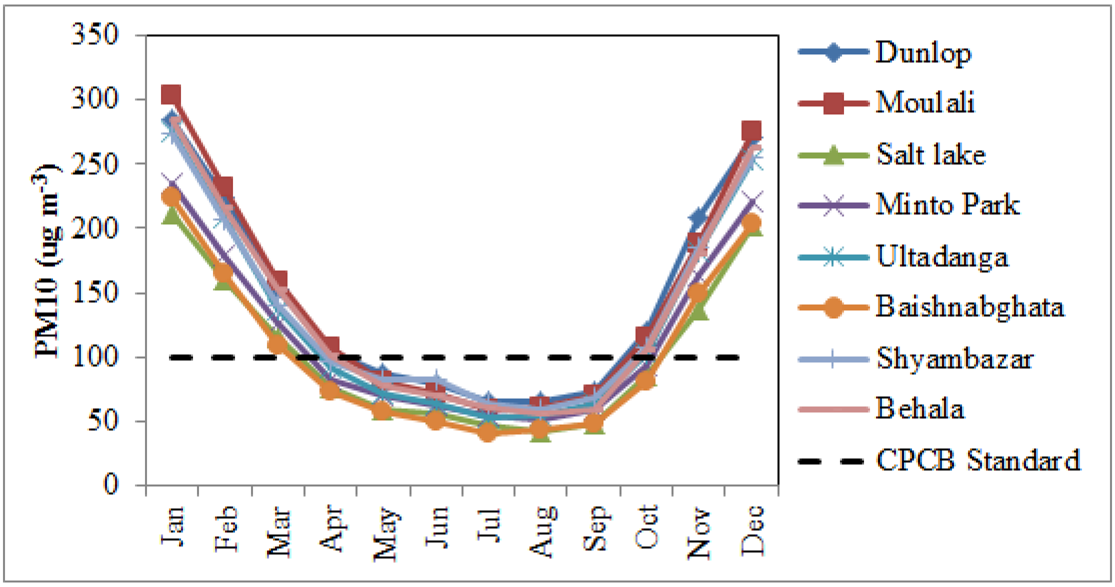


Fig. 1.2c: Monthly Average PM_{10} Concentration in Kolkata during 2012-2018 (Data Source: WBPCB)

1.7 Study Area

Megacity Kolkata located at 14 m above MSL in West Bengal, is situated in the eastern part of river Hooghly (main tributary of River Ganga, the national river of India) and is within the great Ganga-Padma delta. Kolkata district lies between $22^0 37'$ and $22^0 30'$ North latitude and $88^0 23'$ and $88^0 18'$ East longitude (**Fig. 1.3a**). On the north, it has North Twenty Four Parganas district, south is surrounded by South Twenty Four Parganas district. In the west, the district has natural barrier in the form of Hooghly River and Haora (Howrah) district and in the East, the district is bounded by North Twenty Four Parganas district. Kolkata is the only district in the state which is entirely urbanized and comprises almost entirely of Kolkata city. Joka is the only outgrowth of the district (District Census Handbook: Kolkata, Directorate of Census Operations, West Bengal, 2011). Kolkata, as a district itself, is governed by Kolkata Municipal Corporation (KMC) (erstwhile The Calcutta Municipal Corporation or CMC). KMC is responsible for the civic infrastructure and administration of the city of Kolkata. This civic administrative body administers an area of 185 km^2. However later, KMDA (erstwhile CMDA) (Kolkata Metropolitan Development Authority) was proposed in 1970 and was set up in the next year. Its original and crucial purpose is to execute development projects involving capital outlay and once completed, to hand over them to the KMC or other urban local bodies for running and maintenance (District Census Hand Book, Kolkata, 2001).

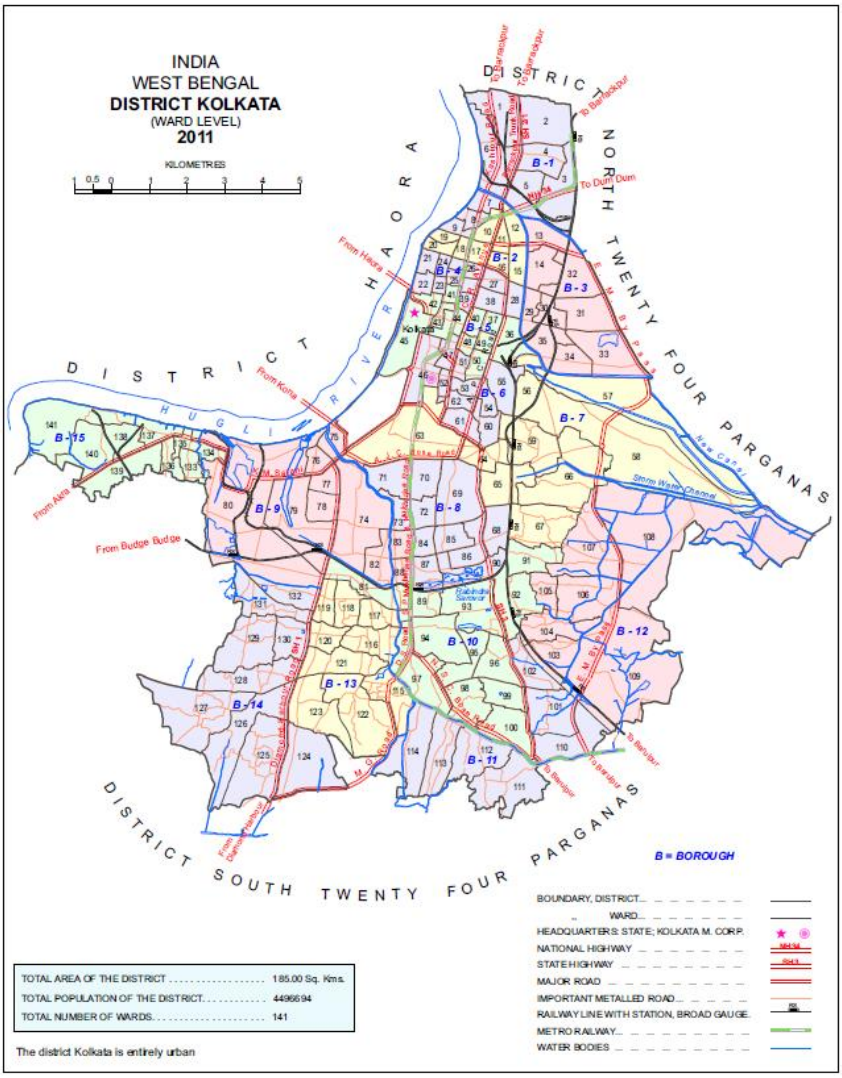


Fig. 1.3a: The Map of Kolkata District (Source: District Census Handbook: Kolkata, Directorate of Census Operations, West Bengal, 2011)

The city of Howrah (or Haora) is located at 12 m above MSL (**Fig. 1.3b**). The Howrah district lies between 22°48′ N and 22°12′ N latitudes and between 88°23′ E and 87°50′ E longitudes. The district is bound by the Hooghly River and the North 24 Parganas and South 24 Parganas districts on the east, by the Hooghly district (Arambagh and Shrirampur sub-divisions) on the north, and by Midnapore East district (Tamluk sub-division) on the south. On the west, Howrah district is bordered by the Ghatal sub-division of Midnapore West district, and partly by the Arambagh sub-division of Hooghly district to the north-west, and the Tamluk sub-division of Midnapore East district to the south-west. Boundaries of the district are naturally determined by Rupnarayan River on west and south-west, and by Bhagirathi-Hooghly river on east and south-east side. On north side, the boundary is an artificial one except for Bally Canal on north-east and Damodar River on north-west.

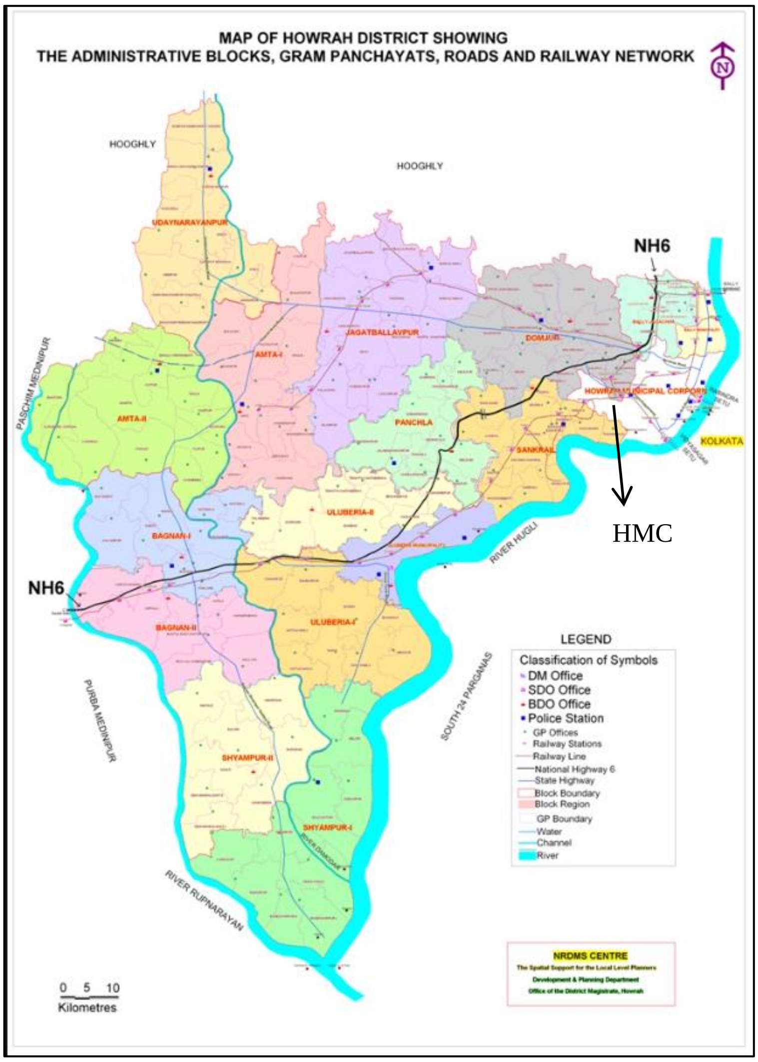


Fig. 1.3b: The Map of Howrah (Haora) District (Source: Official Website of Howrah; http://howrah.gov.in)

The district is industrially active and has several industrial hubs. The district has 2 subdivisions and 14 community development blocks and 2 ULBs (Howrah Municipal Corporation and Uluberia Municipality) (Official Howrah website, http://howrah.gov.in/dmdesk.html). The selected study area is restricted to Kolkata and Howrah municipal boundaries.

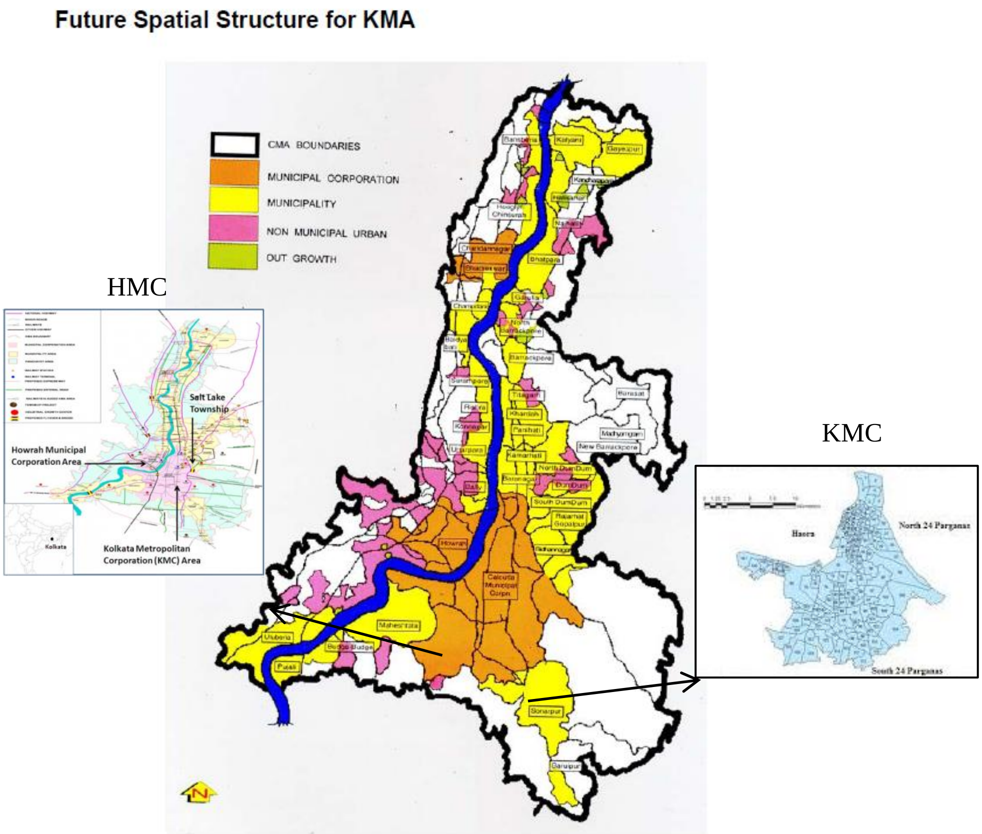


Fig. 1.3c: Future Spatial Structure of KMA **(**Source:JNNURM, http://jnnurm.nic.in/wp-content/uploads/2010/12/Kolkata_CH-II.pdf)

There are other designated areas also that need mention here so as to understand the study area and its surroundings. **Kolkata Metropolitan Area (KMA)** has Kalyani-Budge Budge on east bank and Bansberia-Uluberia on the west bank of the river Hooghly containing the whole of the Kolkata Urban Agglomeration (KUA) along with rural pockets. This is almost similar to the Kolkata Standard Urban Area as defined by the census authority (**Fig. 1.3c**). The **Metro Core** involves the twin city of Kolkata and Howrah with intensively built up surrounding areas spreading from Bally-Dakhineswar-Kamarhati to Andul-Garden Reach-Garia occupying about 34% of the KMA area. **Central Business District** has major focus of urban activities and covers 8% of the city’s municipal area and about 1% of the KMA area

(JNNURM, http://jnnurm.nic.in/wp-content/uploads/2010/12/Kolkata_CH-II.pdf). According to 2011 census, Kolkata District had a population of about 4.5 million while Howrah (District) had a population of 4.85 million. The Districts of Kolkata and Howrah with areas of 185 and 1467 sq. km. had population density of 24,306/km^2 and 3,306/km^2 for, respectively. In 2011, Howrah District had a population growth rate of 13.5% while Kolkata District had the same as -1.67% (Census of India, 2011- http://www.census2011.co.in/census/district/15-haora.html). The study area for both the selected cities would primarily cover the KMC (Kolkata) and HMC area (Howrah) within KMA (**Fig. 1.3c and 1.3d**). The existing air quality monitoring sites of WBPCB has also been considered for setting up the air quality monitoring sites for this study to ensure safety and security of instruments, availability of electricity and other logistics.

Fig.1.3d: Study Area Map

1.8 Organization of the Report

The report is divided into 8 chapters. A detailed table describing the chapter's contents is given below in **Table 1.3**.

Table 1.3: Organization of the Report

Chapter	Description
1.	Introduction and background of the study, general description of the study area, climatic conditions and emission source of particulate matter in the area, objectives and scope of the study, methodology followed and past studies carried out on particulate pollution in the area.
2.	Ambient air quality in terms of particulate matter in two seasons; winter and summer at twin cities, description of sampling sites, methodology adopted for sampling and chemical analysis.
3.	Emission Inventory carried out in the study area.
4.	Receptor Modeling using Chemical Mass Balance (CMB) during summer and winter.
5.	Long-range Transport using back-trajectory analysis and potential source contribution assessment based on meteorological and PM concentration data.
6.	Comparison of receptor modeling and emission inventory results.
7.	Summary of source apportionment study with comparison of two seasons at twin cities.
8.	Sector-specific recommendations are provided.

Chapter 2

Particulate Matter in Kolkata and Howrah: Sampling and Analysis

2.1 Sampling Site Selection

Selection of Ambient Air Quality (AAQ) stations was based on statistical analysis of historical data on PM_{10} monitored and reported by WBPCB and other criteria as specified by CPCB-MoEF (2003) depending on the location of emission sources, population density, meteorological conditions, availability of resources, security of the samplers and personnel involved in the sampling, availability of electricity, building effects and other logistics.

Before selecting the sampling stations for AAQ monitoring, a preliminary survey was conducted to explore the existing AAQ stations of agencies involved in monitoring in Kolkata and Howrah, in order to effectively plan AAQ network for the present study based on the the knowledge on existing AAQ stations. Statistical cluster analysis was carried out on the historical PM_{10} concentrations observed during 2012-2015 to extract information on the similarity amongst existing stations in terms of PM_{10} concentrations.

2.1.1 Spatial Analysis for Site Selection

In order to finalize AAQ network, PM_{10} concnetrations encountered at WBPCB AAQ stations were subjected to cluster analysis to extract information on similar stations and make clusters based on the similarity analysis using squared Euclidean distance. The notion is, if only one site is selected among the similar sites, it will be the representative of air pollution characteristics of all the similar sites. The analysis projects similar clusters based on available data and does not include other qualitative characteristics such as land use pattern etc. Cluster analysis has been used in the past for monitoring network design (Saksena et al., 2003). With the help of cluster analysis, network density is reduced by making groups of similar stations without loss of much information.

Ambient PM_{10} data during 2012-2015 were subjected to cluster analysis by selecting hierarchical agglomeration algorithm, squared Euclidean distance measure and between group linkage method. Since the most recent historical data i.e. during 2012-2015 was available only for the locations at Kolkata, cluster analysis was not carried out for Howrah as it had particulate matter data only at two locations. It is observed from **Fig. 2.1** that in all two clusters existed. Minto Park, Baruipur, Salt Lake, Baishnabghata and Amtala were in one cluster while Moulali, Ultadanga, Dunlop, Behala and Shyambazar formed another cluster. One can select any of the stations from an individual cluster for AAQ monitoring which could be the representative of the entire cluster.

The above analysis only included information on PM_{10} data and information on land-use characteristics, the sources present in the area/sites also needed to be looked into while selecting sampling sites. A reconnaissance survey was therefore carried out in Kolkata and Howrah. Based on discussions and reconnaissance with WBPCB, availability of sampling sites, land-use characteristics and diversity of sources in various locations, 12 sites were selected for the study. From cluster 1, Minto Park and Baishnabghata and from cluster 2, Dunlop and Moulali were selected along with Shyambazar considering the euclidiean distance of the sites. The details of the sites are presented in **Table 2.1** while **Fig. 2.2a** shows locations of the sites and **Fig. 2.2b** depicts actual monitoring/ sampling operations carried out at these sites. The site characteristics (**Table 2.1**) shows the diversity in land-use activity at the AAQ sites.

For Howrah, the stations were selected based on the factors such as logistics, land-use activity, availability of permissions by the land owners and in counsultation with WBPCB. For this a visit was made along with the WBPCB to select the study sites.

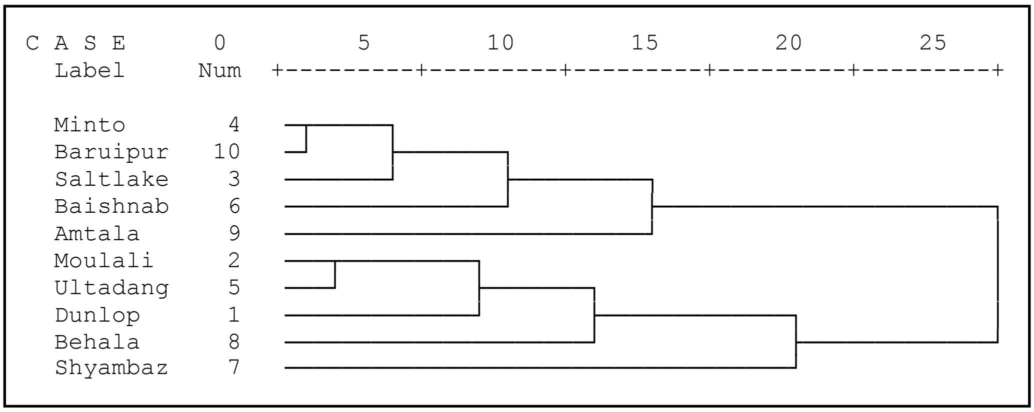


Fig.2.1: Dendogram for PM_{10} during 2012-2015

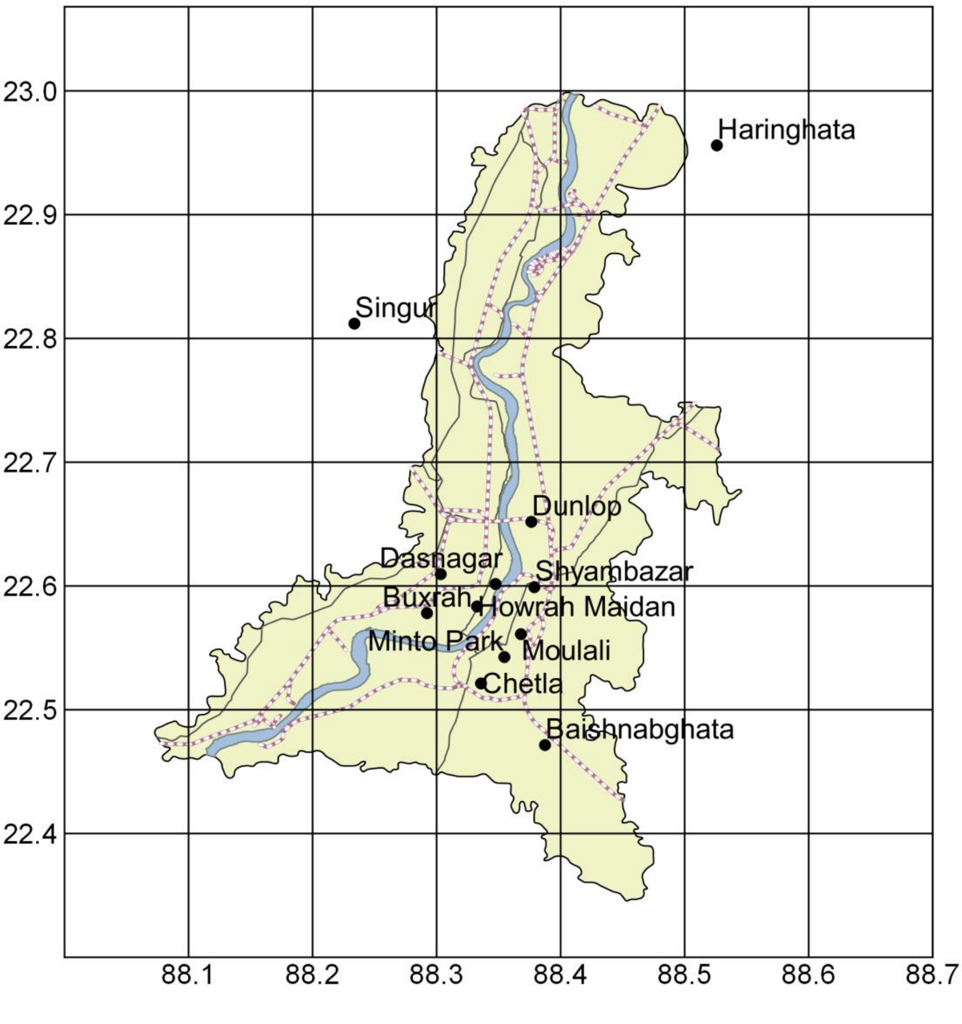


Fig. 2.2a: Ambient Air Quality Monitoring Stations in Kolkata and Howrah

Table 2.1: Characteristics of AAQ Sites

S. No.	Station Name	Coordinates	Station Classification	Observed sources
Kolkata				
1.	Baishnabghata	22.471452 N, 88.387409 E	Residential-Traffic	Residential Area, covered market within 500 m, playground, light traffic, a few Roadside tea stall and construction sites are present nearby
2.	Minto Park	22.542518 N, 88.354637 E	Traffic – Commercial	Flyover within 100 m, near main road with heavy traffic, residential and commercial activity with roadside food stalls within 100 m
3.	Moulali	22.561041 N, 88.367994 E	Traffic - Commercial	Commercial, 2 petrol pumps within 100 m, vegetation (thick within 50 m), moderately heavy traffic
4.	Shyambazar	22.59899351 N, 88.378831 E	Residential-Traffic	Main road with heavy traffic within 50 m, construction activity observed, Parked vehicles, West Canal Road with occasional traffic within 10 m, Residential (major) and commercial (few) activities prominent
5.	Dunlop	22.651771 N, 88.37639 E	Traffic - Commercial	Beside main road with heavy traffic, construction activity observed, one or two stacks observed, parked vehicle, residential (major) and commercial (few) activities are predominant
6.	Chetla	22.521206 N, 88.335803 E	Residential-Traffic	About 100 m from main road, small roads are there within residential settlements, slum settlement in adjacent area, mixed activity of residential and commercial
7.	Control (Haringhata/ Mohanpur)	22.955947 N, 88.5259710 E	Agricultural-Residential	No prominent source other than biomass burning by local residents and construction activity in IISER campus
Howrah				
1.	Bandhaghat	22.601539 N, 88.347545 E	Residential-Commercial	Residential (major), minor construction (2-3 nos.), Mandir (2-3 nos.), slum (small), Feeder road in 10 m, light traffic, commercial (minor)
2.	Control (Singur)	22.81193542 N, 88.2337113 E	Agricultural-Residential	Biomass burning including coal and waste observed, a few roadside eateries and tea

				stall nearby, the nearby road outside main gate has low but continuous vehicular movements.
3.	Advanced Training Institute (Dasnagar)	22.6095317 N, 88.3033096 E	Residential-Industrial	Advanced Training Institute campus, Residential area with hostels; Flanked by old industrial area of Das Nagar
4.	Akshay Shikshayatan (Howrah Maidan)	22.5833869 N, 88.3326047 E	Residential-Commercial	Traffic movements in nearby roads, residential area nearby along with commercial activities
5.	Buxrah High School (Buxrah)	22.5780083 N, 88.2922288 E	Residential-Traffic	Traffic movements in adjacent road, Residential area along with limited commercial activities

Singur

Shyambazar

Moulali

Minto Park

Fig. 2.2b: Sampling Locations

Bandhaghat

Haringhata

AIIH & PH, Chetla

Howrah Maidan

Baishnabghata

NSSO GH, Dunlop

Das Nagar

Buxrah

Fig. 2.2b: Sampling Locations

2.2 Ambient Air Quality

Sampling of ambient PM_{10} and $PM_{2.5}$ was carried out with various samplers as per the guidelines of Central Pollution Control Board. Partisol 2300 Speciation Samplers, Partisol™ 2025i Sequential Air Samplers, Partisol-FRM Model 2000 samplers and other equivalent fine particulate samplers were used for the sampling of PM_{10} and $PM_{2.5}$ at the sites. PTFE and quartz filters were used simultaneously for at least 10 days at each site in 12 locations. Requisite conditioning and gravimetric preparation of filter papers as per QA/QC protocols were undertaken before sampling. A 6-digit microbalance was used for initial and final gravimetric estimation of the filters. PTFE filters were used for analysis of ions and elements and quartz filters were used for OC-EC and PAHs. Details of the techniques and instruments used for sampling and analysis are given in **Table 2.2 and Fig. 2.3**.

Table 2.2: Sampling Instrument and Analysis Method

Particulars	**OC/EC**	**Ions**	**Organic Markers**	**Elements**
Sampling Instrument	Partisol 2300 Speciation Samplers, Partisol™ 2025i Sequential Air Samplers, Partisol-FRM Model 2000and PM_{10}/$PM_{2.5}$ samplers (indigenous samplers)			
Filter paper	Quartz filter	PTFE filter	Quartz filter	PTFE filter
Particulate fraction	PM_{10} and $PM_{2.5}$	PM_{10} and $PM_{2.5}$	PM_{10} and $PM_{2.5}$	PM_{10} and $PM_{2.5}$
Sampling Principle	Filtration of aero-dynamic sizes with a size cut by impaction	Filtration of aero-dynamic sizes with a size cut by impaction	Filtration of aero-dynamic sizes	Filtration of aero-dynamic sizes
Analytical instrument	OC/EC Analyser	Ion Chromatograph	GC-MS	XRF
Analytical method	TOR/TOT Method	Ion Chromatograph	Gas Chromatography-Mass Spectrometry	XRF X-ray fluorescence

Speciation sampler

Sequential sampler

Envirotech

Netel

Polltech

FRM sampler

IC Dionex

GC-MS

Fig. 2.3: Instruments for Sampling and Characterization

2.3 Quality Assurance and Quality Control

Before initiation of the study, all involved project personnel were given training by the trained staff on sampling and chemical analyses. Standard Operating Procedures (SOPs) based on CPCB guidelines (CPCB, 2011) were prepared and handed over to the project staff. Likely variability in sampling was minimized by fielding the same staff during both seasons. Filters were pre-conditioned and packed as per the SOPs to avoid contamination before and after samplings. Calibration of the samplers was done before start of the sampling during each season. A dedicated staff for chemical analyses was deployed individually for ions and molecular markers.

2.4 Ambient Air Quality: Summer

Ambient air quality of Kolkata and Howrah was monitored during two seasons; summer 2017 and winter 2017-18. Ambient air quality was monitored at 9 stations (7 in Kolkata and 2 in Howrah, including 2 control stations, 1 each for Kolkata and Howrah) in summer 2017. Air sampling for summer season was started from 21st April 2017 (at least 10 days monitoring with 24 hours frequency, three sites at a time), continued till second week of June and completed before onset of monsoon., Sampling at 3 selected stations in Howrah viz. Howrah Municipal Corporation, Ghusuri Pump House and Batore Heath Centre could not be done during summer 2017 due to administrative reasons; hence 3 new air quality stations were scrutinized and finalized in Howrah (ATI in Das Nagar, Buxrah High School in Buxrah and Akshay Shikshayatan in Howrah Maidan). However, summer sampling at the newly selected stations could only be undertaken during summer 2018 as these stations could not be finalized during summer 2017. The sampling schedule in summer 2017 at 9 stations is given in **Table 2.3**.

Table 2.3: Sampling Schedule Followed for Summer Season

Month	**Schedule**								
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
April-May 2017	20-03	20-03	20-03						
May-June 2017				4-20	4-20	4-20	23-31	24-31	24-31
June 2017							1-4	1-5	1-4

N.B.: The duration includes station set-up and dismantling

Site 1 - Dunlop, Site 2 - Singur, Site 3 – Shyambazar, Site 4 - Chetla, Site 5 - Minto Park, Site 6 – Baishnabghata, Site 7 -Moulali, Site 8 - Bandhaghat, Site 9 - Haringhata

PM_{10} and $PM_{2.5}$ observed at 9 locations is plotted in **Fig. 2.4**. It can be observed that $PM_{2.5}$ was below the CPCB standard limit at all the locations except on few days at Shyambazar and Minto Park. PM_{10} exceeded CPCB standard more frequently than $PM_{2.5}$. While comparing PM_{10} and $PM_{2.5}$ concentration at various locations, it can be observed form **Fig. 2.5** that $PM_{2.5}$ and PM_{10} both were highest at Shyambazar followed by Dunlop.

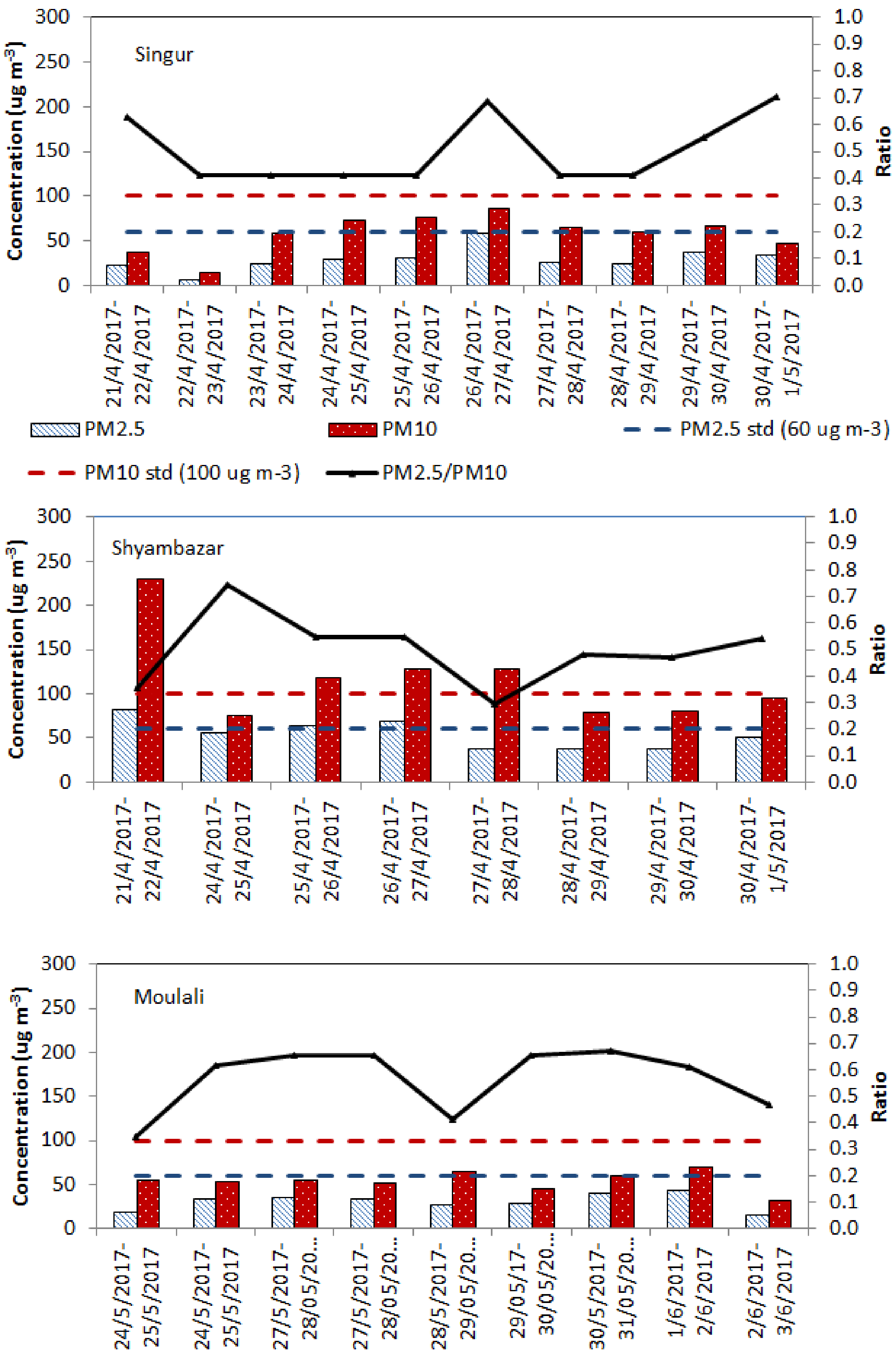


Fig. 2.4: PM_{10} and $PM_{2.5}$ Concentration at Different Locations: Summer

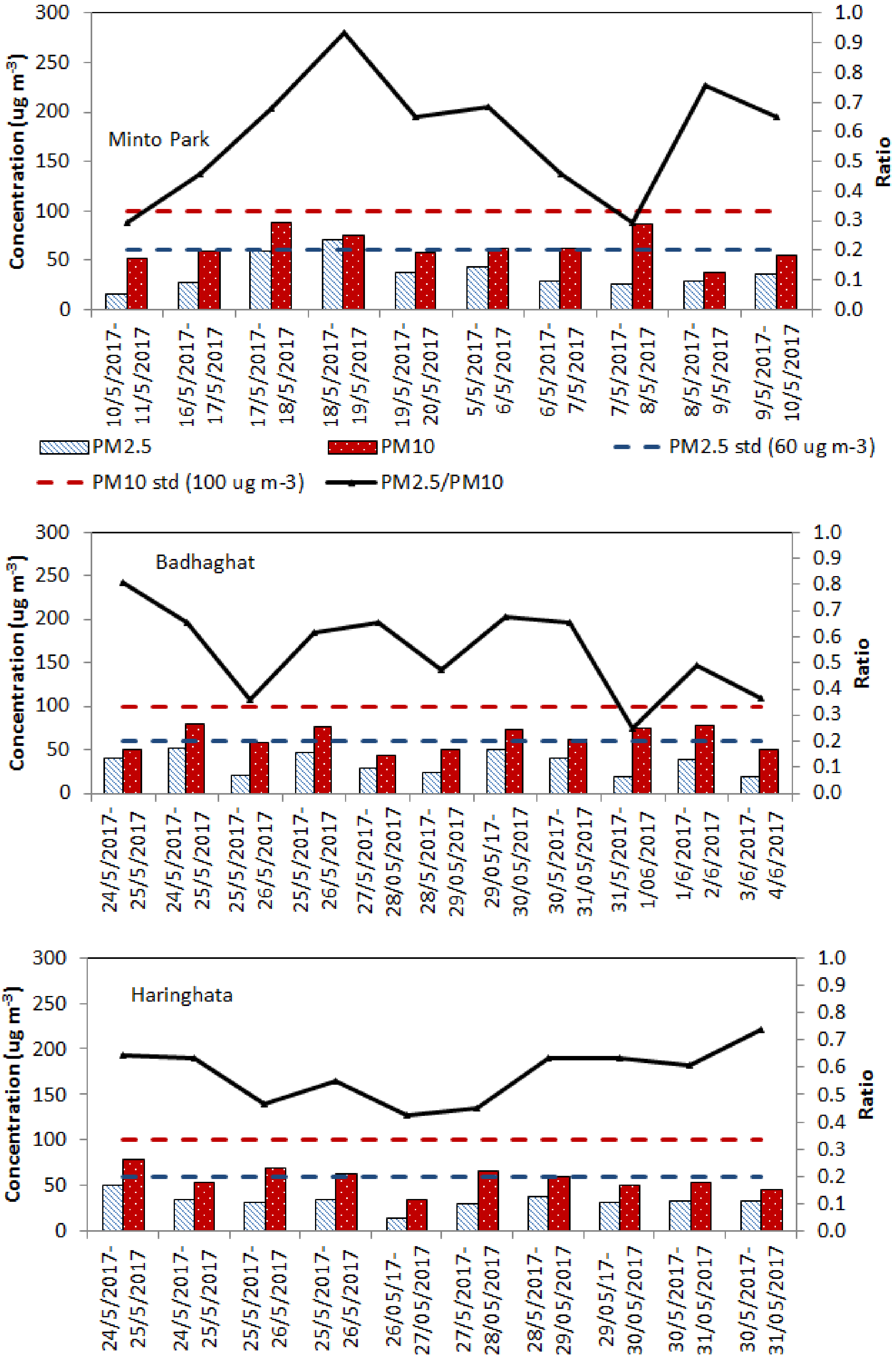


Fig. 2.4: PM_{10} and $PM_{2.5}$ Concentration at Different Locations: Summer

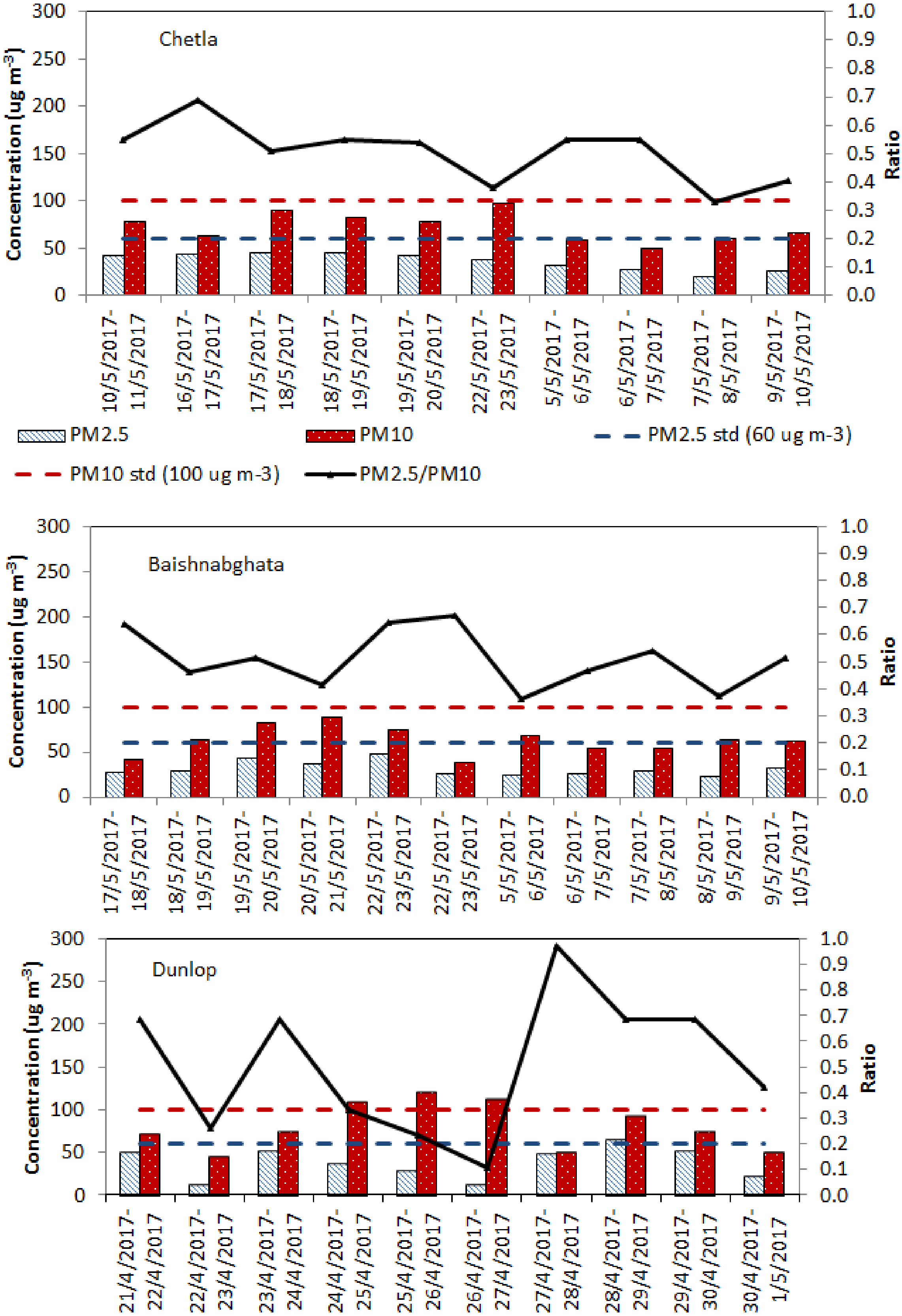


Fig. 2.4: PM_{10} and $PM_{2.5}$ Concentration at Different Locations: Summer

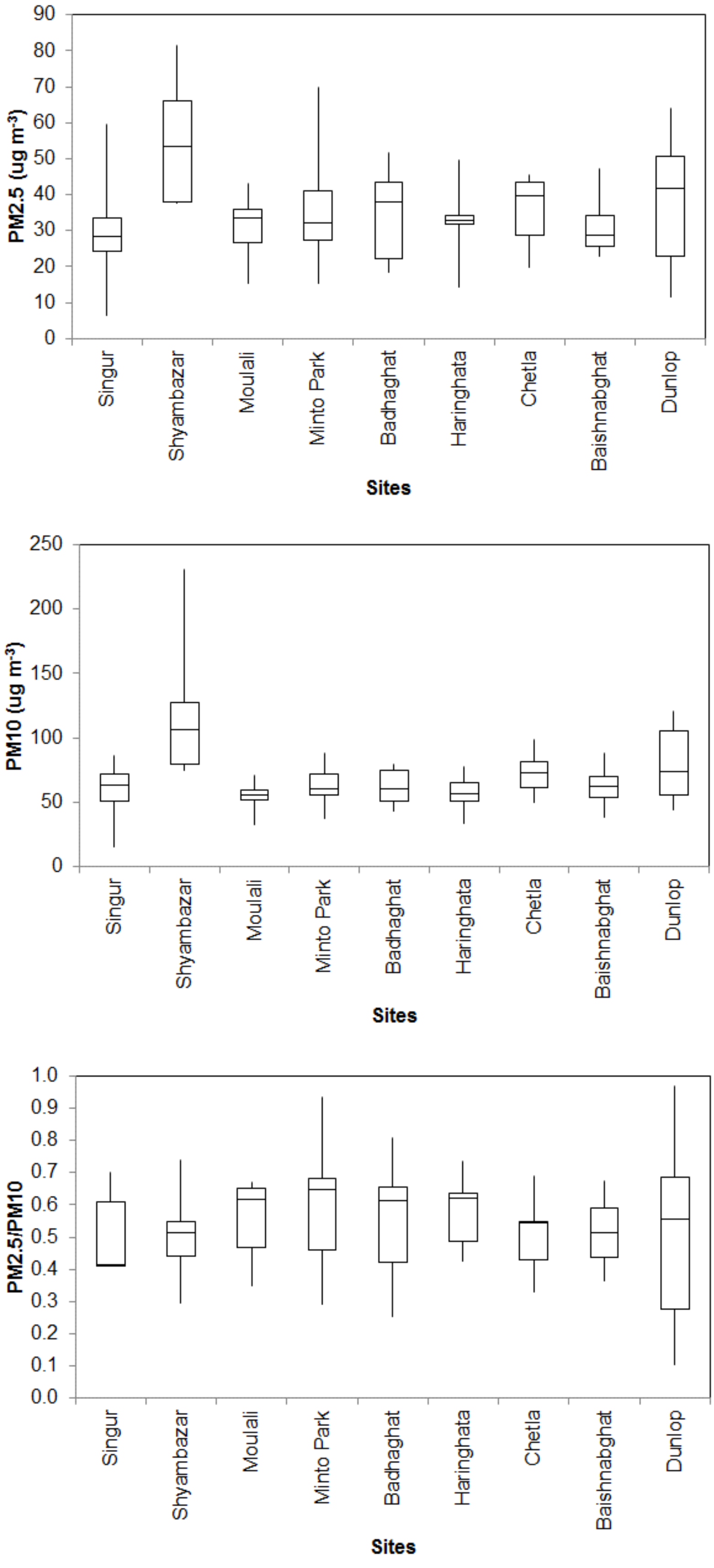


Fig. 2.5: Preliminary Observations: $PM_{2.5}$, PM_{10} and $PM_{2.5}/PM_{10}$ Ratio at Various Sites: Summer

(Middle line indicate median, 25^{th} and 75^{th} quartiles are reflected in boxes, vertical bar lines indicate minimum and maximum)

2.5 Ambient Air Quality: Winter

During winter of 2017-18, ambient air sampling has been carried out at 12 (twelve) sampling locations. Three new locations in Howrah were selected afresh for winter. The locations of the sampling sites along with the 3 newly selected sites in Howrah are presented in **Fig. 2.2a**. The summary characteristics and observed activities at the sampling sites are presented in **Table 2.1**. Air sampling for winter season was started from 20th December 2017 (at least 10 days monitoring with 24 hours frequency, three sites at a time) and continued till last week of January 2018.

Sampling for PM_{10} and $PM_{2.5}$ at each of the 12 locations was carried out on PTFE and quartz filters by using Partisol 2300 Speciation Samplers, Partisol™ 2025i Sequential Air Samplers, Partisol-FRM Model 2000 samplers and other equivalent fine particulate samplers for at least 10 days. The sampling schedule for 12 locations is given in **Table 2.4**. Requisite conditioning and gravimetric preparation of filter papers as per QA/QC protocols were undertaken before sampling. A few photographs of the AAQM sites and AAQ monitoring are collated in **Fig. 2.2b**. A microbalance was used for initial and final gravimetric estimation of the filters. The $PM_{2.5}$ and PM_{10} concentrations estimated from the gravimetric analyses were plotted for the selected sites at Kolkata and Howrah (**Fig. 2.6**).

During winter, maximum ambient PM_{10} concentration was observed at Shyambazar (632.5μg m^{-3}) in Kolkata followed by Howrah Maidan in Howrah (610.7 μg m^{-3}) while the lowest concentrations were 37 μg m^{-3} at Singur followed by 63 μg m^{-3} at Bandhaghat. On the other hand, maximum $PM_{2.5}$ concentrations were observed at Howrah Maidan (~379 μg m^{-3}) followed by Buxrah (376 μg m^{-3}) in Howrah and at Moulali (263 μg m^{-3}) in Kolkata while the lowest $PM_{2.5}$ concentrations were 23 μg m^{-3} at Singur followed by 38 μg m^{-3} at Bandhaghat.

In case of ambient PM_{10}, NAAQS was breached in 100% cases (all sampling days) at all the sites in Kolkata except at Baishnabghata (90% breached), which is a residential site. In Howrah, PM_{10} standard was breached in 100% cases at Das Nagar, Buxrah and Howrah Maidan, but at Singur (control site) and Bandhaghat, 67% and 89% cases had breached NAAQS. On the other hand, NAAQS for $PM_{2.5}$ was breached again at all sites in Kolkata except Basihnabghata (80% breached) and at all sites in Howrah also, except Singur (control site) (89%) and Bandhaghat (89%). Average of both PM_{10} and $PM_{2.5}$ concentration was ~2-4 times above the CPCB threshold. At control sites (Singur and Harighata), average PM_{10} and $PM_{2.5}$ concentrations were 1.5 and ~2 times above the CPCB threshold. The $PM_{2.5}/PM_{10}$ ratio (range: 0.32–0.99), that reflects variation in source-wise emissions of particulates, showed wide variations in Dunlop, Shyambazar, Chetla (all in Kolkata) and Singur and Buxrah (in Howrah), implying temporal variations in source-wise emissions. Howrah Maidan was one exceptional site where along with high concentrations of PM_{10} and $PM_{2.5}$, dispersion in daily average PM_{10} and $PM_{2.5}$ concentrations were highest amongst all.

Box diagrams (**Fig. 2.7**) were plotted for all the locations for spatial comparison of air pollution scenario in terms of PM_{10} and $PM_{2.5}$. The $PM_{2.5}$ concentration was highest at Chetla. PM_{10} concentration was observed to be highest at Shyambazar. Both exceeded the standards at all the sites. $PM_{2.5}/PM_{10}$ ratio was highest at Minto Park and lowest at Shyambazar and it was observed to be more than 50% frequently at all the sites, suggesting dominant contribution of combustion activities in ambient particulates at these sites.

