Correlation and Source Profiling of Organic Tarry Matter and PAHs in Fine Particulate Matter in Urban Ambient Air

A Thesis

Submitted in fulfillment of the requirement for the
award of the degree of

DOCTOR OF PHILOSOPHY

By

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CANDIDATE'S DECLARATION

I hereby declare that the research work presented in this thesis entitled **"Correlation and Source Profiling of Organic Tarry Matter and PAHs in Fine Particulate Matter in Urban Ambient Air"** submitted for the award of the degree of Doctor of Philosophy in the School of Energy and Environment of Thapar Institute of Engineering and Technology, Patiala is an authenticated record of my own research work carried out under the supervision of Dr. Amit Dhir Associate Professor & Head (School of