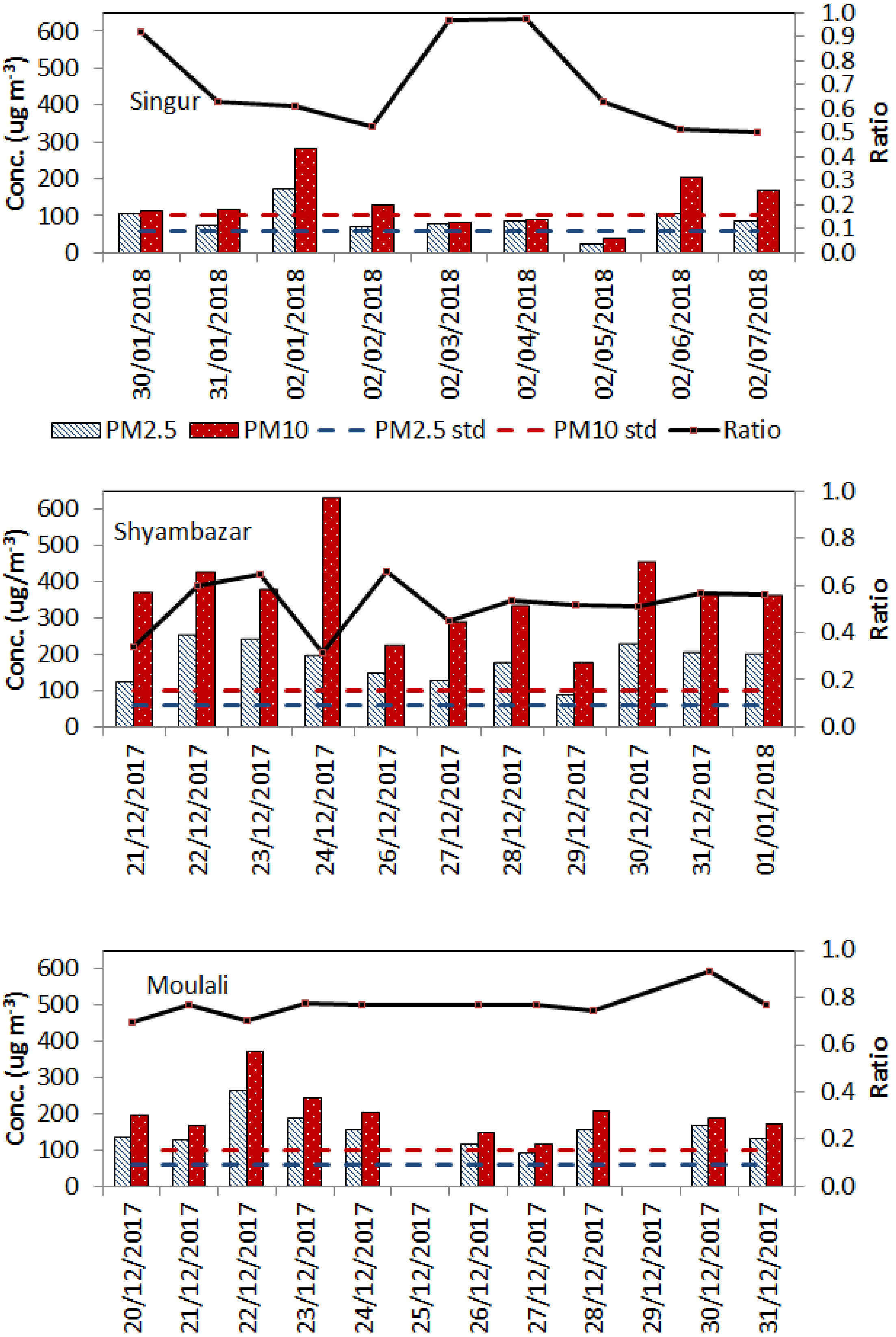


Fig. 2.6: PM_{10} and $PM_{2.5}$ Concentrations Along With $PM_{2.5}/PM_{10}$ Ratios during Winter 2017-18

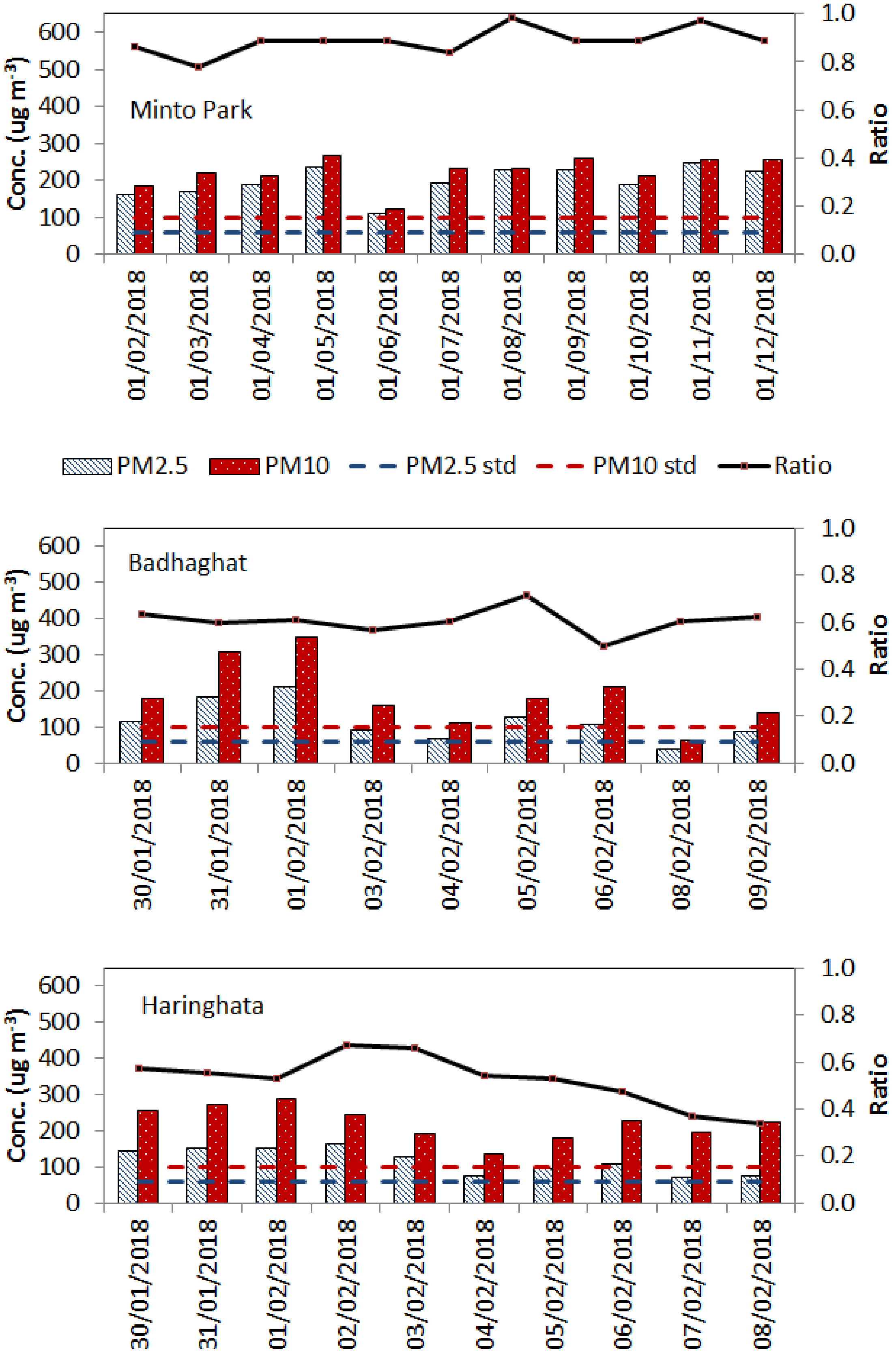


Fig. 2.6: PM_{10} and $PM_{2.5}$ Concentrations Along With $PM_{2.5}/PM_{10}$ Ratios during Winter 2017-18

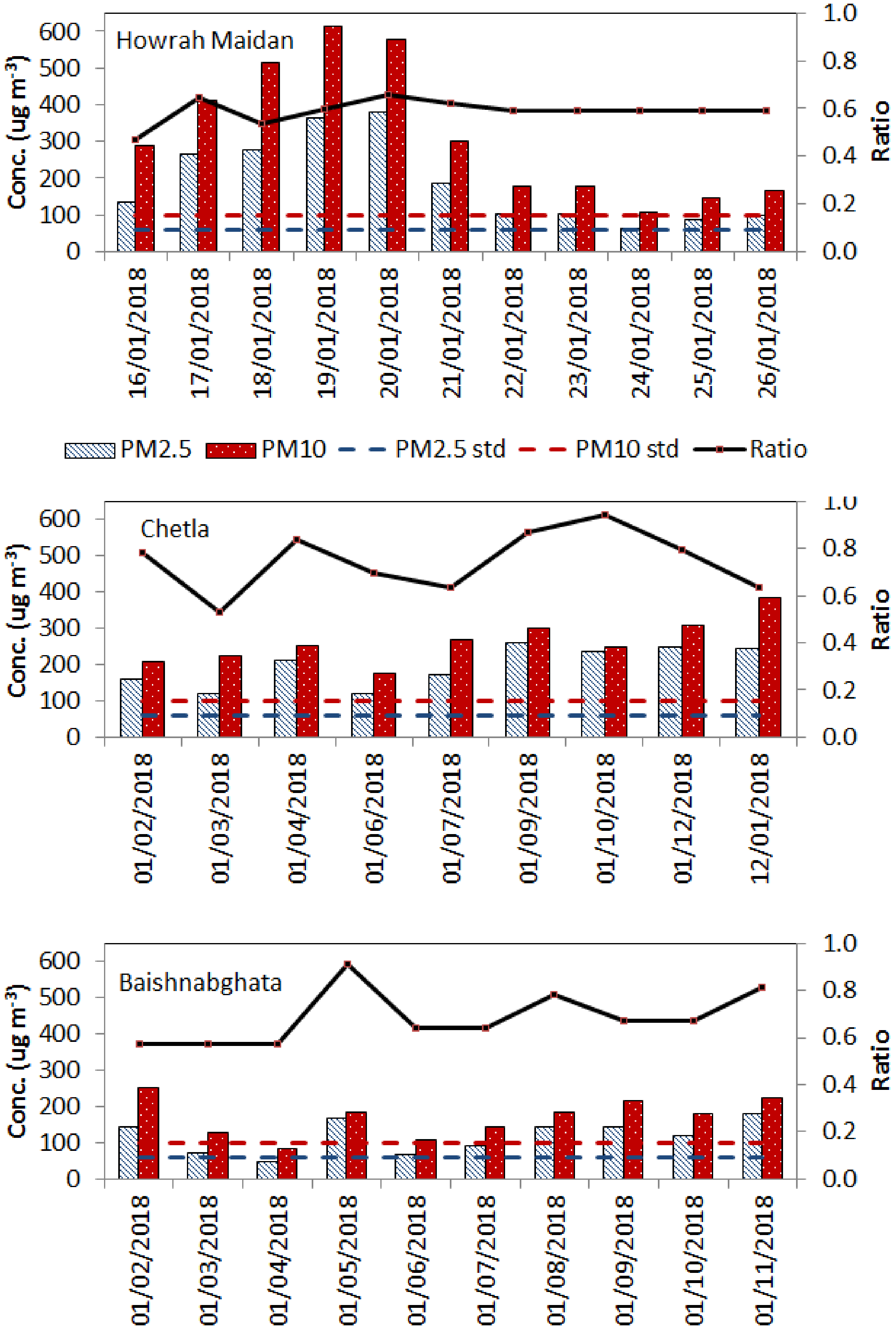


Fig. 2.6: PM_{10} and $PM_{2.5}$ Concentrations Along With $PM_{2.5}/PM_{10}$ Ratios during Winter 2017-18

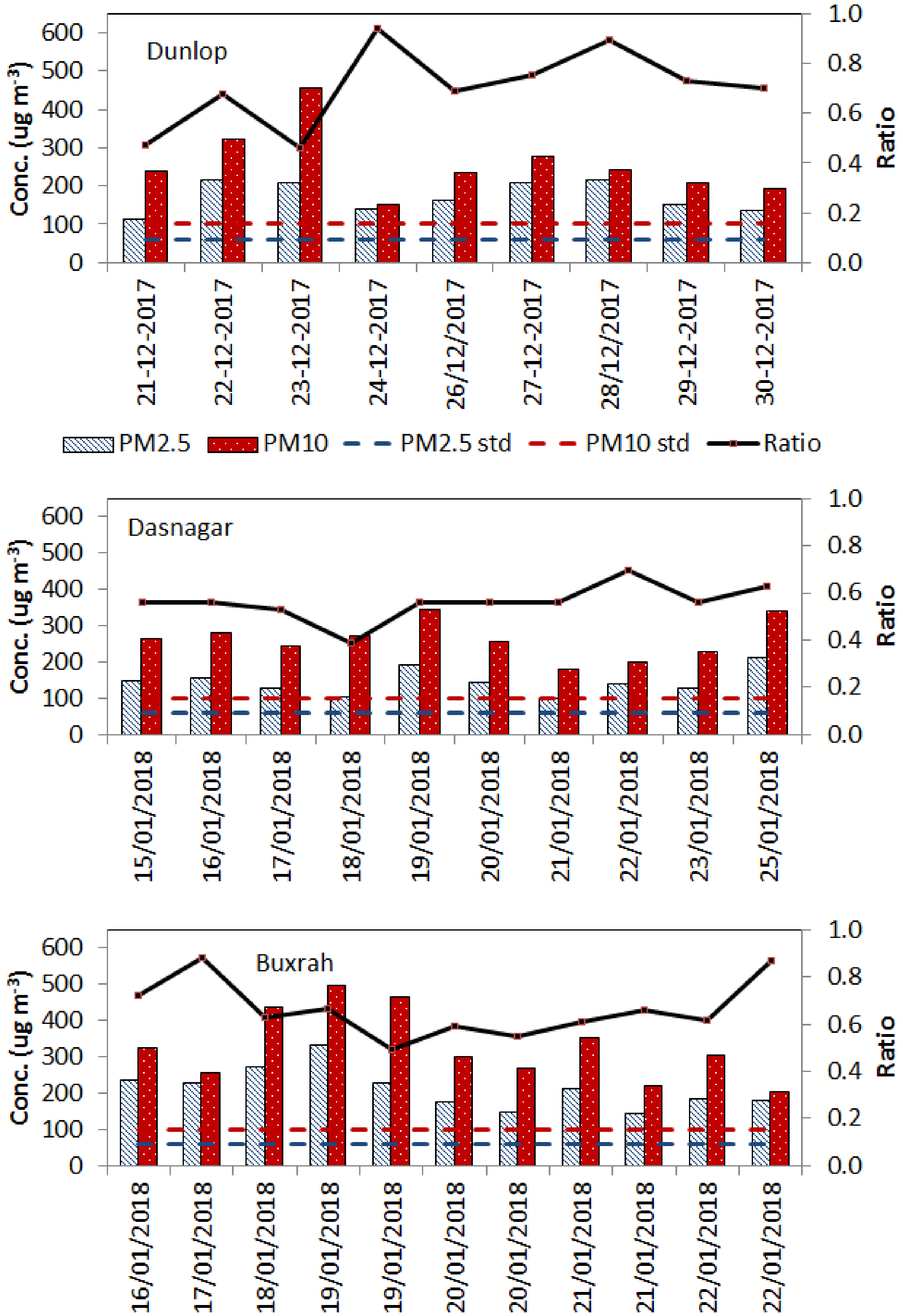


Fig. 2.6: PM_{10} and $PM_{2.5}$ Concentrations Along With $PM_{2.5}/PM_{10}$ Ratios during Winter 2017-18

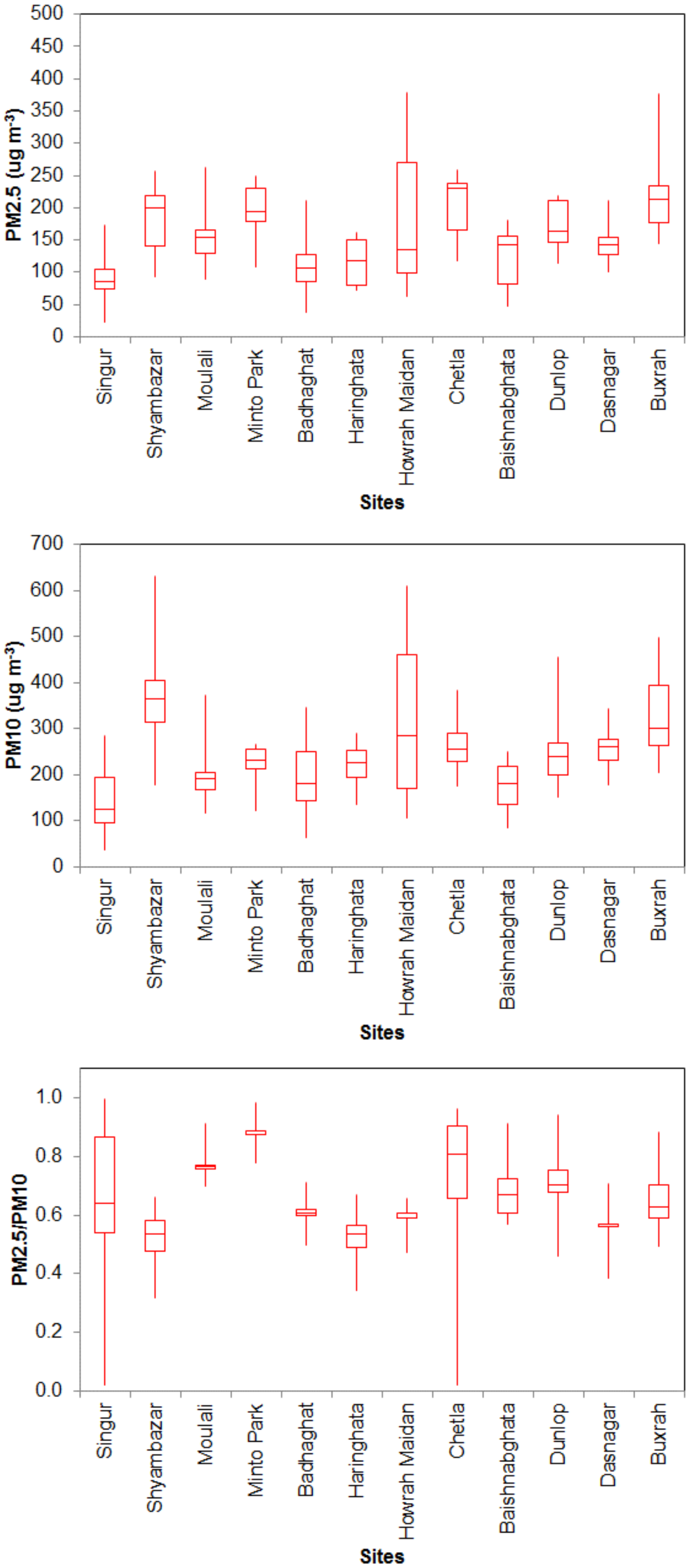


Fig. 2.7: $PM_{2.5}$, PM_{10} and $PM_{2.5}/PM_{10}$ ratio at Various Sites during Winter 2017-18
(Middle line indicate median, 25th and 75th quartiles are reflected in boxes, vertical bar lines indicate minimum and maximum)

Table 2.4: Sampling Schedule in Winter (2017-18)

S. No.	Site Name	Start Date	End Date
Kolkata			
1.	Moulali	20.12.2017	31.12.2017
2.	Shyambazar	21.12.2017	1.1.2018
3.	Dunlop	21.12.2017	1.1.2018
4.	Baishnabghata	2.1.2018	12.1.2018
5.	Chetla	2.1.2018	13.1.2018
6.	Minto Park	2.1.2018	12.1.2018
7	Haringhata (Control)	30.1.2018	8.2.2018
Howrah			
1.	Howrah Maidan (Akshaya Sikshayatan)	16.1.2018	26.1.2018
2.	Das Nagar (Advanced Training Institute)	15.1.2018	25.1.2018
3.	Buxrah (Buxrah High School)	16.1.2018	26.1.2018
4.	Badhaghat	30.1.2018	9.2.2018
5.	Singur (Control)	30.1.2018	9.2.2018

2.6 Ambient Air Quality: Summer (2018)

Air sampling for summer 2018 was started from 8th May 2018 (at least 10 days monitoring with 24 hours frequency, three sites at a time) and continued till 11th June 2018. Sampling schedule for summer 2018 is given in **Table 2.5**. Filters generated during summer 2018 monitoring (3 new sites in Howrah along with the control site i.e. Singur) have been allocated for chemical analysis including elements, EC/OC and select molecular markers. Filters for analysis of ions were allocated after receipt of Teflon filters from elemental analysis by EDXRF.

Ambient air quality was monitored in summer 2018 at four sites (including control at Singur) in Howrah only. Three amongst these sites located in Howrah could not be undertaken during summer 2017 campaign due to unavailability of permission for three shortlisted sites from Howrah Municipal Corporation. However, three new air quality sites were freshly selected subsequently and could only be monitored in winter 2017-18 and in summer 2018 exclusively. Along with these sites, the control site for Howrah i.e. Singur was also monitored to allow comparison.

The time-series air quality data is presented in **Fig. 2.8**. The obtained data indicate that except for few days, ambient PM_{10} and $PM_{2.5}$ concentrations were within NAAQS of CPCB at all sites. PM_{10} breached NAAQS only in Das Nagar (25% of sampled days) which is bordered by an industrial estate. On one particular day, PM_{10} surpassed the NAAQS limit by several folds but reason thereof could not be traced. On the other hand, $PM_{2.5}$ never breached the NAAQS on any occasion at any site. The ratio of $PM_{2.5}/PM_{10}$ was found to fluctuate substantially at Howrah Maidan, indicating to the variation in the contribution of multiple sources.

Box diagrams (**Fig. 2.9**) were plotted for all the locations for spatial comparison of air pollution scenario in terms of PM_{10} and $PM_{2.5}$. The PM_{10} concentration was highest at Howrah Maidan.

Table 2.5: Sampling Schedule in Summer (2018)

S. No.	Site Name	Date of initiation	Date of termination
1.	Buxrah (Buxrah High School)	10.05.18	23.05.18
2.	Howrah Maidan (Akshaya Sikshayatan)	08.05.18	25.05.18
3.	Das Nagar (Advanced Training Institute)	29.05.18	07.06.18
4.	Singur (Control)	28.05.18	11.06.18

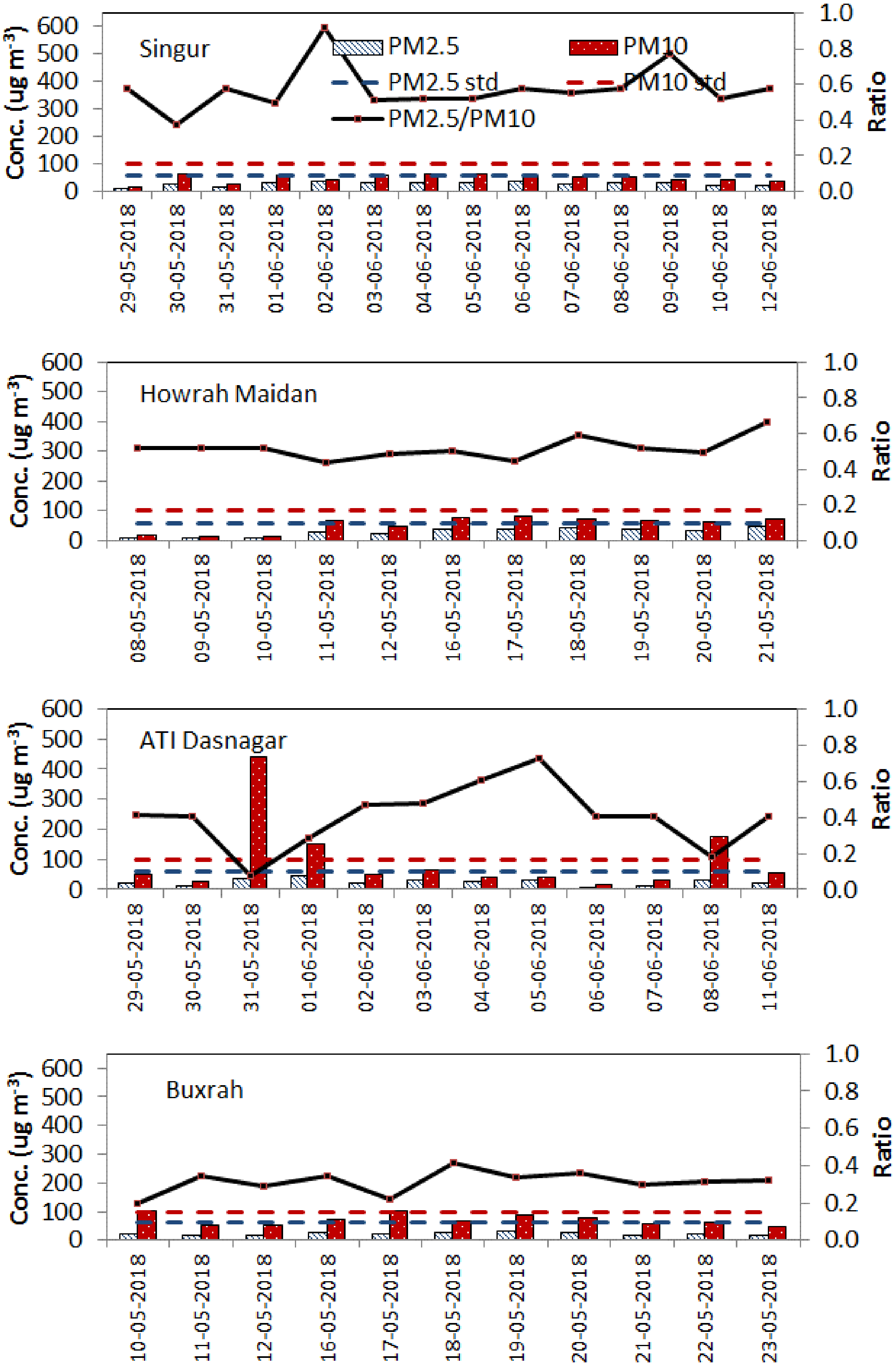


Fig. 2.8: PM_{10} and $PM_{2.5}$ Concentrations Along With $PM_{2.5}/PM_{10}$ Ratios at Different Locations during Summer 2018

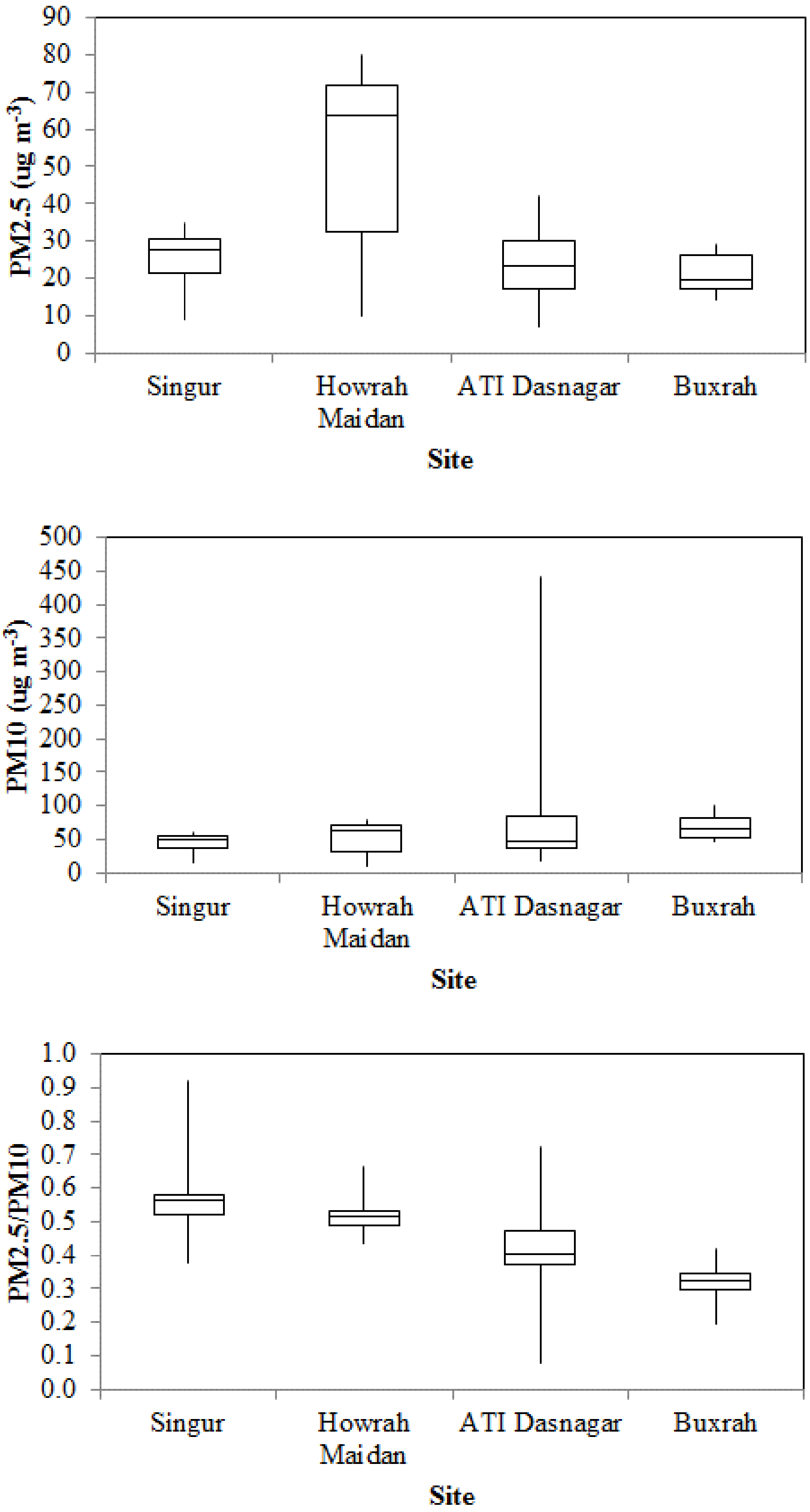


Fig. 2.9: $PM_{2.5}$, PM_{10} and $PM_{2.5}/PM_{10}$ Ratio at Various Sites during Summer 2018

(Middle line indicate median, 25th and 75th quartiles are reflected in boxes, vertical bar lines indicate minimum and maximum)

2.7 Comparison of PM during Winter and Summer

As per generally known character of air quality in different seasons, it was observed that ambient air quality in winter at the same stations in Kolkata and Howrah were worse than in summer in terms of daily average values of PM_{10} and $PM_{2.5}$ and observed cases of exceedance of National Ambient Air Quality Standards (NAAQS). Almost all values of 24-hourly $PM_{2.5}$ and PM_{10} in winter exceeded the NAAQS stipulated by CPCB.

For three new Howrah sites and also the Howrah control site i.e. Singur, monitored in summer 2018, the ambient PM_{10} and $PM_{2.5}$ concentrations were significantly higher in winter over summer 2018. Also, there were notable escalations in minimum and maximum recorded concentrations of $PM_{2.5}$ and PM_{10} in winter over summer.

The mean $PM_{2.5}/PM_{10}$ ratios are plotted to assess the nature of sources during the summer 2017 (nine sites only), winter 2017-18 (all 12 sites) and summer 2018 (4 sites only) (**Fig. 2.10a** and **2.10b)** which shows that the ratio was higher in winter at all the sites as compared to summer 2017, suggesting increase in combustion activities. During summer 2018, however, the ratio was almost similar to winter. The ratio was >0.50 at all the sites during both the seasons. In order to compare the PM concentration between summer 2017 and 2018, the average PM concentration at control site Singur are plotted in **Fig. 2.10c.** It is observed that the $PM_{2.5}/PM_{10}$ ratio has slightly increased from 0.5 to 0.58, whereas $PM_{2.5}$ and PM_{10} has decreased slightly in 2018. General nature and extent of 24-hourly PM deposition on filters exposed in summer and winter is presented in **Fig. 2.10d**.

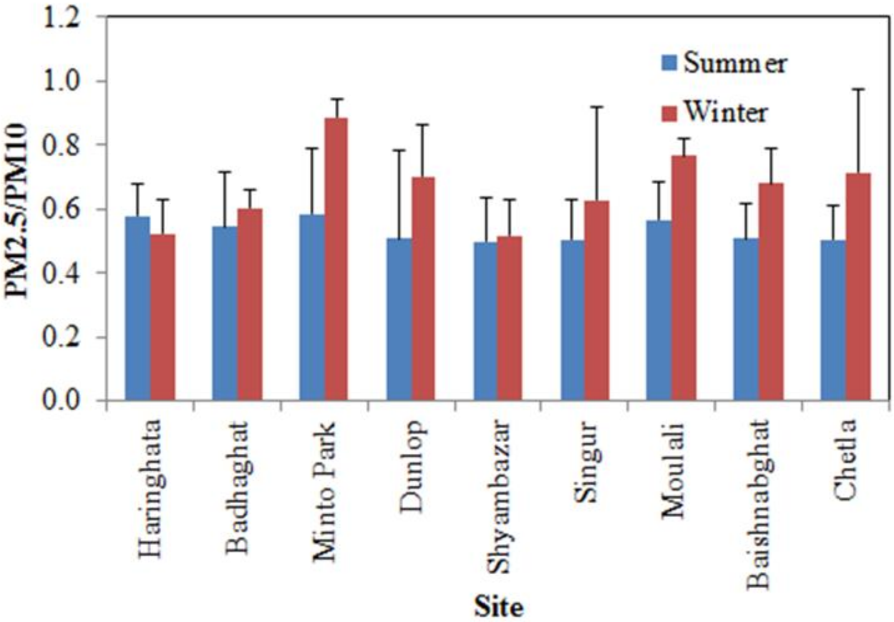


Fig. 2.10a: Average $PM_{2.5}/PM_{10}$ Ratios at Various Sites during Summer 2017 and Winter 2017-18

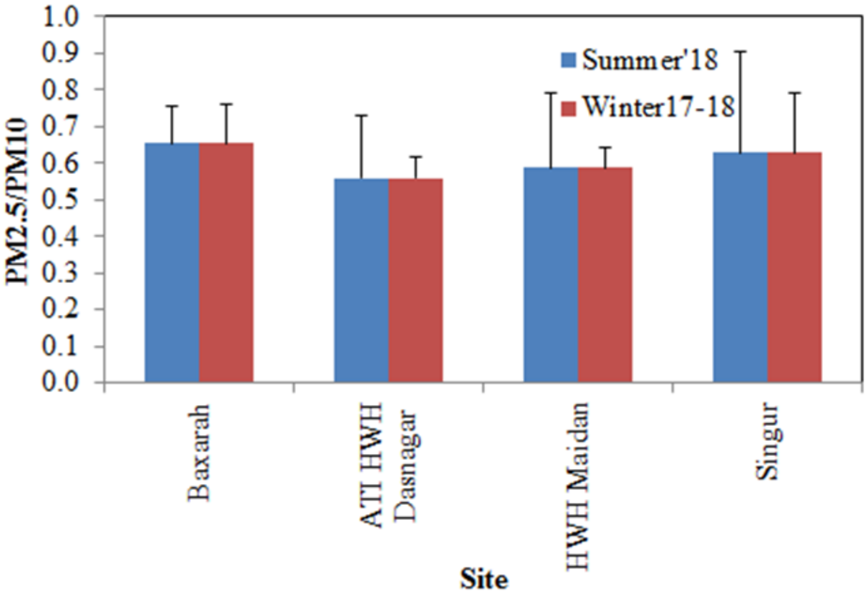


Fig. 2.10b: Average $PM_{2.5}/PM_{10}$ Ratios at Various Sites during Summer 2018 and Winter 2017-18

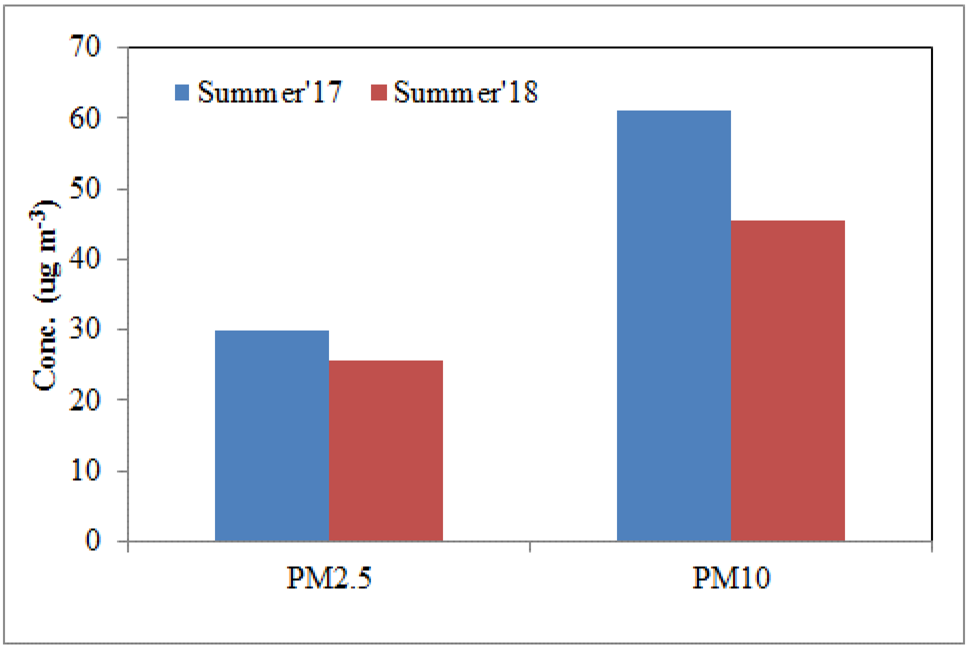
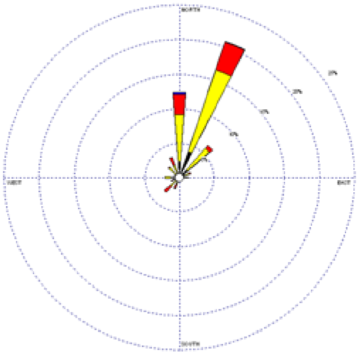


Fig. 2.10c: Comparison between Summer 2017 and Summer 2018 for PM at Singur

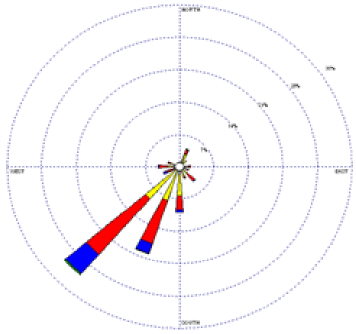
Fig. 2.10d: Difference in Nature and Extent of PM Deposition (24-hourly) on Filters Exposed in Summer and Winter in Kolkata

2.8 Wind Patterns in Kolkata and Howrah

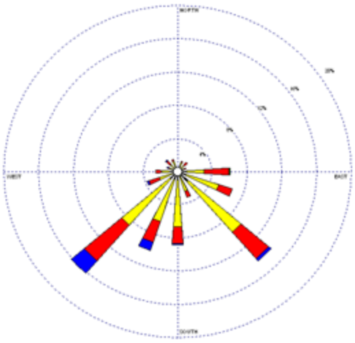
Wind patterns in Kolkata and Howrah were studied during 2017-2018 by collecting meteorological data from IMD office in Kolkata and from CPCB website for Howrah to prepare windrose using WRPLOT software (**Fig. 2.11a and Fig. 2.11b**). In Kolkata, annual wind pattern showed that the prevailing wind direction was from SW sector with calm conditions prevailing around 25% of times. In winter, calm condition had a share of 42% and prevailing wind direction was from N and NE directions. In summer, calm condition was 7% and prevailing wind direction was from SW. In Monsoon, calm condition had around 19% share and prevailing wind direction was from SW and SE. In post-monsoon season, calm condition was prevailing for about 32% time and prevailing wind direction was SW and NE. In Howrah, in winter, calm condition had a share of 10% and prevailing wind direction was from NW. In summer, calm condition was 2% and prevailing wind direction was from S. In Monsoon, calm condition had around 1% share and prevailing wind direction was from SE and SW. In post monsoon season, calm condition was prevailing for about 12.5% time and prevailing wind direction was W. Annual wind pattern shows that the prevailing wind direction was from SE-SW sector with calm conditions prevailing around 6.4% of times.



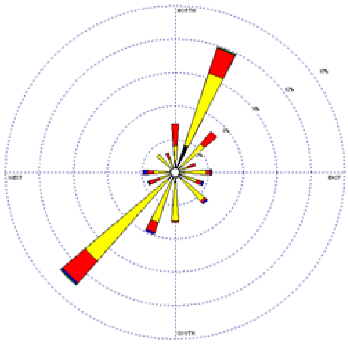
Winter



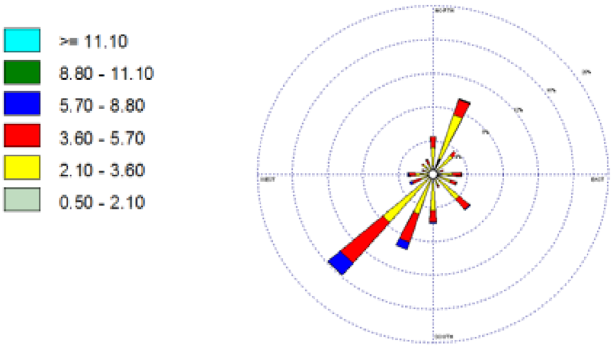
Summer



Monsoon



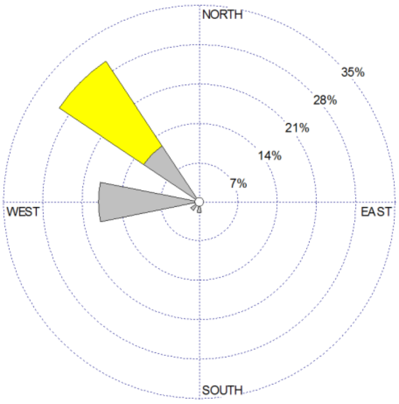
Post-Monsoon



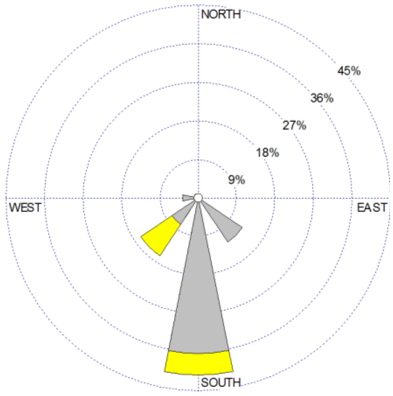
Season	Calm%
Winter	42
Summer	7
Monsoon	19
Post-Monsoon	32
Annual	25

Annual

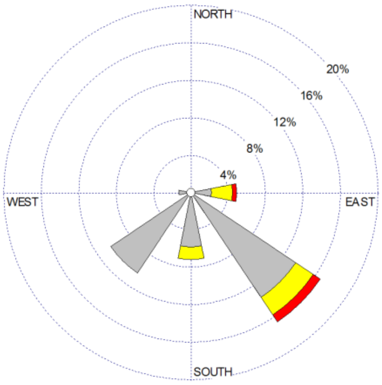
Fig. 2.11a: Windrose Diagrams of Summer, Monsoon, Post-Monsoon and Winter in Kolkata



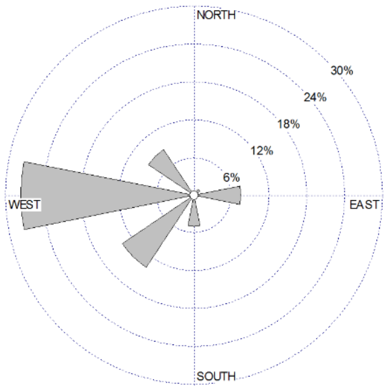
Winter



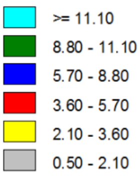
Summer

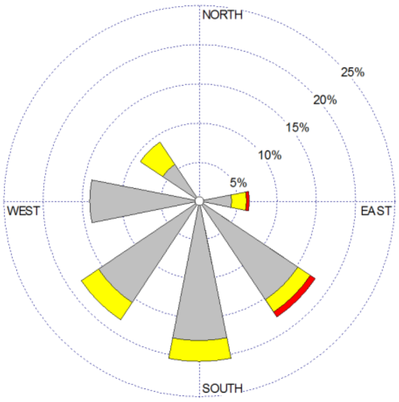


Monsoon



Post-Monsoon





Season	Calm%
Winter	10
Summer	2
Monsoon	1
Post-Monsoon	12.5
Annual	6.4

Annual

Fig. 2.11b: Windrose Diagrams of Summer, Monsoon, Post-Monsoon and Winter in Howrah

Chapter 3

Emission Inventory

3.1 Introduction

Emission inventory was prepared for the city of Kolkata (KMC Area) and Howrah (HMC Area) by identifying sector-wise major and minor sources of PM_{10} and $PM_{2.5}$, their respective activity data i.e. fuel type, fuel usage rate, total fuel usage, human population and number of entities like hotels and restaurants, households, crematoria, ironing vendors, vehicles (with types, vintage, numbers, mileage etc.), numbers of ferries operating on Hooghly river and also numbers or quantity of other relevant units in operation. The emission inventory exercise aimed to prepare sector-wise PM_{10} and $PM_{2.5}$based on best available activity database at the time of finalization of study results. It must be noted that emission estimates are as good as the quality of activity data and hence availability of proper activity data will determine the quality of emission estimates. Best efforts have been made to collect most relevant and realistic activity data from various sectors but collected data may not have been equally robust for all sectors or cities due to incomplete database, absence of proper database specifically needed for this type of study, absence of database in a particular region or on a specific aspect and below par willingness of general public, vendors, users and local bodies to spare time to take interviews or share data. Therefore, there may be low to moderate uncertainty in emission estimates. Also, such emission estimates might not remain relevant for several years as activity data is known to change fairly quickly.

For emission estimates, 2016 has been considered to be the base year. For transport (tailpipe emission), data available up to 2018 has been used. The methodology for making Emission Inventory of Kolkata and Howrah was streamlined after accessing various reports. Detail survey/ reconnaissance of air pollution sources, activities *vis a vis* population and density within 2 × 2 km area around the selected air quality stations in the two cities was conducted and also in many other areas that represented commercial, residential, industrial, kerbsite and mixed areas. Also, various reports, research papers and maps of KMC and HMC were consulted to understand possible types and density sources of air pollution in KMC and HMC areas. Delineation of sources was done after the initial exercise and detail activity data collection was undertaken by conducting field surveys in shortlisted areas. Also, various organizations and govt. departments were approached for collection of secondary activity data. The following major and minor sources of air pollution in Kolkata and Howrah city were identified and shortlisted for activity data collection (**Table 3.1**). Importance and weightage were assigned to the sources based on their possible density, approx. numbers per area and potential of emitting PM_{10} and $PM_{2.5}$.

Table 3.1: Various Identified Sources and Sectors in Kolkata and Howrah

S. No.	Name of Source	Importance/ Weightage		Source of identification	Justification for weightage/ other remarks
		Kolkata (KMC)	Howrah (HMC)		
1.	Vehicle	High	High	Source identified from general information, previous reports, works of NEERI and research papers	There are lakhs of registered vehicles in Kolkata and Howrah
2.	Industry/ Manufacturing units	High	High	Source identified from previous reports of various organizations, previous works of NEERI, research papers	There are many small and medium industrial/ manufacturing units in Kolkata and Howrah
3.	Road dust	High	High	Source identified from previous works of CSIR-NEERI, various urban air pollution reports, reconnaissance and research papers	Dust was found to be prevalent over some parts of Kolkata and Howrah roads due to constant inputs from uncovered roadside soils, broken roads etc.
4.	Domestic fuel combustion	High	High	Source identified from reconnaissance, previous works of CSIR-NEERI	Population density in Kolkata and Howrah is very high. There is

					substantial presence of slums in these cities and wood, kerosene and coal, usage is prominent
5.	Construction	High	High	Source identified from surveys, reconnaissance, previous works of CSIR-NEERI	Growth of construction sector including urban development activities like flyover and tunnel construction in Kolkata and Howrah is high
6.	Hot Mix Plants	Moderate	Moderate	Source identified from primary survey and past knowledge; Meeting with KMC officials	Two permanent KMC controlled Hot Mix plants are operated in Kolkata for road laying and repairing; Many other mobile ones are used whenever and wherever needed through private contractors and sub-contractors
7.	Open burning	Moderate	Moderate	Source identified from primary survey, newspaper reports and public interviews	Open burning of MSW and other waste does exist as an unorganized activity; Smouldering fire is reported from dumpsites at Dhapa and on Belgharia Expressway (latter is outside KMC limit but can significantly contribute to city pollution). But, no estimate is available on amount of waste on fire
8.	Power Plants	Moderate	Moderate	Previous works of CSIR-NEERI and WBPCB database	There is only one operating power plant (CESC Southern Generating Station) within KMC and none in HMC area and hence this source is considered minor in terms of presence
9.	Restaurants/ Hotel kitchens/Mobile food vendors	Moderate	Moderate	Source identified from reconnaissance, previous works of CSIR-NEERI and research papers	Restaurants and hotels, guest houses and commercial establishments having kitchens,

					roadside eateries, bhujiawalas and tea shops are commonly found all over Kolkata and to a lesser extent in Howrah. Many of these eateries use coal, wood, kerosene apart from LPG
10.	Crematoria	Low	Low	Source identified from KMC and HMC websites, other web sources, reconnaissance and meetings with stakeholders	There are several crematoria in Kolkata and Howrah
11.	Marine vessels	Low	Low	Source identified from reconnaissance and previous knowledge	Permanent source; Visible smoke emanates from these vessels run by diesel engines
12.	Ironing vendors	Low	Low	Source identified from primary survey and also, stressed by WBPCB	As per primary survey of NEERI, there are a several hundreds of ironing vendors in Kolkata and Howrah, who use electricity and also coal for warming the ironing machines

3.2 Reconnaissance / Primary Survey

Primary survey was conducted by CSIR-NEERI Team around the selected air quality monitoring stations and many other residential, commercial, industrial, kerbsite and mixed areas in Kolkata and Howrah to identify major and minor air pollution sources, interview public, customers and vendors to record activity data on fuel consumption in households, hotels and restaurants and other commercial establishments, ironing huts etc. (**Fig. 3.1-3.3**). (**Annexure I, *English and Bengali questionnaires***). Questionnaire Survey on vehicles was conducted at several petrol pumps (**Annexure II**) in the two cities to record types of vehicles running in the respective cities, their average mileage within KMC/ HMC, miles ran/unit fuel, vehicle vintage, usage rate (days run per year) etc. (**Annexure III**) for estimation of likely emissions of PM_{10} and $PM_{2.5}$ from vehicular fleet (**Fig. 3.4**). Further, registered vehicular data with vintage was collected from various RTO offices in Kolkata (Beltala, Kasba, Behala, Salt Lake, Alipore) and RTO office in Howrah. Road dust was collected from eleven different locations distributed over the cities and silt content in road dust were determined to apply into the USEPA model on road dust emission calculation.

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Fig. 3.1: Survey of Roadside Eateries and Ironing Vendors

Fig. 3.2: Use of Coal by Ironing Vendors and Roadside Eateries

Fig. 3.3: Instances of Open Burning Witnessed at Various Parts of Kolkata and Howrah

Fig. 3.4: Vehicular Survey at Petrol Pumps

3.3 Secondary Data sources

Secondary data on fuel and energy usage in industrial sector was extracted from filed-in consent to operate forms accessed through online database maintained by WBPCB (http://emis.wbpcb.gov.in/emis/). The consent to operate forms submitted on or after 2015 were only considered for industrial fuel consumption database preparation as suggested by

WBPCB, as these reflected the present industrial scenario. Also, data was shared by KMC officials for this study on static hot-mix plants operated by KMC in Kolkata, list of registered businesses in Kolkata including eateries, data on base area of construction (only for residential construction) etc. Data on total fuel supply in automobile, consumer, retail, aviation, road construction and industrial sectors for the two cities was collected from Indian Oil Corporation Ltd. (IOCL) office in Kolkata and were used wherever required. Secondary data on population was collected census database and from various other reports. The various sources of data collection are summarized in **Table 3.2**.

Table 3.2: Source of Activity Data

Source/Sector	Source of data
Industrial/ Manufacturing units	WBPCB database, CSIR-NEERI Archives
Transport/Vehicular	RTO databases; CSIR-NEERI Archives; Primary surveys by CSIR-NEERI
Restaurants/Hotel kitchens/Mobile food vendors	KMC database, HMC database, Kolkata Police, WBPCB, CSIR-NEERI Archives, Primary Survey by CSIR-NEERI
Construction	KMC database; other data sources
Road dust	Primary Survey by CSIR-NEERI; Laboratory analysis, KMC/HMC websites on roads, various reports
Domestic fuel consumption	Primary Survey by CSIR-NEERI; Census data on population, Data given by Food and Supplies Dept. of West Bengal Govt.
Crematoria	KMC database; Online resources
Ironing vendors	Primary Survey by CSIR-NEERI
Open burning	Primary Survey by CSIR-NEERI; KMC/HMC data on waste generation; Online sources
Marine vessels	Web resources
Hot Mix Plants	KMC database; Emission Test Results of State-run plants shared by WBPCB; IOCL database
Thermal Power Plant (CESC Southern)	Specific data from CESC Southern; Online resources

3.4 Methodology for Preparation of Emission Inventory

The basic logic behind emission inventory calculation involves collection of sector-wise activity data (e.g. type of fuel used and their consumption in various sectors, mileage and vintage of vehicles, their number, rates of production of a commodity, number of industrial units operating in the cities, their hours of operation per day and year, city-wise population etc.) from secondary databases or primary survey or direct estimation and then integrating these with suitable pollutant-specific and activity-specific emission factors (emission per amount of fuel burnt in various sectors/activities /operations, emission per km travelled for vehicles, emission per unit of a commodity produced etc.) and relevant population database to calculate likely emissions of a pollutant from that particular activity/source/sector (**Fig. 3.5**). Further, number of operating units like number of households, number and types of registered and on-road vehicles with vintage (registered vehicles in last 15 years i.e. 2004-2018), survival rate of vehicles (type wise vehicle survival rates for registered vehicles in Kolkata and Howrah in last 15 years; Ref: Goel and Guttikunda, 2015, DoI: 10.1016/j.atmosenv.2015.01.045), number of restaurants/eateries, types and number on industries, number of bodies burnt in crematoria etc. are important information required to develop the emission inventory. For emission inventory estimates, along with reliable activity data, relevant emission factors or emission coefficients that represent emission per unit fuel, production, number of product, vehicle mile ran and so on is required. The calculation methodology for emission estimates is summarized in **Table 3.3**.

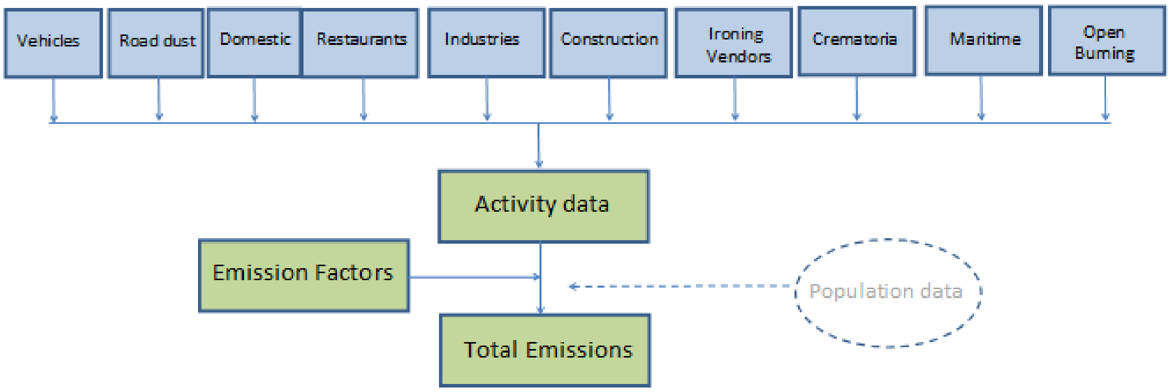


Fig. 3.5: Emission Inventory Procedure

Table 3.3: Summary of Methodologies for Estimation of Sector-Wise Emissions

Name of Source/Sector	**Activity data type**	**Formula (Emission per year)**
Industry/ Manufacturing units	Fuel (diesel, FO, wood, coal, LPG, etc.) consumption per unit time	$E = \sum_{i,j=1}^{n} F_{ij} \times EF_{ij}$ Where, E= Total city emission (kg/y) F= fuel consumption (e.g. MT/y) EF= Relevant emission factor (e.g. kg/MT) i= i^{th} industry j= j^{th} fuel
Transport (tailpipe emission)	Vehicle mileage and vintage, types and numbers of vehicles registered; Vehicle survival rate data with age in India was taken into account for estimating registered vehicles in operation during last 15 years (Ref: Goel and Guttikunda, 2015; DoI: 10.1016/j.atmosenv.2015.01.045)	$E = \sum_{i,j=1}^{n} EF_{ij} \times VKT_{ij}$ E= Total city emission (g/y) EF = Relevant emission factor (g/km) VKT = Vehicle kilometer travelled per year (km/y) i= i^{th} vehicle (vintage considered) j= j^{th} fuel
Restaurants/Hotel kitchens/Canteens/ Eating Houses/ Mobile food vendors/Tea and snacks stalls	Fuel (LPG, wood, kerosene, coal, etc.) consumption per unit time	$E = \sum_{i=1}^{n} F_i \times EF_i \times$ No. of restaurants Where, E = Total city emission (kg/y) F_i= Av. Consumption of i^{th} fuel (e.g. LPG/coal/wood/kerosene) in city per restaurant (e.g. MT/y)

		EF= Relevant emission factor for i^{th} fuel (e.g. kg/MT)
Construction	Base area of construction	$E = \sum_{i=1}^{n} BA_i \times EF$ E = Total city emission (MT/y) BA_i = Base area of construction (acre-month/year) of i^{th} activity (e.g. residential construction/commercial construction/road/flyover) EF = Relevant emission factor (MT/acre-month)
Road dust	Silt content in road dust, average weight of vehicles run of road, mileage per year, vehicle survival rate data with age, RTO database on types and number of vehicles	Total city emission calculated from USEPA formula that is based on road silt loading, Av. weight of on-road vehicles, particle size multiplier for particle size range, emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear, vehicle kilometer traveled. USEPA's model for road dust emissions is the only internationally accepted methodology for estimating road dust emissions and hence, was used, as following: $E=K(sL/2)^{0.65} \times (W/3)^{1.5}$ Where, E= Emission factor (lb/VMT), sL= silt loading (g/m^2), W= Mean vehicle wt (MT), k = particle size multiplier or k factor (lb/VMT)
Domestic	Fuel (LPG, wood, coal, etc.) consumption per unit household per year; Number of households; KMC/HMC population	$E = \sum_{i=1}^{n} F_i \times EF_i \times$ No. of households Where, E = Total city emission (kg/y) F_i= Av. Consumption of i^{th} fuel (e.g. LPG/coal/wood) in city per household (MT/y) EF= Relevant emission factor for i^{th} fuel (e.g. kg/MT)
Crematoria	Fuel (wood) consumption per unit time; Number of bodies burnt per unit time	$E = \sum_{i=1}^{n} (F_i \times EF_w) + (B_i \times EF_b)$ Where, E = Total city emission (kg/y) F= Wood consumption (e.g. MT/y)

		EF_w= Relevant emission factor for wood (e.g. kg/MT) B= Body burnt (number) EF_b= Relevant emission factor for dead body (e.g. kg/body) i= i^{th} crematoria
Ironing vendors	Average fuel (coal) consumption per vendor; Number of vendors, days worked in a year (only coal using ironing vendors data are used)	E = F × EF× No. of ironing vendors Where, E = Total city emission (kg/y) F = Coal consumption per vendor (MT/y) EF= Relevant emission factor for coal (e.g. kg/MT)
Hot Mix plants	Actual PM emission test results (2019) of state-owned plants used for total emission estimation of four large plants; Bitumen supplied per year to mobile hot-mix plants by IOCL to Kolkata and Howrah as reported by IOCL (assumed 70% used for road laying, rest for industries), This bitumen amount upscaled to Hot Mix Asphalt (HMA) by 92% as bitumen in HMA is about 8%.	E = F × EF Where, E = Total city emission (kg/y) F = Bitumen consumption in city (MT/y) EF= Relevant emission factor for HMA (kg/MT HMA)
Open burning	Waste generated per year in KMC and HMC (KMC and HMC data); General extent of open burning; Percent combustible in MSWs	E = F × EF Where, E = Total city emission (kg/y) F= Total waste burnt (MT/y) EF= Relevant emission factor for open burning (kg/MT)
Marine vessels	Number of routes; Length of routes; Number of trips per route per day; Number of ferries per route, Rate of fuel usage by ferries	E = (M/R_f) × EF Where, E = Total city emission (kg/y) M = Total miles ran by fleet (km/y) Rf = Rate of fuel consumption (l/km) EF= Relevant emission factor for fuel (kg/L)
Thermal power plant	Only CESC Southern generating station operates under KMC area. Its coal	E = F × EF Where,

	and LDO usage limits as per PCB consent 2019 with respect to PLF (85%) was used to estimate its actual coal and LDO usage. Emission for uncontrolled EF was used to calculate uncontrolled emission, which was later downscaled by applying ESP control efficiency of the specific plant (99.76%), In Howrah, no power plant is under operation.	E = Total emission (kg/y) F= Total coal burnt (MT/y) EF= Relevant emission factor for industrial boiler (kg/MT)

3.5 Collection of Activity data

A glimpse of actual activity data use for KMC and HMC areas is presented in **Table 3.4** to highlight the nature of activity data used for development of emission inventory. The activity data is dynamic in nature and represents the scenario at the time of data collection.

Table 3.4: Summary of Activity data (KMC/ HMC)

Name of Source/Sector	**Activity data (KMC)**	**Activity data (HMC)**
Industry/ Manufacturing units	Fuel usage data in by industries /manufacturing units within KMC area were extracted from WBPCB database (**Table 3.5**). Data on specific pollution control devices as found in the database were used for downscaling respective emissions	Fuel usage data in by industries /manufacturing units within HMC area was extracted from WBPCB database (**Table 3.6**). Data on specific pollution control devices as found in the database were used for downscaling respective emissions
Transport	Number of registered vehicles with vintage as per RTO department database is detailed in **Table 3.7** (Kolkata). The database was received on request from RTO/ PVD offices in Beltala, Kasba, Salt Lake, Behala and Alipore	Number of registered vehicle with vintage as per transport department is detailed in **Table 3.8** (Howrah). The database was received on request from RTO office in Howrah
Restaurants/ Roadside eateries/Mobile food vendors/Office canteens/Tea stalls/Sweet makers	Number of roadside eateries (as reported by Kolkata Police, data furnished by WBPCB) is 2491 in KMC area Also, data on registered eateries/ restaurants was extracted from KMC database on registered businesses in KMC area. The extracted data on registered eateries pertains to entries as restaurants, fast food centres, eating	Combined number of registered restaurants/eateries and roadside eateries as reported by HMC) is 3771 (2611+1160) within HMC area

	houses, 3-/4-wheeler mobile eateries, eateries, bank with canteen, boarding house with kitchen, tea stalls, jalpan shops, workshop for food items, sweetmeat/ chips/ chanachur manufacturers, bakeries. This number was found to be about 14694 in KMC. Therefore, a total of 17185 eateries are considered to be present within KMC.	
Construction	KMC data on land base area (acre) under residential construction (i.e. dug up land) in 2016 was used for KMC area (371 acres). Construction land area under commercial sector was not available for KMC, hence was assumed to be 30% of residential area (111.3 acre)	No construction area data from HMC was made available. Hence, for HMC area, possible land area under construction was calculated proportionately from KMC area; Construction land area under commercial sector was also not available for HMC and hence was assumed to be 30% of calculated residential area
Road dust	Silt content of road dust measured at various locations distributed over the cities; Silt loading range was found to be 0.20-0.46 g/m^2	Silt content of road dust measured at various locations distributed over the cities; Silt loading range was found to be 0.37-0.51 g/m^2
Household/ Domestic	Number of households in KMC area was arrived at by dividing KMC population as per last census data by average number of family members (i.e. 5). Fuel usage per house per day (kg or L) as found in primary survey was used with number of households to estimate total emission	Number of households in HMC area was arrived at by dividing HMC population as per last census data by average number of family members (i.e. 5). Fuel usage per house per day (kg or L) as found in primary survey was used with number of households to estimate total emission
Crematoria	As per KMC data made available for this project, 765.54 MT wood was used and 63,015 numbers of bodies were burnt in KMC crematoria in 2016	As no data was available for HMC crematoria, number of bodies burnt in HMC was extrapolated from HMC:KMC population ratio and amount of wood used was extrapolated from above extrapolated body number, based on KMC database on amount of wood used per body
Ironing vendors	Ironing vendors using coal as fuel (Note: ironing vendors using electrical ironing machine were not included) was estimated to be about 850 in KMC area (excl. vendors using electricity), which was based on extrapolation of their numbers found in sample study areas. Annual working days are about 315, taking 4 Sunday-offs per month as found during survey	Ironing vendors using coal as fuel (Note: ironing vendors using electrical ironing machine were not included) was estimated to be about 300 in HMC area (excl. vendors using electricity) which was based on extrapolation of their numbers found in sample study areas. Annual working days are about 315, taking 4 Sunday-offs per month as found during survey
Hot Mix plants	Actual PM emission test results (2019) of state-owned plants used for total emission estimation of four large plants; As per IOCL and KMC data, 14000 MT bitumen (excluding state-owned plants) was supplied to Kolkata	As per IOCL, 20000 MT bitumen was supplied to Howrah in 2016-17. No data was available on bitumen usage or emission control in HMC run hot mix plants, if any. This bitumen amount was used for

	in 2016-17. It was assumed that 70% of the this Bitumen (14000 MT) was used in mobile plants with no emission control while the 30% amount went to other uses	emission estimation. It was assumed that 70% of the this Bitumen was used in mobile plants with no emission control while the 30% amount went to other uses
Open burning	KMC generates about 3932 MT solid waste per day (https://www.kmcgov.in/KMCPortal/jsp/Solid_Waste_Services.html; accessed on 18.9.2019); 70% of this waste is combustible (assumed); 5% of this combustible part gets accidentally fired (assumed)	HMC generates about 3000 MT solid waste per day (http://www.millenniumpost.in/howrah-municipal-corporation-to-reach-agreement-for-setting-up-solid-waste-powered-plant-during-bgbs-176990); 70% of this waste is combustible (assumed); 5% of this combustible part gets accidentally fired (assumed)
Marine vessels	Approximate ferry distance covered on Hooghly was calculated from ferry service chart and number of trips per day per vessel. Total diesel consumed was calculated by using diesel required per kilometer travelled by a vessel (Cotrell, 2011). Only regular passenger ferries were considered for this calculation	No separate calculation was made for HMC area as Hooghly river lies in between KMC and HMC areas and once considered under KMC, cannot be repeated
Thermal power plant	Only CESC Southern generating station operates within KMC area. Its coal and LDO usage limits as per WCPCB consent 2019 (72839 MT/month coal; 231 kL/month LDO) were used and downscaled by using PLF (85%) to estimate actual coal and LDO usage (742957.8 MT/y and 2356.2 kL/y, respectively). Uncontrolled EF was used to calculate uncontrolled emission, which was later downscaled by ESP control efficiency (99.76%) [reported by CESC]	In HMC area, no power plant is in operation.

During the primary survey of eateries and restaurants in Kolkata and Howrah conducted by CSIR-NEERI, several zones were identified having high density of eateries and restaurants including small, footpath encroaching, food-vending shanties (**Table 3.5 and 3.6**). These zones have substantial number of temporary eateries (mostly shanties) using substantial amounts of coal, kerosene and wood apart from LPG which is used by only a small proportion of these eateries. The abundance and density of roadside eateries and number of large restaurants in Howrah were observed to be much lesser than Kolkata. Numbers of roadside eateries in KMC and HMC areas were provided by Kolkata Police through WBPCB and HMC. Also, KMC data on registered businesses in KMC were analyzed to shortlist businesses that were in the league of eateries, canteens, restaurants, tea shops etc. Total number of restaurants in KMC and HMC areas were finally arrived at from the roadside eatery data provided by Kolkata police and HMC and registered business data provided by KMC.

Table 3.5: List of Areas in Kolkata (KMC area) having Moderate to High Density of Restaurants and Eateries

S. No.	Name of Area	S. No.	Remarks
1	Anandapur-Ruby hospital area	36	KMC Office Area, near Esplanade
2	Fortis-Emami-Monobikas Kendra Area	37	Zakaria Street
3	VIP Bazar area	38	Tiretti Bazar
4	Jadavpur University campus (gates 2,3,4) area, 8B bus stand	39	Rabindra Sadan
5	Ballygunj Circular road	40	Beltala PVD Office
6	Kalighat Metro area	41	College Street
7	Gariahat square	42	Razabazar Science College
8	Ajay Nagar on EM Bypass	43	Hazra Square
9	Garia Bus Stand	44	Ultadanga square incl. Bidhan Nagar Railway Station Area
10	Garia Bazar	45	Ultadanga Main Road
11	Garia (KaziNazrul) Metro Area	46	Lake Mall area
12	Acropolis Mall area	47	Jodhpur Park main road
13	Highland Park Area	48	Behala Thana
14	Ballygunj railway station area	49	Parnashri bus stand area
15	Jadavpur railway station area	50	Behalatrum depot
16	Chingrihata crossing	51	Behala Bazar Area
17	Moulali, near KMC Stores	52	Alipore court
18	Sealdah Railway Station area	53	New market area
19	NRS hospital area	54	Vardan Market, Camac Street
20	On MG Road, Raja Bazar	55	Southern Avenue
21	Shyambazar	56	Burrabazar area
22	High court area	57	Bankshall Court
23	Hatibagan	58	Lake View Road

24	SinthiSqaure	59	Jatin Das Park Metro Station
25	Dunlop -NSSO area	60	South City (near Lords Square)
26	Bagbazar Ferry Ghat	61	Purna Das Road
27	India Exchange place	62	BNCCI area, R.N. Mukherjee Road
28	Fairly Place	63	Chetla Bridge area
29	Dalhousie, in front of Millennium Park	64	Ekbalpore
30	Decker's Lane/James Hickey Sarani	65	Entally Market
31	Mangoe Lane near Lalbazar	66	BBD Bag area
32	Alley opposite Lalit Great Eastern Hotel	67	Park Street (Middleton Row)
33	Esplanade, near Shree Leathers	68	Mullick Bazar
34	Shakespeare Sarani, Theatre Road	69	Belgachia (adjacent to tram depot)
35	Esplanade, New Market Area	70	R.G. Kar Hospital

Source: Primary survey by CSIR-NEERI

Table 3.6: List of Areas in Howrah (HMC area) having Prominent Presence of Restaurants including Roadside Eateries

Sl. No.	Name of Area
1	Howrah Station
2	Bandhaghat (Salkia Square)
3	Shibpur (near IIEST)
4	Batore
5	HMC entrance and surroundings
6	Howrah Maidan
7	Howrah Court

Source: Primary survey by CSIR-NEERI

WBPCB online database on 'consent to operate' issued to industries have been accessed to extract data on fuel usage by industries and manufacturing units, hours of operation per day, days of operation per year, emission control device used. Prominent fuels are Diesel, wood, coal, coke, biomass, furnace oil, L.D.O., kerosene and L.P.G. These industries/manufacturing units comprise of bakeries, hotels, printers, battery recyclers, metal recovery units, waste recovery units, ferrous and non-ferrous metal extraction, iron and steel, other metallics, foundries, railway locos, food processing apart from manufacturing units like iron and steel, rubber, Dyeing and bleaching, Pickling & electroplating, Lead-Acid battery manufacturing, Basic Chemicals etc. (**Table 3.7-3.8**). It was noted that many industries use multiple types of fuels.

Table 3.7: Summary of fuel usage by Industrial Sector in KMC Area

Fuel with unit	Number of user Industry (approx.)	Major types of user Industry/ Operation Types	Consumption (unit/y)
Coal gas (m^3)	2	Dyeing and bleaching	1200000.0
LPG (kL)	177	Lead acid battery, Hotel, Heavy engineering, Dyeing and bleaching	21646.6
Coal (MT)	4	Synthetic detergent and soap manufacturing, Producer gas plant, Hotel, Jute processing	17403.0
Furnace Oil (kL)	26	Producer gas plant, Synthetic detergent and soap manufacturing, Bakery, Rolling Mill, Milk and Dairy, Veg. Oil Makers, Ferrous non-ferrous, Basic Chemicals, Coal tar distillation, Others	11200.9
Agro-based Biomass (MT)	1	Non-alcoholic beverage (soft drink)	7152.0
Diesel + HSD (kL)	123	Hotels, Dyeing & bleaching, Pickling & electroplating, Lead-Acid battery manufacturing, Bakeries, Ferrous Non-ferrous, Food processing, Others	8727.3
LDO (kL)	50	Synthetic rubber, Manufacturing of lubricating oils, Dyeing and bleaching, Ferrous non-ferrous, Others	3873.6
Firewood (MT)	82	Bakeries, Others	1976.6
Jute Caddies (MT)	1	Jute processing	900.0
Charcoal (MT)	23	Ferrous & Non-ferrous, Hotels, Gold and Silver smiths	252.3
Kerosene (kL)	8	Spray painting, Others	17.9
Coke (MT)	2	Ferrous & Non-ferrous, Other	3.9

Table 3.8: Summary of Fuel Usage Data by Industrial Sector in HMC Area

Fuel with unit	Number of user industries (Approx.)	Industry type	Consumption (Unit/y)
Producer gas (m^3)	4	Rolling mill	56880000.0
Coal gas (m^3)	5	Industry or process involving metal surface treatment, Rolling mill (oil or coal fired)	21601596.0
Coke (MT)	266	Aluminium smelter, Ferrous and non-ferrous metal extraction, Large no of foundry, Metal surface treatment, Railway locomotive workshop, Rolling mill, Yarn /textile	142334.9
Coal (MT)	57	Foundry operation, manufacturing of glass, Yarn/textile processing, manufacturing of chemicals, brick field, rolling mill	40671.6
Furnace Oil (kL)	154	Ferrous and non-ferrous metal, Engineering and fabrication units, Heat treatment using oil fired furnace, Rolling mill, Aluminium smelter, Manufacturing of chemicals, Jute processing, Manufacturing of lubricating oils	40547.2
Jute Waste (MT)	8	Jute processing, Yarn/Textile	14400.0
Husk (MT)	5	Food processing, Pulp and paper industries	13854.3
Diesel (kL)	140	Bakery, Engineering and fabrication units, Forging of ferrous and non-ferrous metal, Heat treatment using oil fired furnace	11787.2
Wood (MT)	20	Bakery, Yarn/textile	5523.4
LDO (kL)	19	Engineering and fabrication units, Heat treatment using oil fired furnace, Petrochemicals Manufacturing, others	1031.7
LPG (kL)	17	Aluminium and extraction industries, Forging of ferrous and non ferrous metal, Hotels, Manufacturing of tooth powder, Oil fired furnace	416.8
Charcoal (MT)	2	Ferrous and non-ferrous metal extraction,	139.2
Kerosene (kL)	3	Engineering and fabrication units, Ferrous and non-ferrous metal extraction	106.9

Amongst industrial units, some specific types of manufacturing units or operations were found to be prominently present (in their share of fuel consumption) in Kolkata and Howrah. Fuel usage pattern of some of the prominent types of industries/ manufacturing units present in KMC and HMC areas were extracted and documented (**Table 3.9-3.10**). In KMC, the prominent ones are bakeries, hotels, producer gas plant, ferrous and non-ferrous industries, dyeing and bleaching, ceramics, pickling and electroplating etc. while in HMC, foundries, ferrous and non-ferrous industries, pickling and electroplating, Steel and Steel products, Textile/Yarn, Al Smelter/Al-Cu extraction, synthetic rubber, bakeries, hotels, railway loco sets were prominent fuel users. A separate sub-emission inventory was also prepared for these prominent industries.

Table 3.9: Approximate Fuel Usage (*MT/y or #kL/y) Pattern in Select Categories of Industries having major share in fuel consumption in Kolkata (KMC)

Industry /Operation	*Firewood	*Coal	*Charcoal	*Coke	*Jute Caddies	#LPG	#LDO	#Diesel+ HSD	#Furnace Oil	*Biomass
Bakery	1208.6	-	-	-	-	92.3	320.7	122.6	127.8	-
Hotels	18.0	3.0	2.4	-	-	9652.0	-	5583.5	-	-
Ferrous and non-ferrous	720.0	-	240.0	3.6	-	8.3	211.6	19.9	100.8	-
Rolling Mill	-	-	-	-	-	-	-	-	85.6	-
Pickling and Electroplating	-	-	-	-	-	721.5	284.0	60.0	96.0	-
Jute Processing	-	1200.0	-	-	900.0	-			-	-
Rubber goods	-	-	-	-	-	-	1496.5	387.0	-	-
Dyeing and bleaching	30.0	-	-	-	-	77.6	169.1	590.9	-	-
Gold and silver smiths	-	-	9.9	-	-	18.2	-	0.2	-	-
Pd-acid battery Manufacturing	-	-	-	-	-	74.3	-	34.6	-	-
Ceramic	-	-	-	-	-	7366.1	-	-	150.0	-
Producer gas plant/coal gasification	-	9000.0	-	-	-	-	-	-	4200.0	-
Non-alcoholic beverage	-	-	-	-	-	-	-	-	1072.8	7152.0
Synthetic detergents and soaps	-	7200.0	-	-	-	-	-	12.0	-	-
Milk and dairy	-	-	-	-	-	-	-	-	3942.0	-
Basic Chemicals	-	-	-	-	-	3.2	-	-	450.2	-
Food and food processing	-	-	-	-	-	33.5	-	87.6	-	-
Lube oils, grease and petroleum products	-	-	-	-	-	-	657.5	-	113.6	-

Table 3.10: Approximate fuel usage (*MT/y or #kL/y) pattern of select categories of Industries having major share in fuel consumption in Howrah (HMC)

Industry /Operation	*Charcoal	*Coke	*Furnace Oil	*Coal	#Diesel+ HSD	*Wood	#LPG	#LDO	*Jute caddies	*Husk
Foundry	-	130866.0	-	3183.6	874.5	46.2	148.2	-	-	-
Al Smelter/Al-Cu extraction	-	56.2	4256.4	30.0	68.4	-	117.6	-	-	-
Bakery	-	-	-	-	28.8	128.2		-	-	-
Ferrous and Non-ferrous	139.2	6957.6	3654.2	914.9	136.2	-	37.8	44.3	-	-
Rolling Mill	-	600.0	20874.0	19600.0	1264.9	-	-	-	-	-
Steel and Steel products	-	-	672.0	1792.4	28.8	-	-	71.5	-	-
Railway Locomotives	-	3.5	151.5	-	-	-	-	-	-	-
Pulp and Paper	-	-	-	-	-	-	-	-	-	12600.0
Jute processing	-	-	734.4	-	396.0	-	-	-	6240.0	-
Pickling and Electroplating	-	2014.9	2543.5	778.5	2266.3	-	47.0	24.0	-	-
Engineering and fabrication	-	-	3575.9	6.0	660.7	-	-	48.0	-	-
Textile/Yarn	-	1800.0		636.0	1764.0	480.0	-	-	7200.0	-
Gas fired boiler	-	71.6	225.6	6076.8	-	4200.0	-	-	-	300.0
Heat treatment (Oil fired furnace)	-	-	741.7	-	337.0	-	-	537.0	-	-

For transport sector, vehicle registration dataset with vintage was collected from RTO Offices in Kolkata and Howrah (**Table 3.11-3.12**), so that vintage-specific tailpipe PM emission factors of ARAI/CPCB could be applied to the data for generating emission from transport sector. Numbers of prominent vehicle types (Bus, Motor cars, Goods carriers, 2-wheelers, 3-wheelers) were analyzed and extracted (**Table 3.13**) from the database to represent emission from these specific categories of vehicles.

Table 3.11: Number of Registered Vehicles in Kolkata

Vehicle type	1991-95	96-2000	2001-2003	2004-2005	2006-2010	2011-13	2014-18	Total
Animal Ambulance	0	0	1	0	0	0	1	**2**
Ambulance	182	347	186	105	544	534	917	**2815**
Bus	1711	2290	1290	676	3029	1989	3875	**14860**
Cash Van	0	7	39	22	84	66	141	**359**
Dumper	0	0	2	0	2	18	31	**53**
Excavator (Commercial)	1	0	1	1	8	10	210	**231**
Fire fighting vehicle	5	0	0	0	82	27	229	**343**
Goods carrier	5867	9480	5387	1982	7994	12090	22018	**64818**
Hearses	1	2	1	6	12	12	57	**91**
Luxury cab	683	1431	700	545	1892	2444	20503	**28198**
Maxi cab	18	140	107	29	26	28	136	**484**
Mobile clinic	1	3	3	0	5	1	4	**17**
Motor cab	3254	6218	2912	1522	8068	6888	5921	**34783**
Omni bus	49	161	96	118	706	1285	2093	**4508**
Private service vehicle	0	0	0	0	0	0	7	**7**
Three wheeler (goods)	220	2565	1015	1090	2579	300	782	**8551**
Three wheeler (Passenger)	2599	7352	5805	1249	11654	6422	4423	**39504**
Articulated Vehicle	58	55	27	3	16	53	118	**330**
Camper van/Trailer	0	1	12	0	8	4	14	**39**
Educational Institution Bus	1	1	4	0	0	0	9	**15**
Motor cycle/scooter used for hire	0	0	0	0	0	0	54	**54**
Tractor (commercial)	5	9	10	4	32	27	38	**125**
Trailer(commercial)	17	28	4	6	14	4	1	**74**
Recovery Vehicle	0	0	0	0	0	0	13	**13**
Agricultural tractor	34	57	10	6	27	56	159	**349**
Construction equipment vehicle	0	0	0	0	0	0	51	**51**
Crane mounted vehicle	22	15	17	17	354	261	210	**896**
Earth moving equipment	0	2	1	2	5	7	19	**36**
Fork lift	9	4	4	1	4	2	3	**27**
M-cycle/Scooter	12194	50998	63711	40964	134696	145251	308666	**756480**
M-cycle/Scooter with side car	9	91	3	55	205	112	220	**695**
Moped	42	78	24	32	121	395	2058	**2750**
Motor car	35549	54653	29736	23894	80042	76591	130654	**431119**
Motorised cycle (CC>25cc)	0	0	0	0	1	1	256	**258**
Omni bus (Private use)	548	12605	6467	3631	8300	4486	3943	**39980**
Three wheeler (personal)	2	0	0	0	1	0	4	**7**
Tower wagon	0	0	0	0	0	0	1	**1**
Tow truck	1	0	0	0	0	0	1	**2**
Vehicle fitted with compressor	0	0	1	0	0	0	0	**1**
Excavator (NT)	0	0	0	0	0	0	93	**93**

Trailer for personal use	0	0	0	12	0	0	0	**12**
Vehicle fitted with generator	1	0	3	0	22	23	136	**185**
Vehicle fitted with rig	0	0	2	0	0	0	1	**3**
Invalid carriage	0	2	1	0	0	1	6	**10**
Break Down Van	0	0	0	0	0	0	6	**6**
Camper van/Trailer (private use)	0	0	0	0	0	0	0	**0**
Mobile workshop	0	0	1	0	0	0	2	**3**
Fire Tenders	0	0	0	0	0	0	9	**9**
Library van	0	0	1	0	0	0	0	**1**
Total	63083	148595	117584	75972	260533	259388	508093	**1433248 (1991-2018); 1103986 (2004-2018; last 15 year)**

Source: Primary survey conducted by CSIR-NEERI in Beltala, Kasba, Alipore, Behala and Salt Lake RTO offices

Table 3.12: Number of Registered Vehicles in Howrah

Vehicle Type	**1991-95**	**96-2000**	**2001-2003**	**2004-2005**	**2006-2010**	**2011-13**	**2014-18**	**Total**
Ambulance	21	83	52	23	132	148	202	**661**
Bus	955	769	216	256	1308	360	970	**4834**
Cash Van	0	0	0	1	0	1	2	**4**
Dumper	10	12	54	0	3	0	6	**85**
Excavator (Commercial)	0	0	0	0	0	20	74	**94**
Fire fighting vehicle	0	0	0	0	0	0	0	**0**
Goods carrier	6209	3595	1585	1398	4873	6088	12205	**35953**
Hearses	0	0	0	0	5	4	4	**13**
Luxury cab	0	0	0	0	0	0	1409	**1409**
Maxi cab	0	0	0	0	1	12	75	**88**
Mobile clinic	0	0	0	0	0	1	1	**2**
Motor cab	408	350	584	154	369	253	1342	**3460**
Omni bus	2	20	45	32	417	172	237	**925**
Private service vehicle	0	0	0	0	0	0	0	**0**
Three wheeler (goods)	12	95	309	644	1718	949	1346	**5073**
Three wheeler (Passenger)	214	28	40	1	768	89	191	**1331**
Articulated Vehicle	405	82	10	4	130	117	227	**975**
Camper van/Trailer	0	0	0	0	0	1	1	**2**
Educational Institution Bus	4	0	2	2	0	0	0	**8**
Motor cycle/scooter used for hire	0	0	0	0	0	0	0	**0**
Tractor (commercial)	0	0	0	0	11	12	10	**33**
Trailer(commercial)	8	1	2	0	1	0	0	**12**
Recovery Vehicle	0	0	0	0	0	0	0	**0**
Agricultural tractor	13	5	2	3	10	6	27	**66**

Construction equipment vehicle	0	0	0	0	0	0	12	**12**
Crane mounted vehicle	41	18	2	0	170	216	181	**628**
Earth moving equipment	0	0	0	0	2	0	11	**13**
Fork lift	0	2	5	0	12	122	3	**144**
M-cycle/Scooter	9799	34529	41366	32415	104051	90043	152590	**464793**
M-cycle/Scooter with side car	2	1	0	0	56	47	28	**134**
Moped	132	68	0	2	19	6	150	**377**
Motor car	2237	2884	1968	1662	6158	8471	16618	**39998**
Motorised cycle (CC>25cc)	0		0	0	0	0	54	**54**
Omni bus (Private use)	48	1712	1482	758	1748	1254	1134	**8136**
Three wheeler (personal)	0	0	0	0	0	0	2	**2**
Tower wagon	0	0	0	0	0	0	0	**0**
Tow truck	0	0	0	0	0	0	0	**0**
Vehicle fitted with compressor	0	0	0	0	0	0	0	**0**
Excavator (NT)	0	0	0	0	0	0	36	**36**
Trailer for personal use	0	0	0	0	0	0	0	**0**
Vehicle fitted with generator	0	0	0	2	2	2	15	**21**
Vehicle fitted with rig	0	0	0	0	0	0	0	**0**
Invalid carriage	0	0	0	0	2	0	1	**3**
Break Down Van	0	0	0	0	0	1	2	**3**
Camper van/Trailer (private use)	0	0	0	0	0	0	0	**0**
Mobile workshop	0	0	0	0	2	0	1	**3**
Fire Tenders	0	0	0	0	0	0	0	**0**
E-Rickshaw	0	0	0	0	0	0	109	**109**
Total	**20520**	**44254**	**47724**	**37357**	**121968**	**108395**	**189276**	**569494 (1991-2018); 456996 (2004-2018; last 15 year)**

Source: Primary survey conducted by CSIR-NEERI in Howrah RTO office

Table 3.13: Number of Select Categories of Vehicles in Kolkata and Howrah (last 15-y registration)

City	Bus+Omni Bus	Motor Car+Cab	Goods carrier (incl. 3-W) [LCV category, except 3-W]	Passenger 3-Wheeler	2-Wheelers	Others	Total number of registered vehicles (2004-2018)
Kolkata	34140	359183	48835	23753	633087	4988	1103986
Howrah	8648	36524	28361	1051	379461	2951	456996

Source: Extracted from primary survey database collected by CSIR-NEERI in RTO offices

3.5 Selection of Emission Factors

For development of Emission Inventory for various sectors, emission factors were taken from various documents of USEPA, CPCB, ARAI, WHO or reports endorsed by CPCB, which have been listed (or links given) under the 'Reference' column (**Table 3.14**). Detailed emission factors for industrial sector and transport sector (vehicle tailpipe exhaust) are listed separately in **Tables 3.15 and 3.16**, respectively.

Table 3.14: Emission Factors

Sector	EF		Unit	Reference
	PM_{10}	$PM_{2.5}$		
Industrial/ Manufacturing units	**Table 3.15** Data on APC systems associated with industrial units was available in WBPCB database (http://emis.wbpcb.gov.in/emis/) containing .pdf files of consent to operate of industrial manufacturing/processing units. Hence, EF were used to generate controlled emission from industrial sector	**Table 3.15** Data on APC systems associated with industrial units was available in WBPCB database (http://emis.wbpcb.gov.in/emis/) containing .pdf files of consent to operate of industrial manufacturing/processing units. Hence, EF were used to generate controlled emission from industrial sector	kg/MT or kg/kL	USEPA AP-42 (www3.epa.gov/ttn/chief/ap42/ch01/final/*c01s01.pdf)* CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf) CPCB (https://cpcb.nic.in/displaypdf.php?id=TXVtYmFpLXJlcG9ydC5wZGY=)
Vehicle (tailpipe exhaust)	**Table 3.16** PM ≅ PM_{10} (assumed)	**Table 3.16** $PM_{2.5}/PM_{10}$ = 0.95 (assumed)		ARAI/CPCB
Restaurants/Hotel kitchens/Mobile food vendors (uncontrolled)	12 (coal), 0.06* (LPG), 0.61 (kerosene), 17.3 (wood)	8.16 (coal), 1.89 (LPG), 0.41 (kerosene), 11.76 (wood) $PM_{2.5}/PM_{10}$=0.68	kg/MT fuel	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)

	PM_{10}/SPM=0.6	$PM_{2.5}/PM_{10}$=0.9 (for LPG)		*WHO (https://apps.who.int/iris/bitstream/handle/10665/58750/WHO_PEP_GETNET_93.1-A.pdf?sequence=1&isAllowed=y)
Construction (uncontrolled)	1.2	0.24 $PM_{2.5}/PM_{10}$=0.2 (South Coast Air Quality Management District, 2006) as construction releases coarse PM	MT/Acre-month area	AP-42 (US EPA) https://www3.epa.gov/ttn/chief/ap42/ch13/final/c13s02-3.pdf
Road dust (uncontrolled)	0.00472 (sL = 0.31 g/m^2, k= 0.016 (USEPA), W = 3.18 MT) [for Kolkata] 0.00584 (Av. sL = 0.31 g/m^2, k= 0.016 (USEPA), W = 3.18 MT) [for Howrah]	0.000829 (sL = 0.31 g/m^2, k= 0.004(USEPA), W = 3.18 MT) [for Kolkata] 0.00110 (Av. sL = 0.46 g/m^2, k= 0.016 (USEPA), W = 3.04 MT) [for Howrah]	lb/VMT	AP-42 (US EPA) https://www3.epa.gov/ttn/chief/old/ap42/ch13/s021/final/c13s02-1_2002.pdf
Household (uncontrolled)	12 (coal), 0.06* (LPG), 0.61 (kerosene), 17.3 (wood) PM_{10}/SPM=0.6	8.16 (coal), 1.89 (LPG), 0.41 (kerosene), 11.76 (wood) $PM_{2.5}/PM_{10}$=0.68 $PM_{2.5}/PM_{10}$=0.9 (for LPG)	kg/MT fuel	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf) *WHO (https://apps.who.int/iris/bitstream/handle/10665/58750/WHO_PEP_GETNET_93.1-A.pdf?sequence=1&isAllowed=y)
Crematoria (uncontrolled)	17.3 (wood), 0.000025 (body)	11.76 (wood), 0.000017 (body) $PM_{2.5}/PM_{10}$= 0.68	kg/MT wood, kg/body	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
Ironing vendors (uncontrolled)	12 PM_{10}/SPM=0.6	8.16 PM_{10}/SPM=0.6	kg/MT	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
Open burning (uncontrolled)	8.0	5.44	kg/MT MSW	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
Marine Vessels	1.03	0.7	kg/MT	CPCB

(uncontrolled)		$PM_{2.5}/PM_{10}$= 0.68	fuel	(https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018
Hot Mix plants (Uncontrolled)	3.25 Emission test reports of the state-owned hot mix plants (4 in number) were shared by WBPCB (dated January and February, 2019) and were used to estimate actual emissions from these 4 plants EF was used for other mobile plants. No emission control applied to HMA produced from rest of Bitumen used in Kolkata. No emission control applied to HMA produced from Bitumen used in Howrah due to non-availability of data on emission control	0.195 [$PM_{2.5}/PM_{10}$= 0.06, taken from the $PM_{2.5}/PM_{10}$ emission factor ratio in batch mix plants reported by USEPA] Emission test reports of the state-owned hot mix plants (4 in number) were shared by WBPCB (dated January and February 2019) and were used to estimate actual emissions from these 4 plants EF was used for other mobile plants. No emission control applied to HMA produced from rest of Bitumen used in Kolkata No emission control applied to HMA produced from Bitumen in Howrah due to non-availability of data on emission control	kg/MT product (i.e. HMA)	AP-42 (USEPA) https://www3.epa.gov/ttnchie1/ap42/ch11/final/c11s01.pdf
Power plant (controlled)	2.3 A where A= %ash (bituminous and sub-bituminous coals for boilers) (uncontrolled) 5.9 A (A =1.12*S+0.37) (LDO) (S= S% in LDO, assumed to be 1.8% as per IOCL data) (uncontrolled) (Ash=50% assumed) For controlled emission calculations ESP efficiency (99.76%) applied later (CESC data)	0.6 A where A= %ash (bituminous and sub-bituminous coals for boilers) (uncontrolled) 4.3 A (A =1.12*S+0.37) (LDO) (S= S% in LDO, assumed to be 1.8% as per IOCL data) (uncontrolled) (Ash=50% assumed) For controlled emission calculations ESP efficiency (99.76%) applied later (CESC data)	lb/ton	AP-42 (USEPA) https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s01.pdf https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s03.pdf https://www.iocl.com/Products/LightDieseloil.aspx

Table 3.15: Emission Factors (uncontrolled) for Industrial Sector

Fuel	Unit	EF (kg/Unit)			Reference
		TSP	**PM_{10}**	**$PM_{2.5}$**	
Coal /Coke/Carbon/ Charcoal	MT	-	2.3A *0.5 [A=ash%] (Ash=50% assumed)	0.6A *0.5 [A=ash%] (Ash=50% assumed)	USEPA AP-42 (www3.epa.gov/ttn/chief/ap42/ch01/final/*c01s01.pdf)*
Biomass/Husk/Jute/ Wood	MT	-	17.3	11.764 [$PM_{2.5}/PM_{10}$ = 0.68]	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
HSD/Diesel/LDO/ Petrol	kL	0.25	0.15 [PM_{10}/TSP= 0.6]	0.10 [$PM_{2.5}$/TSP= 0.4]	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
F.O./Furnace oil	kL	1.25 S + 0.38 [S (sulphur) = 4%] = 5.38	3.228 [PM_{10}/TSP= 0.6]	2.152 [$PM_{2.5}$/TSP = 0.4]	CPCB (https://cpcb.nic.in/displaypdf.php?id=TXVtYmFpLXJlcG9ydC5wZGY=)
Kerosene	MT	-	0.61	0.024 [$PM_{2.5}$/TSP = 0.4]	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf)
LPG	kL	-	0.21	0.2037 [$PM_{2.5}/PM_{10}$ = 0.97]	CPCB (https://cpcb.nic.in/NGT/Annexure_3.1_27.02.2018.pdf) CPCB (https://cpcb.nic.in/displaypdf.php?id=TXVtYmFpLXJlcG9ydC5wZGY=); https://www.mfe.govt.nz/sites/default/files/media/Air/national-air-emissions-inventory.pdf
Coal Gas/Producer Gas/CNG./Pipe Gas	10^6 m^3	-	121.6	115.52 [$PM_{2.5}/PM_{10}$ = 0.97]	https://cpcb.nic.in/displaypdf.php?id=RmluYWxOYXRpb25hbFN1bW1hcnkucGRm https://www.mfe.govt.nz/sites/default/files/media/Air/national-air-emissions-inventory.pdf

Table 3.16: Vehicular (Line Source) Emission Factors

VEHICLE TYPE	MODEL YEAR	PM (g/km)
2 Wheelers (2 Strokes) Scooters	1991-1995	0.073
	1996-2000	0.073
	2001-2005	0.049
	2006-2010	0.057
2 Wheelers (2 Strokes) Scooters	2001-2005	0.015
2 Wheelers (2 Strokes) Scooters	2006-2010	0.015
2 Wheelers (4 Stroke) Motorcycle	1991-1995	0.01
	1996-2000	0.015
	2001-2005	0.035
	2006-2010	0.013
3 Wheeler (CNG-4S OEM)	2006-2010	0.015
3 Wheeler Auto-rickshaw (Petrol 2S)	Post 2000	0.045
3 Wheeler Auto-rickshaw (LPG 2S)	Ret-Pre 2000	0.721
	Ret-Post 2000	0.13
3 Wheeler Auto-rickshaw (Diesel)	Post 2000	0.347
	Post 2005	0.091
4 Wheeler (Petrol)	1991-1995	0.008
	1996-2000	0.008
	2001-2005	0.004
	2006-2010	0.002
4 Wheeler(Diesel)	1996-2000	0.145
	2001-2003	0.19
	2003-2005	0.06
	2006-2010	0.015
4 Wheeler (LPG)	1996-2000	0.001
	2001-2005	0.002
	2006-2010	0.002
4 Wheeler (CNG)	2006-2010	0.006
LCVs (Light Commercial Vehicles)	1991-1995	0.998
	1996-2000	0.655
	2001-2005	0.475
	2006-2010	0.475
Large Trucks + MAV	1991-1995	1.965
	1996-2000	1.965
	2001-2005	1.24
	2006-2010	0.42
Buses (Diesel)	1991-1995	2.013
	1996-2000	1.213
	2001-2005	1.075
	2006-2010	0.3

Source: ARAI Emission Factor Report, January 2008

3.6 Emission Estimates

3.6.1 Kolkata

Emission estimate has been prepared for important sectors in Kolkata. **Table 3.17** presents emission estimates from Kolkata (KMC area only) in decreasing order of PM_{10} from sectors viz. Road, Household, Transport, Industry, Construction, Hot Mix Plants, Open Burning, Restaurants and eateries, Thermal Power, Ironing Vendors, Crematoria and Marine Vessels (**Table 3.17).** The share of various sectors in PM_{10} and $PM_{2.5}$ emissions is presented in **Fig. 3.6 and 3.7**.

Table 3.17: Emissions of $PM_{2.5}$ and PM_{10} (MT/y) from various sectors in Kolkata (KMC)

Sector	**Emission (MT/y)**	
	PM_{10}	**$PM_{2.5}$**
Road	7153.5	1003.3
Household	1663.7	1133.6
Transport *	1004.6	954.4
Industry	745.1	285.4
Construction	667.7	133.5
Hot Mix Plants	420.0	25.3
Open Burning	401.8	273.3
Restaurants and eateries	289.8	197.2
Thermal Power	102.5	26.7
Ironing Vendors	17.1	11.6
Crematoria	13.2	9.0
Marine Vessels	1.4	0.9
Total	**12480.4**	**4054.2**

***** Inclusive of estimated emissions from 2,19,137 numbers of commercial vehicles of >15 y old vehicles plying in Kolkata (MoRTH Report submitted to NGT, https://timesofindia.indiatimes.com/city/kolkata/state-to-confiscate-commercial-vehicles-more-than-15-years-old/articleshow/70321447.cms, dated July 22, 2019)

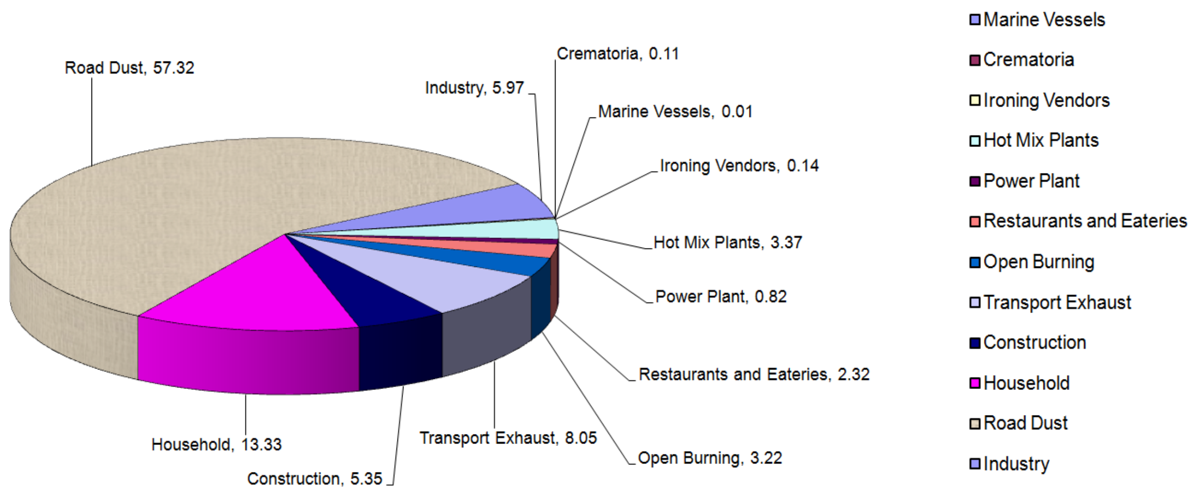


Fig.3.6: PM_{10} Emission Estimates (% share) from Various Sectors in Kolkata (KMC)

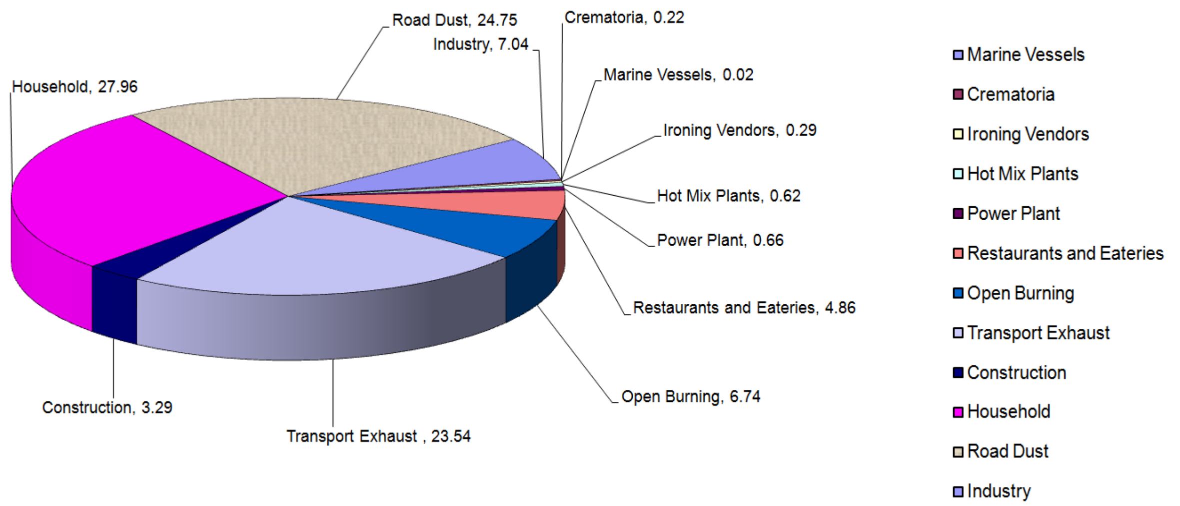


Fig. 3.7: $PM_{2.5}$ Emission Estimates (% share) from Various Sectors in Kolkata (KMC)

Emissions (with ESP as control option) from Southern Generating Station of CESC (coal based thermal power station) present within KMC boundary was estimated. Further, a database on consent to operate issued to industries (shared by WBPCB) (submitted on or after 2015) was analyzed to enlist and sort industries /manufacturing units present within KMC area. Fuel usage data listed under 'emission' field in the submitted forms of the above industries /manufacturing units were compiled and emission estimate from the industrial sector was prepared. Emission control (ESP, Bag Filter, Scrubbers, Settling Chamber etc.) as listed by industries were considered for calculating the emissions. Road sector bagged the major share (%) in sectoral contribution in PM_{10} and $PM_{2.5}$ emissions. Apart from developing sectoral emission inventory, intra-sectoral emission inventory was also prepared for industrial sector, based on intra-sectoral fuel usage estimates extracted from consent to operate database. Emissions from select types of industries and manufacturing units in Kolkata are presented in **Table 3.18.** Industries/ manufacturing units classified as Producer Gas Plant was found to be the largest emitter of PM_{10} and $PM_{2.5}$ followed by 'ferrous and non-ferrous metal extraction units' and so on.

Table 3.18: PM_{10} and $PM_{2.5}$ emissions (MT/y) from Select Categories of Industries having the major share in fuel consumption in Kolkata (KMC area)

Industry Type	**PM_{10} (MT/y)**	**$PM_{2.5}$ (MT/Y)**
Producer gas plant/coal gasification	531.06	144.04
Jute Processing	22.47	12.39
Bakery	21.41	14.56
Ferrous and non-ferrous	14.03	8.93
Basic Chemicals	13.56	9.04
Milk and Milk products	12.72	8.48
Synthetic detergents and soaps	4.14	1.08
Non-alcoholic beverage	3.67	2.45
Hotels	3.49	2.82
Ceramic	1.83	1.69
Dyeing and bleaching	0.65	0.44
Gold and Silver-Smiths	0.57	0.15
Lube oils, grease and petroleum products	0.47	0.31
Pickling and Electroplating	0.40	0.29
Rubber goods	0.28	0.19
Rolling Mill	0.25	0.17
Food and food processing	0.02	0.02
Pd-acid battery Manufacturing	0.01	0.01

Emissions from transport sector and road sector were calculated considering vehicle survival rate with time. Further, emission from transport sector was sub-divided into emissions from various categories of vehicles as presented in **Table 3.13**. Goods Carriers (including 3-

wheeler Goods Carriers) were found to be the highest emitter of PM_{10} and $PM_{2.5}$ **(Table 3.19)** on account of their substantial numbers and much higher emission factors than motor cars or two-wheelers which had more numbers over Goods Carriers (treated under LCV category, except 3-W Goods Carriers). It was followed by emissions from buses and 2-wheelers and so on. The share of Goods Carriers in total PM_{10} and $PM_{2.5}$ emissions were about 49% and 49.5%, respectively **(Fig. 3.8-3.9)**.

Table 3.19: Comparative Scenario of PM_{10} and $PM_{2.5}$ Emissions (MT/y) from Select Types of Vehicles in Kolkata (KMC)

PM_{10} (MT/y)					
Buses +Omni Buses	**Motor Car (personal)+ Motor Cab (commercial) [Petrol + Diesel]**	**Goods Carrier (Incl. 3-W)**	**Passenger 3-Wheelers**	**2-Wheelers**	**Others**
102.298	25.948	214.113	36.014	46.751	7.583
$PM_{2.5}$ (MT/y)					
97.183	24.651	203.407	34.213	44.413	7.204

N.B.: Vehicles registered in last 15 years used for this analysis

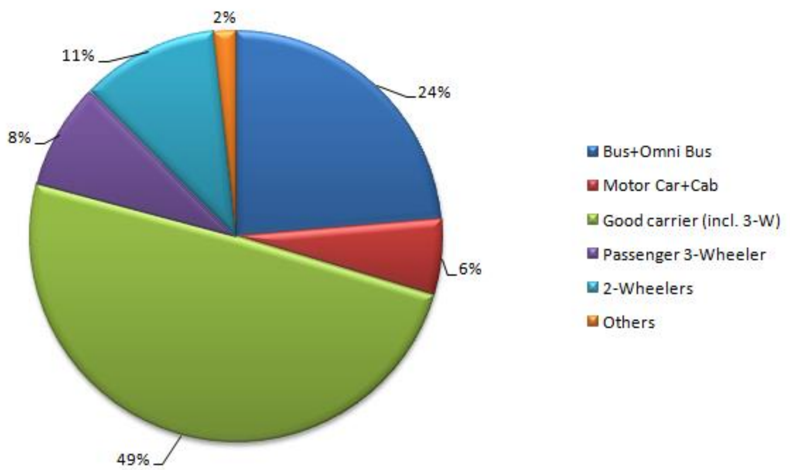


Fig. 3.8: Share (%) of types of vehicles in PM_{10} emissions in Kolkata (KMC) [N.B.: Vehicles registered in last 15 years used for this analysis]

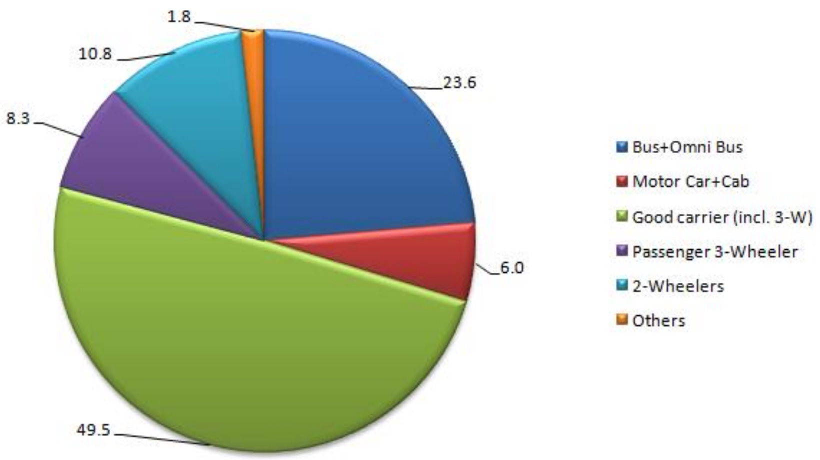


Fig. 3.9: Share (%) of types of vehicles in $PM_{2.5}$ emissions in Kolkata (KMC) [N.B.: ehicles registered in last 15 years used for this analysis]

Ministry of Road Transport and Highways (MoRTH) in a recent affidavit submitted before National Green Tribunal, Eastern Zone Bench (https://timesofindia.indiatimes.com/city/kolkata/state-to-confiscate-commercial-vehicles-more-than-15-years-old/articleshow/70321447.cms dated July 22, 2019), stated that about 2,19,137 commercial vehicles of more than 15 years age [registered before 15 years from now] were still plying in Kolkata Metropolis. No information was available on the number or proportion of categories of these vehicles, their actual mileage or how frequently these vehicles ran on streets. If the reported vehicle number is treated as equivalent to diesel-run 4W vehicles (as commercial vehicles are mostly diesel based 4-wheelers) and assuming that these vehicles run for about 300 days a year with an average mileage of 60 km/day within KMC (as was found for diesel commercial vehicles during petrol pump survey), these vehicles would emit about 572 MT of PM_{10} per year and 543 MT of $PM_{2.5}$ per year, taking into account the lowest PM_{10} emission factor of 0.145 g/km for diesel 4-wheelers of >15 year age **(Table 3.16)**. These estimated emissions from >15 y old diesel commercial vehicles would be higher by about 32% over total PM_{10} and $PM_{2.5}$ emissions estimated from all types of vehicles registered within last 15-year. As this study was done during 2017-2019, it can be safely assumed that these reportedly >15 year vehicles were plying on roads during the study period. Hence, emission estimation from these vehicles were accounted for in the emission estimate from transport sector. But, as these vehicles are being phased out as per recently available open-access information (https://auto.economictimes.indiatimes.com/news/commercial-vehicle/mhcv/west-bengal-govt-to-phase-out-15-yr-old-commercial-vehicles/71662176 dated Oct 19, 2019), a substantial portion of PM_{10} and $PM_{2.5}$ emissions from transport sector as estimated above, could be reduced.

3.6.2 Howrah

This section is devoted to emission estimates for Howrah (HMC area). **Table 3.20** presents emission estimates from Howrah (HMC area only) in decreasing order of PM_{10} sectors like Industry, Road, Hot Mix Plants, Open Burning, Construction, Transport, Household, Restaurants and eateries, Ironing vendors and Crematoria (**Table 3.20).** The share of various sectors in PM_{10} and $PM_{2.5}$ emissions is presented in **Fig. 3.10, 3.11**.

Table 3.20: Emissions of $PM_{2.5}$ and PM_{10} (MT/y) from Various Sectors in Howrah

Sector	**PM_{10} (MT/y)**	**$PM_{2.5}$ (MT/y)**
Industry	5091.77	1439.51
Road	4046.5	729.0
Hot Mix plants	568.75	34.13
Open burning	306.60	208.49
Construction	186.79	37.36
Transport *	180.52	171.49
Household	163.5	111.9
Restaurants and eateries	67.1	45.6
Ironing vendors	5.82	4.17
Crematoria	4.98	3.38
Total	**10622.3**	**2785.0**

*registered vehicles (2004-18)

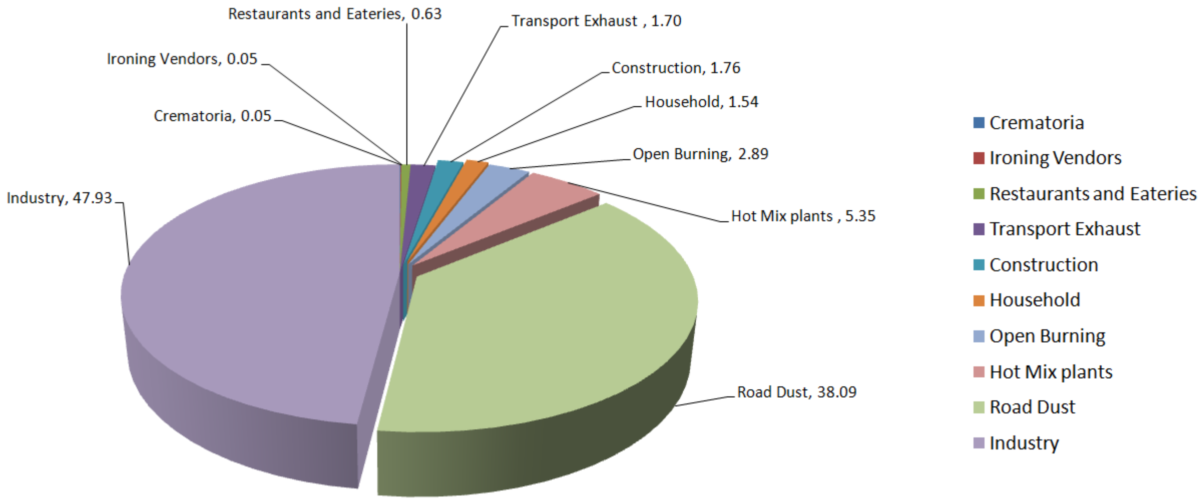


Fig. 3.10: PM_{10} Emission Estimates (% share) from Various Sectors in Howrah (HMC)

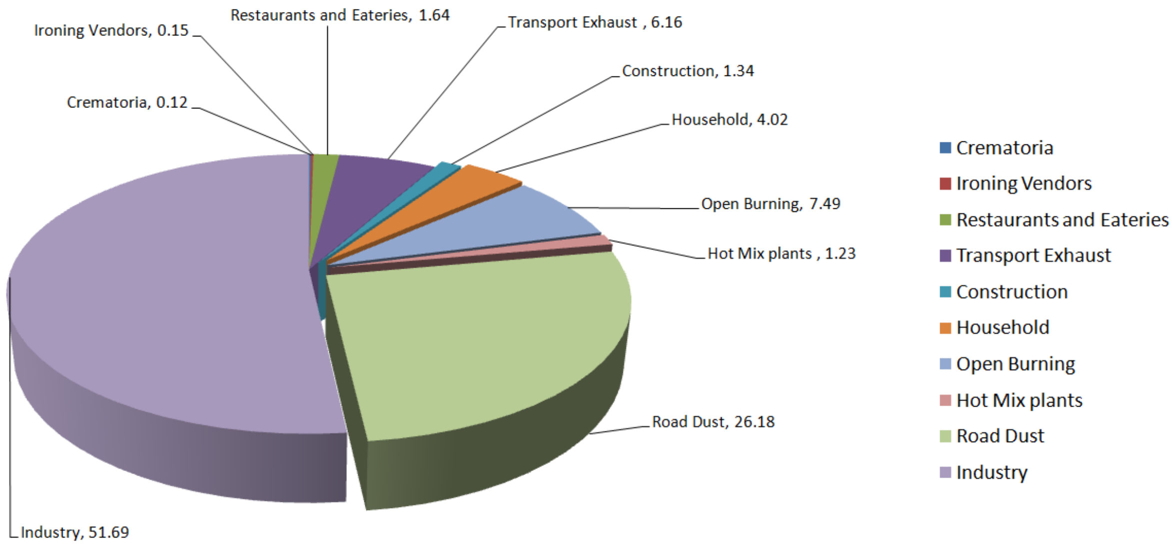


Fig. 3.11: $PM_{2.5}$ Emission Estimates (% share) from Various Sectors in Howrah (HMC)

The database on consent to operate issued to industries (shared by WBPCB) (submitted on or after 2015 only) was analyzed to enlist and sort industries and manufacturing units present within HMC area also. Fuel usage data listed under emission field in the submitted forms of the above industries were compiled and emission estimate from the industrial sector was prepared. Emission control as listed by industries were considered for calculating the emissions. Industrial emission had the major share (%) in sectoral contribution in PM_{10} and $PM_{2.5}$. Apart from developing sectoral emission inventory, intra-sectoral emission inventory was also prepared for industrial sector, based on intra-sectoral fuel usage estimates extracted from consent to operate database reported earlier in this chapter. Emission from select types of industries and manufacturing units in Howrah is presented in **Table 3.21.** Industries/ manufacturing units classified as foundries was found to be the largest emitter of PM_{10} and $PM_{2.5}$ followed by Al Smelter and Al-Cu Extraction, Bakeries, non-ferrous metal units and so on.

Table 3.21: PM_{10} and $PM_{2.5}$ emissions (MT/y) from select categories of industries having the major share in fuel consumption in Howrah (HMC area)

Industry Type	**PM_{10} (MT/y)**	**$PM_{2.5}$ (MT/y)**
Foundry	2715.4	708.7
Rolling Mill	621.8	188.8
Ferrous/Non-ferrous	175.2	49.5
Textile/Yarn	132.8	34.8
Jute processing	101.0	68.7
Gas fired boiler	98.2	31.0
Steel and Steel products	93.6	25.3
Pickling/Electroplating	81.5	24.2
Pulp and Paper	21.8	14.8
Al Smelter/Al-Cu extraction	18.7	10.5
Engineering and fabrication	10.6	6.9
Heat treatment (Oil fired)	2.5	1.7
Bakery	2.2	1.5
Railway Locomotives	0.7	0.4

Emission from transport sector was sub-divided into emissions from select categories of registered vehicles (within 15 years of registration) as presented in **Table 3.13**. Goods Carriers (including 3-wheeler Goods Carriers) were found to be the most prominent emitter of PM_{10} and $PM_{2.5}$ **(Table 3.22)** on account of their high numbers and high emission factor. It was followed by emissions from buses and 2-wheelers and so on. The share of Goods Carriers in total PM_{10} and $PM_{2.5}$ emissions were about 67% **(Fig. 3.12-3.13)**.

Table 3.22: Comparative scenario of PM_{10} and $PM_{2.5}$ emissions (MT/y) from Select Types of Vehicles in Howrah (HMC) [registered in between 2004-2018]

PM_{10} (MT/year)					
Buses +Omni Buses	**Motor Car (personal)+ Motor Cab (commercial) [Petrol + Diesel]**	**GoodsCarrier (Incl. 3-W)**	**Passenger 3 Wheelers**	**2-Wheelers**	**Others**
24.0	2.7	120.9	2.3	30.0	0.6
$PM_{2.5}$ (MT/year)					
22.8	2.6	114.9	1.3	28.5	1.4

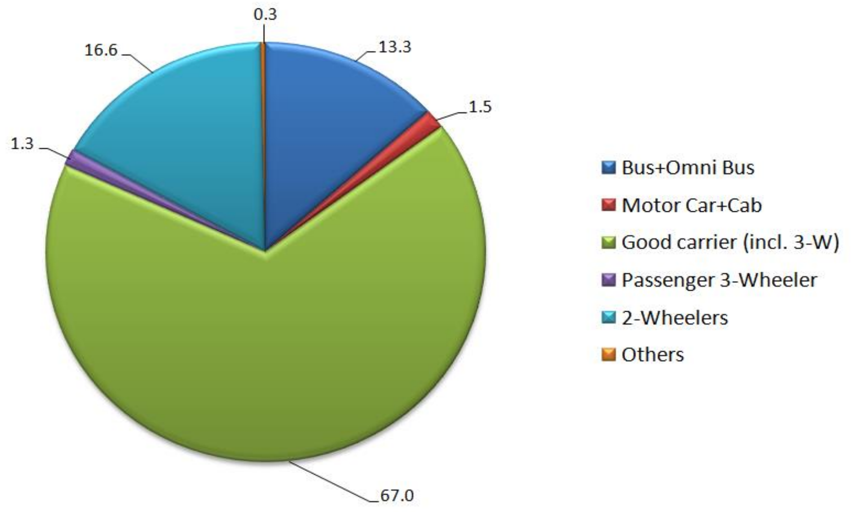


Fig. 3.12: Share (%) of Types of Registered Vehicles in PM_{10} Emissions in Howrah (HMC)

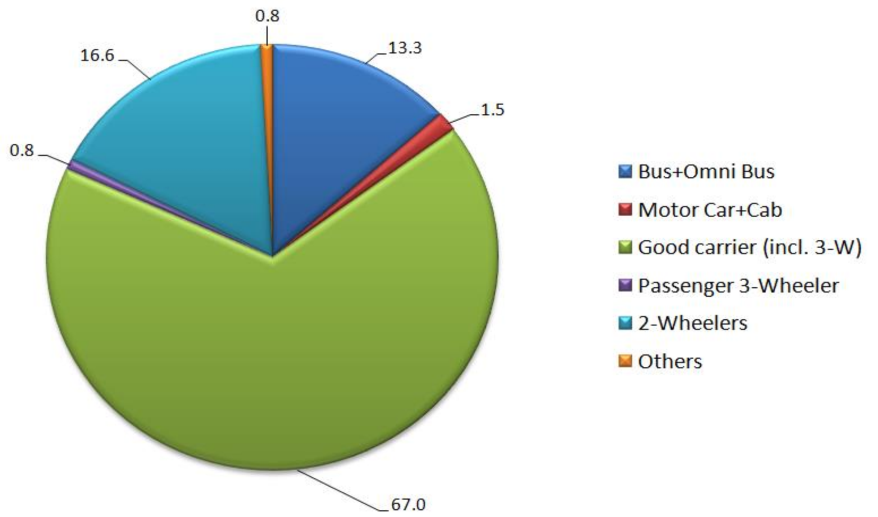


Fig. 3.13: Share (%) of Types of Registered Vehicles in $PM_{2.5}$ Emissions in Howrah (HMC)

There could be other minor sources of particulate resuspension in the air of Kolkata and Howrah e.g. temporary dumps of soil excavated during construction activities, silt excavated from the storm-water canals and drains of Kolkata, both of which are periodical activities. Part of soil dug out during excavation and piled up, could get airborne by wind movements but estimation of such dust resuspension is difficult and fraught with huge uncertainty as there is no data on amount of soil excavated and piled up (incl. periods of piling up) in the city per unit time and how much soil could eventually be airborne from such dumps is governed by soil moisture content, air velocity, soil looseness which will be ever changing in the short span of time. Further, such dumps are kept for short periods before being cleared and used elsewhere for land-filling etc. Hence, there is no clarity on how long resuspension of loose soil from dumps would take place. In case of very occasionally dredged and piled-up canal sediments long canal banks, the sediment has high moisture content and it takes substantial time for it to get dry and suspended in air. Such dumps are only temporarily kept at site and sooner or later removed for other uses somewhere and hence cannot be considered major or permanent source of particulates in air.

Other minor sources of airborne particulates could be loading and unloading of construction materials which are difficult to estimate due to non-availability of data on type and amount of raw material actually loaded or unloaded per unit time and absence of material-specific emission factors for such fugitive emissions. Moreover, this activity is ever fluctuating and there are several kinds of raw materials which may have different fugitive emission patterns depending on process of unloading, actual precautions taken during handling, air velocity at that point etc. which are highly variable over space and time, making such estimation extremely difficult to make and unreliable.

There could be some other sources of particulates relevant to Kolkata and Howrah viz. fugitive emissions in industrial premises, open transportation of construction materials/ raw materials, firecracker burning during festivals etc. Since the above emissions are fugitive in nature, do not have proper and relevant database or reliable documentation to make realistic assumptions on activity data, preparing emission inventory of these sources is deemed unrealistic.

3.7 Future Emission Scenarios

It is projected that number of motorized vehicles will cross 4 million in KMC area by 2025 (https://www.kmcgov.in/KMCPortal/downloads/Car_Parking_Policy_05_05_ 2017.pdf) which is about four times than present (https://www.kmcgov.in/ KMCPortal/jsp/BasicStatistics.jsp) and in that scenario, it is expected that PM emissions from transport sector could also increase in spite of advent better engines with lower emissions. It is therefore, necessary to have robust future planning on tailpipe emission control programme as well as better and clean roads to minimize road dust emissions. Numbers of highly emitting vehicular fleet like Goods Carriers are definitely on a conspicuous increasing trend apart other vehicles like commercial and private motor cars and 2-wheelers that take major share in total transport emissions. Possibility on increasing road length within KMC or HMC is limited and hence the existing road length has to accommodate increasing number of vehicles, leading to higher congestion, idling, stoppages and therefore, higher individual tailpipe emissions. On the other hand, existing high population with 60,00,000 of floating population at present that might also surge in future due to increasing business opportunities in Kolkata and Howrah(KMC; https://www.kmcgov.in/KMCPortal/jsp/BasicStatistics.jsp), can also play a big role in shaping city emissions. With population surge, substantial additional demand on local transport (more vehicles on road, increased mileage) might lead to more tailpipe and road dust emissions, also putting increased pressure on other resources (viz. readily cooked food leading to higher fuel usage in domestic and hotel/ restaurant sector). This will also add on to the amount of waste generated in the city, which has a role to play in increasing city emissions through unregulated open burning. Kolkata being the densest District (24,306 persons per square km) in the State (http://www.censusindia.gov.in/2011census/dchb/1916_PART _B_DCHB_KOLKATA.pdf), the city population will have to bear the risk of perpetually higher exposure to ambient particulates, if emissions are not minimized.

Chapter 4

Receptor Modeling

4.1 Introduction

Particulate matter (PM) emission sources are abundant and their contribution in urban and rural set up could be distinctly different or even somewhat similar. Particulate control strategies can be directly targeted to the sources present in an area and estimation of contribution of the sources helps in deciding the magnitude of efforts required, time and resources. Source contribution assessment of particulate matter or source apportionment (SA) study helps decision makers to improve air quality by adopting appropriate control and management policies.

Traditionally, source apportionment techniques included dispersion modeling that relied on obtaining the information on the emission sources and projected it to assess the impact on the receptor. These models were mainly based on the emission estimates and meteorological data. One limitation of these models is the availability of accurate emission estimates. Meteorological data is also projected based on the field observations at one site, the approach which itself had lot of uncertainties. Receptor models are popular as lack of source emission information is not a hindrance to these techniques rather the information on receptor concentration along with its chemical characterization offers the application of several techniques of receptor modeling. Factor analysis, positive matrix factorization, chemical mass balance, multiple regression analysis along with factor analysis and cluster analysis are the few receptor modeling techniques applied in the past to ascertain the source of particulate matter in an area or region. Chemical mass balance is a promising technique that utilizes the data on the emission source profiles as well as the chemically speciation of particulate matter at receptor. Other techniques are statistical in nature and require the data on the chemical characterization of ambient particulate matter at the receptor site.

Receptor modeling based on chemical mass balance (CMB) approach is based on the chemical composition of particulate matter released by source (called as source profile) and measured at receptor location. Uncertainty associated with individual measurements both at source and receptor is also required by CMB. The output of the model delineates contribution of each source to particulate matter at a given monitoring station or receptor site. This technique is more reliable than factor analysis that uses only the chemical composition of ambient particulate matter at receptor site.

The major sources of PM within KMC Area in Kolkata identified through reconnaissance are vehicles, road dust, small and medium scale industries, construction, domestic wood and kerosene combustion, coal/LPG/wood/kerosene combustion in hotels and restaurants, crematoria, occasional open burning etc. To carry out receptor modeling exercise, fine ($PM_{2.5}$) and coarse (PM_{10}) particulate matter concentration along with their chemical characterization data at various sites in Kolkata and Howrah in summer 2017 and winter 2017-18 were subjected to analysis by CMB. Following section is devoted to a brief description of CMB technique and its application to particulate matter source apportionment.

4.2 Chemical Mass Balance Model

For source apportionment of particulate matter, CMB8.2 program/model (available via www.epa.gov/scram001/receptor_cmb.htm) was used. The model uses chemical composition of ambient particulate samples to estimate the contribution of different source types to the measured pollutant concentrations (Watson et al., 2004). The chemical mass balance model requires knowledge of parameters like number of sources present in the study area, variability in emissions, composition of each source (source profiles) and chemical composition of ambient particulate samples. The CMB model quantifies contributions of sources from chemically distinct source-types rather than contributions from individual emitters. The CMB model is derived from physical principles and some of the assumptions are the following:

- The compositions of source emissions are constant over the period of ambient and source sampling
- The chemical species do not react with each other
- All sources with potential for significantly contributing to the receptor have been identified and had their emissions characterized
- The number of sources is less than or equal to the number of species
- The source profiles are sufficiently different from one another so as to have distinct individual signature
- Measurement uncertainties are random, uncorrelated and normally distributed

Chemical mass balance consists of a least square solution to a set of linear equations which express receptor concentration of a chemical species as a linear sum of product of source profile species and source contributions. The CMB model consists of the following equations:

$$C_i = \sum_j m_j x_{ij} \alpha_{ij} \qquad \text{- - - - - (1)}$$

Where C_i = Concentration of species i measured at a receptor site, x_{ij} is the concentration of the i^{th} species from the j^{th} type of source. The term α_{ij} is included as an adjustment for any gain or loss of species i between the source and receptor. The term is assumed to be unity for most chemical species. The solution of above equation provides the estimate of source strength m_j, that can be obtained by using effective variance least squares method. The equation has a unique solution only when the number of species is equal to or greater than the number of sources. More number of species reduces uncertainty in the model output. The method minimizes the function as given in equation (2).

$$x^2 = \sum_{i=1}^{n} \frac{\left(C_i - \sum_j m_j x_{ij}\right)^2}{\sigma_{ci}^2 + \sum_j \sigma_{xij}^2 m_j^2} \qquad \text{- - - - - (2)}$$

Where σ_{ci} and σ_{xij} are the measurement uncertainties.

The normal checks, as specified in the manual of USEPA to accept the model are; χ^2 should be less than 4, R^2 should be greater than 0.8, % mass explained should be between 80% and 120%, t-statistics i.e. source contribution divided by error of source contribution should be greater than 2, the ratio of computed and measured concentration of each element (C/M ratio) should be close to 1 and R/U ratio i.e. the ratio of residuals to uncertainty should be less than 2. Although the % mass explained should be in the range of 80-120, a range of 60-120 was considered, as due to variability in the sources and meteorological conditions in Indian scenario, it is not always possible to get >80% mass accounted for. For detailed discussion, CMB 8.2 User's Manual may be referred.

4.3a PM_{10} and $PM_{2.5}$ Concentration and Chemical Analysis: Summer

Sampling for ambient PM_{10} and $PM_{2.5}$ was carried out at 7 sites (including control) in Kolkata and 2 sites in Howrah (including control) during summer 2017 in order to know the contribution of various sources. Sampling was carried out during May–June, 2017. At each site, about 10 days sampling was performed wherein PTFE and Quartz filter papers were exposed simultaneously to sample ambient particulate ($PM_{2.5}$ and PM_{10}) on all sampling days to comply with requirements of SA. The chemical composition of $PM_{2.5}$ and PM_{10} were then obtained using various relevant analytical methods as prescribed in CPCB (2011). For elemental analysis, PTFE filter samples were subjected to analysis by EDXRF (at WBPCB, Kolkata) and the same samples were subsequently analyzed for Ions by Ion Chromatography (IC) at CSIR-NEERI, Nagpur. Quartz filters were subjected to analysis in GC-MS for quantitative detection of select molecular markers and EC-OC analyzer for elemental carbon (EC) and organic carbon (OC) estimation.

The results of the above chemical analyses are presented in **Fig. 4.1a-b**. The chemical species were further grouped and plotted in **Fig. 4.2**. It is observed that carbon and ionic fractions dominated ambient particulate matter at all sites. Amongst ions, $SO_4^{=}$ and NH_4^{+} were predominant while amongst metals (all incl. alkali and alkaline earth metals), crustal species such as Mg, Ca and Fe dominated others.

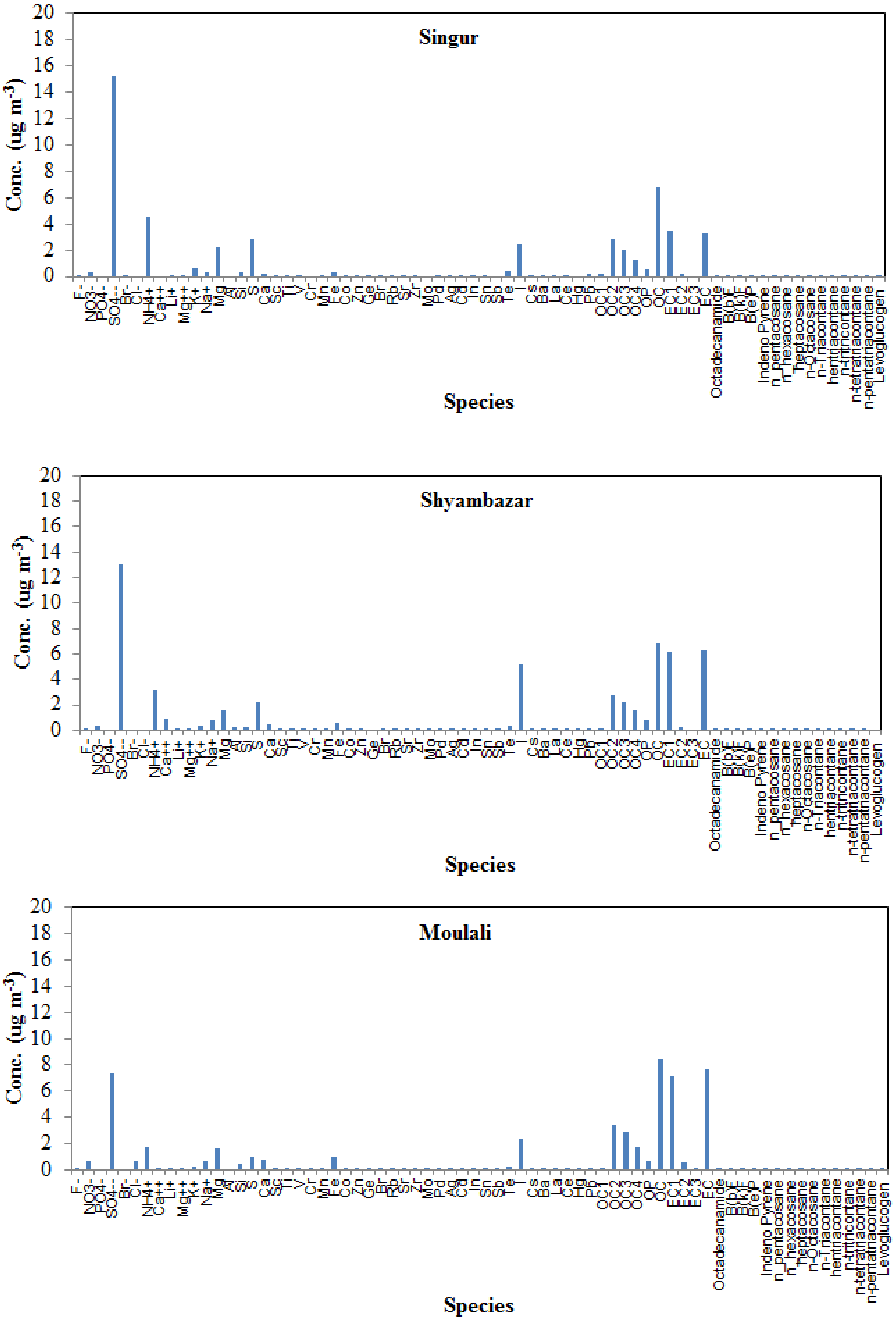


Fig. 4.1a: Chemical Composition of $PM_{2.5}$: Summer

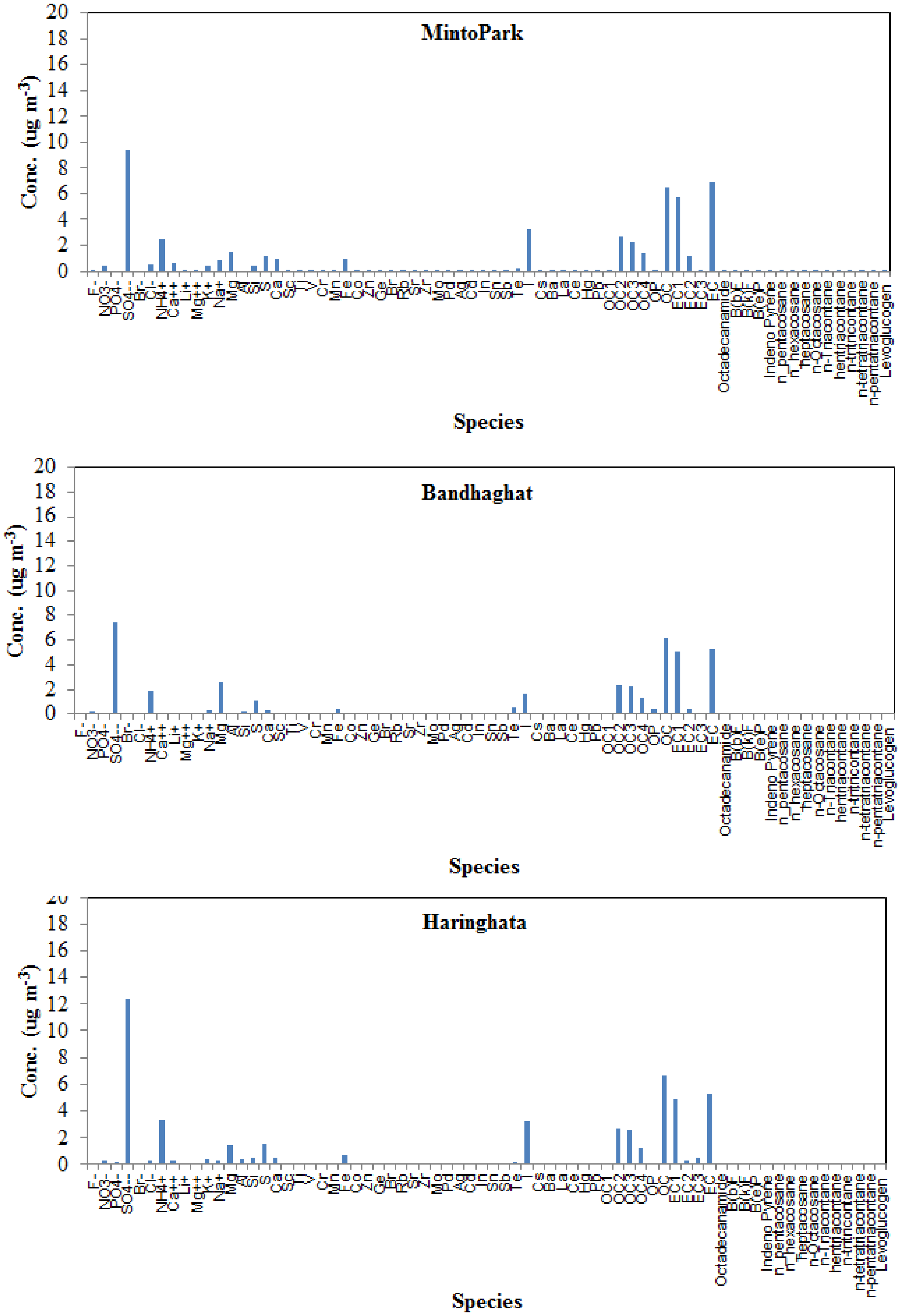


Fig. 4.1a: Chemical Composition of $PM_{2.5}$: Summer

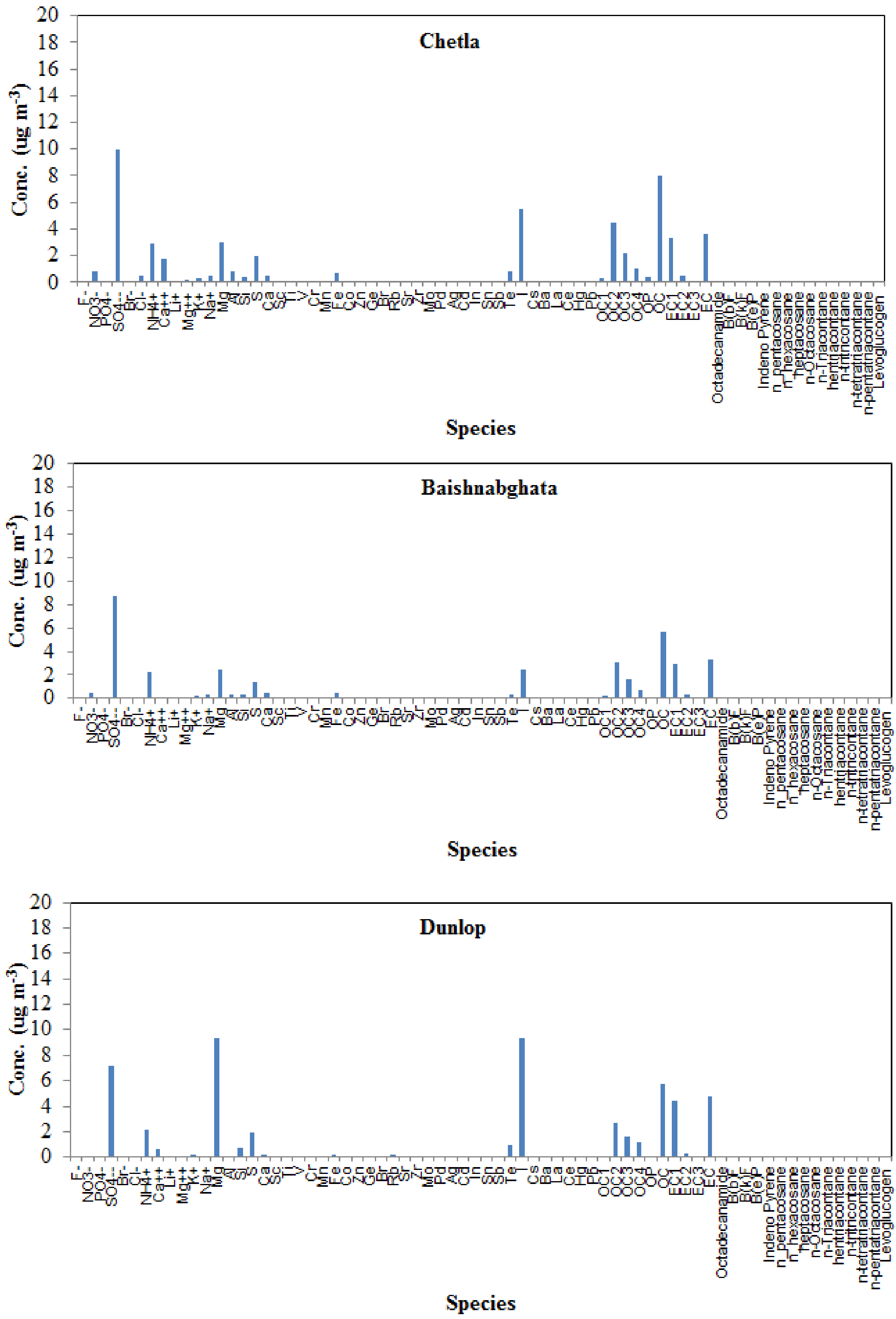


Fig. 4.1a: Chemical Composition of $PM_{2.5}$: Summer

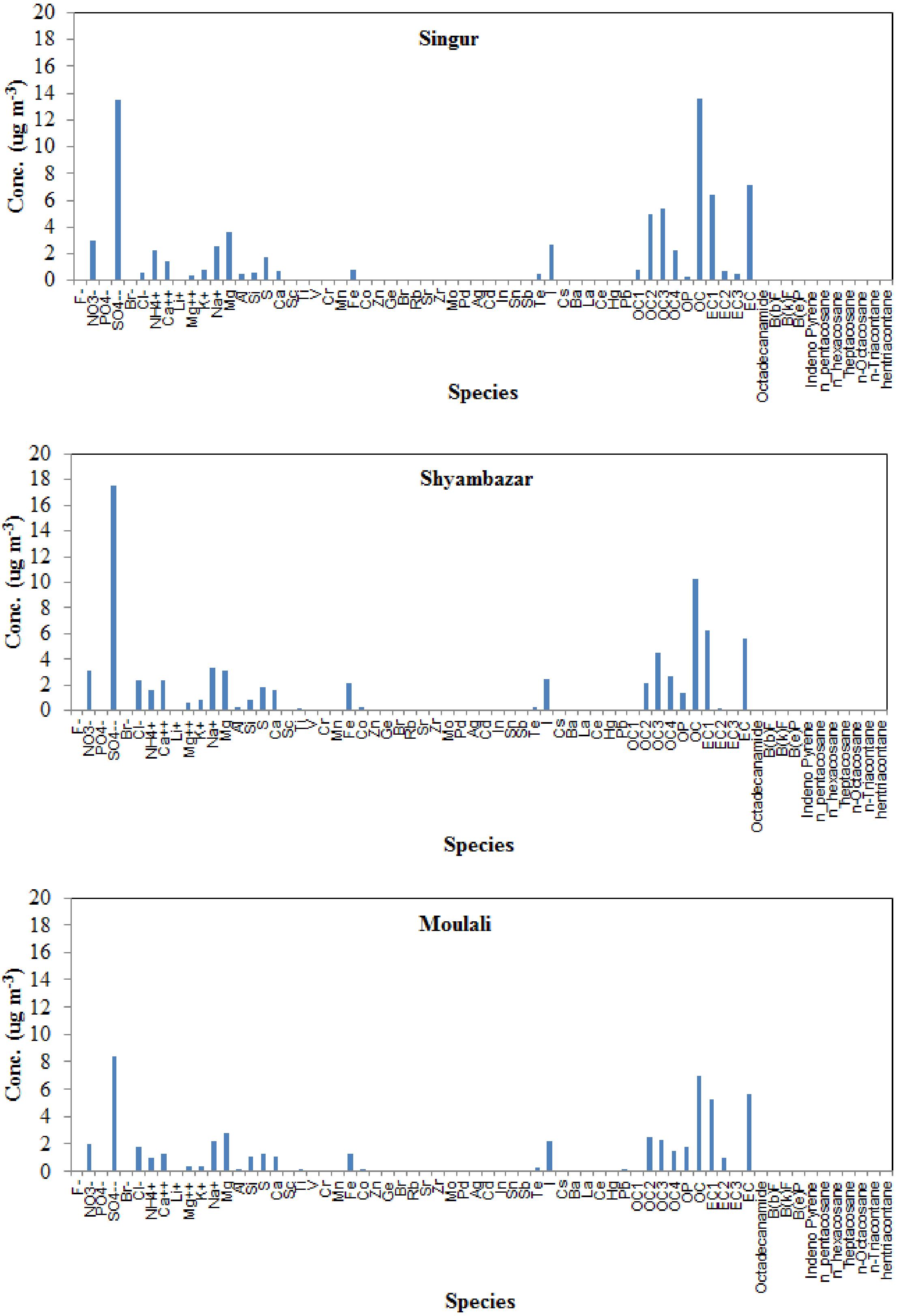


Fig. 4.1b: Chemical Composition of PM_{10}: Summer

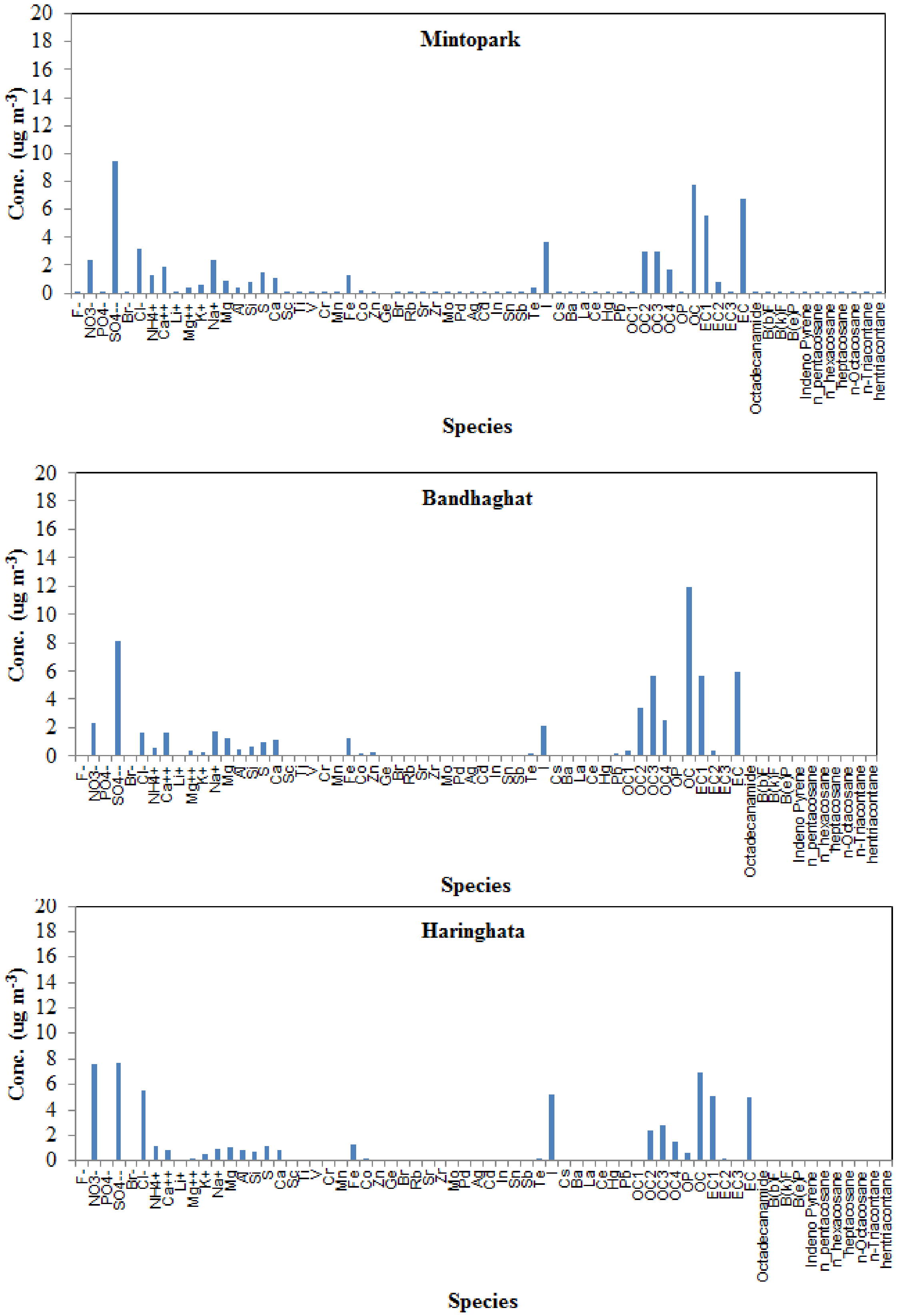


Fig. 4.1b: Chemical Composition of PM_{10}: Summer

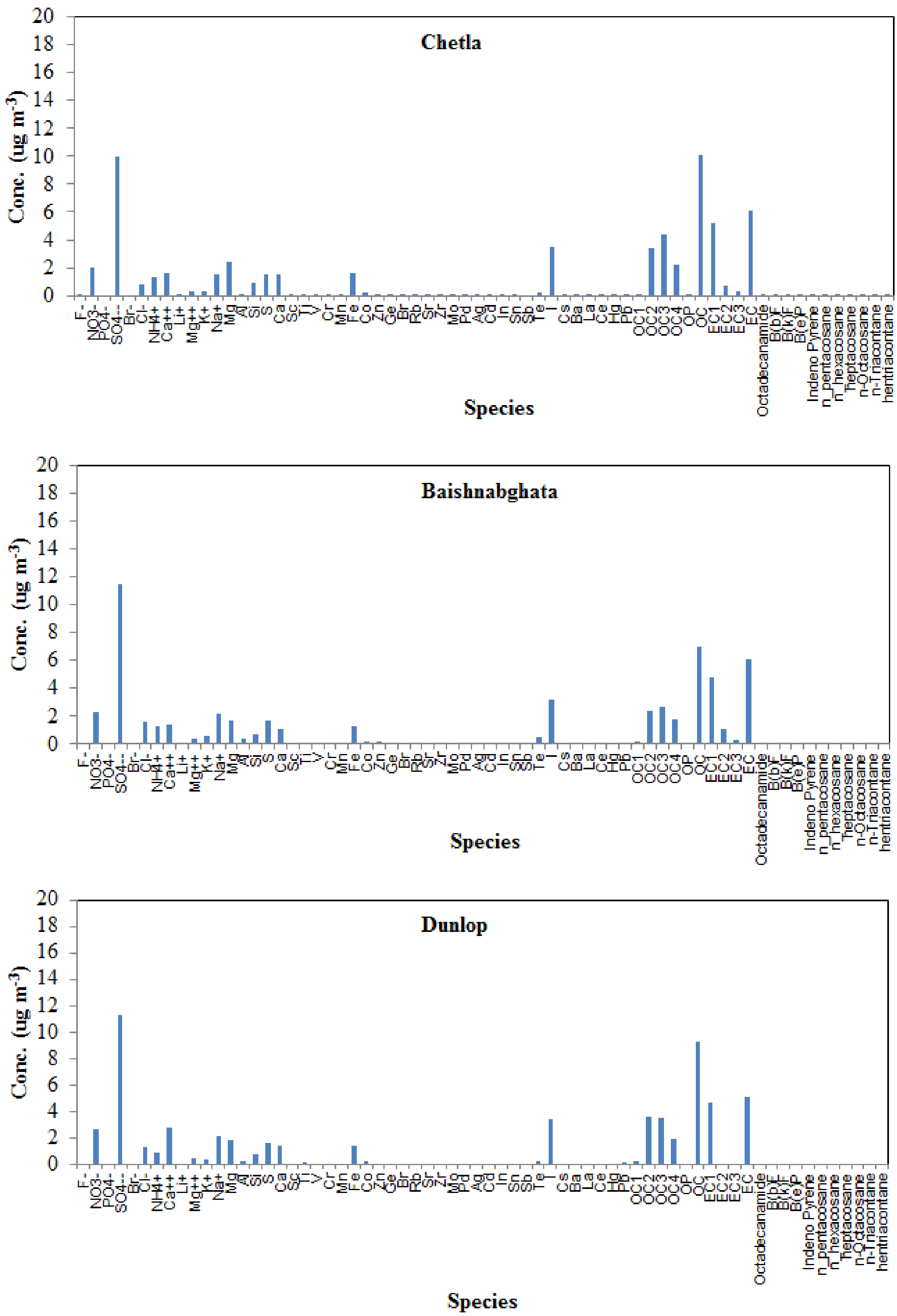


Fig. 4.1b: Chemical Composition of PM_{10}: Summer

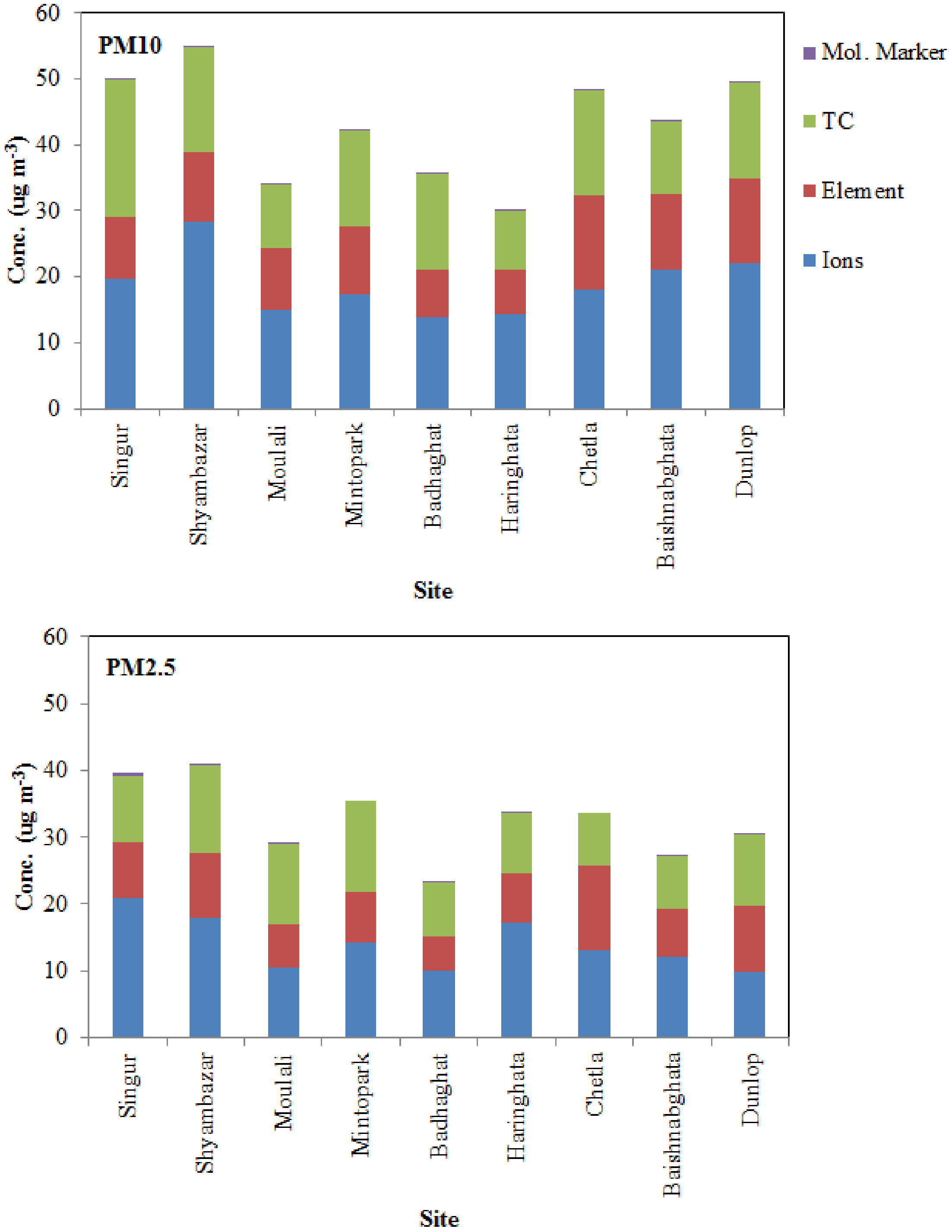


Fig. 4.2: Carbon, Ions and Elements in PM : Summer

Ions had the highest share (w/w) in ambient particulate matter followed by total carbon (EC+OC) and elements (**Fig. 4.2)**. Contribution of molecular markers, including PAHs, had negligible contribution. Amongst ions, highest share (w/w) was taken by $SO_4^{=}$ in both $PM_{2.5}$

and PM_{10}. Amongst elements, S and I were observed to be higher in $PM_{2.5}$, whereas in PM_{10}, S, I along with crustal elements; Ca and Fe were dominant. Oceans are the main source of iodine in atmosphere through volatilization of iodine carriers including mono-halogenated organic compounds such as methyl iodide (CH_3I), ethyl iodide (C_2H_5I), and propyl iodide (1- and 2-C_3H_7I), more reactive polyhalogenated compounds such as chloroiodomethane (CH_2ICl), bromoiodomethane (CH_2IBr), and diiodomethane(CH_2I_2), and I_2. These compounds photodissociate rapidly in the atmosphere to generate iodine atoms. Kolkata and Howrah may have slight influence of iodine generated in Bay of Bengal about 100 km away through movement of trade winds. Average EC and OC concentrations, along with the OC/EC ratio, are presented in **Fig. 4.3**. It is observed that OC concentration is higher than EC (>50%) in both $PM_{2.5}$ and PM_{10} at most sites except in $PM_{2.5}$ at Minto Park, suggesting dominant presence of organics in ambient particulate matter.

4.3b Molecular Markers in PM_{10} and $PM_{2.5}$: Summer

The average concentrations of molecular markers including PAHs were also analyzed in PM_{10} and $PM_{2.5}$ separately. **Fig. 4.4a-b** shows the measured concentrations of molecular markers at all the sites. The analyzed compounds were: Octadecanamide, n_pentacosane, n_hexacosane, heptacosane, n-Octacosane, n-Triacontane, hentriacontane, n-tritricontane, n-tetratriacontane, n-pentatriacontane, levoglucosan while analyzed PAHs were Benzo (b) Fluoranthene (B(b)F), Benzo (k) Fluoranthene (B(k)F), Benzo (e) Pyrene (B(e)P) and Indeno (1,2,3-cd) Pyrene.

In $PM_{2.5}$, the major share (w/w) was taken by Indeno (1,2,3-cd) Pyrene at Dunlop; Indeno (1,2,3-cd) Pyrene, heptacosane, n-Octacosane at Baishnabghata; Indeno (1,2,3-cd) Pyrene, levoglucosan at Bandhaghat and Singur; n_hexacosane, heptacosane, n-Octacosane, Indeno

(1,2,3-cd) Pyrene at Haringhata; Indeno (1,2,3-cd) Pyrene, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene at Shyambazar and Chetla; Indeno (1,2,3-cd) Pyrene, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene, levoglucosan at Mintop Park and Moulali. In PM_{10}, the major share (w/w) was taken by n_pentacosane, Octadecanamide, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene at Dunlop; Benzo (b) Fluoranthene, Benzo (k) Fluoranthene at Baishnabghata; n_pentacosane, Octadecanamide, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene, levoglucosan at Bandhaghat; n_hexacosane, heptacosane, n-Octacosane, n_pentacosane, Indeno (1,2,3-cd) Pyrene at Haringhata; Indeno (1,2,3-cd) Pyrene, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene at Shyambazar, Mintopark,Singur and Chetla; Indeno (1,2,3-cd) Pyrene and levoglucosan at Moulali.

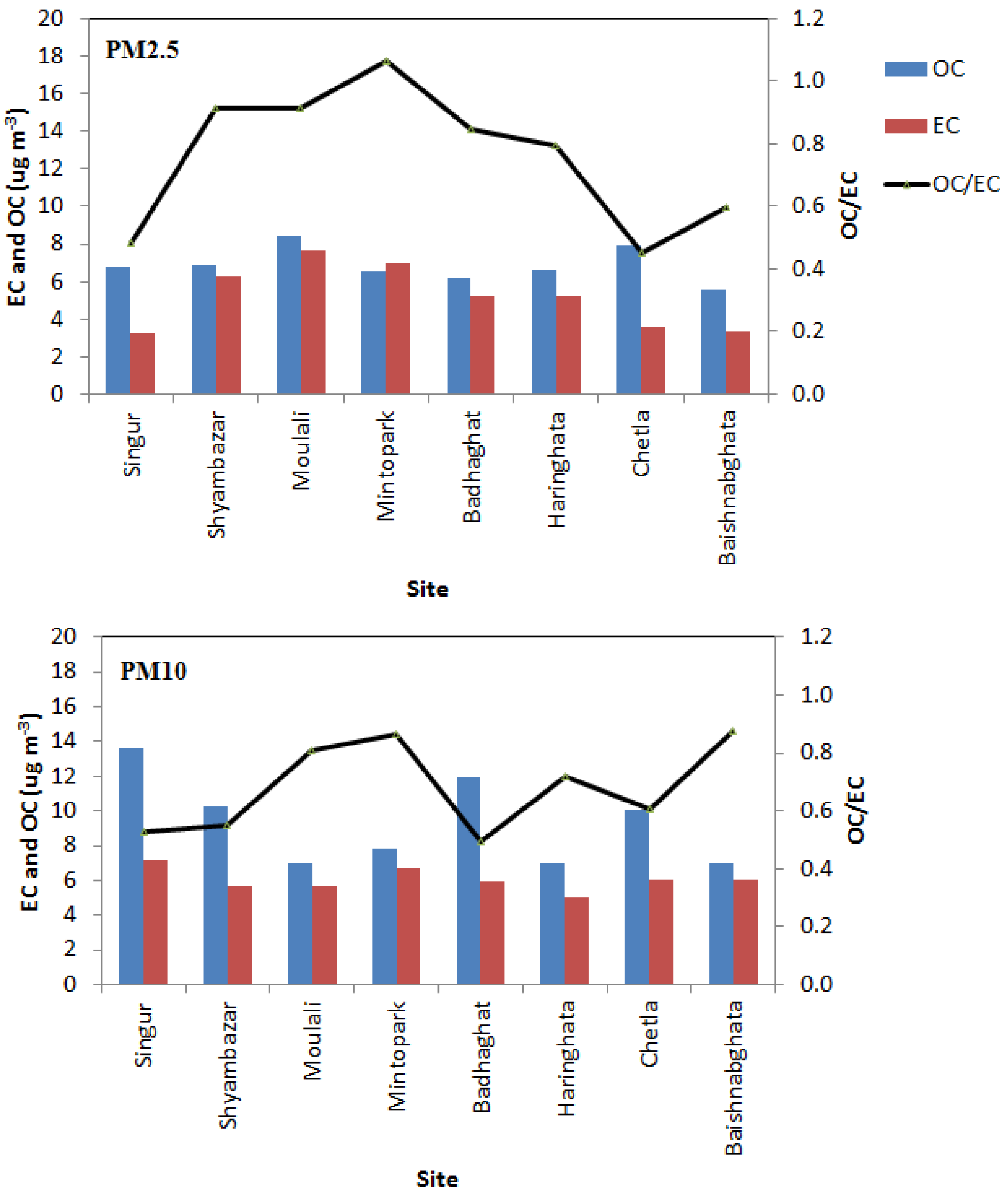


Fig. 4.3: EC and OC Concentration in $PM_{2.5}$ and PM_{10}: Summer

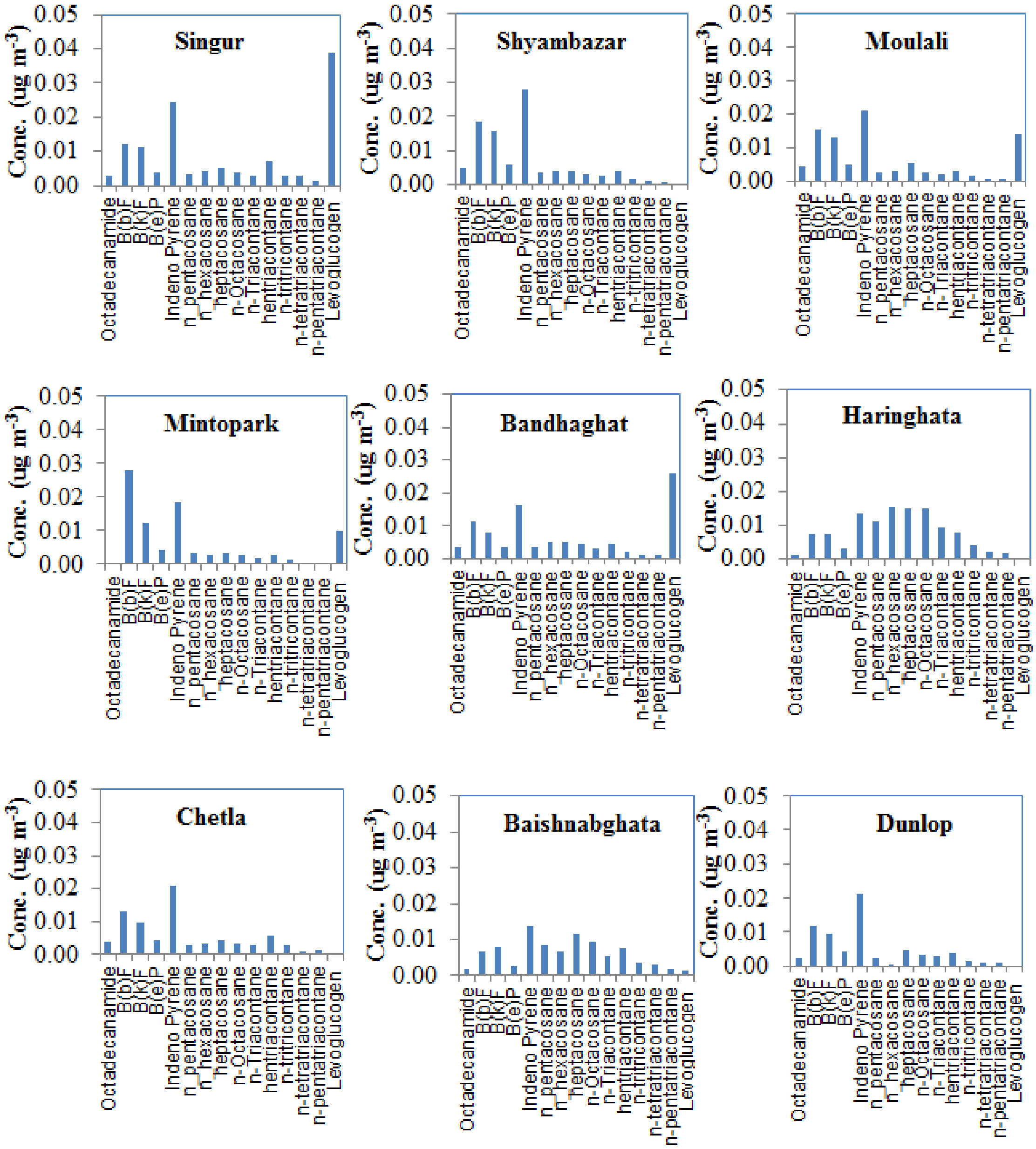


Fig. 4.4a: Molecular Markers in $PM_{2.5}$: Summer

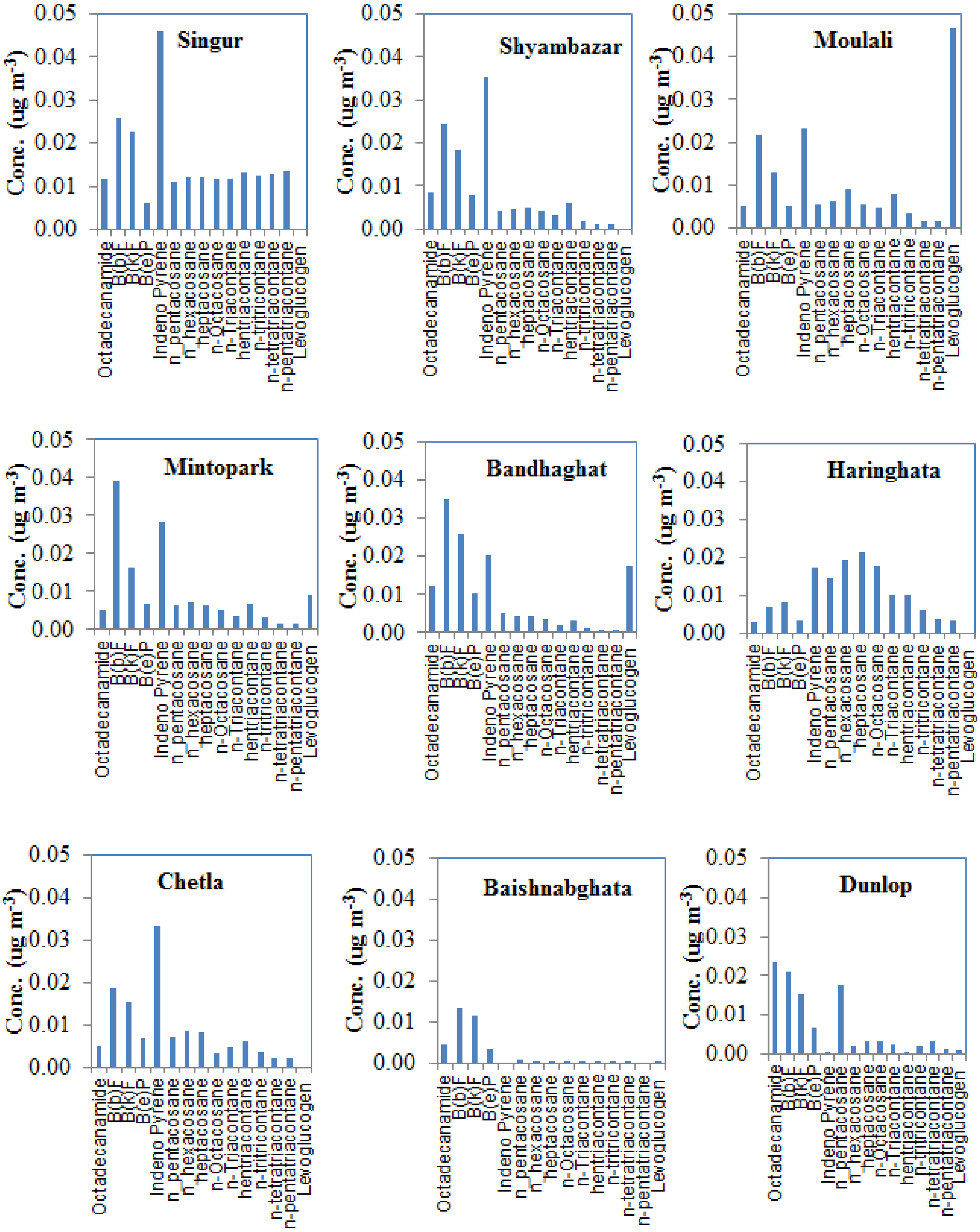


Fig. 4.4b: Molecular Markers in PM_{10}: Summer

4.3c Comparison of Chemical Composition of $PM_{2.5}$ and PM_{10} : Summer

In order to understand the dominance of particulate size fractions ($PM_{2.5}$ and PM_{10}) in the partitioning of analysed chemical species, ratios of analysed species in $PM_{2.5}$ and PM_{10} were obtained and then averaged over all the sites. **Fig. 4.5** presents ratio of chemical species as present in $PM_{2.5}/PM_{10}$. It can be seen that major ions and elements are more dominant in $PM_{2.5}$ fraction while OC is less dominant than EC in $PM_{2.5}$ fraction. Molecular markers are observed to be higher in $PM_{2.5}$ than in PM_{10} with Benzo (b) Fluoranthene being >1500% times in the former.

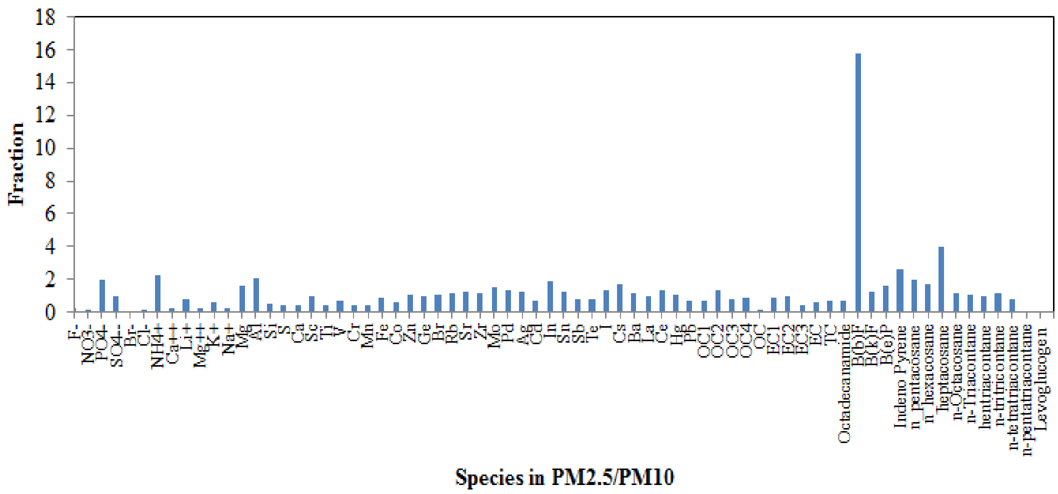


Fig. 4.5: Comparison of Chemical Composition in $PM_{2.5}$ and PM_{10}

4.3d Mass Closure: Summer

Out of the several complimentary SA techniques, mass closure is one of the methods which can be considered as preliminary SA method. In this, the gravimetric mass is compared with the chemical mass, which is obtained as sum of chemical components such as crustal or geological matter, non-crustal matter, secondary ions as; ammonium sulphate ($(NH_4)_2SO_4$), ammonium nitrate (NH_4NO_3); sea salt, organic and inorganic matter. The material balance equation that allocates mass to these components with factors and chemical mass can then be obtained (Harrison et al., 2003). With the help of this method, the contribution of secondary inorganic aerosols such as ammonium nitrate and ammonium sulphate can be assessed. **Fig. 4.6** shows the aerosol type contribution to all the sites.

For PM_{10}, the correlation between gravimetric mass and chemical mass was more than 0.9 at all the sites except at one site. It can be seen that unidentified mass contribution is highest at all the sites except at Badhaghat and control sites Haringhata and Singur. Of the identified mass, ammonium sulphate contribution is highest i.e. 14-31%, and ammonium nitrate contribution is 3-13%. Geological matter contribution is 5-10%, organic matter contribution is 13-25%, EC contribution is 7-9% whereas sea-salt contribution is 1-12%. Organic matter (OM) contribution is generally attributed to wood and biomass burning and vehicles. Further, in Howrah, OM contribution is more than $(NH_4)_2SO_4$ suggesting organic nature of coarse particulate whereas at all the sites (except Chetla) in Kolkata, $(NH_4)_2SO_4$ is observed to be higher, suggesting inorganic nature of coarse particulate. Secondary organic carbon (SOC) was also estimated, which showed its contribution to OC as ~27%.

For $PM_{2.5}$, the unidentified mass is quite low as compared to PM_{10}. At some sites, the species over-represent the mass (e.g. at Dunlop, Haringhata, Baishnabghata, Moulali and Singur), as evident from negative unidentified mass (**Fig. 4.6**). The contribution of the components such as ammonium sulphate and organic matter is high followed by non-crustal mass. High $(NH_4)_2SO_4$ suggests inorganic nature of fine particulate in Kolkata and Howrah. Geological matter contribution is 4-11%, whereas sea-salt and NH_4NO_3 contribution is almost negligible. Contribution of SOC to OC is observed to be ~28%.

The above analysis allocates the aerosol type to PM_{10} and $PM_{2.5}$ in Kolkata and Howrah. With the help of this method, one can assess the presence of secondary inorganic aerosol contribution. It is observed that PM_{10} is contributed in the range 14-31% and 3-13%, and $PM_{2.5}$ is contributed in the range 25-50% and 0-3% by secondary ammonium sulphate and ammonium nitrate, respectively.

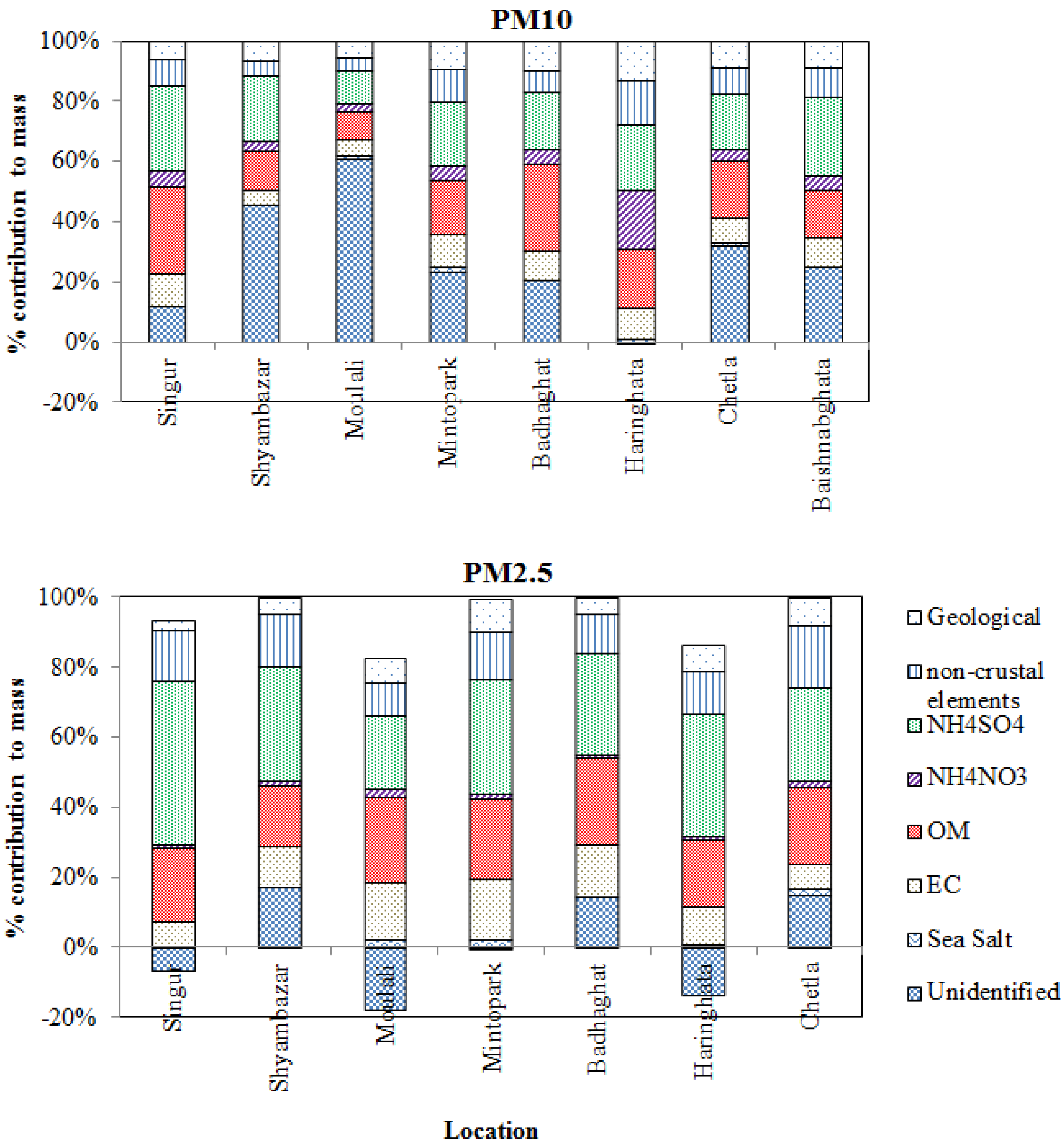


Fig. 4.6: Mass Closure of PM_{10} and $PM_{2.5}$ at Different Locations: Summer

4.4a PM_{10} and $PM_{2.5}$ Concentration and Chemical Analysis: Winter

Sampling for ambient PM_{10} and $PM_{2.5}$ was carried out at 7 sites (including control) in Kolkata and 5 sites in Howrah (including control) during winter 2017-18. Sampling was carried out during December 2017 to February 2018. At each site, about 10 days sampling was performed. PTFE and Quartz filter papers were exposed simultaneously to sample ambient particulate ($PM_{2.5}$ and PM_{10}) on all sampling days to comply with requirements of SA. The chemical composition of $PM_{2.5}$ and PM_{10} were then obtained using various relevant analytical methods as prescribed in CPCB (2011). For elemental analysis, PTFE filter samples were subjected to analysis by EDXRF (at WBPCB, Kolkata) and the same samples were subsequently analyzed for Ions by Ion Chromatography (IC) at CSIR-NEERI, Nagpur. Quartz filters were subjected to analysis in GC/ GC-MS for quantitative detection of select molecular markers and EC-OC analyzer for elemental carbon (EC) and organic carbon (OC) estimation.

The results of the chemical analyses are presented in **Fig. 4.7a-b**. The chemical species were further grouped and plotted in **Fig. 4.8**. It is observed that carbon and ionic fractions dominated ambient particulate matter at all sites. Amongst ions, $SO_4^{=}$, Br^- and NH_4^+ are predominant while amongst metals (all incl. alkali and alkaline earth metals), crustal species such as Ca and Fe dominated others.

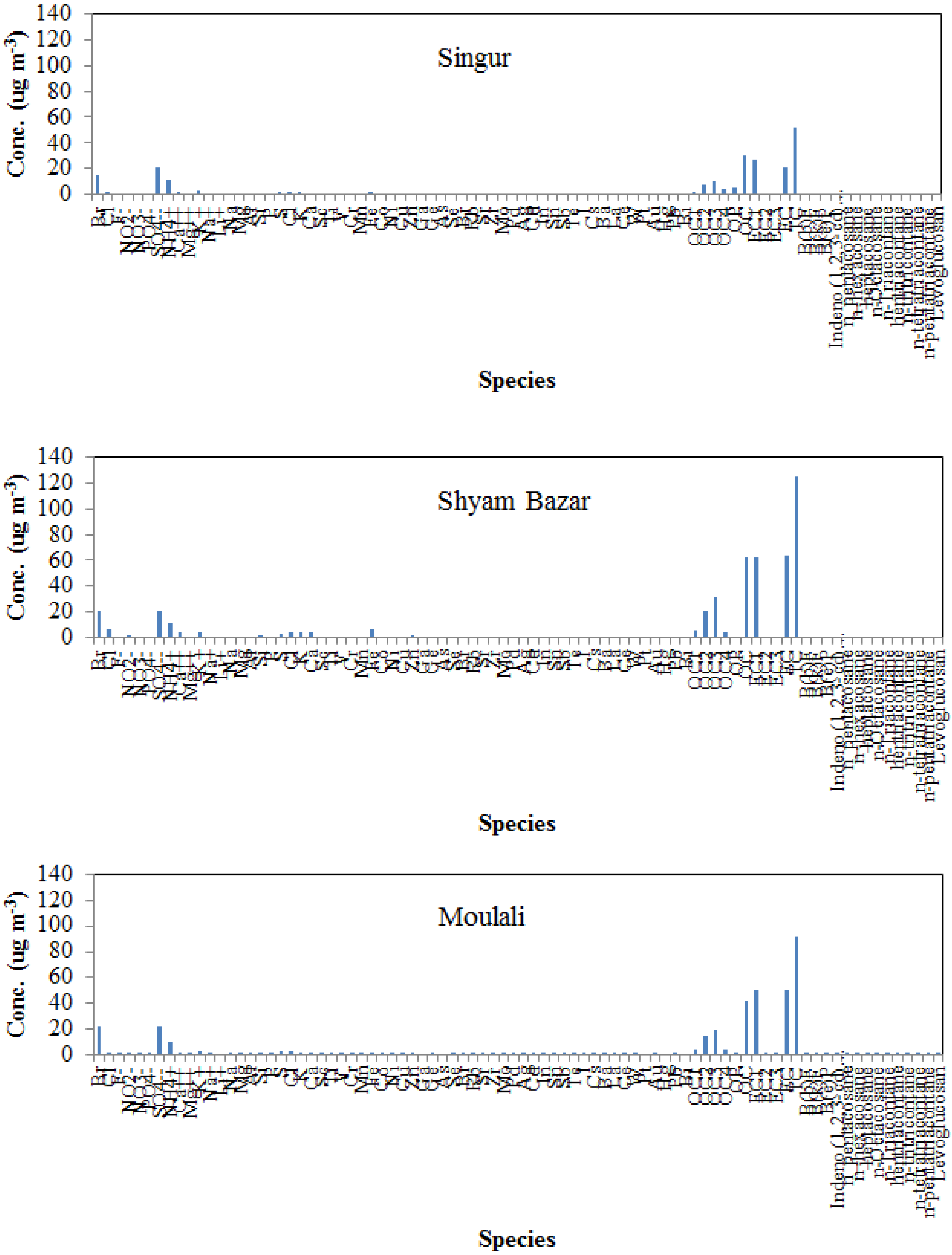


Fig. 4.7a: Chemical Composition of PM_{10}: Winter

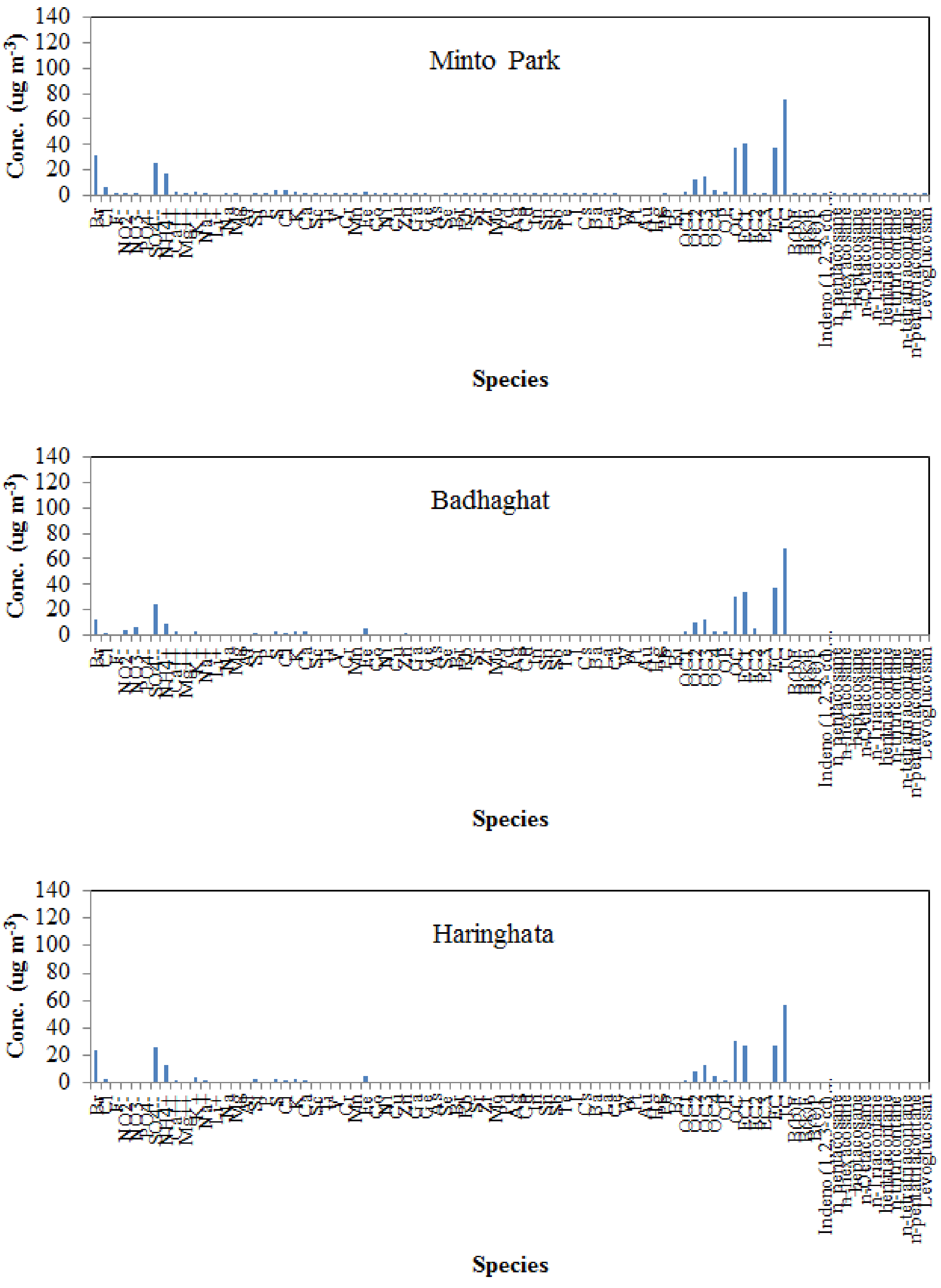


Fig. 4.7a: Chemical Composition of PM_{10}: Winter

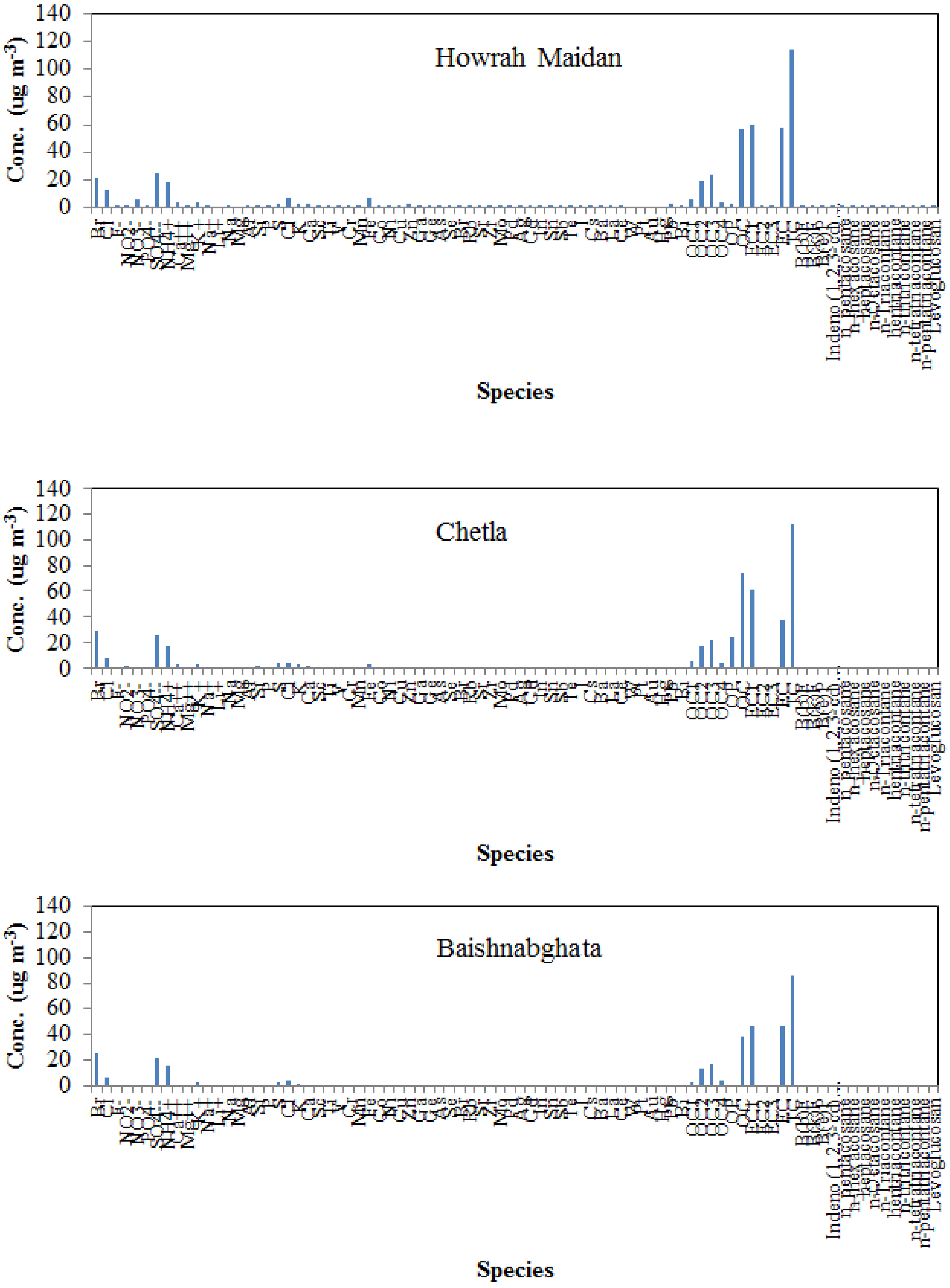


Fig. 4.7a: Chemical Composition of PM_{10}: Winter

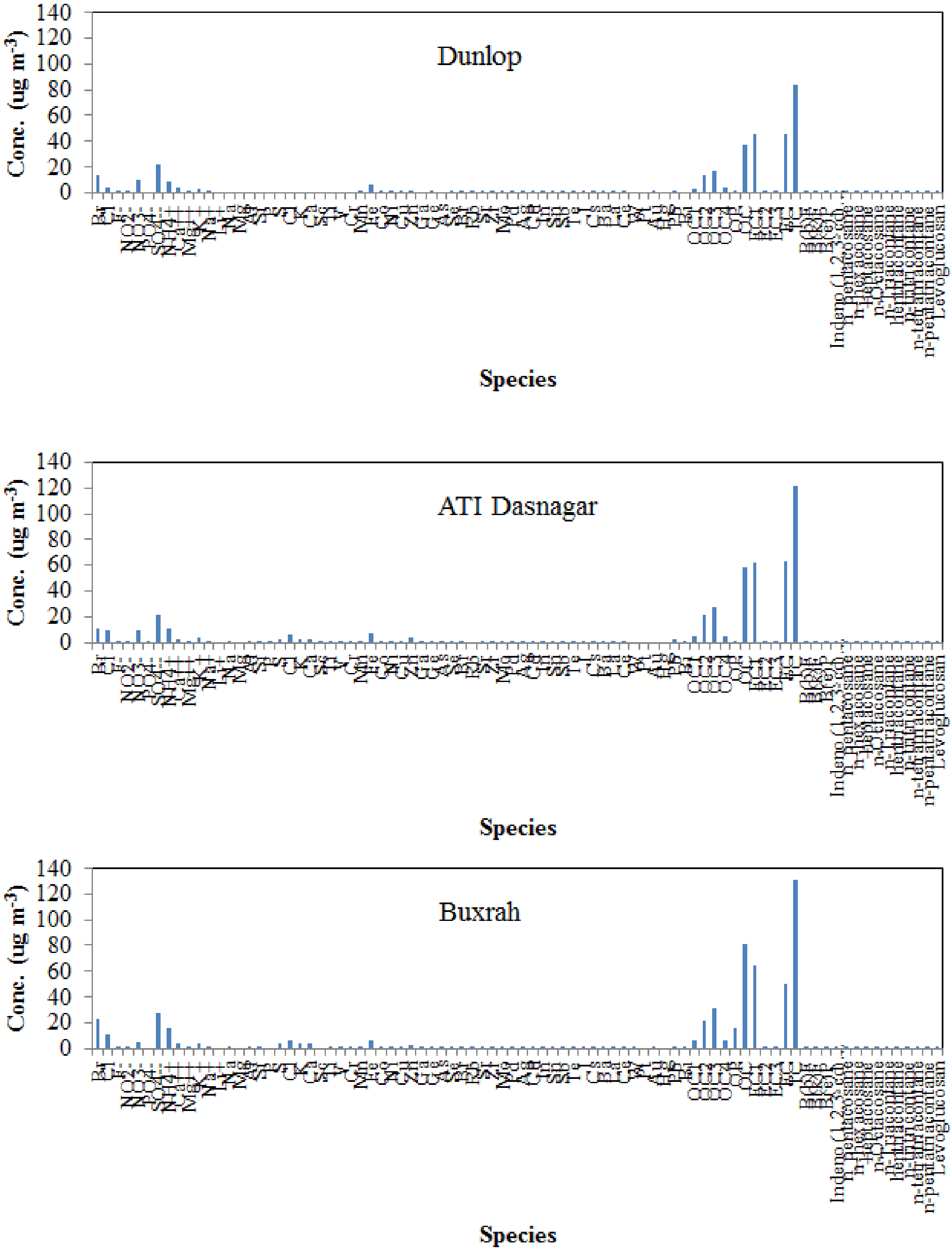


Fig. 4.7a: Chemical Composition of PM_{10}: Winter

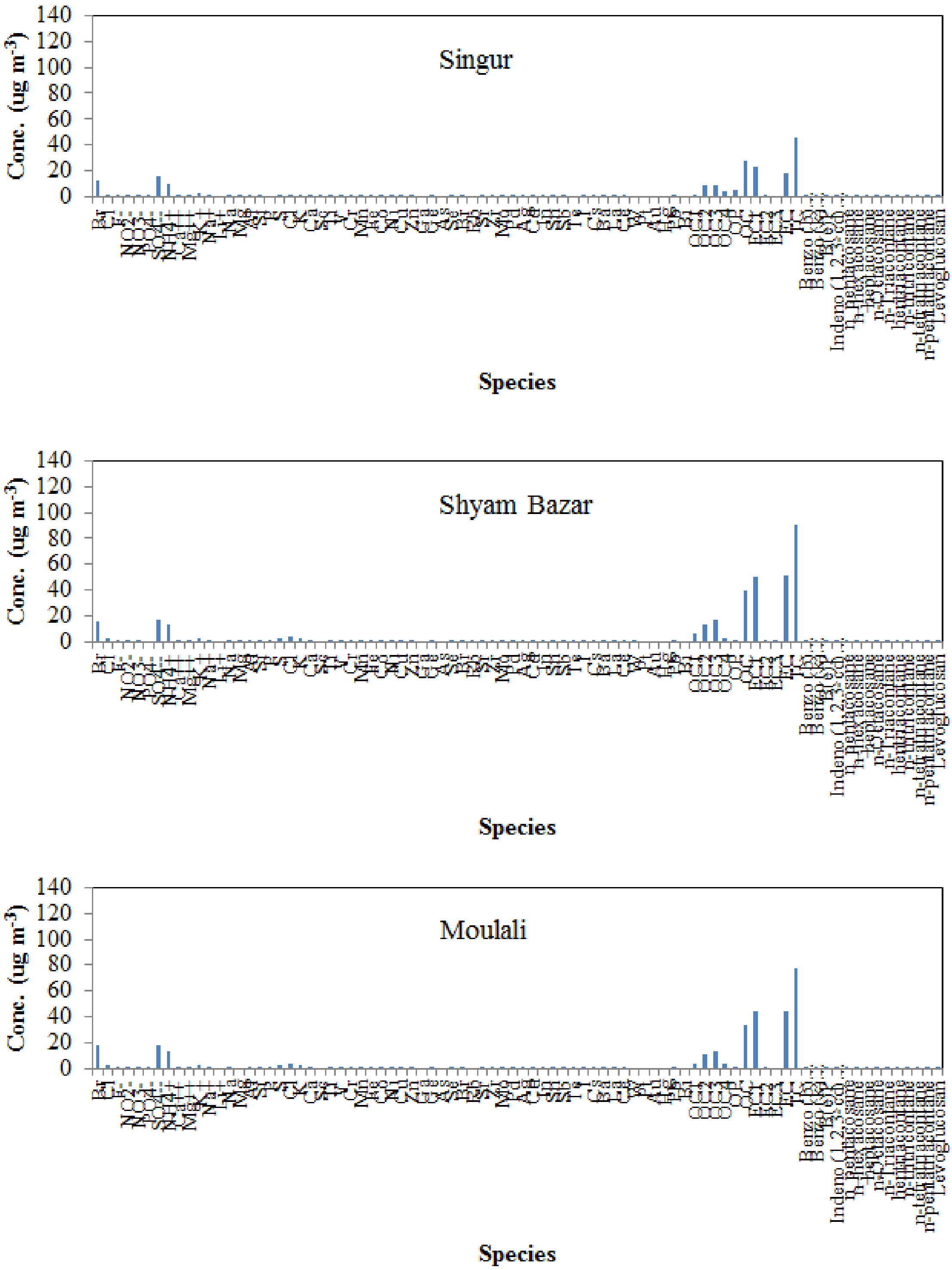


Fig. 4.7b: Chemical Composition of $PM_{2.5}$: Winter

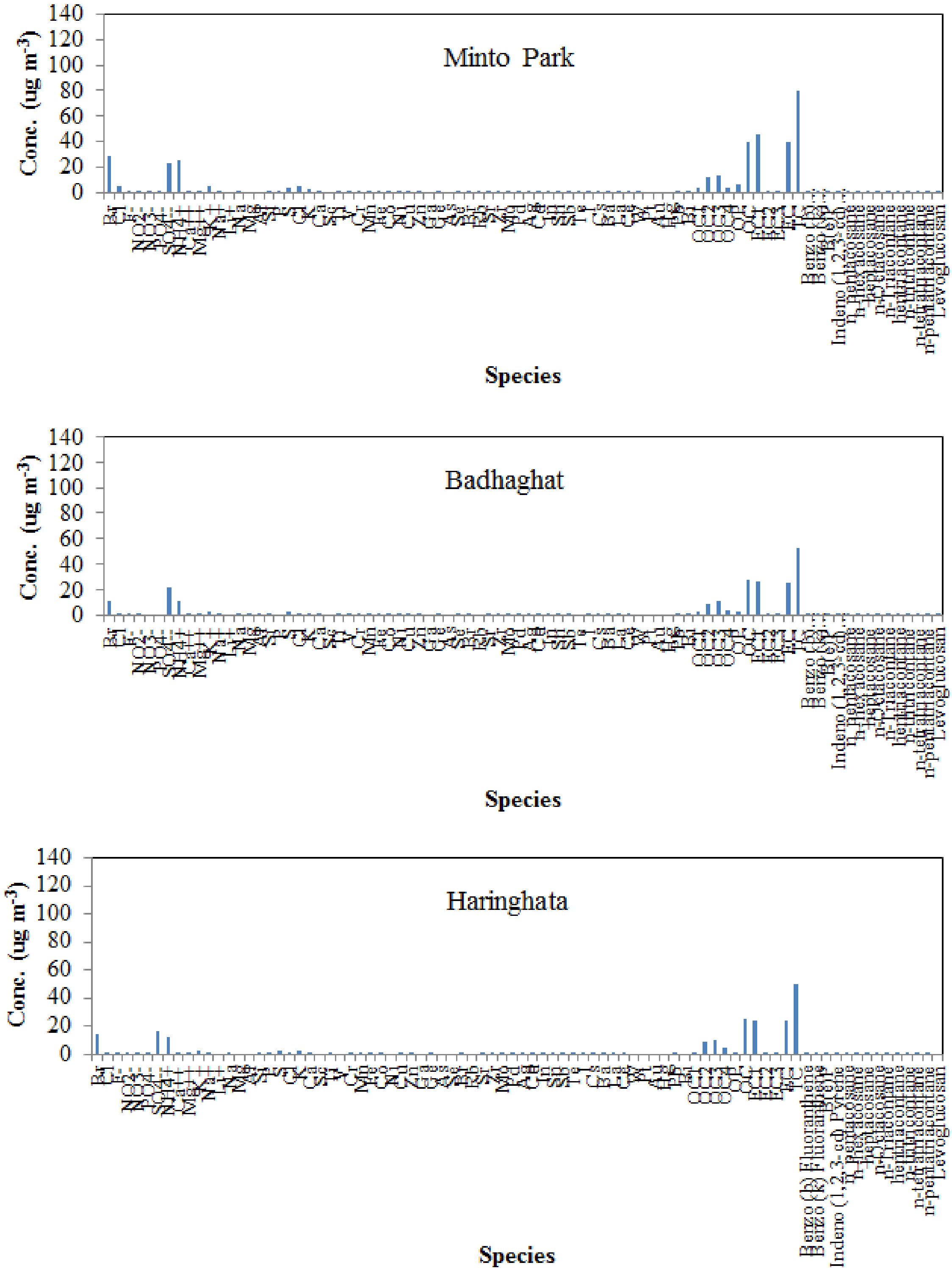


Fig. 4.7b: Chemical Composition of $PM_{2.5}$: Winter

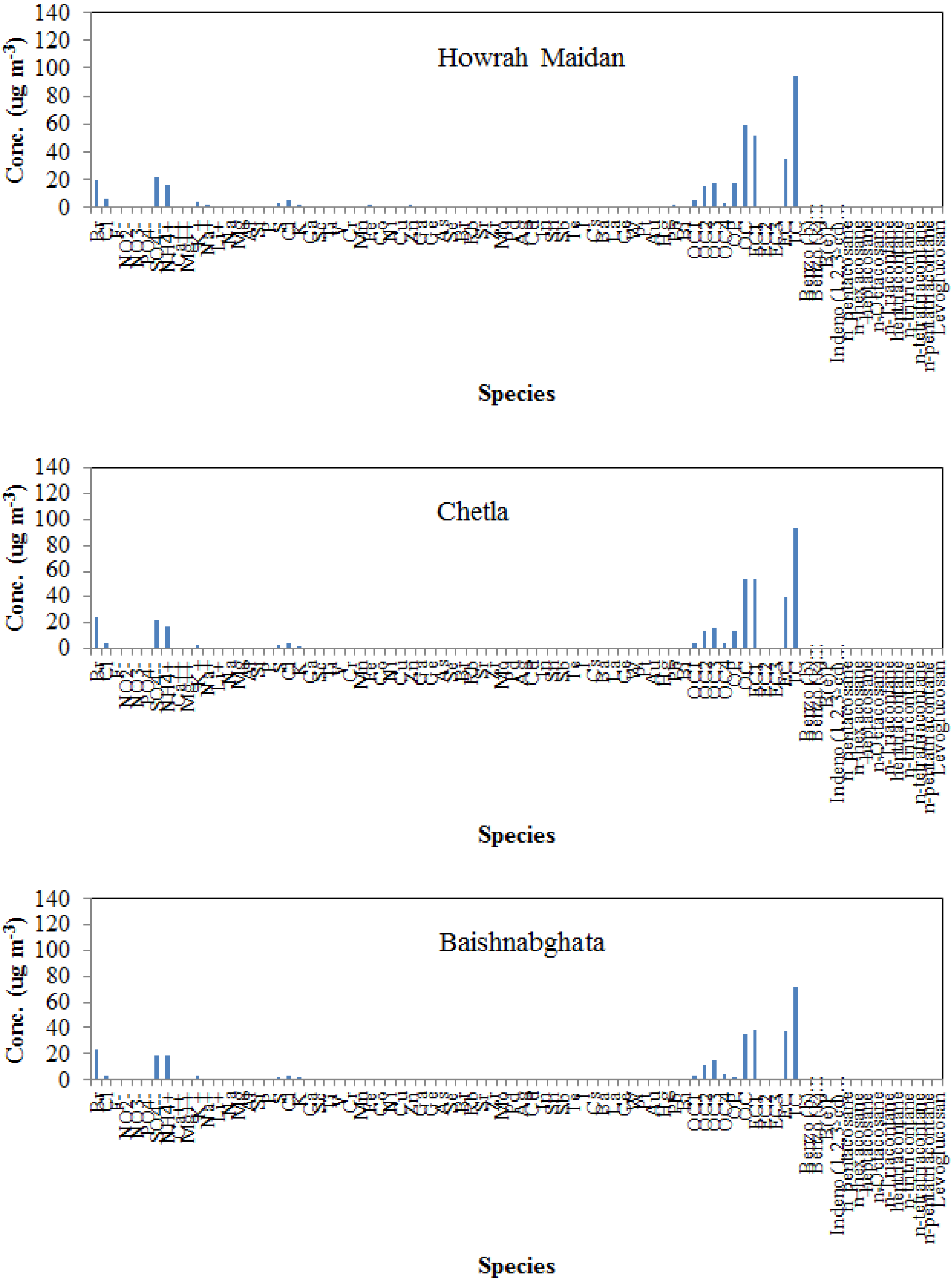


Fig. 4.7b: Chemical Composition of $PM_{2.5}$: Winter

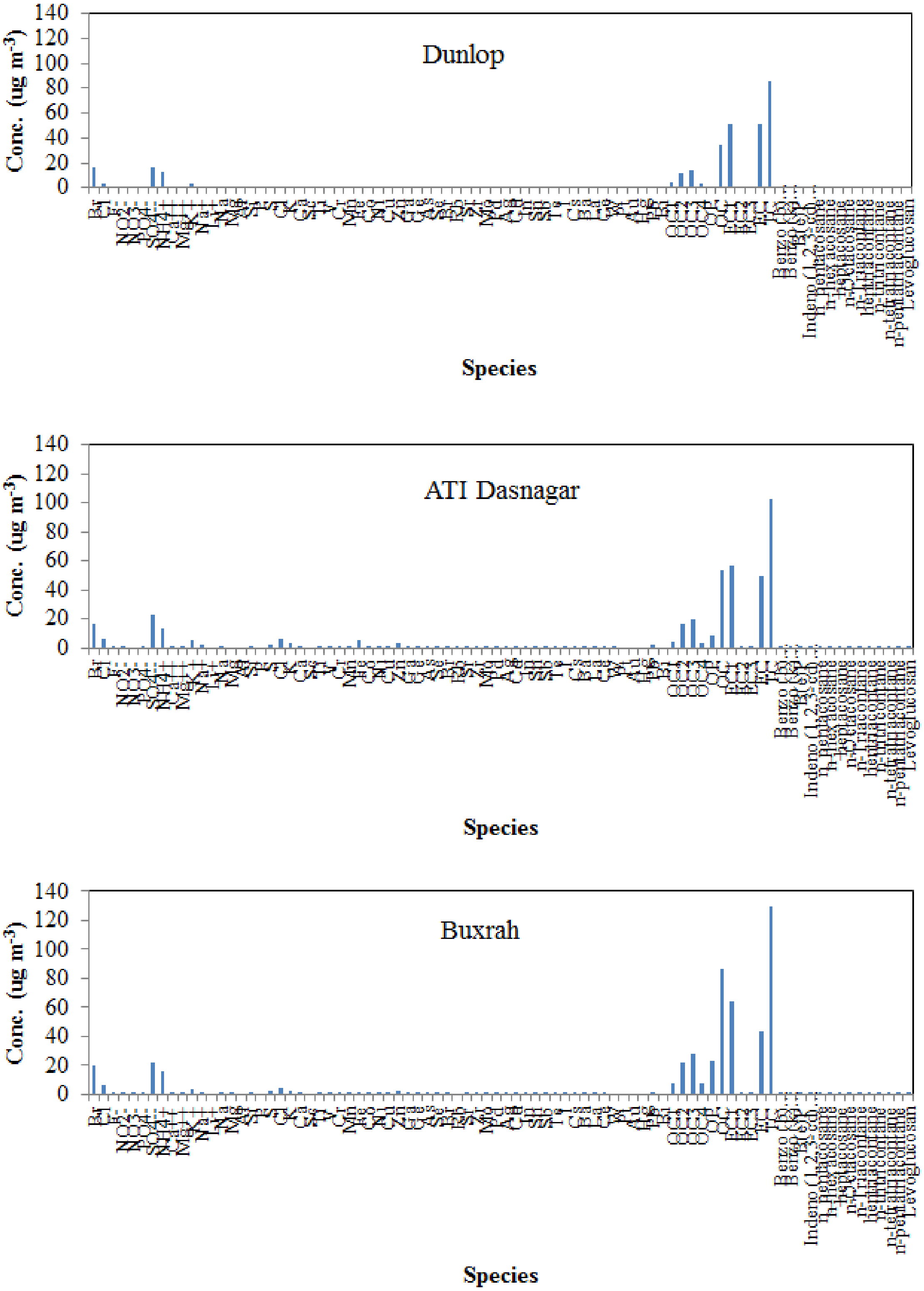


Fig. 4.7b: Chemical Composition of $PM_{2.5}$: Winter

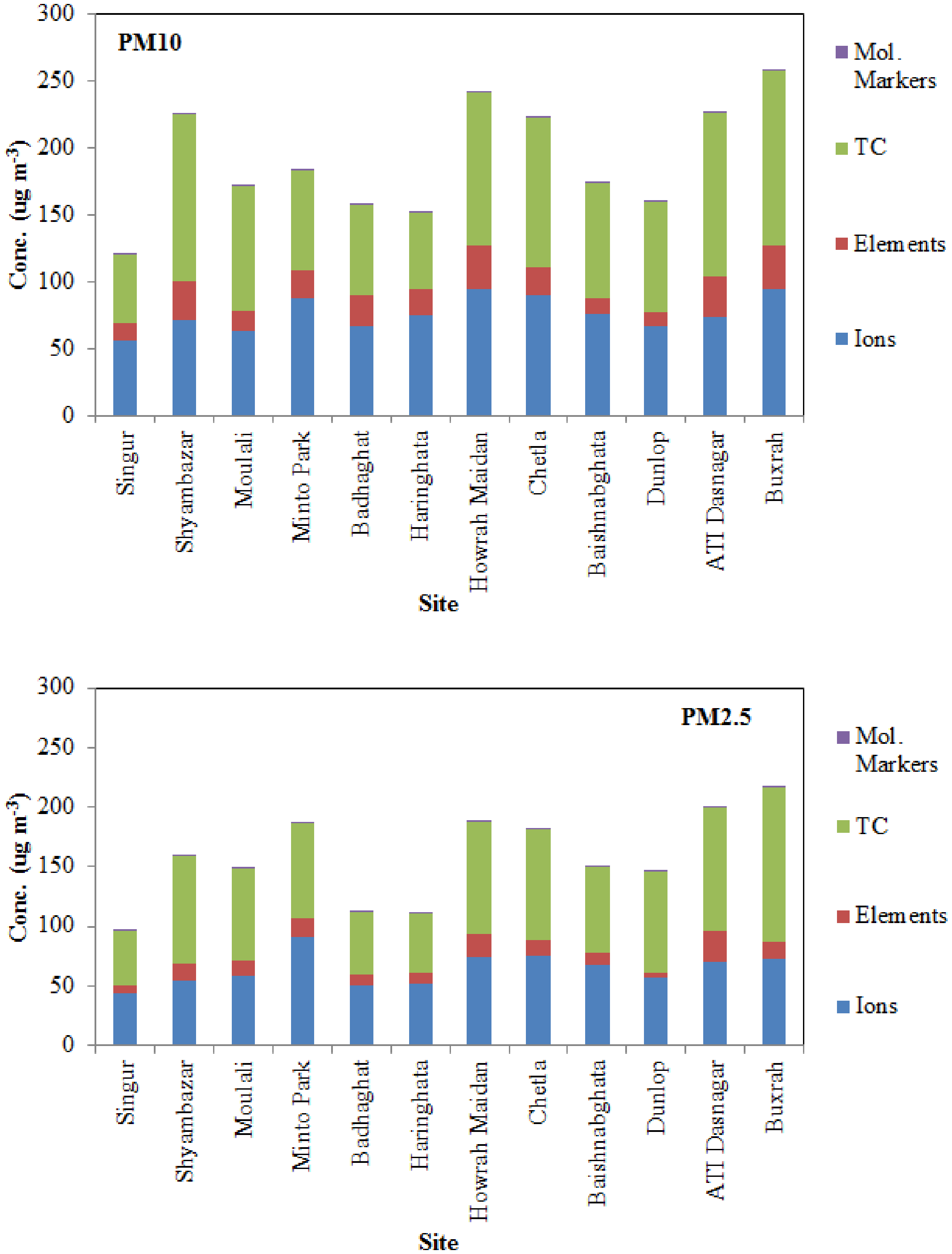


Fig. 4.8: Carbon, Ions and Elements in PM : Winter

Ions had the highest share in ambient particulate matter followed by total carbon (EC+OC) and elements (**Fig. 4.8**). Amongst ions, highest share (w/w) was taken by $SO_4^{=}$ and Br followed by NH_4^+ in both $PM_{2.5}$ and PM_{10}. Amongst elements, S, Cl, Zn and Pb along with crustal elements Ca, Si, K and Fe were observed to be higher in PM_{10}, whereas in $PM_{2.5}$, S, Cl, Zn and Pb along with crustal elements K and Fe were dominant.

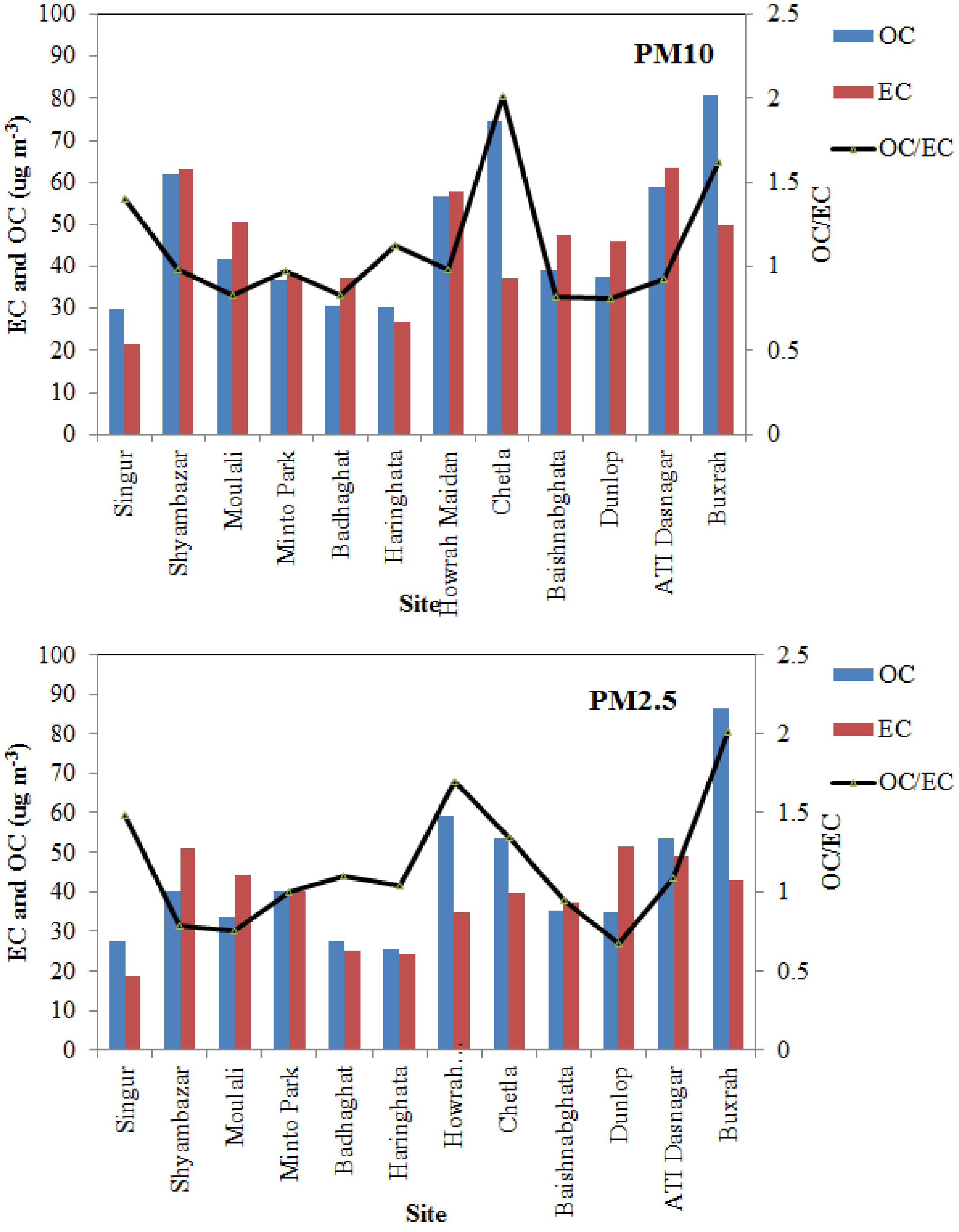


Fig. 4.9a: EC and OC Concentration in $PM_{2.5}$ and PM_{10}: Winter

Average EC and OC concentrations, along with the OC/EC ratio, are presented in **Fig. 4.9a**. It is observed that OC concentration was higher than EC at very few sites for both $PM_{2.5}$ and

PM_{10} suggesting the presence of both organic and inorganic carbon in ambient particulate matter.

OC/EC ratio was compared for winter and summer to determine the nature of carbonaceous content in PM_{10} and $PM_{2.5}$ in both the seasons. It can be seen from **Fig. 4.9b** that OC/EC ratio for $PM_{2.5}$ and PM_{10} is higher in summer except at Chetla for PM_{10} and at Minto Park for $PM_{2.5}$ indicating that organic carbon is more dominant in summer than in winter.

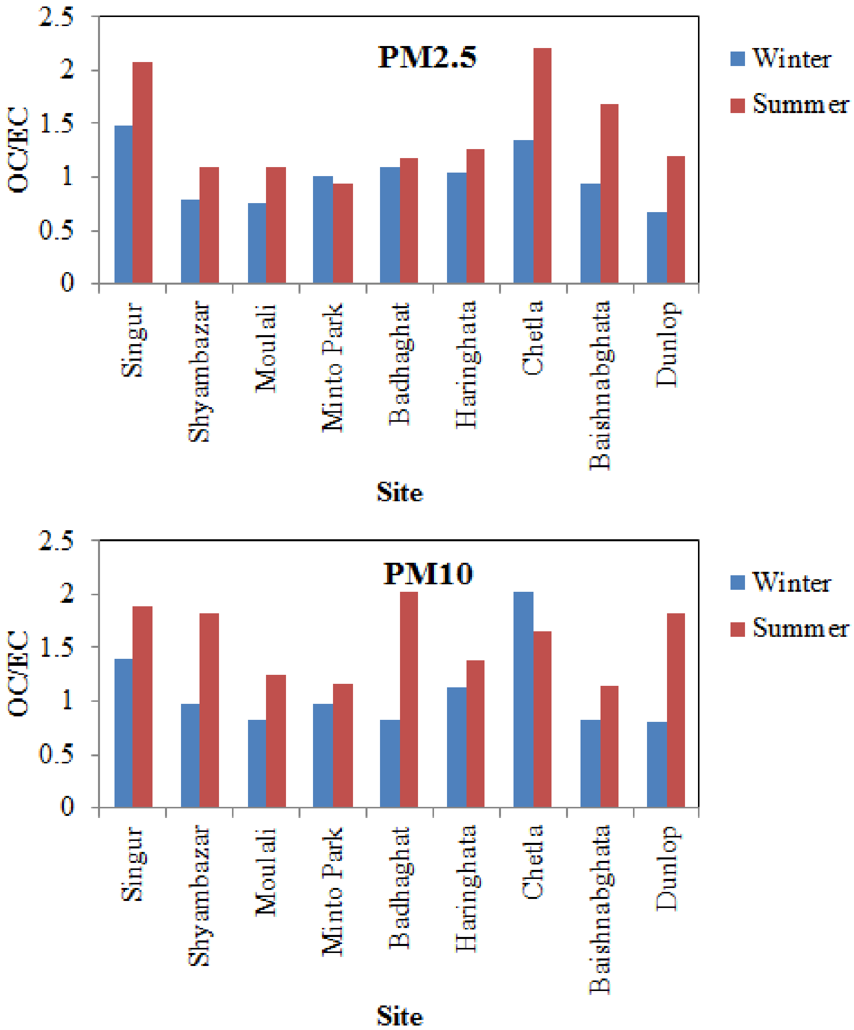


Fig. 4.9b: Comparison of OC/EC in $PM_{2.5}$ and PM_{10} in Winter and Summer

4.4b Molecular Markers in PM_{10} and $PM_{2.5}$: Winter

The average concentrations of molecular markers incl. PAHs are plotted in **Fig. 4.10a-b**. The analyzed compounds were: Octadecanamide, n_pentacosane, n_hexacosane, heptacosane, n-Octacosane, n-Triacontane, hentriacontane, n-tritricontane, n-tetratriacontane, n-pentatriacontane, levoglucosan while analyzed PAHs were Benzo (b) Fluoranthene (B(b)F), Benzo (k) Fluoranthene (B(k)F), Benzo (e) Pyrene (B(e)P) and Indeno (1,2,3-cd) Pyrene.

In $PM_{2.5}$, the major share (w/w) was taken by n-hexacosane at all the sites except at Badhaghat, Singur, Baishnabghata, ATI Dasnagar and Haringhata where the maximum share was taken by n-pentacosane. Other markers significantly present in $PM_{2.5}$ were n-Octacosane and n-triacontane. Among PAHs, B(a)P, B(b)F and B(e)P were significant at all the sites in $PM_{2.5}$ and PM_{10}. n-pentacosane and n-hexacosane along with n-Octacosane, heptacosane and n-triacontane were also significantly present in PM_{10}.

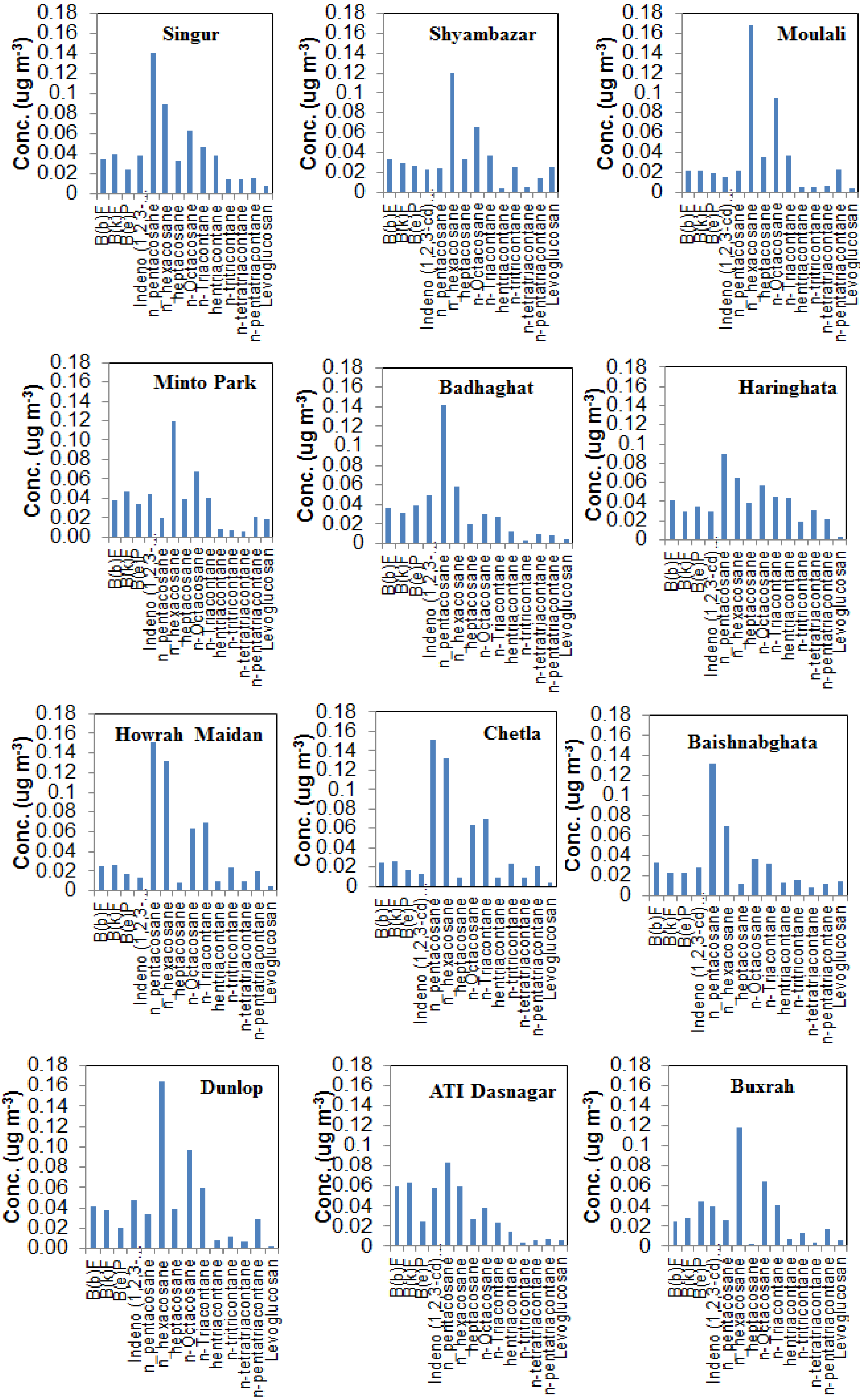


Fig. 4.10a: Molecular Markers in PM_{10} : Winter

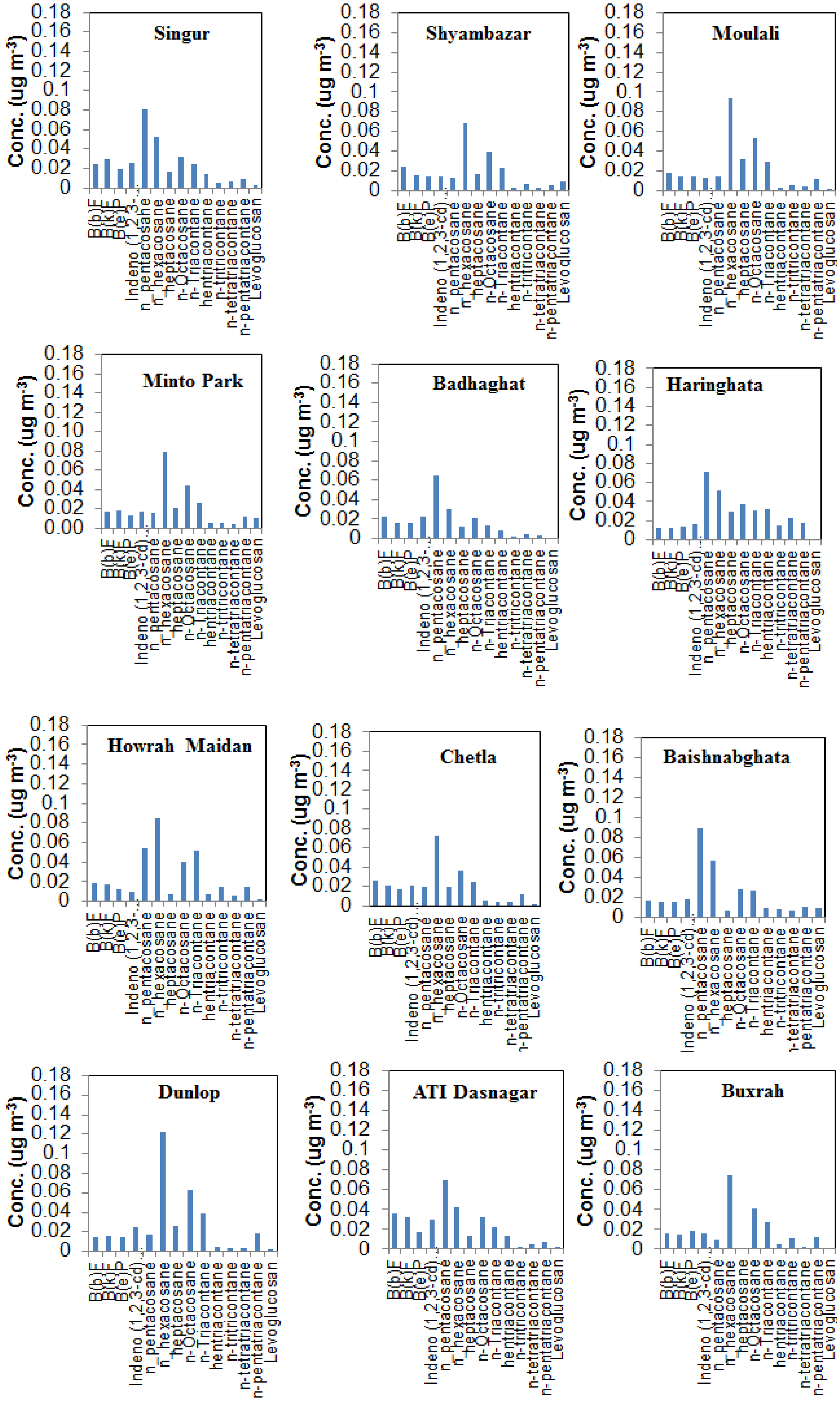


Fig. 4.10b: Molecular Markers in $PM_{2.5}$: Winter

4.4c Comparison of Chemical Composition of $PM_{2.5}$ and PM_{10}: Winter

In order to understand the dominance of particulate size fractions ($PM_{2.5}$ and PM_{10}) in the partitioning of analysed chemical species, ratio of analysed species in $PM_{2.5}$ and PM_{10} were obtained and then averaged over all sites and presented. **Fig. 4.11** presents ratio of chemical species as present in $PM_{2.5}/PM_{10}$. Major ions and elements are more dominant in $PM_{2.5}$ fraction while OC is less dominant than EC in $PM_{2.5}$ fraction.

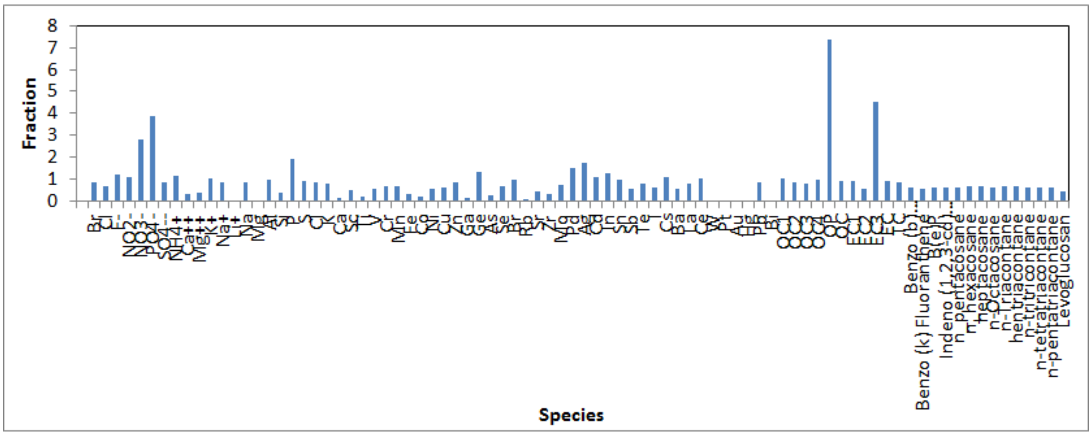


Fig. 4.11: Comparison of Chemical Composition in $PM_{2.5}$ and PM_{10}: Winter

4.4d Mass Closure: Winter

Mass closure was obtained by comparing the gravimetric mass with the chemical mass, i.e. sum of chemical components such as crustal or geological matter, non-crustal matter, secondary ions as; ammonium sulphate ($(NH_4)_2SO_4$), ammonium nitrate (NH_4NO_3); sea salt, organic and inorganic matter. **Fig. 4.12** shows the aerosol type contribution to all the sites.

For PM_{10}, the correlation between gravimetric mass and chemical mass was more than 0.9 at all the sites. It can be seen that unidentified mass contribution is highest at Haringhata, Howrah Maidan, Badhaghat, Minto Park, Dunlop, Shyam Bazar and Singur for PM_{10} and at Minto Park, Dunlop, Moulali, Baishnabghata and ATI Dasnagar for $PM_{2.5}$. Of the identified mass, organic matter contribution is highest i.e. 12-33% followed by EC and ammonium sulphate. Geological matter and sea-salt contribution is ~1-8%. Secondary organic carbon (SOC) was also estimated, which showed its contribution to OC as ~24%.

For $PM_{2.5}$, the unidentified mass is quite low as compared to PM_{10}. The contribution of the components such as organic matter, elemental carbon and ammonium sulphate is high followed by sea-salt and geological matter. Non-crustal matter contribution ranges from 1-5%. Contribution of SOC to OC is observed to be ~40%.

In summary, it is observed that OM and EC contribution is more than $(NH_4)_2SO_4$ suggesting both organic and inorganic nature of coarse and fine particulates. Organic matter (OM) contribution is generally attributed to wood, biomass burning and vehicles.

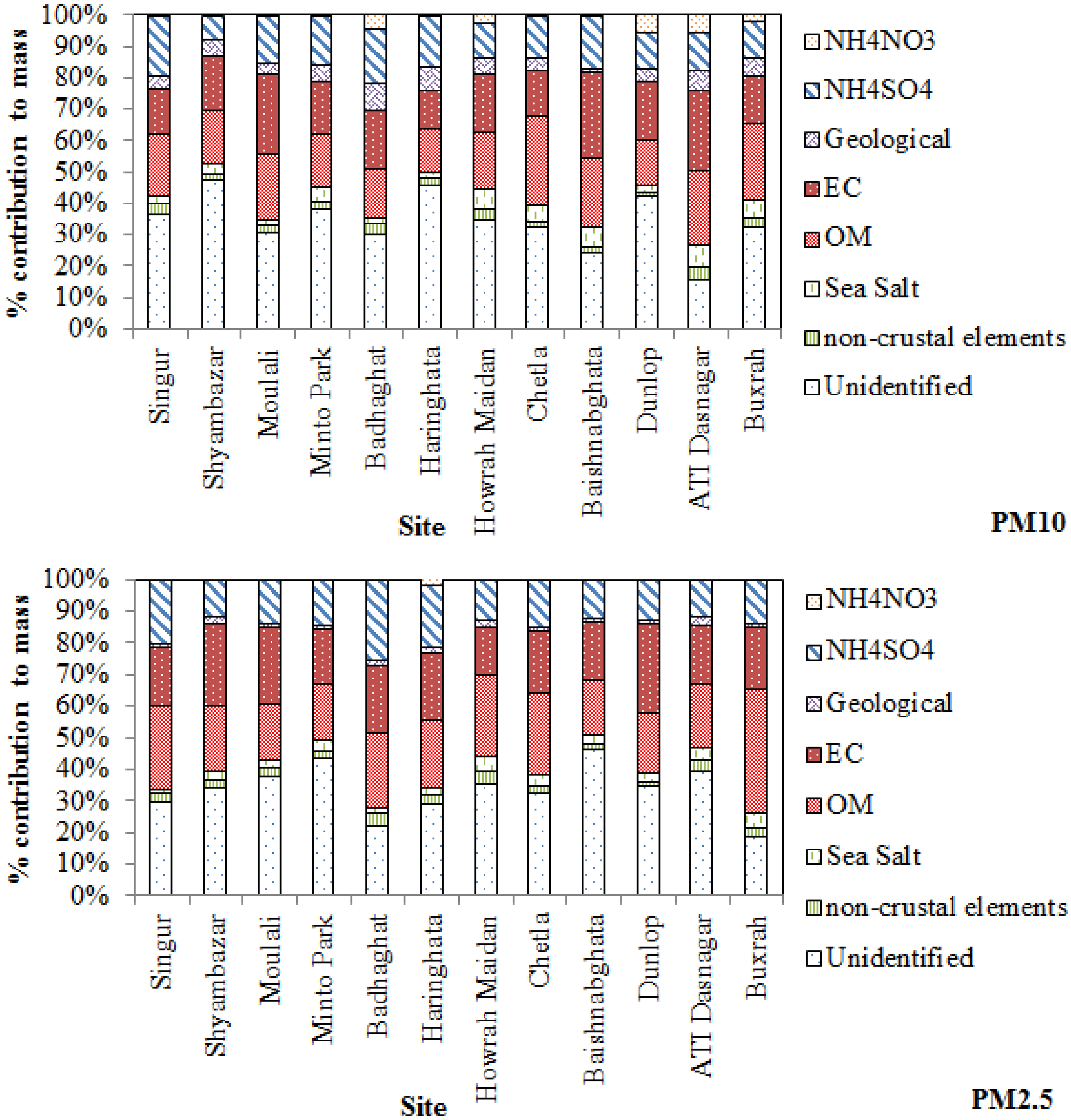


Fig. 4.12: Mass Closure of PM_{10} and $PM_{2.5}$ at Different Locations: Winter

4.5 Emission Source Profiles

To carry out CMB modeling at all the selected air quality monitoring locations, most dominant sources observed during reconnaissance and emission inventory survey viz. wood, coal and kerosene combustion in domestic and commercial (restaurant and hotels) sectors, road dust, vehicles, construction and open burning were considered based on the preliminary surveys in the city, prior knowledge of the city's common practices and also from scientific and general literature on the city. It must be noted that the model can only recognize chemical signatures available from particulate deposits on filters and hence could only be used to identify chemically distinct sources (or activity or fuel) that generates such signature. For example, the model can identify coal, wood and kerosene combustion (activities) as sources but not the place (e.g. ironing vendor, restaurant, household, industry etc.) where such combustion activity was undertaken. The source profiles of each source were borrowed from the source profile database of Central Pollution Control Board which is based on the results of extensive studies conducted by IIT-Mumbai (Sethi and Patil, 2008) and ARAI, Pune (CPCB, 2009). The composite of all the source profiles is given in **Fig. 4.13a-b**. Some source profiles are similar for both $PM_{2.5}$ and PM_{10} and therefore were not plotted separately.

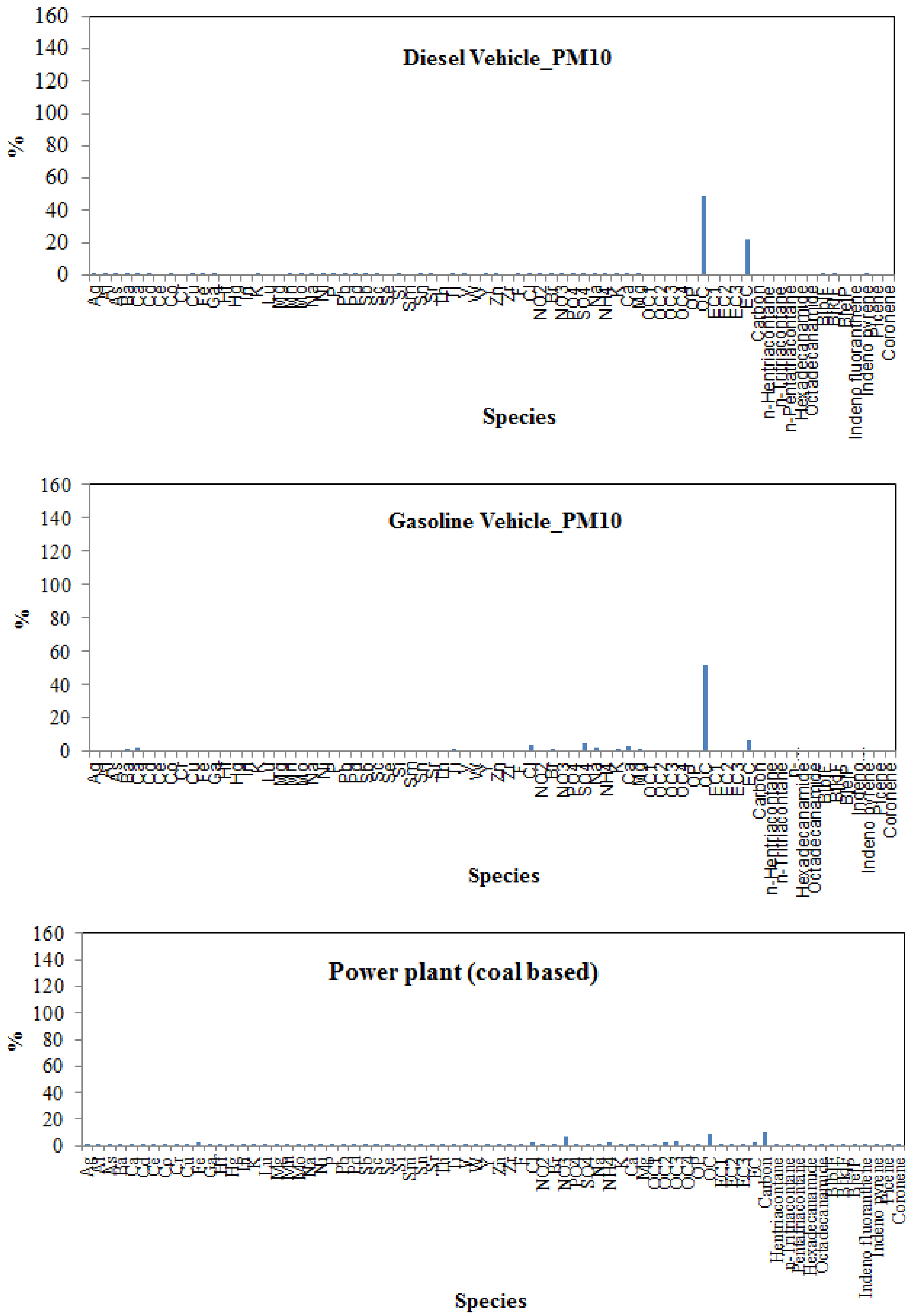


Fig. 4.13a: Source Profiles of Various Sources for PM_{10}

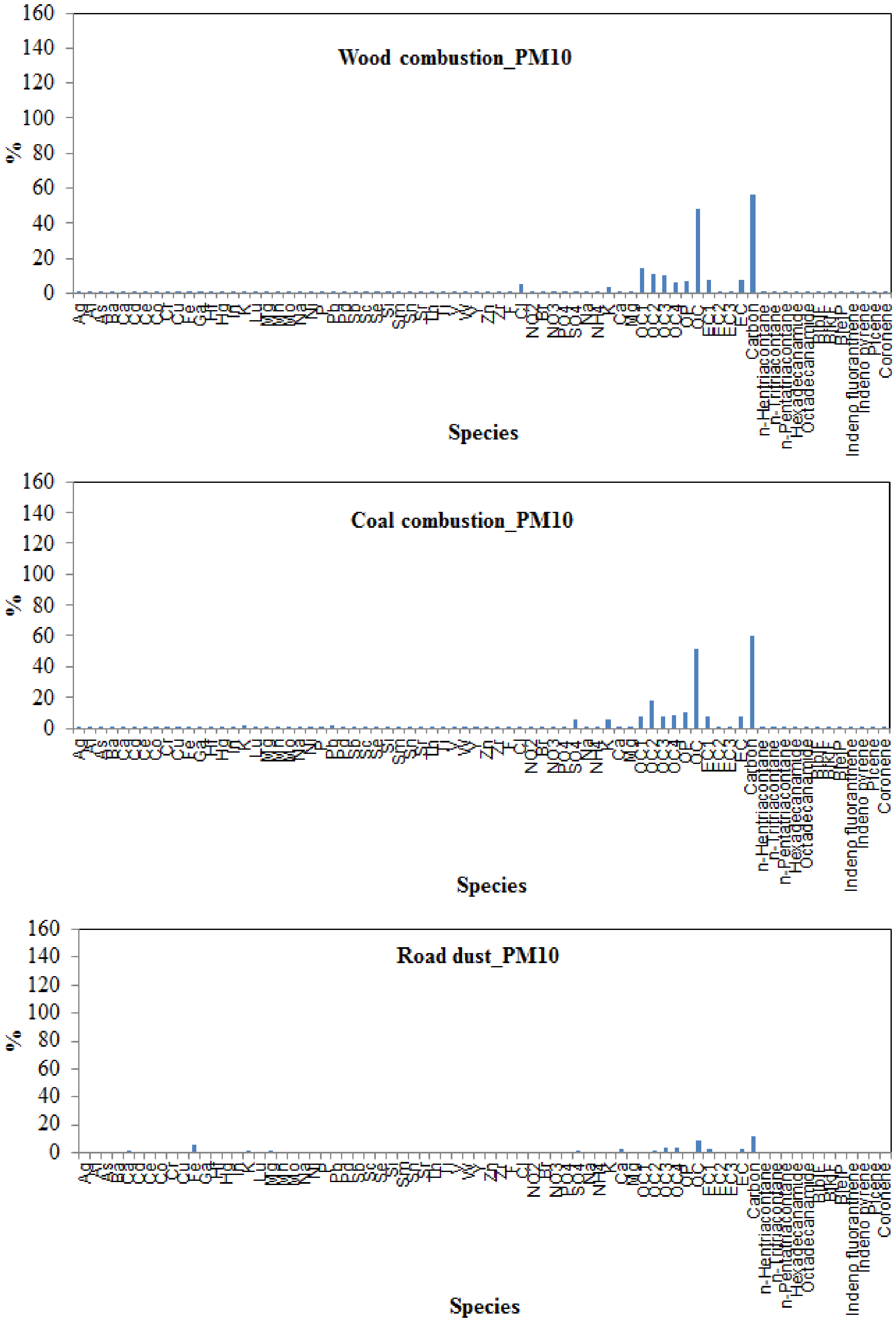


Fig. 4.13a: Source Profiles of Various Sources for PM_{10}

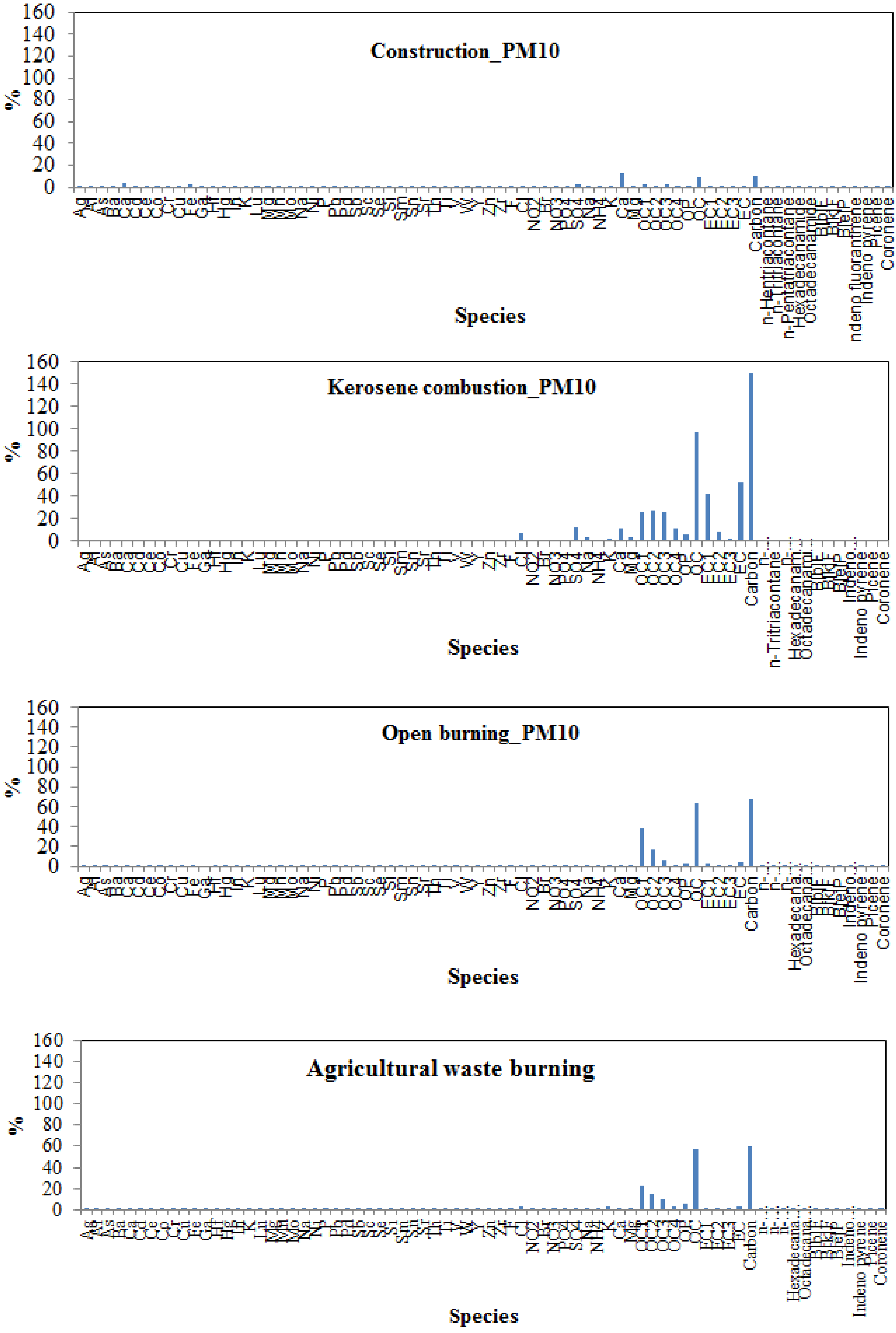


Fig. 4.13a: Source Profiles of Various Sources for PM_{10}

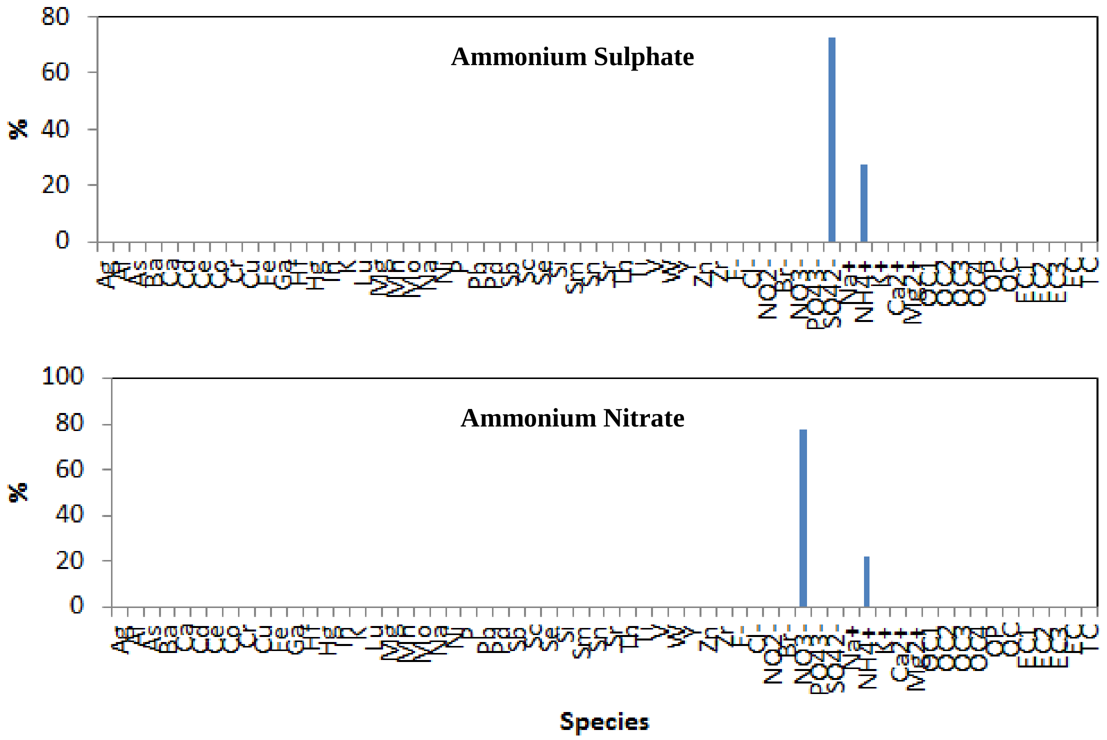


Fig. 4.13a. Source Profiles of Various Sources

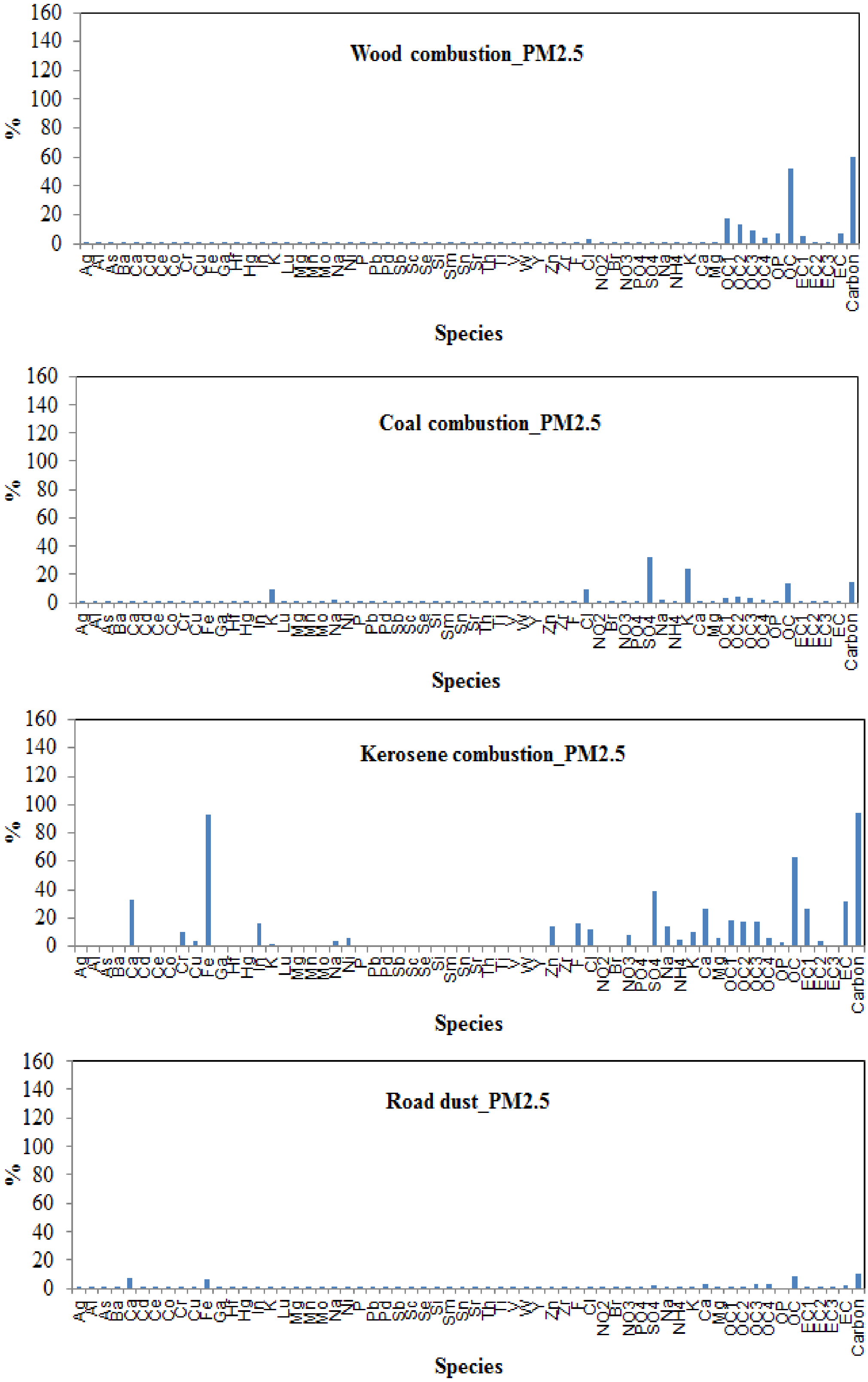


Fig. 4.13b: Source Profiles of Various Sources for $PM_{2.5}$

4.6 Application of CMB to Apportion PM_{10} & $PM_{2.5}$: Summer

With all the above source profiles, CMB modeling exercise was performed on $PM_{2.5}$ and PM_{10} at different sites in Kolkata and Howrah. For $PM_{2.5}$, sources profiles of vehicles and open burning were not available separately; hence source profiles of PM_{10} were considered. Utmost care was taken in accepting the results based only on the model acceptance criteria. Some samples, however did not converge (or satisfy the model's performance criteria) and therefore were not included in the analysis. **Table 4.1** presents the % of number of samples converging to the model performance criteria at each site. The results of CMB runs at each site are shown in **Fig. 4.14.** The statistical summary of model performance at each site is given in **Table 4.2**.

Table 4.1: Percentage Convergence of CMB

Sites	**PM_{10}**	**$PM_{2.5}$**
Singur	75	100
Shyam Bazar	100	100
Moulali	86	75
Minto Park	75	75
Badhaghat	89	90
Haringhata	100	83
Chetla	78	69
Baishnabghata	83	88
Dunlop	100	100

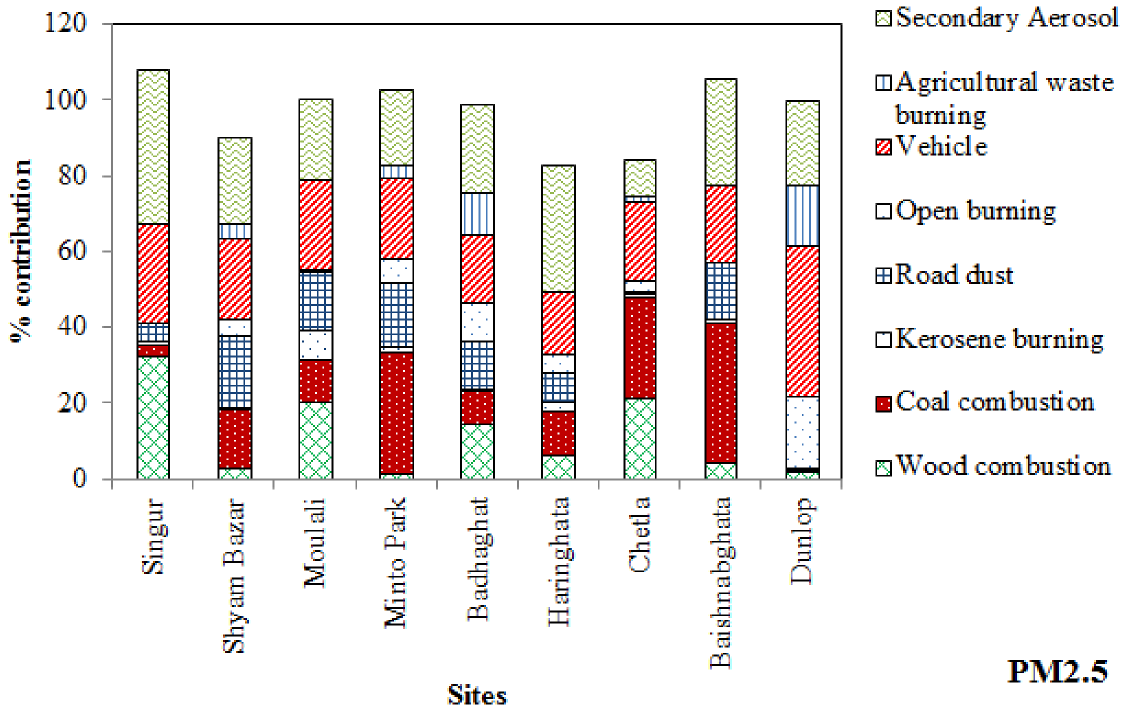
Further, combined results are obtained over all the samples for Kolkata (7 sites, incl. control) and Howrah (2 sites, including control) and plotted in **Fig. 4.15a and 4.15b** for $PM_{2.5}$ and PM_{10}, respectively. It can be observed that contribution of coal combustion and vehicles to $PM_{2.5}$ is same in Kolkata, whereas in Howrah, secondary aerosol contribution is highest followed by vehicular contribution and wood combustion. In Kolkata, the third most contributing source to $PM_{2.5}$ is secondary aerosol. Notably, $PM_{2.5}$ source apportionment is mostly dominated by combustion related sources as combustion generates fine particulates.

Road dust contribution to $PM_{2.5}$ is 10% in both Kolkata and Howrah. PM_{10} is mostly contributed by vehicles, road dust and secondary aerosol with moderate contribution from construction and minor contribution from wood, coal and kerosene combustion activities in Kolkata. In Howrah, PM_{10} is contributed by vehicles, secondary aerosols and wood combustion. Moderate contribution to PM_{10} from road dust and coal combustion is also observed in Howrah. The uncertainty of the estimated sources is given in **Table 4.3a&b**. The contribution of various sources is summarized in **Table 4.4a**. The combustion source mainly included wood, coal and kerosene combustion contributed by domestic heating and cooking activities, commercial cooking and heating by restaurants and eateries/joints. Vehicles included all types of gasoline and diesel powered vehicles. Based on the above analysis, biomass combustion and fossil fuel burning contributions were grouped and given in **Fig. 4.16** for all the sites. In **Table 4.4b**, overall contribution for Kolkata and Howrah is presented.

Table 4.2: Model Performance of CMB: Summer

Site	**$PM_{2.5}$**				**PM_{10}**			
	R^2	**Chi^2**	**%mass**	**DoF**	**R^2**	**Chi^2**	**%mass**	**DoF**
Singur	0.99	3.5	111.7	6	0.98	2.6	112.3	6
Shyam Bazar	0.98	3.2	76.9	6	0.98	2.7	94.9	7
Moulali	0.96	3.9	101.8	7	0.95	3.6	76.2	8
Minto Park	0.99	3.1	98.7	6	0.97	3.2	91.3	8
Badhaghat	0.99	3.7	99.8	6	0.96	3.7	87.2	9
Haringhata	0.98	3.8	86.6	6	0.97	2.8	98.1	6
Chetla	0.99	3.7	87.1	6	0.97	2.6	90.7	7
Baishnabghata	0.98	3.6	104.7	6	0.97	3.1	98.8	7
Dunlop	0.98	3.6	99.9	6	0.97	2.9	93.6	8

% mass denotes % mass explained, DoF denotes degrees of freedom



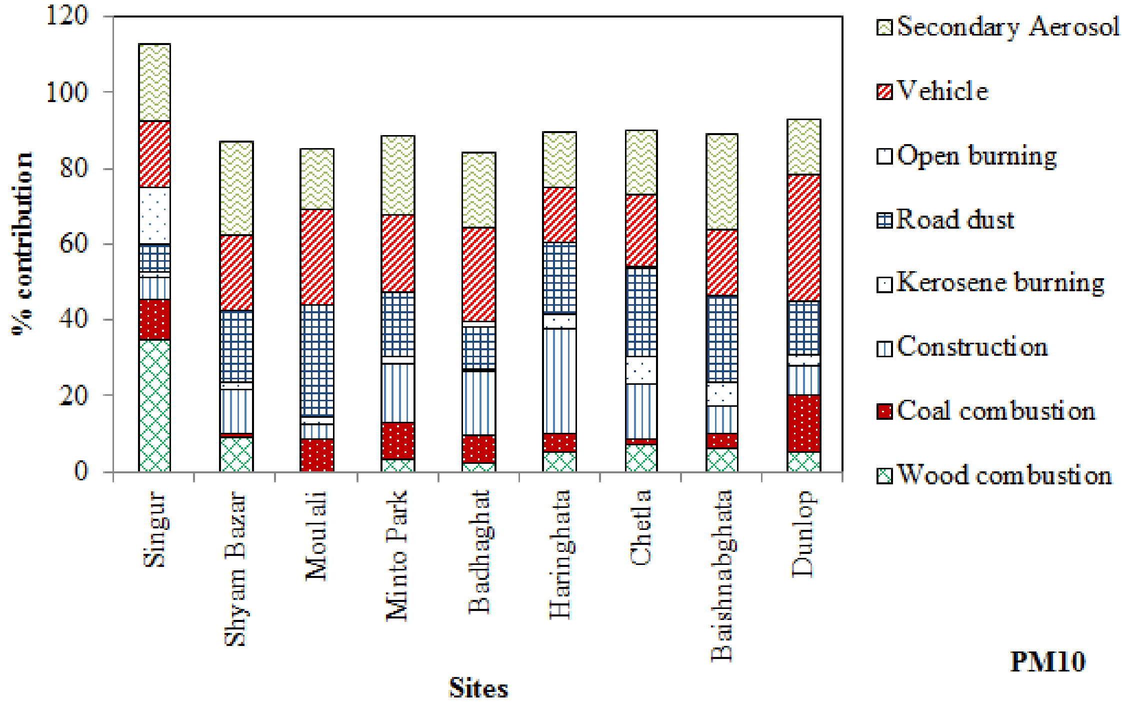
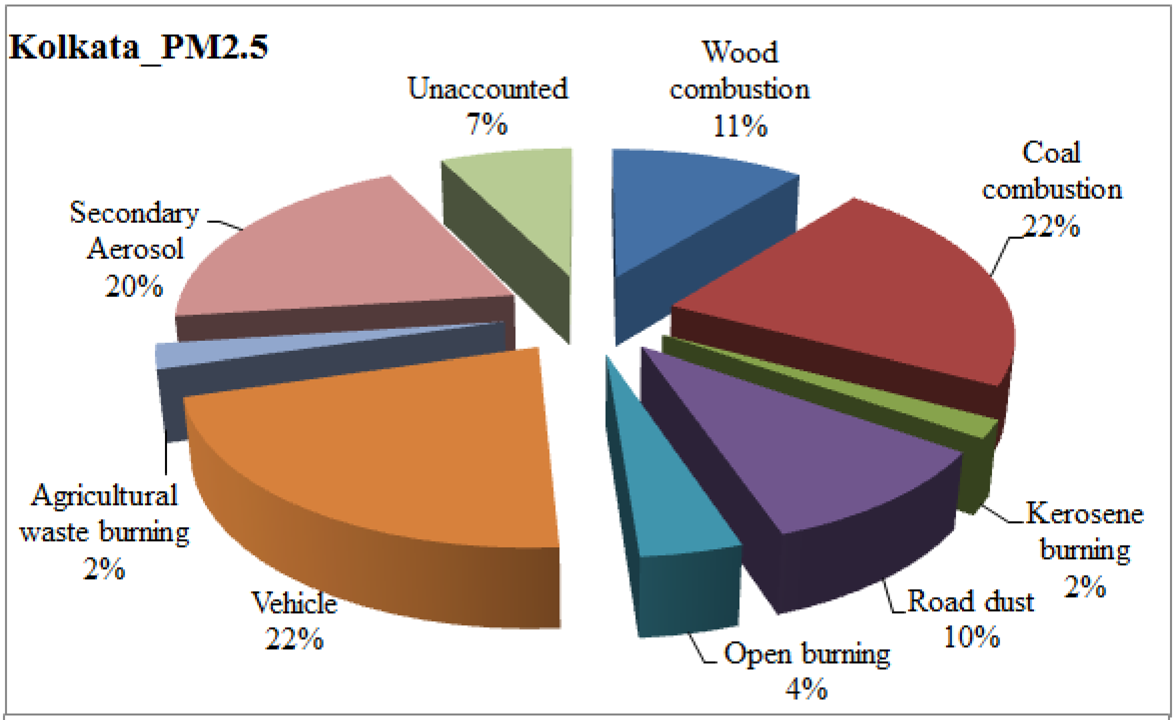


Fig. 4.14: Contribution (%) of Various Sources to $PM_{2.5}$ and PM_{10} at all the Sampling sites: Summer



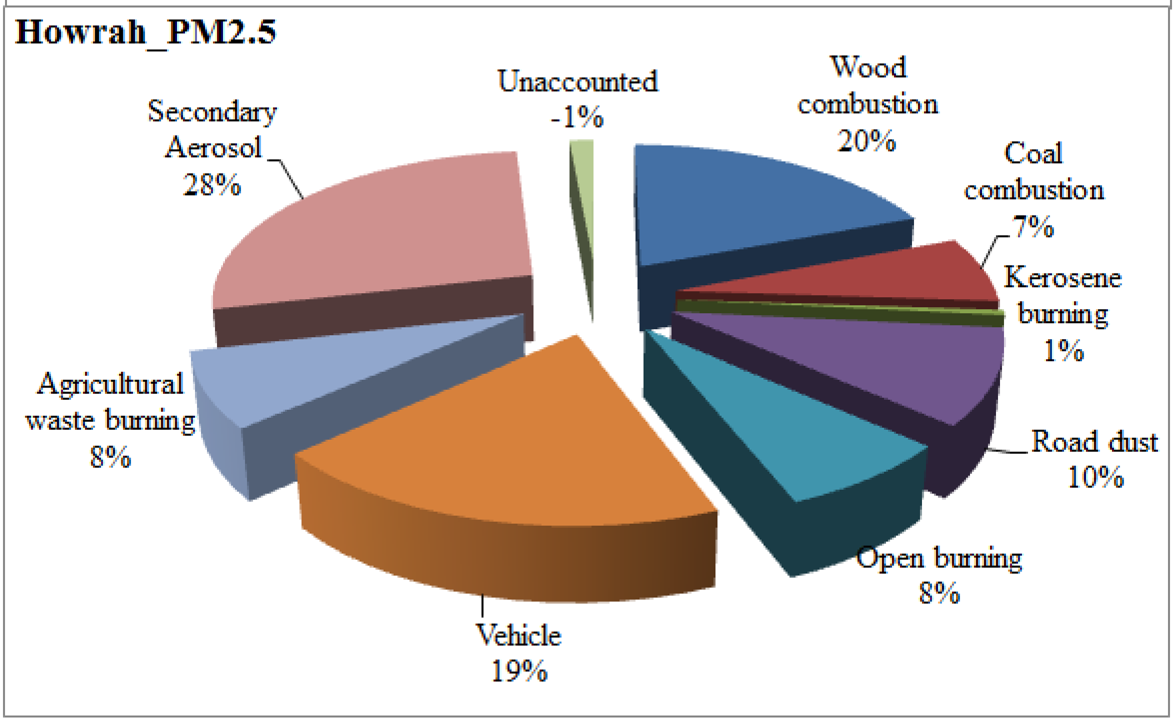


Fig. 4.15a: Overall % Contribution of Various Sources to $PM_{2.5}$ in Kolkata and Howrah: Summer

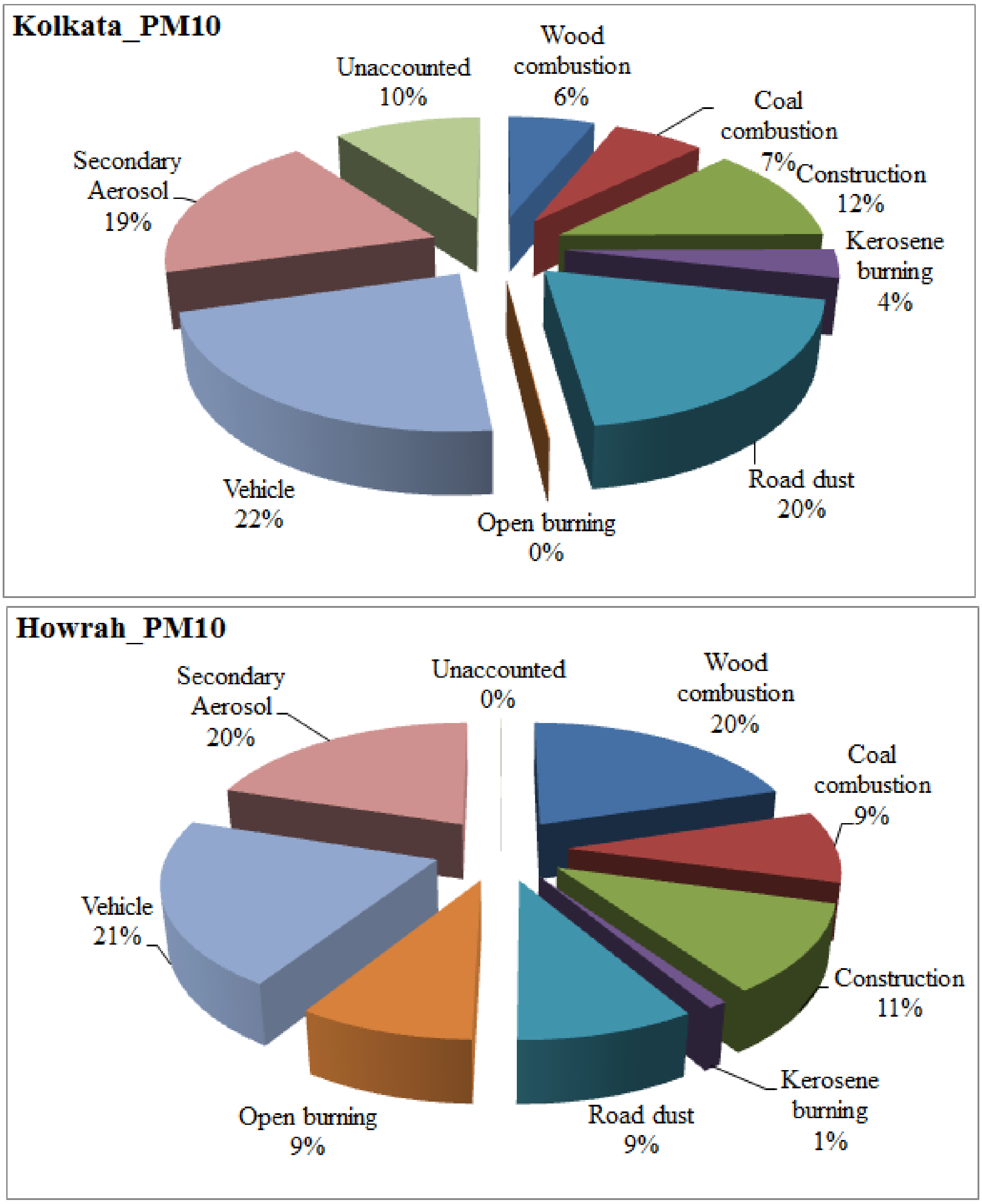


Fig. 4.15b: Overall % Contribution of Various Sources to PM_{10} in Kolkata and Howrah: Summer

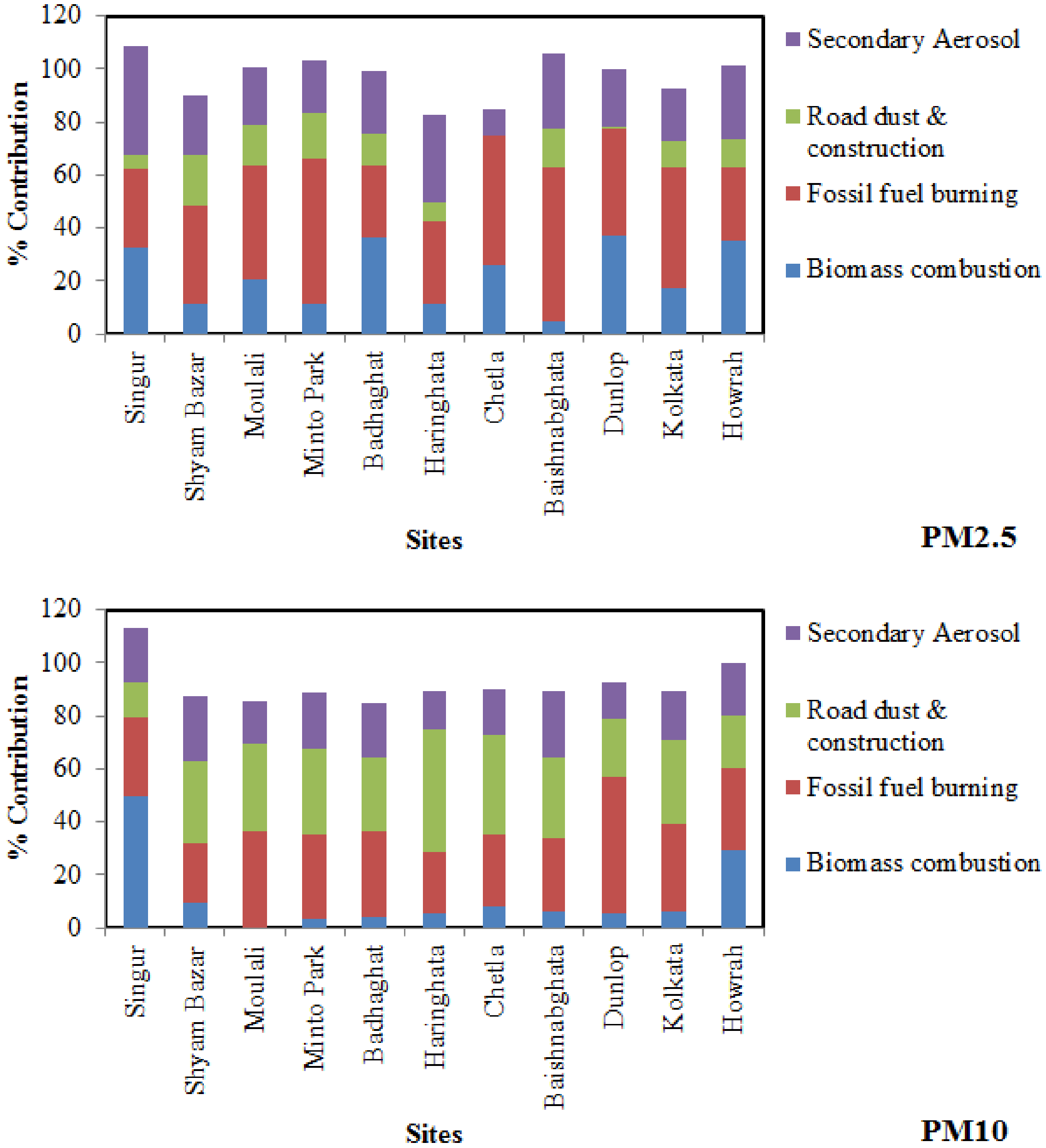


Fig. 4.16: Overall % Contribution Grouped as Biomass Combustion, Fossil Fuel Burning and Road Dust

Table 4.3a: Uncertainty in Source Contribution Estimates by CMB for $PM_{2.5}$: Summer

Sites	Wood combustion	Coal combustion	KC	Road dust	Vehicle	Open burning	AW burning	Sec. aerosol
Singur	14.4	3.5	1.0	7.9	14.4	1.0	-	2.7
Shyam Bazar	5.4	19.7	1.0	17.3	20.0	11.5	10.5	17.8
Moulali	13.5	15.8	15.3	18.7	14.9	1.0	-	14.4
Minto Park	2.7	13.7	1.7	15.8	13.4	9.7	8.7	14.1
Badhaghat	12.4	12.8	1.0	18.3	12.4	19.1	13.8	6.6
Haringhata	14.1	11.2	5.7	4.8	19.0	11.7	-	12.6
Chetla	17.1	15.6	2.1	1.0	13.7	9.2	4.45	12.9
Baishnabghata	7.8	11.2	1.4	13.3	19.7	-	-	19.6
Dunlop	3.1	1.0	1.0	1.0	9.1	27.1	12.6	17.0

KC-kerosene combustion, AW burning-agricultural waste burning, sec. aerosol-secondary aerosol formation

Table 4.3b: Uncertainty in Source Contribution Estimates by CMB for PM_{10}: Summer

Sites	Wood combustion	Coal combustion	Const.	KC	Road dust	Vehicle	Open burning	Sec. aerosol
Singur	11.6	16.9	4.9	12.8	16.7	13.8	18.8	13.9
Shyam Bazar	6.8	0.9	7.1	2.8	9.4	16.1	0.0	5.4
Moulali	0.0	6.0	7.1	4.2	19.7	16.1	0.0	11.1
Minto Park	6.5	9.4	7.8	2.7	19.8	19.8	0.0	10.9
Badhaghat	5.4	6.0	8.4	0.8	10.0	14.7	1.7	10.9
Haringhata	8.7	7.0	18.3	2.4	15.2	14.5	0.0	4.2
Chetla	16.5	3.2	18.2	7.0	17.7	18.7	1.3	8.7
Baishnabghata	9.7	3.4	10.8	8.9	13.7	18.5	0.0	11.8
Dunlop	9.7	16.2	8.8	4.8	12.3	19.8	0.0	11.2

KC-kerosene combustion, Const-construction, AW burning-agricultural waste burning, sec. aerosol-secondary aerosol formation

Table 4.4a: Contribution (%) of Major Sources to Particular Matter in Kolkata and Howrah: Summer

Sources	**Kolkata**		**Howrah**	
	PM_{10}	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**
Combustion (domestic and commercial activities)	16.3	34.7	30.3	27.4
Road dust & construction	31.7	10.1	20.0	10.2
Vehicle	22.5	21.6	21.0	20.0
Open burning (including agricultural burning)	0.1	6.4	8.7	15.7
Secondary Aerosols	19	19.7	20.0	28.1
Unaccounted	10.4	7.5	0.0	-1.5

Table 4.4b: Contribution (%) of Biomass and Fossil Fuel Burning to Particulate Matter in Kolkata and Howrah: Summer

Source	**Kolkata**		**Howrah**	
	PM_{10}	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**
Biomass combustion	6.2	17.3	28.9	35.4
Fossil fuel burning	32.6	45.4	31.0	27.8
Road dust & construction	31.7	10.1	20.0	10.2
Secondary Aerosols	19.1	19.7	20.0	28.1
Unaccounted	10.4	7.5	0.0	-1.5

4.7 Application of CMB to Apportion PM_{10} & $PM_{2.5}$: Winter

CMB modeling exercise was performed on $PM_{2.5}$ and PM_{10} at different sites in Kolkata and Howrah. Almost similar source profiles were used as in summer. As seen in the chemical analysis of PM_{10} and $PM_{2.5}$ in summer, more than 15% contribution of secondary aerosols was observed. Utmost care was taken in accepting the results based only on the model's acceptance criteria. Some samples, however did not converge (or satisfy the model's performance criteria) and therefore were not included in the analysis. **Table 4.5** presents the % of number of samples converging to the model performance criteria at each site. The results of CMB runs at each site are shown in **Fig. 4.17.** The statistical summary of model performance at each site is given in **Table 4.6**.

Table 4.5: Percentage Convergence of CMB and Average Concentrations at All Sites: Winter

Sites	**$PM_{2.5}$**	**PM_{10}**
Singur	77.8	70.0
Shyam bazar	90.9	86.7
Moulali	88.9	93.3
Minto Park	100.0	94.1
Bandhaghat	100	85.7
Haringhata	100.0	93.3
Howrah Maidan	100.0	75.6
Chetla	90.0	100.0
Baishnabghata	80.0	80.0
Dunlop	90.9	80.0
ATI Dasnagar	100.0	80.0
Buxrah	100.0	100.0

Table 4.6: Model Performance of CMB: Winter

Site	$PM_{2.5}$				PM_{10}			
	R^2	Chi^2	%mass	DoF	R^2	Chi^2	%mass	DoF
Singur	0.97	3.8	96.3	8	0.97	2.7	80.2	9
Shyam bazar	0.98	3.8	81.6	9	0.96	3.8	80.6	11
Moulali	0.98	3.9	80.0	8	0.97	3.7	82.5	9
Minto Park	0.98	3.8	84.2	8	0.97	2.3	93.9	10
Badhaghat	0.97	3.9	90.4	8	0.95	3.9	82.2	12
Haringhat	0.98	4.0	97.6	7	0.97	2.6	80.2	9
Howrah Maidan	0.96	4.0	94.2	8	0.96	3.9	87.5	12
Chetla	0.98	3.6	86.0	7	0.98	2.7	99.5	9
Baishnabghata	0.98	3.9	88.6	8	0.95	4.0	95.8	10
Dunlop	0.97	3.2	98.9	6	0.96	4.0	87.0	7
ATI Dasnagar	0.97	3.9	84.0	7	0.97	3.5	97.2	11
Buxrah	0.97	3.6	80.8	8	0.97	3.2	94.1	11

% mass denotes % mass explained, DoF denotes degrees of freedom

Further, combined results were obtained over all the samples for Kolkata (7 sites, incl. control) and Howrah (5 sites, incl. control) and plotted in **Fig. 4.18a and 4.18b** for $PM_{2.5}$ and PM_{10}, respectively. It can be observed that contribution of secondary aerosols to $PM_{2.5}$ is highest followed by vehicular activities in both Kolkata and Howrah except at Howrah Maidan, Dunlop and ATI Dasnagar, where vehicular activities are dominant. Wood and coal combustion are the largest contributor to $PM_{2.5}$ after secondary aerosols and vehicular activities. The uncertainty of the sources at various sites is given in **Table 4.7a &b**. The contribution of various sources is summarized in **Table 4.8a**. The combustion source mainly included wood, coal and kerosene combustion contributed by domestic heating and cooking activities, commercial cooking and heating by restaurants and eateries/joints. Vehicles included all types of gasoline and diesel powered vehicles. Based on the above analysis, biomass combustion and fossil fuel burning contributions were grouped and given in **Fig. 4.19** for all the sites. In **Table 4.8b**, overall contribution for Kolkata and Howrah is presented.

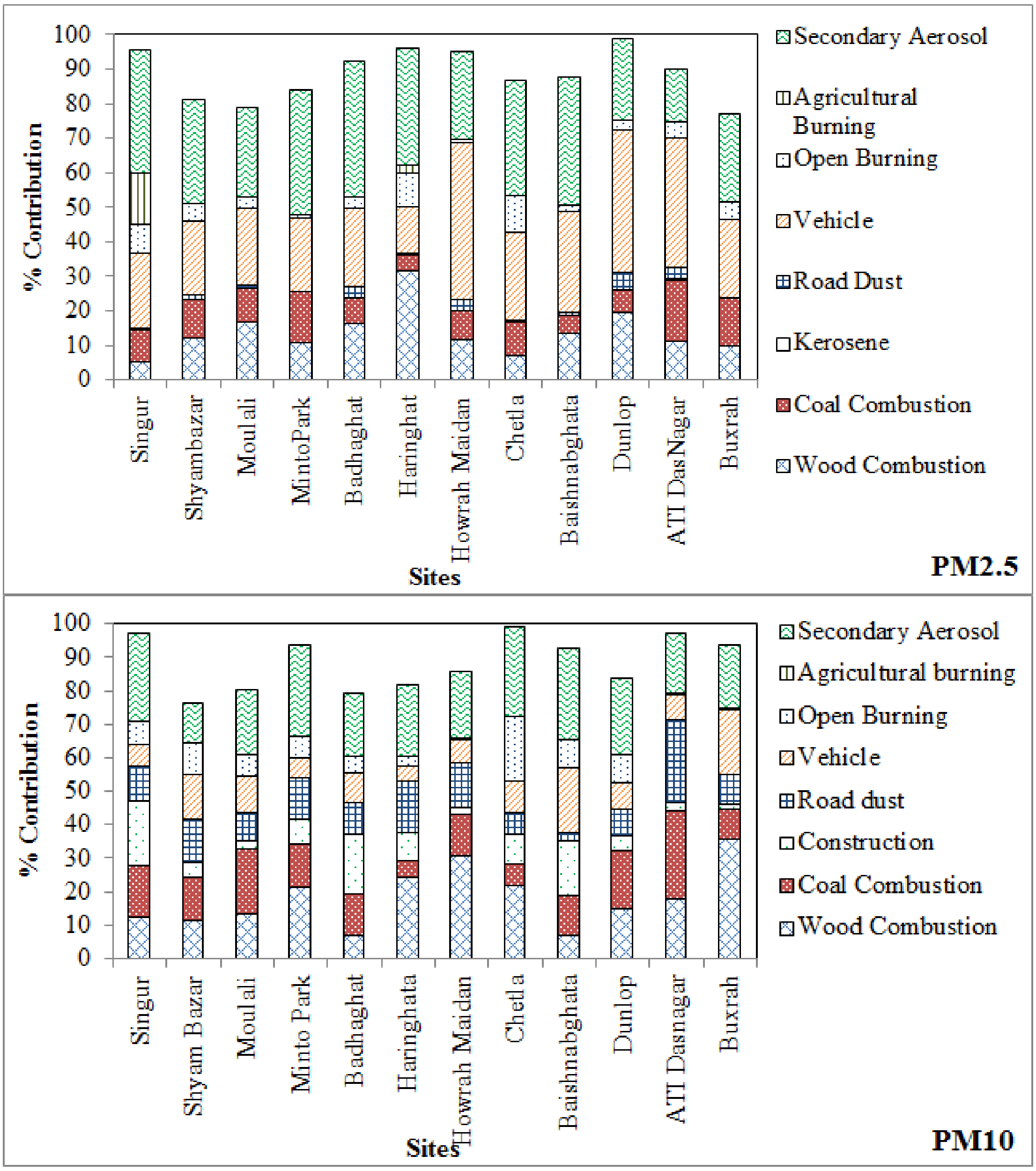


Fig. 4.17: Contribution (%) of Various Sources to $PM_{2.5}$ and PM_{10} at all the Sampling Sites: Winter

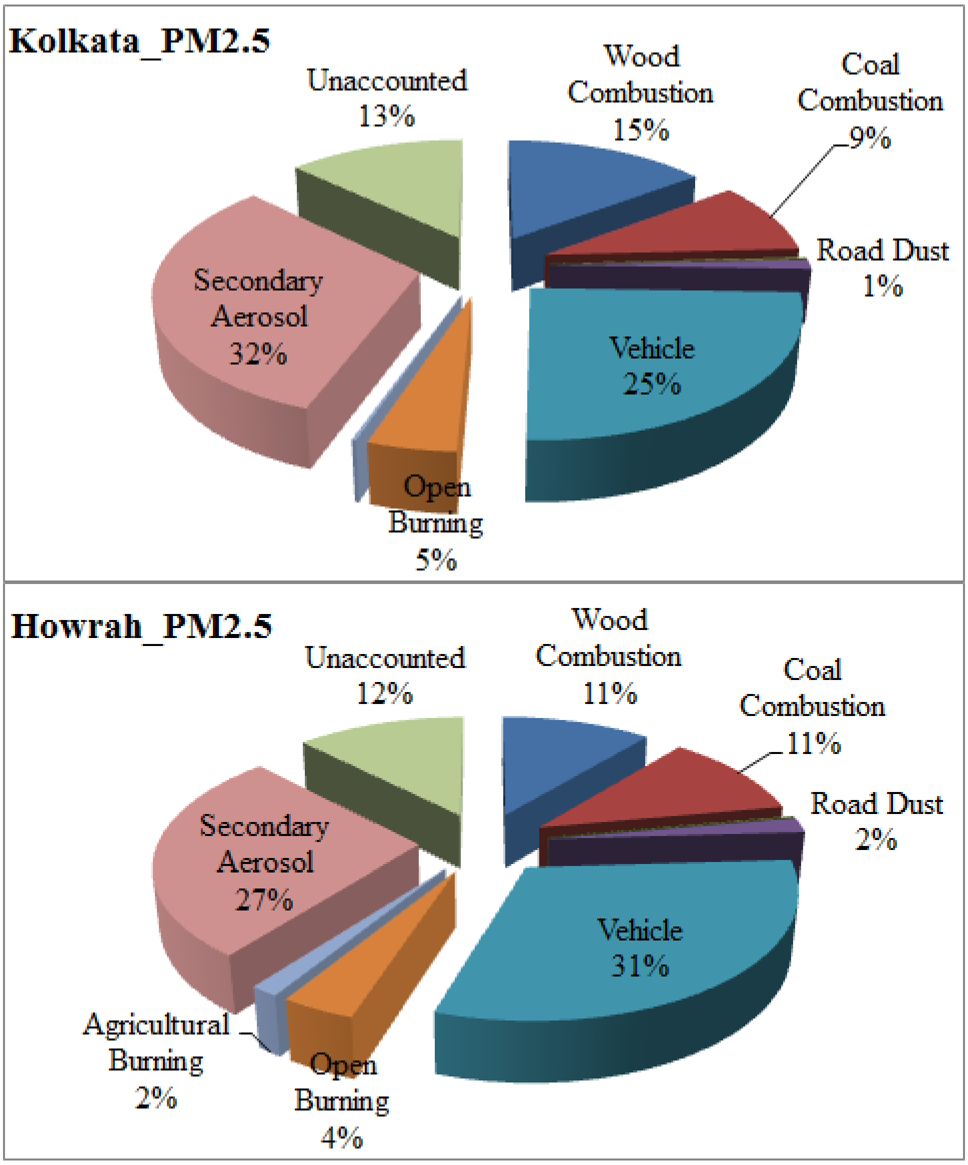


Fig. 4.18a: Overall % Contribution of Various Sources to $PM_{2.5}$ in Kolkata and Howrah: Winter

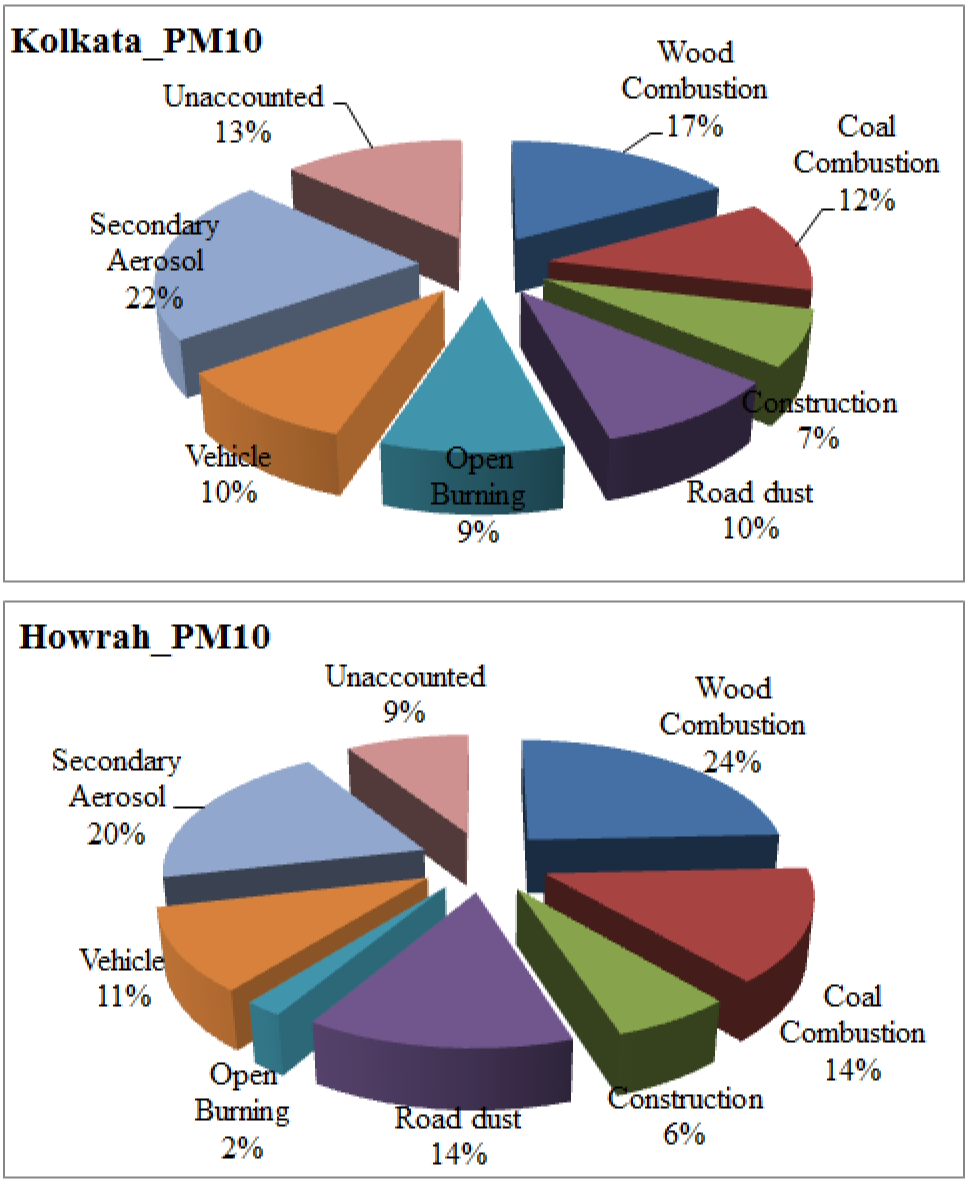


Fig. 4.18b: Overall % contribution of Various Sources to PM_{10} in Kolkata and Howrah: Winter

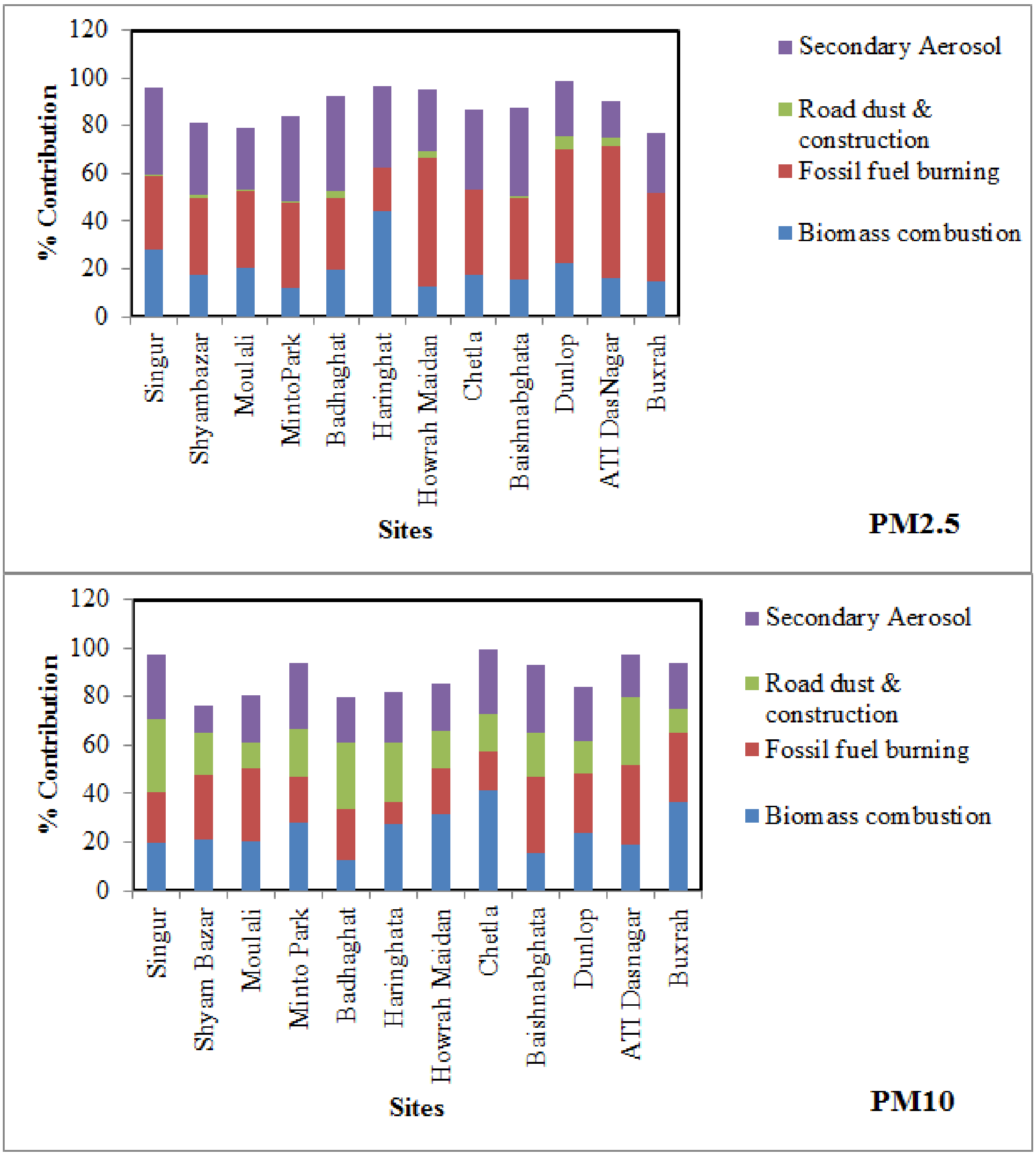


Fig. 4.19: Overall % Contribution Grouped as Biomass Combustion, Fossil Fuel Burning, Secondary aerosols and Road Dust & Construction

Table 4.7a: Uncertainty (%) in Source Contribution Estimates by CMB for PM_{10}: Winter

Location	Wood combustion	Coal combustion	Const.	Road dust	Open burning	Vehicle	Sec. Aerosol
Singur	17.2	11.4	19.1	-	10.3	-	16.5
Shyam Bazar	10.0	7.2	7.2	10.2	7.3	16.3	6.6
Moulali	13.6	5.8	2.2	19.5	6.9	13.6	7.4
Minto Park	12.4	17.7	15.7	9.7	6.4	-	12.6
Badhaghat	4.6	9.9	11.7	7.1	14.9	9.1	15.4
Haringhata	11.8	10.4	9.4	14.6	9.5	5.5	9.9
Howrah Maidan	13.1	13.6	4.0	15.3	-	-	9.4
Chetla	16.4	5.7	14.2	5.5	20.5	11.0	12.3
Baishnabghata	5.1	9.9	11.5	2.7	6.9	16.1	15.5
Dunlop	18.2	14.4	-	7.6	11.6	13.4	16.0
ATI Dasnagar	12.2	13.3	2.6	13.5	0.0	8.2	7.2
Buxrah	17.2	11.8	3.5	8.6	-	17.1	8.1

Const-construction, Sec. aerosol-secondary aerosol formation

Table 4.7b: Uncertainty in Source Contribution Estimates by CMB for $PM_{2.5}$: Winter

Location	Wood combustion	Coal combustion	KC	Road dust	Vehicle	Open burning	Sec. Aerosol
Singur	13.2	2.6	0.05	-	16.5	18.5	17.5
Shyam Bazar	9.0	6.5	0.3	4.0	18.1	13.5	10.9
Moulali	15.7	1.9	0.5	0.6	14.0	8.7	15.2
Minto Park	12.8	9.6	0.1	0.5	15.0	3.3	11.3
Badhaghat	18.0	2.3	0.3	2.0	17.5	13.2	14.6
Haringhata	14.5	3.3	0.3	1.3	19.7	12.2	16.7
Howrah Maidan	13.7	6.5	-	9.3	13.1	1.1	-
Chetla	17.6	4.2	0.09	-	15.6	12.8	9.2
Baishnabghata	10.8	2.0	0.21	1.9	18.0	7.0	17.1
Dunlop	19.2	3.8	0.8	10.1	-	16.2	13.5
ATI Dasnagar	8.8	11.0	0.12	-	-	-	-
Buxrah	9.8	12.1	0.01	0.6	17.4	12.4	10.1

KC-kerosene combustion, Sec. aerosol-secondary aerosol formation

Table 4.8a: Contribution (%) of Major Sources to Particular Matter in Kolkata and Howrah: Winter

Sources	Kolkata		Howrah	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Combustion (domestic and commercial activities)	28.7	24.3	38.8	22.2
Construction	7.2	-	6.2	-
Road dust	9.9	1.2	13.6	1.9
Vehicle	10.0	25.1	10.7	31.0
Open burning	9.3	4.8	2.0	5.3
Secondary Aerosols	21.6	31.7	19.6	27.3
Unaccounted	13.3	12.9	9.0	12.3

Table 4.8b: Contribution (%) of Biomass and Fossil Fuel Burning to Particulate Matter in Kolkata and Howrah: Winter

Source	Kolkata		Howrah	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Biomass combustion	26.2	19.6	26.3	16.3
Fossil fuel burning	21.9	34.6	25.3	42.1
Road dust & Construction	17.1	1.2	19.8	1.9
Secondary Aerosols	21.6	31.7	19.6	27.3
Unaccounted	13.3	12.9	9.0	12.3

4.8 Discussion on Sources Contributing to PM_{10} and $PM_{2.5}$ in Kolkata and Howrah

In this section, the source contributions estimated through CMB are discussed. An attempt has been made to explain the contributions through past studies and other methods. The concentration, variation and relationship of chemical species help in evaluating the sources present in the area. Chemical ratios of the species also provide the indication about the presence of biomass or fossil fuel burning in the area. The diagnostic ratios are usually used for validating the results of source contribution estimation using quantitative models such as CMB and PMF. Various ratios are estimated in this study to have an idea about the dominance of the sources in the region. **Table 4.9** lists the ratios and their utility in the particular diagnosis. Below, each contributing source is discussed from the viewpoint to validate its presence, % contribution and seasonal variations.

4.8.1 Secondary aerosol

Secondary aerosols contribution observed through CMB analysis in winter is about 21% and 30%, respectively for PM_{10} and $PM_{2.5}$. During summer, the secondary aerosol contribution to PM_{10} and $PM_{2.5}$ is about 19% and 24%, respectively in both Kolkata and Howrah. Since the source profiles considered were ammonium sulphate and ammonium nitrate, this source represent mainly secondary inorganic aerosols. The contributions estimated by CMB although seem to be large, but the presence of secondary inorganic aerosols in the ambient air of Kolkata and Howrah cannot be countered. A likely explanation in terms of literature review and data analysis for the estimated % contributions is given below.

Looking at the chemical profile, the anthropogenic ionic species (AIS) i.e. the sum of NH_4^+, NO_3^- and SO_4^{2-} constitute nearly 16% and 20% of PM_{10} and $PM_{2.5}$ mass, respectively during winter and 20% and 34% of PM_{10} and $PM_{2.5}$ mass during summer. The order of the ionic species is $SO_4^{2-} > NH_4^+ > NO_3^-$ for both PM_{10} and $PM_{2.5}$ during winter and summer. Higher contribution of AIS has been observed at various urban sites (Rengarajan et al., 2007; Andreae and Merlet, 2001). It can be seen from the mass closure analysis that during winter, ammonium sulphate and ammonium nitrate contribution to total PM_{10} mass is about 13% and 2% and to total $PM_{2.5}$ mass is about 14% and 0.3% during winter and summer, respectively. Mass closure estimates are almost 1/4th and 1/2nd of the contribution estimated by CMB for PM_{10} and $PM_{2.5}$, respectively. During summer, the mass closure analysis reveals that the contribution of ammonium sulphate and ammonium nitrate to total PM_{10} mass is about 19% and 1%, respectively and to $PM_{2.5}$ mass is about 32% and 2%, respectively. Mass closure analysis suggests that PM_{10} and $PM_{2.5}$ mass is significantly contributed by secondary inorganic aerosols which is confirmed through CMB analysis as well.

Several studies conducted over Indo Gangetic Plain (IGP) of India observed the presence of secondary aerosol contribution to total PM mass. In a study on spatial and temporal variations in chemical characteristics of PM_{10} source apportionment over IGP, Jain et al. (2019) observed highest contribution of secondary sulphate (13%) and secondary nitrate (12%) followed by soil dust, vehicular emissions, biomass burning, sodium and magnesium salt and industrial emissions. Together secondary inorganic aerosol's contribution was about 25% using PMF and 32% using UNMIX model, which quite matches with the findings in this study. In a study conducted on Delhi, Sharma et al. (2015) reported the secondary aerosol contribution to PM_{10} as 21%. In a study on chemical characterization of fine particulates over eastern Indo-Gangetic Plain, Priyadharshini et al. (2019) observed 25% contribution of secondary inorganic aerosols (NH_4^+, NO_3^-, and SO_4^{2-}) to total water soluble ions.

Precursor gases form particulate NH_4^+, NO_3^- and SO_4^{2-} in the atmosphere through chemical reactions. Being near to Bay of Bengal, high relative humidity in the study area favors in the formation of secondary aerosols as $(NH_4)_2SO_4$ and NH_4NO_3 (Song et al. 2006). Further, contribution of ammonium sulphate is observed to be higher than ammonium nitrate. The nss-SO_4^{2-} (non sea-salt) calculated with the help of Na^+ showed its contribution from 95-99% during summer-winter to total SO_4^{2-}. This suggests that the sulphate is mainly originated from the anthropogenic sources in both Kolkata and Howrah. Sulphate is mainly emitted from coal and wood combustion, whereas agricultural and industrial activities contribute ammonium in the atmosphere (Pant and Harrison, 2012; Jain et al., 2019).

The results suggest that emission control strategies to mitigate PM pollution in Kolkata and Howrah need to address secondary aerosol precursors mainly SO_2 and NH_3. High contribution of secondary inorganic aerosol to PM_{10} and $PM_{2.5}$ emphasize the need to control the emissions from coal and wood combustion along with the agricultural and industrial activities.

4.8.2 Road dust

The road dust contribution is observed to be about 10% in Kolkata and 14% in Howrah for PM_{10}; and 1% in Kolkata and 2% in Howrah for $PM_{2.5}$ in winter. In summer, the road dust contribution is observed to be 9% in Howrah and 20% in Kolkata for PM_{10}; and 10% in Howrah and Kolkata for $PM_{2.5}$. A plausible explanation for the higher contribution in summer than in winter has been given through literature analysis, diagnostic ratio and enrichment factor of crustal species.

Road dust has been found to be dominated by species typically associated with crustal species, which often resonates the local geology of the area. Si and Al are often considered as the tracers for road dust emissions in various studies (Contini et al., 2016; Pervez et al., 2018; Thorpe and Harrison, 2008). Si/Al ratio has been used to represent the emissions from geological source as earth crust or crustal source. For winter, Si/Al ratio is observed to be 36.36 and 7.24 for PM_{10} and $PM_{2.5}$, whereas in summer it is observed to be 4.54 and 0.86 for PM_{10} and $PM_{2.5}$, respectively. Looking at the source profiles used in the study, Si/Al ratio of 21.76, 1.7 and 5.19 is observed for paved road dust, unpaved road dust and soil dust, respectively. Contini et al. (2016) suggested the ratio of 1.45-1.98 for resuspended dust. Higher ratio during winter suggests emissions from other sources in addition to road dust in the area. Ratio during summer suggests higher contribution from road dust.

Enrichment factor of crustal species Al and Fe was calculated based on the relative abundance of the selected elements in the PM samples by their reference abundance in the earth crust (Lide, 2005). Enrichment factor (EF) ~1 suggests crustal origin, whereas EF>10 suggests contributions by anthropogenic sources such as traffic and fossil fuel combustion. It can be seen from **Table 4.9** that during winter, PM_{10} and $PM_{2.5}$ are significantly enriched suggesting the influence of fossil fuel and traffic source, whereas during summer, the EF<10 suggests the road dust as a major source.

Jain et al. (2019) observed the soil dust contribution of 15% to PM_{10} in Kolkata, which matches quite well with findings in this study. Gupta et al. (2007) observed the contribution of road dust to PM_{10} to be about 21% at a residential site in Kolkata. The higher contribution of road dust during the summer than winter at a residential site in Kolkata is also observed by Gupta et al. (2007). Higher road dust contribution in summer is mainly due to dry conditions and high wind velocity. The lower % contribution of road dust to fine particulate matter is attributed to the presence of substantial road dust particulates in coarse mode, which has been observed in several other studies (Harrison, 1983; Herner, 2006; Masri et al., 2015; Gupta et al., 2007).

The lesser contribution in winter than summer can also be validated through mass closure analysis. It can be seen that geological/ crustal species contribution to PM_{10} and $PM_{2.5}$ is 5.4% and 2% in winter and 7.8% and 7.3% in summer, respectively. When comparing the road dust contribution at Kolkata and Howrah, it is more at Howrah than at Kolkata in winter whereas in summer, it is less at Howrah for PM_{10} and same for $PM_{2.5}$. The similar variations were observed in mass closure analysis.

4.8.3 Vehicular Contribution

Vehicular contribution is observed to be in the range of 10-11% (Kolkata-Howrah) for PM_{10} and 25-31% (Kolkata-Howrah) for $PM_{2.5}$ in winter and in the range of 21-22% (Howrah-Kolkata) for PM_{10} and about 19-22% (Kolkata-Howrah) for $PM_{2.5}$ in summer. Jain et al. (2019) using PMF and UNMIX models observed 18% and 22% contribution of vehicles to PM_{10} in Kolkata, respectively. For PM_{10} in summer and winter, and $PM_{2.5}$ in summer, the results match moderately with Jain et al. (2019), whereas for $PM_{2.5}$ in winter, higher contribution of vehicular emissions has been observed in the present study.

The contribution of vehicular emissions through CMB can be validated through diagnostic ratios. Usually organic and elemental carbon ratio is studied to have an understanding of the presence of local sources in urban areas. An OC/EC ratio < 2 has been considered to represent the emissions from local sources (Park et al., 2001; Cao et al., 2004). In Asian cities, average OC/EC ratio of 2.3 was observed (Fang et al., 2008). OC/EC ratio >3 has been suggested to indicate the presence of secondary organic aerosols (Ho et al., 2002). During winter, OC/EC ratio of 1.11, 1.16 and during summer, OC/EC ratio of 1.57, 1.42 for PM_{10} and $PM_{2.5}$, respectively was observed in this study. This suggests that OC is mainly a primary organic carbon and could be affected by local sources e.g. vehicle emissions.

4.8.4 Wood, Coal and Open burning

Wood burning contribution has been observed to be in the range 17-24% (Kolkata-Howrah) and 11-15% (Howrah-Kolkata) for PM_{10} and $PM_{2.5}$ in winter and 6-20% (Kolkata-Howrah) and 11-20% (Kolkata-Howrah) for PM_{10} and $PM_{2.5}$ in summer. Coal burning contribution on the other hand, is observed to in the range of 12-14% (Kolkata-Howrah) and 9-11% (Kolkata-Howrah) for PM_{10} and $PM_{2.5}$ in winter and 7-9% (Kolkata-Howrah) and 7-22% (Howrah-

Kolkata) for PM_{10} and $PM_{2.5}$ in summer. Open burning contributed 2-9% (Howrah-Kolkata) and 4-5% (Howrah-Kolkata) for PM_{10} and $PM_{2.5}$ in winter and 1-9% (Kolkata-Howrah) and 4-8% (Kolkata-Howrah) for PM_{10} and $PM_{2.5}$ in summer.

Jain et al (2019) in the PMF analysis for PM_{10} in Kolkata observed a 21% contribution of mixed source representing biomass and coal combustion that included the species such as K^+, Cl^- and OC. In this study, higher contribution of the coal and biomass burning has been attempted to be explained by diagnostic ratio analysis. K^+ has been considered as a tracer for biomass burning, whereas anthropogenic emissions of Cl^- are mainly coal combustion and wood burning (Harrison et al., 2012). K^+ concentration is observed to be 3.34±0.60 μg m^{-3} and 3.42± 0.81 μg m^{-3} for PM_{10} and $PM_{2.5}$ during winter and 0.53±0.19 μg m^{-3} and 0.34±0.14 μg m^{-3} for PM_{10} and $PM_{2.5}$ during summer. The higher concentration of K^+ during winter corresponds to the notion of high biomass burning in winter as wood and other biofuel are generally used for heating purpose. Various diagnostic ratios are illustrated in **Table 4.9**. K^+/EC ratio >0.2 suggests active biomass burning (Andreae and Merlet, 2001), whereas EC/OC ratio near to 1 suggests fossil fuel combustion as the significant source in the area. K^+/OC ratio >0.2 suggests fossil fuel burning (Andreae and Merlet, 2001; Tiwari et al., 2016; Srinivas et al., 2014; Duan et al., 2004). It is observed that the K^+/EC ratio is <0.09 during winter and summer for both PM_{10} and $PM_{2.5}$ suggesting the presence of fossil fuel burning source. K^+/OC ratio <0.09 on the other hand suggests the presence of biomass burning. EC/OC ratio is near to 1 indicating the presence of fossil fuel burning. Based on the ratio analysis, it can be inferred that both biomass and fossil fuel burning in the study area. As can be seen, CMB analysis also confirmed the presence of both wood and coal combustion during both the seasons for PM_{10} and $PM_{2.5}$.

4.8.5 Construction

The construction activity contribution is found to be 6-7% (Howrah-Kolkata) during winter and 11-12% (Howrah-Kolkata) during summer for PM_{10}. For $PM_{2.5}$, construction source is not observed to be contributing. Ca^{++} has been considered as a tracer for construction activity (Watson et al., 2004). It is observed that the Ca^{++} is in the range of 2.82±1.1 μg m^{-3} and 0.76±0.35 μg m^{-3} for PM_{10} and $PM_{2.5}$ in winter and 1.7±0.6 μg m^{-3} and 0.6±0.26 μg m^{-3} for PM_{10} and $PM_{2.5}$ in summer, respectively. Ca^{++} in PM_{10} is observed to be about 3 and 4 times to Ca^{++} in $PM_{2.5}$ in summer and winter, respectively. Fe has also been considered as one of the species which can also come from construction dust (Pant and Harrison, 2012). Fe is seen to be 4.64±2.1 μg m^{-3}, 0.98±0.45 μg m^{-3} for PM_{10} and $PM_{2.5}$ in winter and 1.37±0.38 μg m^{-3} and 0.6±0.27 μg m^{-3} for PM_{10} and $PM_{2.5}$ in summer. Fe in PM_{10} is about 2 and 3 times to Fe in $PM_{2.5}$ in summer and winter, respectively. Very low concentration of Ca^{++} and Fe concentration in fine fraction justifies the absence of construction source in $PM_{2.5}$.

Table 4.9: Diagnostic Ratios Used in the Study

Ratio	Indicative source	Diagnosis	Reference	Our study		Remark/ observation
				Winter	Summer	
OC/EC	Biomass burning/traffic source	High ratio 2.9-8.4 – biomass burning	Park et al. (2001); Cao et al. (2004)	1.11, 1.16	1.57, 1.42	Traffic source
EC/OC	Fossil fuel burning	Near to 1	Andreae and Merlet (2001)	0.98, 0.95	0.67, 0.77	Fossil fuel source
SO_4^{2-}/EC	relative dominance between fossil-fuel combustion and biomass/biofuel burning	lower values - pure biomass-burning 1.9 - biomass 3.9 - fossil fuel low values 0.28-0.32 – wildfires	Andreae and Merlet (2001) Tiwari et al. (2016); Srinivas et al. (2014); Ferek et al. (1998); Mkoma et al. (2013)	0.58, 0.56	1.84, 2.19	Biomass burning
K^+/OC	Biomass burning	0.04–0.13 0.07 ± 0.04 (found over eastern IGP) 0.2 : wheat straw burning	Andreae and Merlet (2001); Tiwari et al. (2016) Srinivas et al. (2014) Duan et al. (2004)	0.07, 0.09	0.06, 0.05	Biomass burning in winter & summer
K^+/EC	biomass burning	0.63	Srinivas et al.	0.08, 0.09	0.06, 0.05	Fossil fuel

	Ratio~0 for fossil fuel burning	0.2-0.69: biomass burning 0.10–0.63: Vegetation burning 0.90 ± 0.33 & 1.60 ± 0.54 : savannah biomass burning	(2014) Andreae and Merlet, (2001) Mkoma et al. (2013)			burning in winter & summer
Cu/Sb	brake wear particles	Local crustal material – 125, brake lining – 4.6±1.2 4.95±0.50, 7.5±0.79 in UK, 11.5 in Delhi for brake wear 3.3 to 4.6 - brake lining wear	Harrison et al. (2012) Pant et al. (2015) Salma and Maenhaut, (2006)	4.09, 7.64	--	In winter- the ratio corresponds to brake wear particles
Si/Al	Road dust (RD)	2.57 – RD 1.58 – coal power plant 1.45-1.98– paved or resuspended dust 3.19 – upper continental crust	Contini et al. (2016) Pant et al. (2015) Sethi and Patil (2008)	36.36, 7.34	4.54, 0.86	Summer – Road dust is the significant contributor, Winter – road dust is not the significant contributor
Enrichment factor (EF) – Fe/Al	Road dust (RD)	EF~1 represent enrichment, EF>10 : significant enrichment, may be due to influence of other sources	Pant et al. (2015)	143.8, 24.06	6.76, 2.20	RD in winter is influenced with other sources, mainly traffic, RD contribution in summer are significant

Chapter 5

Long Range Transport

The long range transport of particulate matter was studied using back-trajectory analysis. Statistical bi-polar plots were obtained by associating each observed PM concentration with the wind velocity. The details are given as below.

5.1 Introduction

The contribution of transport of pollutants from other areas can be identified qualitatively through long range transport modeling and trajectory analysis. The trajectory analysis is based on the meteorology for angular sector source apportionment. It helps in identifying the source regions contributing to the PM pollution in an area. Potential Source Contribution Function (PSCF) and Concentration weighted trajectory (CWT) methods help in locating the potential source regions contributing to the high PM emission regions. HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed at the NOAA Air Resources Laboratory ARL calculates Lagrangian trajectories from observed wind fields (Draxler and Rolph, 2011). Calculated back-trajectories and CWT for different seasons are given in their respective sections. Statistical bi-polar plots in R programming (R Development Core Team, 2012) are also obtained to associate the observed PM concentration with the local meteorological data. The bi-polar plots help in locating the possible source directions. The details can be found in Carslaw and Ropkins (2012).

5.2 Back-Trajectories and CWT: Summer

The results of the calculated back-trajectories at arrival height of 500m and CWT are given in **Fig. 5.1a-b** for Kolkata and **Fig. 5.2a-b** for Howrah for PM_{10} and $PM_{2.5}$, respectively. It can be seen from **Fig. 5.1a-b** and **Fig. 5.2a-b** that most of the trajectories are from SSW direction in Kolkata and Howrah (mainly sea source). The CWT is also observed in the same direction, however CWT associated with high PM_{10} concentration in Kolkata is local in nature. For $PM_{2.5}$ concentration in Kolkata, a trail of CWT in the range of 40-60 is observed from SSW direction with no local grid of high CWT. For Howrah, it can be seen from **Fig. 5.2a-b** that CWT is higher (in the range 80-100) for PM_{10} in SSW direction, whereas no CWT associated with high $PM_{2.5}$ is observed. This suggests that moderate PM_{10} (in the range 20-80 $\mu g\ m^{-3}$ in Kolkata and 20-100 $\mu g\ m^{-3}$ in Howrah) concentration is very slightly contributed by the sources in the SSW direction in summer. The contribution seems to be not very significant in Kolkata. $PM_{2.5}$ contribution from nearby areas looks to be very less as compared to PM_{10}. The analysis above however is indicative and does not quantify the contribution of long-range transport to PM in the area.

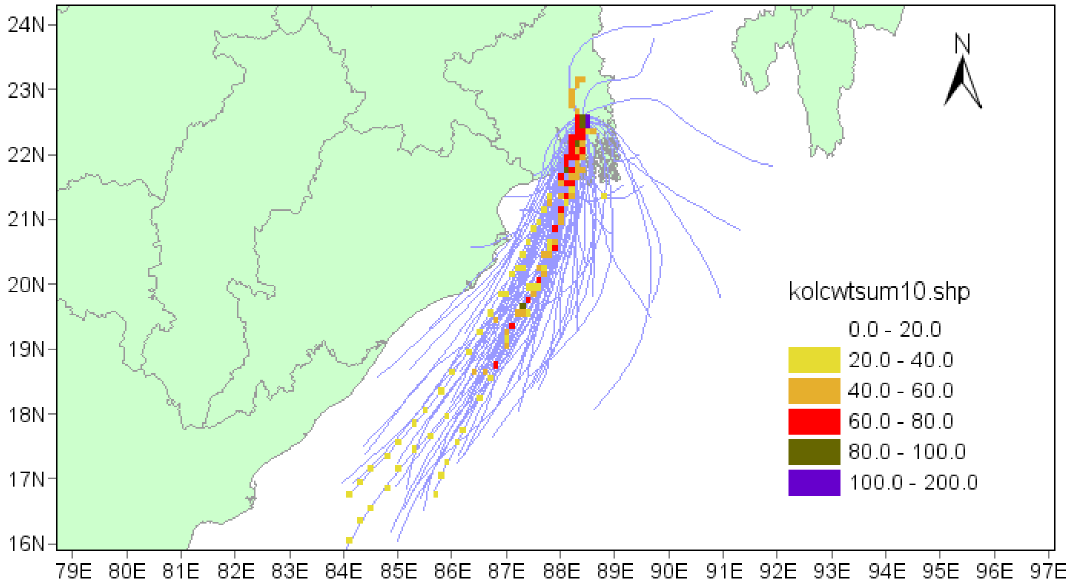


Fig. 5.1a: Back-trajectories and Concentration Weighted Trajectory for PM_{10} in Kolkata: Summer

(trajectories are marked in blue lines, CWTs are marked in colorful boxes), unit of legend is in $\mu g/m^3$

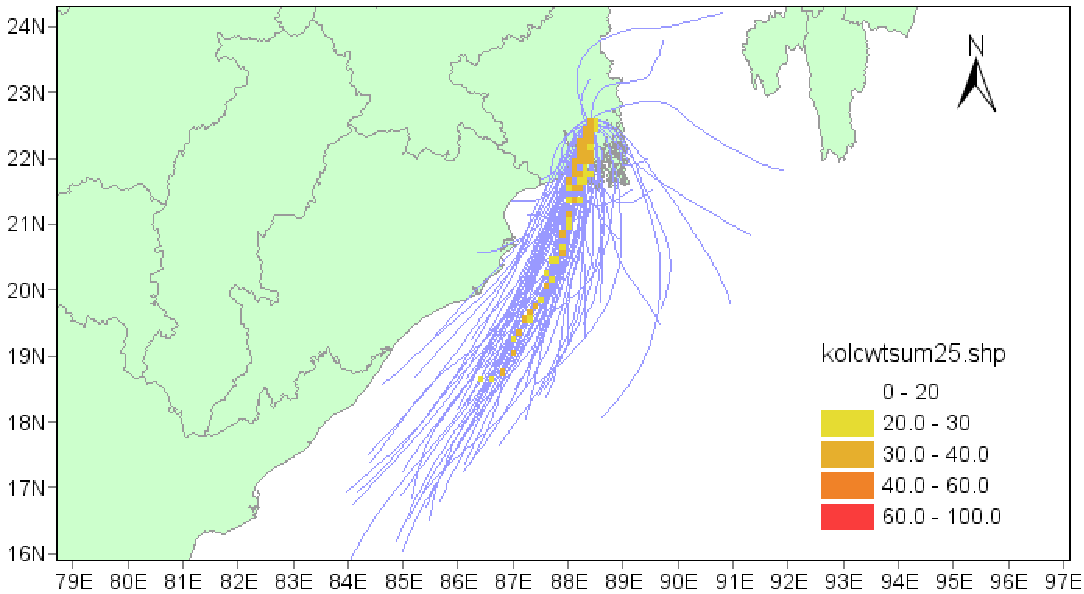


Fig. 5.1b: Back-trajectories and Concentration Weighted Trajectory for $PM_{2.5}$ in Kolkata: Summer

(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

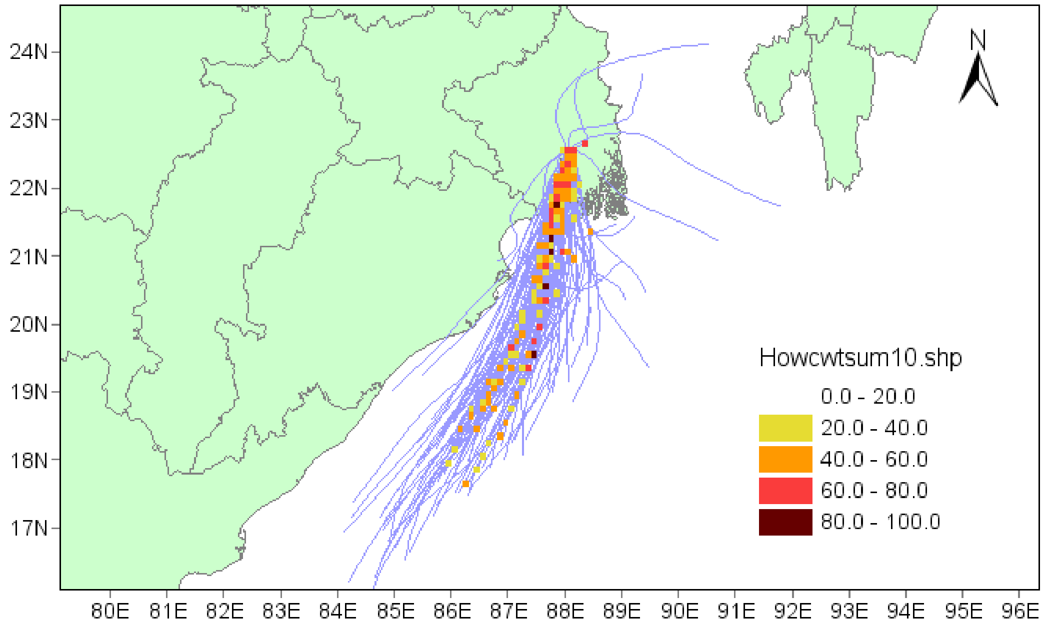


Fig. 5.2a: Back-trajectories and Concentration Weighted Trajectory for PM_{10} in Howrah: Summer

(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

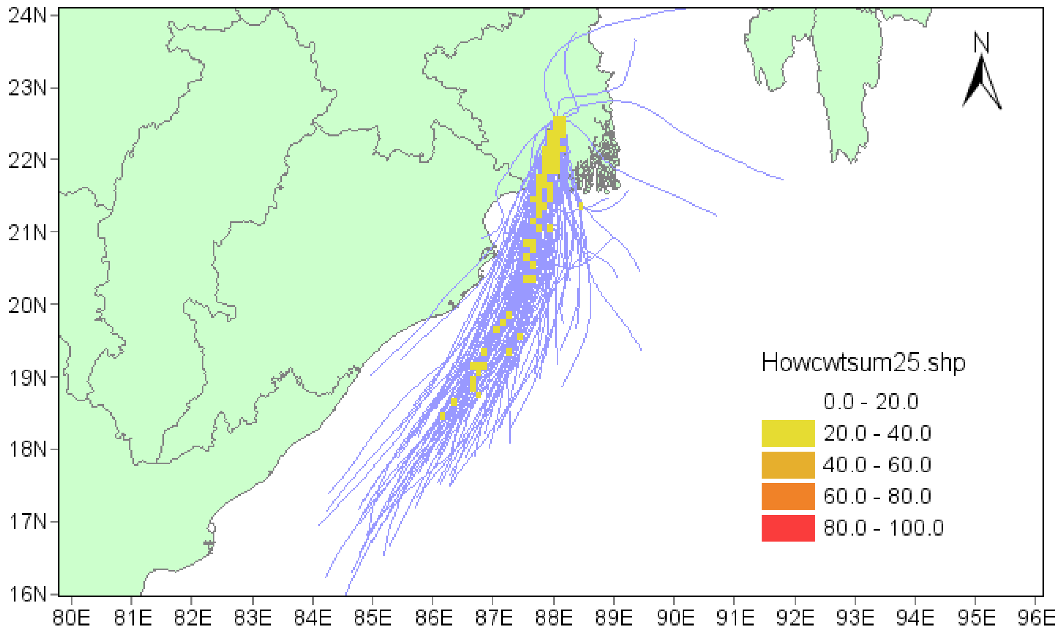


Fig. 5.2b: Back-trajectories and Concentration Weighted Trajectory for $PM_{2.5}$ in Howrah: Summer

(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

5.3 Back-Trajectories and CWT: Winter

The results of the calculated back-trajectories and CWT for winter season are given in **Fig. 5.3a-b** and **Fig. 5.4a-b** for Kolkata and Howrah, respectively. It can be seen that most of the trajectories are from NNW direction in Kolkata and Howrah with few exceptions. The Concentration weighted trajectory was projected on the sample plots of trajectories. For PM_{10} and $PM_{2.5}$ in Kolkata, high and moderated CWT (>200 µg m^{-3} and 150 µg m^{-3} for PM_{10} and $PM_{2.5}$, respectively) was observed in NNW direction. Magnifying the plot showed that high CWT is local as well as contributed by nearby areas. For PM_{10} and $PM_{2.5}$ in Howrah, trajectories and high CWT (>200 µg m^{-3} and >100 µg m^{-3} for PM_{10} and $PM_{2.5}$, respectively) is observed in NNW direction. Zooming the plot however showed no local CWT rather all the high CWTs were from nearby areas.

This suggests that in Howrah, PM_{10} and $PM_{2.5}$ are contributed mostly by nearby areas in the NNW direction. In Kolkata, local and nearby source contributions (mainly from NNW direction) are significant. Further, $PM_{2.5}$ contribution from nearby areas is lesser than PM_{10}. This however cannot be quantified using the above approach. Any policy on source emission mitigation in Kolkata and Howrah needs to take into consideration the contribution of both local and nearby source emissions.

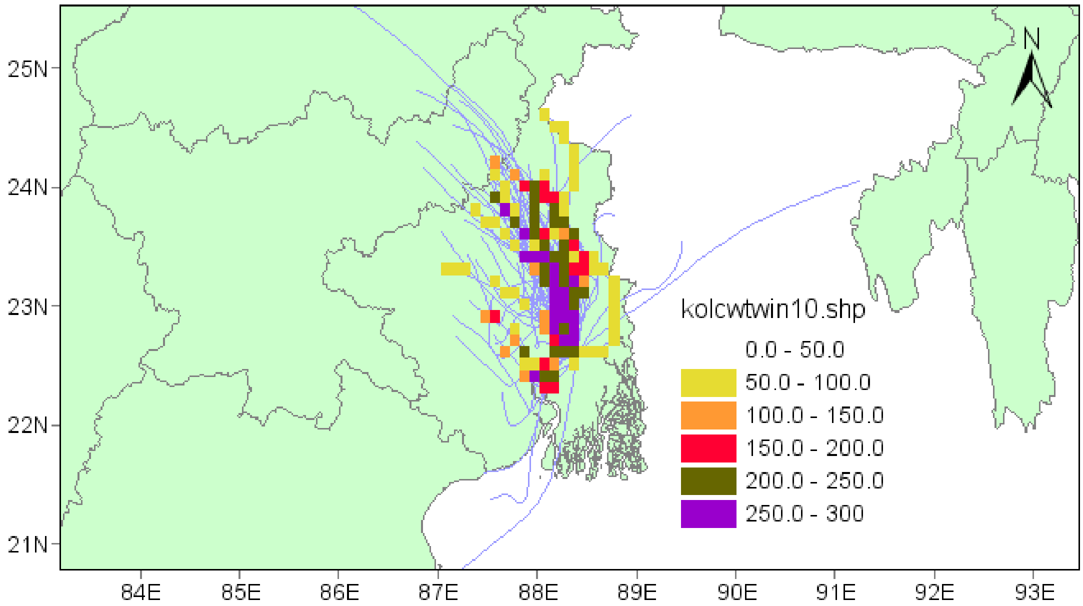


Fig. 5.3a: Back-trajectories and Concentration Weighted Trajectory for PM_{10} in Kolkata : Winter
(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

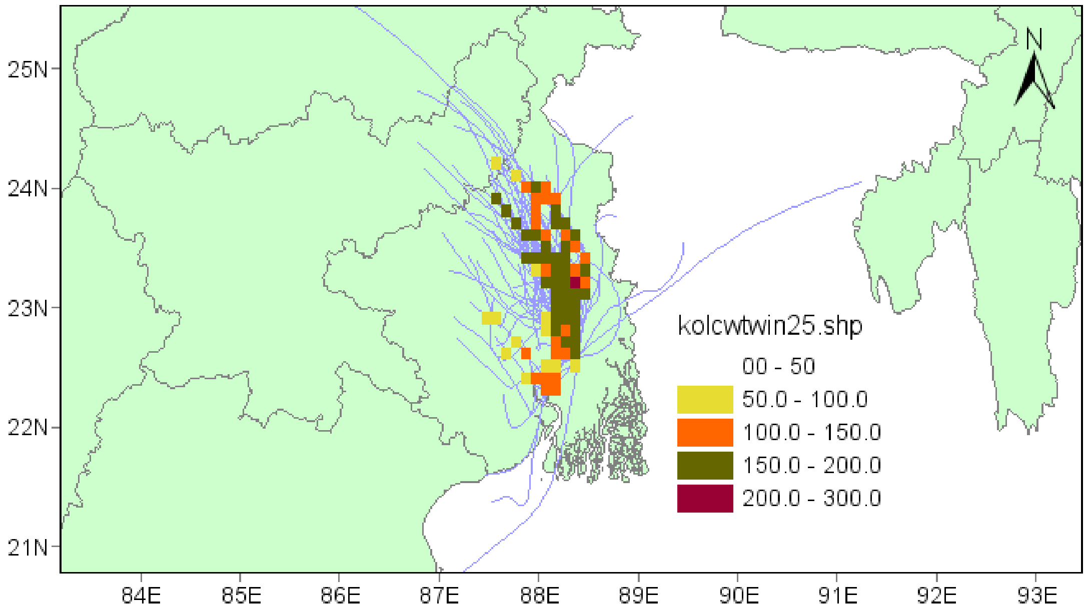


Fig. 5.3b: Back-trajectories and Concentration Weighted Trajectory for $PM_{2.5}$ in Kolkata: Winter
(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

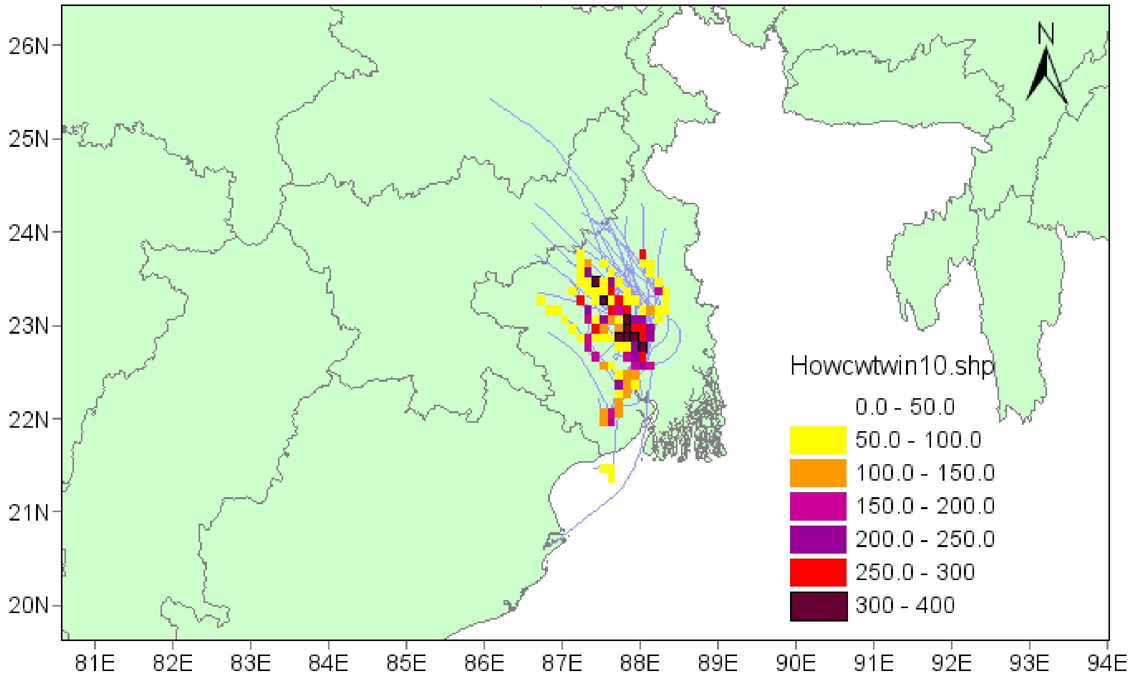


Fig. 5.4a: Back-trajectories and Concentration Weighted Trajectory for PM_{10} in Howrah: Winter

(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

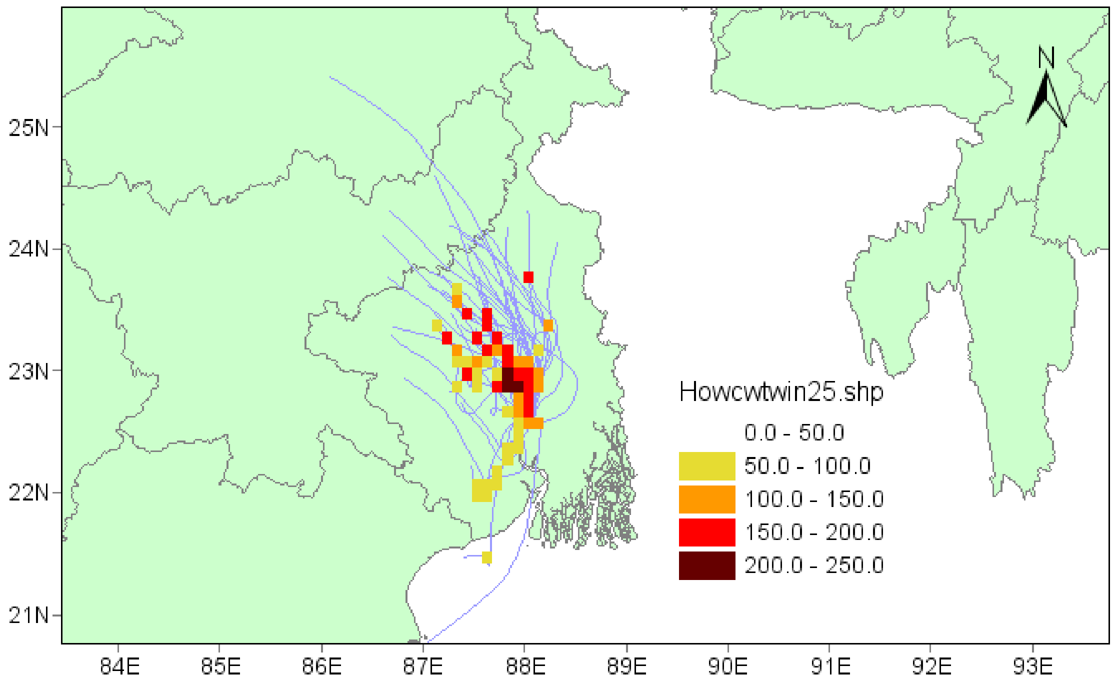


Fig. 5.4b: Back-trajectories and Concentration Weighted Trajectory for $PM_{2.5}$ in Howrah: Winter

(trajectories are marked in blue lines, CWTs are marked in colorful boxes)

The above exercise was carried out for 24h run time. The 72h back trajectories at 500m height are also plotted to assess the intrusions of dust from Indo-Gangetic Plain (IGP) as several authors have shown the contribution of dust from the IGP to the PM at urban sites (Nair et al., 2007; Srinivas et al., 2011; Srivastava et al., 2012; Ram et al., 2012; Srinivas et al., 2014). 72h run time was selected based on the longer residence of fine particulates. As can be seen from **Fig. 5.1a-b** and **Fig. 5.2a-b** that the air masses are mostly originated from Bay of Bengal in summer, the back trajectories are therefore obtained only for winter season. The influx of cleaner air contributes to the reduction in anthropogenic contributions to the air mass in summer. The similar findings were also observed in Ram et al. (2012). **Fig. 5.3a-b** and **Fig. 5.4a-b** although points out the intrusions from IGP but due to the limited run time, the air mass trajectories are restricted to the limited area. It can be seen from **Fig. 5.4c** that most of the trajectories are originated from local as well as distant locations from IGP, which suggests the intrusion of dust particles in Kolkata from the distant sources.

A forward trajectory analysis is also carried out to understand the estrangement of dust in Kolkata. It can be seen from **Fig 5.4d** that during the winter the air masses are carried over longer distances in the SE directions, whereas during summer, the air masses are carried mostly in east direction. Since the PM pollution is observed to be higher (exceeding the CPCB threshold) in winter, the dust load may be carried over Bay of Bengal. During summer, PM pollution is less and mostly below the CPCB threshold, the PM load from Kolkata and Howrah may not contribute to the aggravation of dust load to the eastern region.

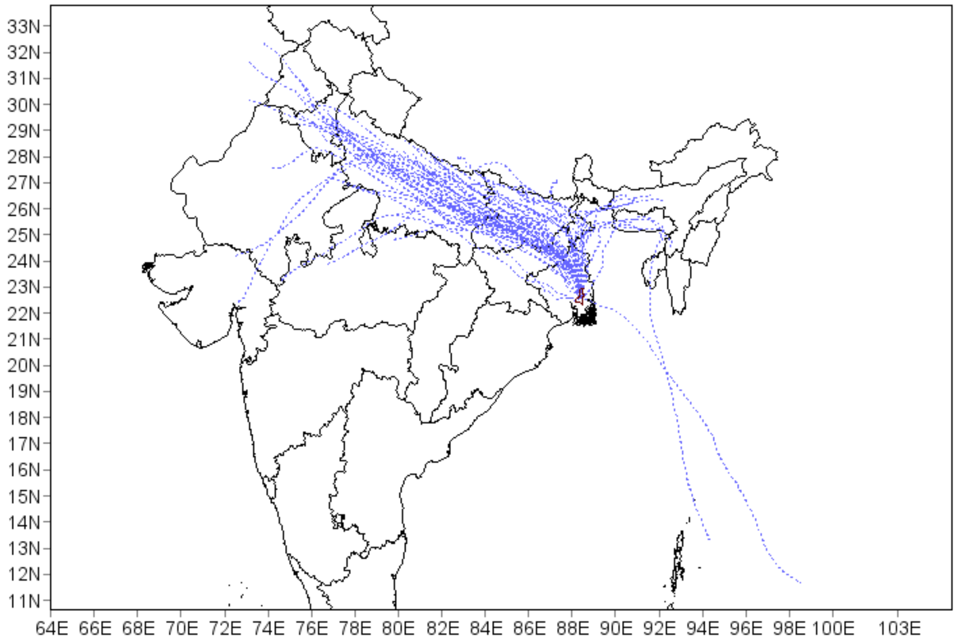


Fig. 5.4c: Back-trajectories in Kolkata for 72h run time: Winter

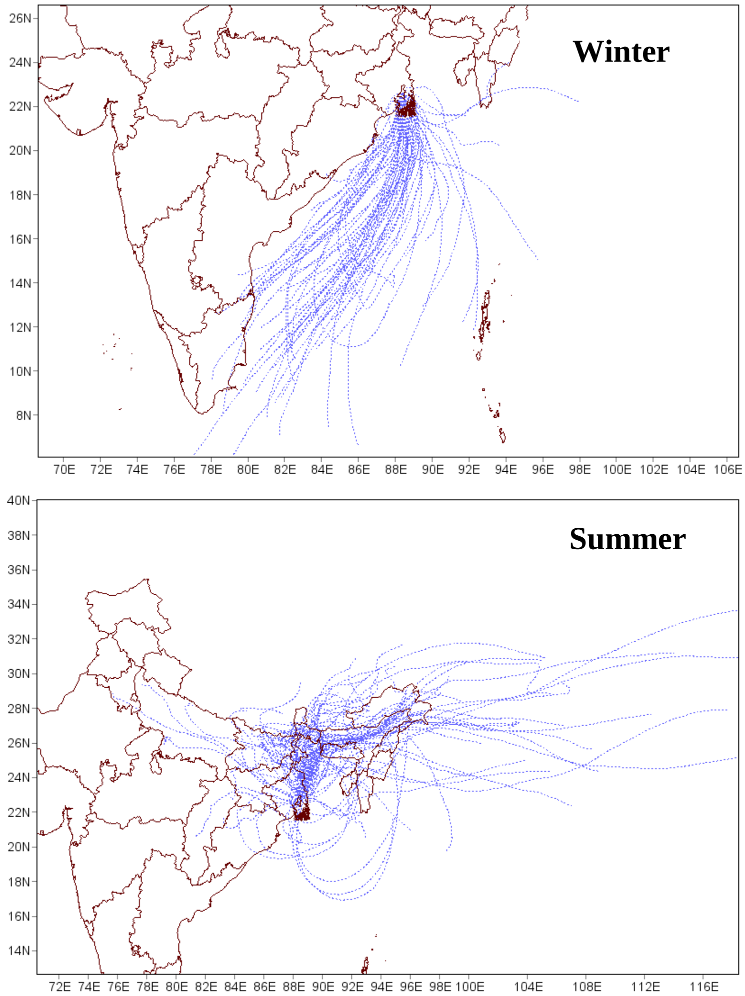


Fig. 5.4d: Forward Trajectory Analysis

5.4 Bi-polar Plots

The statistical bipolar plots are obtained to validate the results of back-trajectory and CWT analysis which is based on global meteorological data. Bipolar plots utilizes the local meteorological data on wind speed and wind direction along with the observed PM concentration to reveal the source regions that may be local or nearby or distant in nature. The analysis is indicative and further application of other SA techniques is however required. The results are given in **Fig. 5.5a and Fig. 5.5b** for Kolkata and Howrah, respectively.

Kolkata: It can be seen that during summer, the PM_{10} concentration >100 μg m^{-3} is accumulated in the center region with wind speed <5 m s^{-1} suggesting the local source of particulate matter in Kolkata. For $PM_{2.5}$, however, concentration >36 μg m^{-3} is observed with the wind blowing from the SW direction with wind speed of 7-10 m s^{-1}. $PM_{2.5}$ can be seen to be contributed from distant sources, the values however are much below the CPCB standard of 60 μg m^{-3} (for 24h). During winter, it can be seen that PM_{10} concentration is much above the CPCB standard of 100 μg m^{-3} for 24h, which is observed locally as well as associated with the wind blowing from the N and NNE direction. This suggests the local contribution along with the distant source contribution located in the N and NE of PM_{10} in winter. Minimal contribution from SW direction can also be seen from the polar plot. Similar results were observed for $PM_{2.5}$ in winter.

Howrah: It can be seen that PM_{10} and $PM_{2.5}$ concentrations are well below the CPCB standard of 100 and 60 μg m^{-3} in summer. PM_{10}>65 μg m^{-3} is contributed locally and marginally from SSE direction and $PM_{2.5}$>32μg m^{-3} is contributed by nearby sources in the SSE direction beside the wind speed in the range of 2-3.5 m s^{-1}. During winter, PM_{10} and

$PM_{2.5}$ concentrations above the CPCB standards are observed to be contributed locally and by the distant sources in the N direction with moderate contribution from SW and W direction.

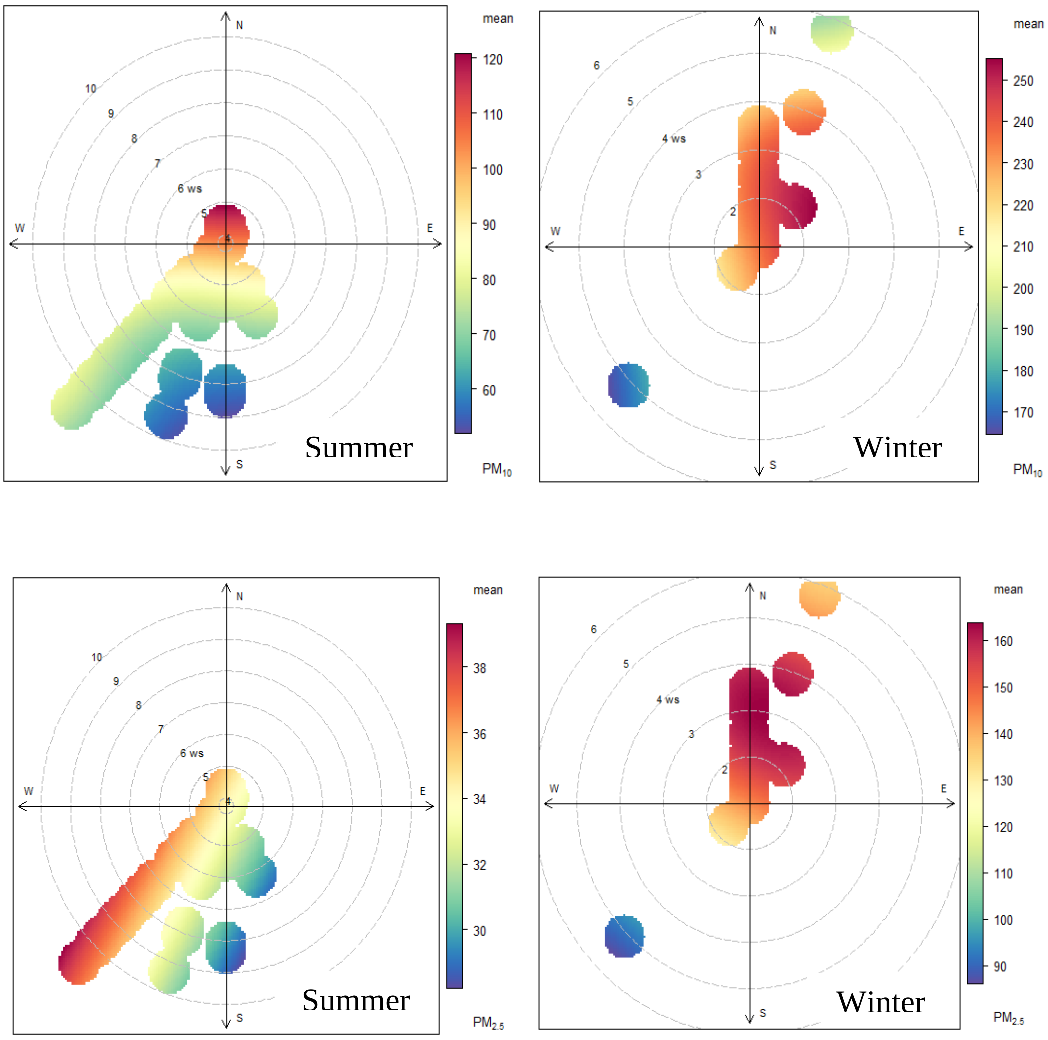


Fig. 5.5a: Bipolar plots for PM in Kolkata

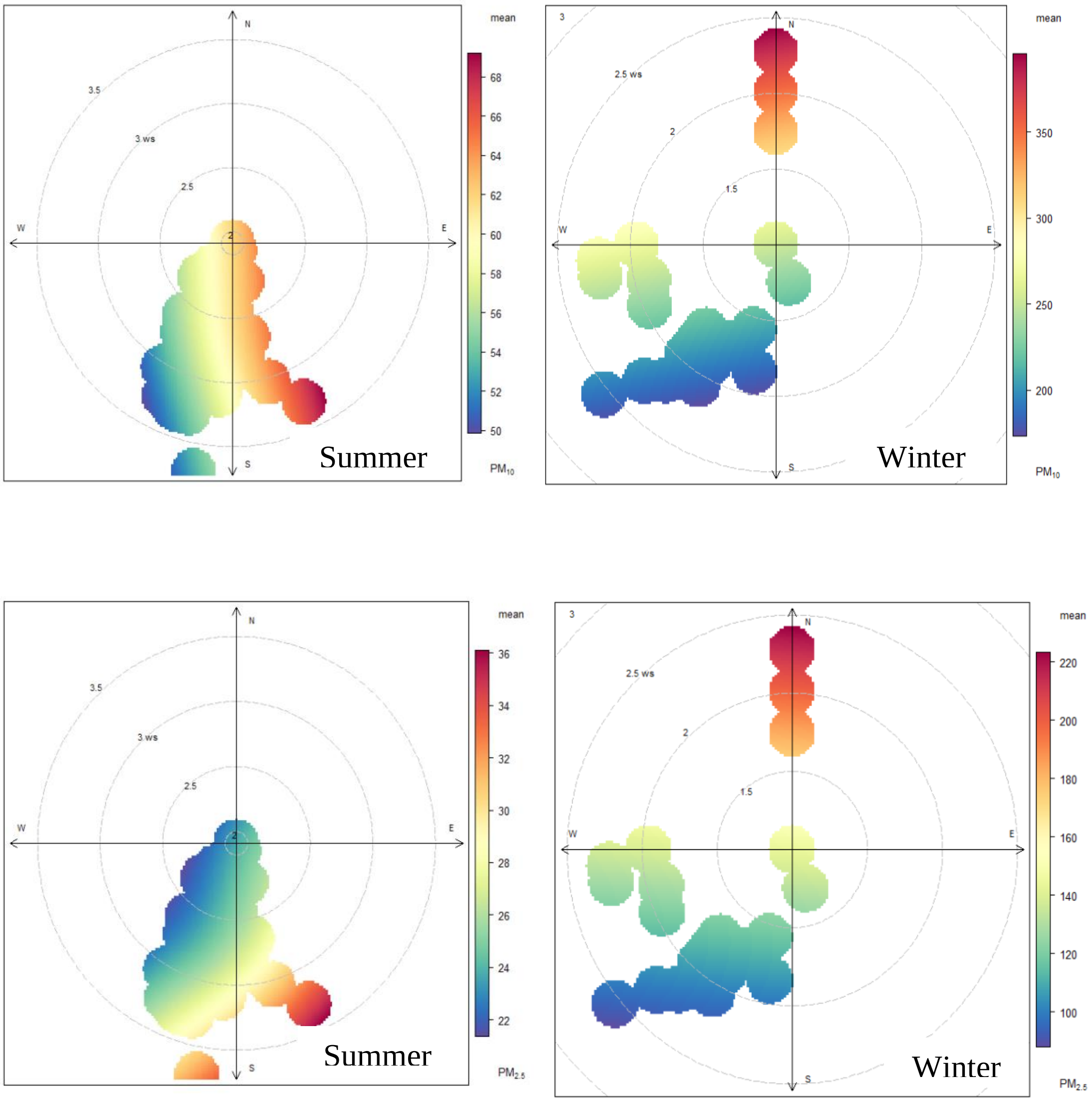


Fig. 5.5b: Bipolar plots for PM in Howrah

Summarizing the findings by bipolar plot, PM_{10} during the summer is mainly from local sources in Kolkata, whereas $PM_{2.5}$ during summer is contributed locally with contributions from nearby and distant sources in Kolkata and Howrah. Contribution from nearby sources to PM_{10} is also seen in Howrah. During winter, PM_{10} and $PM_{2.5}$ are contributed well by local and distant sources in both Kolkata and Howrah. It can be seen that both back-trajectory analysis along with CWT and bipolar plot results match quite well.

Chapter 6

Comparison of Emission Inventory and CMB Results

The EI study aims at delineating the sources of air pollution and their relative contribution in forming the existing scenario in the airshed. The primary emissions from different sources coupled with pollution from immediate neighboring areas, long range transport of pollutants along with secondary particulates formed in atmosphere from gaseous precursors are represented at the receptor points, which is indicated by the CMB modeling results. The CMB results indicate the exposure experienced by receptor. The aim of both the studies is to deal with air pollution, both being essential building blocks towards air pollution management policy formulation for reduction of pollutant at receptor point by target year. However, the validation of the CMB results requires an analysis involving the dispersion modeling with the EI study outcomes considering meteorological influences. The difference is that, the EI result supports the management objective of finding ways and means of reduction of air pollution from their originating sources, and the CMB results provide the foundations for strategies to combat health exposures of individuals and/or communities.

The present study initiated towards the necessaity of preparing an "action plan to tackle the air pollution problem" as mentoned in WBPCB award letter to CSIR-NEERI, relates to the regions covered by the twin city of Kolkata and Howrah. As per reports (State of Environment Report, 2016) ambient levels of PM_{10} and $PM_{2.5}$ persistently breaches the acceptable National Ambient Air Quality Standards (NAAQS) by considerable margins, especially during winter months. As the primary objective of the study was to prepare an action plan for abatement of emission of air pollution from local primary sources, a focus on controlling the local sources indicated by the Emision Inventory outcome may yield immediate results.

Chapter 7

Summary of Source Apportionment Study

A summary of the findings of the above analysis is given below separately for Kolkata and Howrah.

7.1.1 Summer: Kolkata

Based on the preliminary analysis, mass closure, back-trajectory analysis followed by source contribution function and CMB results, it can be observed that PM_{10} is contributed significantly by vehicles (22%), road dust (20%) followed by secondary inorganic aerosols (19%). The contribution of domestic and commercial combustion activities to PM_{10} is 16% followed by construction activity (12%). $PM_{2.5}$ is contributed significantly by domestic and commercial combustion activities (35%), vehicles (22%) and slightly by road dust (10%) and open burning (6%). The secondary aerosol contribution is observed to be 20%. The unaccounted PM_{10} and $PM_{2.5}$ mass is 10.4% and 7.5%, respectively. Secondary ammonium sulphate contribution can be observed to be 11-24% for PM_{10} and 10-21% for $PM_{2.5}$ in mass closure analysis. Ammonium nitrate contribution is observed to be 3-10% for PM_{10} and 0.1-1% for $PM_{2.5}$. The sea salt contribution is observed to be in the range 1-9% and 0-1% for PM_{10} and $PM_{2.5}$, respectively. From back-trajectory analysis, the source regions were identified to be in the SSW direction for air masses associated with PM_{10} concentration, whereas for air masses associated with $PM_{2.5}$ concentration, the contribution of source regions in SSW direction is quite less.

7.1.2 Summer: Howrah

PM_{10} is contributed significantly by domestic and commercial combustion activities (30%) followed by vehicles (21%), road dust and construction (20%) and secondary aerosols (20%). Open burning also contribute to PM_{10} (9%) in Howrah. $PM_{2.5}$ is contributed significantly by domestic and commercial combustion (27%), secondary aerosols (28%) and vehicles (20%). Open burning contribution (16%) is observed to be higher for $PM_{2.5}$ in Howrah as compared to Kolkata. Road dust contributed 10% of $PM_{2.5}$ mass. The unaccounted mass is 0.4% and -1.5% for PM_{10} and $PM_{2.5}$, respectively. The mass closure analysis showed that in Howrah, the secondary ammonium sulphate contribution to PM_{10} and $PM_{2.5}$ mass is 11-18% and 10-21%, respectively. Ammonium nitrate contribution is observed to be in the range 3-3.8% and 0.3-0.4% for PM_{10} and $PM_{2.5}$, respectively. The sea salt contribution is observed to be in the range 1-3% and 0% for PM_{10} and $PM_{2.5}$, respectively.

Based on the above analysis undertaken for summer 2017, it can be inferred that the major source contributing to PM_{10} in Kolkata is road dust followed by vehicles, secondary aerosols and combustion activities. $PM_{2.5}$ is majorly contributed by combustion activities, vehicles and secondary aerosols. In Howrah, the major source contributing to both PM_{10} and $PM_{2.5}$ is combustion activities. $PM_{2.5}$ is also contributed majorly by secondary aerosols in Howrah.

7.2.1 Winter: Kolkata

Based on the preliminary analysis, mass closure, back-trajectory analysis followed by potential source contribution estimation and CMB results, it can be observed that $PM_{2.5}$ is contributed significantly by vehicular activities (25%) after secondary aerosols (32%) and moderately by wood combustion (15%) and coal combustion (9%). The unaccounted $PM_{2.5}$ mass is 13%. Secondary ammonium sulphate and ammonium nitrate contribution is observed to be 32% for $PM_{2.5}$ whereas in mass closure analysis, the contribution of both the compounds was ~15%. OM and EC contribution based on the mass closure analysis were ~23% and 20%, respectively. From back-trajectory analysis, the air masses associated with the high and moderate PM_{10} and $PM_{2.5}$ concentration were observed to be originated in the NNW direction.

7.2.2 Winter: Howrah

Vehicular contribution to $PM_{2.5}$ is observed to be 31% in Howrah. Coal and wood combustion share is 11% each, whereas secondary aerosol contribution is 27%. The unidentified mass is 12%. Back-trajectory analysis revealed that the air masses associated with high and moderate PM contributions have originated from NNW direction.

7.3 Comparison of Summer and Winter Results of CMB

In order to compare the results of Summer and Winter, a comparison table is given in **Table 7.1** and **Table 7.2**. It can be seen that for $PM_{2.5}$, biomass burning contribution has slightly increased in winter in Kolkata. In Howrah, biomass burning contribution has decreased in winter. Fossil fuel burning has decreased considerably in Kolkata during winter as compared to Summer. In Howrah the fossil fuel burning has increased significantly. Road dust (& construction) contribution has also reduced during winter for $PM_{2.5}$ and taken over by secondary aerosol contribution. For PM_{10}, biomass combustion has considerably increased in Kolkata during winter. In Howrah, it is almost similar during summer and winter. Fossil fuel combustion in winter has slightly reduced in Kolkata and Howrah. Road dust (& construction) contribution has reduced in Kolkata. In Howrah, there is as such no significant difference between the two seasons.

Table 7.1: Comparison of Results of CMB for Summer and Winter: $PM_{2.5}$

Source	Summer		Winter	
	Kolkata	Howrah	Kolkata	Howrah
Biomass Combustion	17.3	35.4	19.6	16.3
Fossil Fuel Combustion	45.4	27.8	34.6	42.1
Secondary Aerosol	19.7	28.1	31.7	27.3
Road dust & construction	10.1	10.2	1.2	1.9
Unaccounted	7.5	-1.5	12.9	12.3

Table 7.2: Comparison of Results of CMB for Summer and Winter: PM_{10}

Source	Summer		Winter	
	Kolkata	Howrah	Kolkata	Howrah
Biomass Combustion	6.2	28.9	26.2	26.3
Fossil Fuel Combustion	32.6	31.0	21.9	25.3
Secondary Aerosol	19.1	20.0	21.6	19.6
Road dust & construction	31.7	20.0	17.1	19.8
Unaccounted	10.4	0.0	13.3	9.0

Annexure I

Ironing Vendors (English Version)

Place:	**Nearest landmark:**	**Date:**	**Time:**
Street Name:	Name of vendor:	Shop No.:	Electric iron (Yes/No)
If No, then......			
Fuel Type: 1. 2.	Fuel used/day or Fuel used/month: 1. 2.	Working hours/per day:	Working Days/month:
No. of clothes ironed/day:	Electricity unit used (per month) [or bill paid per month]:	Owner’s signature: Interviewer’s signature:	

ইস্ত্রিওলা (Bengali Version)

স্থান:	**কাছাকাছি বড়ো জায়গা/ বাড়ি:**	**তারিখ:**	**সময়:**
রাস্তার নাম:	ইস্ত্রিওলার নাম:	দোকানের নম্বর :	বৈদ্যুতিক ইস্ত্রি (হ্যাঁ /না)
যদি না হয়, তাহলে......			
জ্বালানির ধরণ: ১. ২.	রোজ / মাসিক জ্বালানি ব্যবহারের পরিমাণ ১. ২.	দৈনিক কাজ (ঘন্টা):	কাজের দিন / প্রতি মাস:
রোজ ইস্ত্রি করা পোশাকের সংখ্যা:	বিদ্যুৎ খরচ (ইউনিট) প্রতি মাসে (গড়ে) অথবা বিল প্রতি মাসে:	মালিকের দস্তখত: সাক্ষাত্কারি দস্তখত:	

Mobile Food Vendors/ Restaurants (English Version)

Place:	**Nearest landmark:**	**Date:**	**Time:**
Street Name:	Van name:		
Name of vendor:	Shop/Stall No.:	Food types:	
Fuel Type: 1. 2.	Fuel used/day or Fuel used/month: 1. 2.	Working hours/per day:	Working Days/month:
Food sold per day (kg):	No. of Air conditioner: Capacity of each AC(tons):	AC usage hours/per day:	Total area(m2): Air conditioned area (m2):
Electricity unit used (per month) [or bill paid per month]:		Owner's signature: Interviewer's signature:	

চলমান / খাদ্য বিক্রেতা (Bengali Version)

স্থান:	**কাছাকাছি বড়ো জায়গা/ বাড়ি:**	**তারিখ:**	**সময়:**
রাস্তার নাম:	ভ্যান নাম:		
বিক্রেতার নাম:	দোকানের নম্বর:	খাদ্যের প্রকার:	
জ্বালানির ধরণ: ১. ২.	রোজ / মাসিক জ্বালানি ব্যবহারের পরিমাণ : ১. ২.	দৈনিক কাজ (ঘন্টা):	কাজের দিন / প্রতি মাস:
প্রত্যহ খাদ্য বিক্রির পরিমাণ (কেজি):		মালিকের দস্তখত: সাক্ষাত্কারি দস্তখত:	

Household (English Version)

Place:	**House Name:**	**Date:**	**Time:**
Street Name:	House No.:	Nearest landmark:	Name of owner:

Number of family member	Occupation	Monthly Family Income
LIG MIG HIG	Owning goods: TV/Radio/Washing machine/ Refrigerator/AC/Personal Computer/Laptop/Heating appliances	Electricity unit used (per month) [or bill paid per month]:
Stove type: Open fire Three brick Traditional Improved Other(specify)	Fuel Types: 1. 2. 3. 4. 5.	Fuel used/day or Fuel used/month: 1. 2. 3. 4. 5.
AC usage hours/per day:	No. of Air conditioner: Capacity of each AC(tons):	Total area(m^2): Air conditioned area (m^2):
Purpose of stove use: Heating/Cooking/Both		Owner's signature: Interviewer's signature:

পরিবার (Bengali Version)

স্থান:	**বাড়ির নাম:**	**তারিখ:**	**সময়:**
রাস্তার নাম:	বাড়ির নং.:	কাছাকাছি বড়ো জায়গা/ বাড়ি:	মালিকের নাম:

পরিবারের সদস্য কজন?	দখলদারি	পরিবারের মাসিক আয়
LIG MIG HIG	জিনিষপত্র: টিভি/রেডিও/ওয়াশিং মেশিন/রেফ্রিজারেটর/এ.সি./ব্যক্তিগত কম্পিউটার/ল্যাপটপ/হিটিং যন্ত্র	বিদ্যুৎ ইউনিট ব্যবহার (প্রতি মাসে) [অথবা প্রতি মাসে বিল শোধ]:
উনুন টাইপ: খোলা আগুন তিনটি ইটের ঐতিহ্যবাহী টাইপ উন্নত অন্যান্য (নির্দিষ্ট নাম)	জ্বালানির ধরণ: ১. ২ . ৩.	রোজ / মাসিক জ্বালানি ব্যবহারের পরিমাণ : ১. ২. ৩.
এ.সি. ব্যবহার (ঘন্টা/দিন)	এ.সি. সংখ্যা: ধারণক্ষমতা (প্রতিটি) (টন):	মোট এলাকা (m^2): এয়ার কন্ডিশন এলাকা (m^2):
উনুন ব্যবহারের উদ্দেশ্য: গরম করতে/রান্না/উভয়		মালিকের দস্তখত: সাক্ষাত্কারি দস্তখত:

Annexure II

Petrol Pump Survey Scheme (As per obtained permission)

Sl No.	Petrol Pump Location (IOCL)	Region	Address	9 AM-12 NOON	12 NOON - 3 PM	3 PM- 6 PM	6 PM - 9 PM	9 PM- 12AM	No. of days of survey in a week
1	Central Kolkata	Sealdah	P-9, C.I.T. Rd, Sealdah, Moula Ali, Kolkata, West Bengal 700014	✓	✓	✓	✓		X 3
2	South Kolkata	Garia	970(P) & 971(P), Baroda Avenue, Baishnabghata - Patuli Connector, Garia Park, Baishnabghata Patuli Twp, Garia, Kolkata, West Bengal 700094	✓			✓	✓	X 2
3	North Kolkata	Dunlop	108, PWD Road, U B Colony, Ashokgarh, Bonhoogly, Kolkata, West Bengal 700035	✓		✓	✓	✓	X 2
4	East Kolkata	SaltLake	2nd Cross Road, DD Block, Sector 1, Salt Lake City, Kolkata, West Bengal 700064	✓		✓	✓		X 2
5	West Kolkata	BBD Bagh	Strand Road BBD Bagh Kolkata WB 700001	✓	✓	✓	✓	✓	X 3
6	Howrah (North)	Jagdishpur	629, Benaras Road, Baigachi Po: Jagdishpurhat, Jagadishpur, Jagadishpur, Howrah, West Bengal 711205	✓	✓	✓	✓		X 2
7	Howrah (~Central)	Panchghora	135/2 Dr. Ahani Dutta Road, Mali Panchghora Howrah 711106		✓	✓	✓		X 2
8	Howrah (East)	Howrah Station area	Howrah Railway Station, Howrah, West Bengal 711101	✓	✓	✓	✓	✓	X 3
9	Howrah (West)	Andul	Haora, NH-117, Kona Express, Howrah, Kamrangu, Andul, Howrah, West Bengal 711112	✓				✓	X 2
10	Howrah (South)	Duliya	Andul Rd, Panchpara, Duillya, Howrah, West Bengal 711109		✓	✓	✓		X 2

Annexure III

Petrol Pump Survey for Vehicular Data Collection

Petrol Pump/Parking lot					Date:							
Address:					Duration:							
Wheel	Stroke	P/D	Sec/First	Y of Pur	km run per day/city	Fuel/mo	Unit	Mileage	Usage freq./mon	CC (Engine)	Make and Model	Av Ocuupancy

Annexure IV

Report on *Air Quality Action Plan*

Count of Coal/Wood/Kerosene users within Kolkata Police jurisdiction

Division Police Station	Total Location	Count of Coal Users	Count of Kerosene Users	Count of Wood Users	Count of Gas/Oven Users	Count of Wood/Kerosene/ Coal/Gas Users
Maidan	12	9	3			
New Alipore	33	11	15			7
Park Street	60	31	23			6
Tollygunge	48	26	20			2
S.P Sarani	73	2	29		32	7
SED	**387**	**199**	**138**	**6**	**25**	**19**
Ballygunge	28	19	9			
Beniapukur	60	38	21			1
Gariahat	42	9	33			
Karaya	84	49	25	5		5
Lake	72	23	15		25	9
Rabindra Sarobar	41	5	33	1		2
Tiljala	38	37	1			
Topsia	22	19	1			2
SSD	**194**	**90**	**92**	**1**		**11**
Bansdroni	5	5				
Garfa	11	11				
Jadavpur	20	15	5			
Kasba	80	38	36			6
Netaji Nagar	13	10	3			
Patuli	17	4	8	1		4
Regent Park	48	7	40			1
SWD	**119**	**80**	**20**	**4**	**8**	**4**
Behala	23	4	16	3		
Haridevpur	18	14	4			
Parnasree	1					
Sarsuna	1					
Taratala	61	48			8	4
Thakurpukur	15	14		1		
Total Count	**2491**	**1346**	**764**	**52**	**176**	**142**

Annexure IV

Report on *Air Quality Action Plan*

Count of Coal/Wood/Kerosene users within Kolkata Police jurisdiction

Division Police Station	Total Location	Count of Coal Users	Count of Kerosene Users	Count of Wood Users	Count of Gas/Oven Users	Count of Wood/Kerosene/ Coal/Gas Users
CD	574	328	128		98	17
Bowbazar	221	71	53		95	2
Burrabazar	90	49	36			5
Girish Park	15	12				3
Hare Street	137	115	21			1
Jorasanko	18	10	1		1	6
Muchipara	40	35			2	
New Market	2		2			
Posta	42	27	15			
TALTALA	9	9				
ED	147	58	31	26		32
Anandapur	32					32
KLC	25			25		
Panchasayar	2	1	1			
Pragati Maidan	33	22	11			
Purba Jadavpur	22	6	16			
Survey Park	33	29	3	1		
ESD	289	223	43	11		12
Beliaghata	67	46	13	7		1
Entally	42	28	9			5
Manicktala	8	1		2		5
Narkeldanga	23	23				
Phoolbagan	13	11		1		1
Tangra	73	51	21	1		
Ultadanga	63	63				
ND	219	144	71	2		2
Amherst Street	40	38	2			
Burtolla	25	20	2	1		2
CHITPUR	33	33				
Cossipore	55	4	51			
Jorabagan	25	15	10			
Shyampukur	8	6	2			
Sinthi	21	20		1		
Tala	12	8	4			
PD	145	89	35			20
Ekbalpore	24	22	1			
Garden Reach	10		1			9
Metiabruz	8	8				
Nadial	7	5				2
NPPS	41	16	23			2
Rajabagan	16	3	7			6
SPPS	22	22				
Watgunge	12	11	1			
WPPS	5	2	2			1
SD	417	138	206	2	45	25
Alipore	51	11	27		13	
Bhowanipore	60	30	30			
Charumarket	8		6	2		
Chetla	23	12	8			3
Hastings	8		8			
Kalighat	41	3	37			

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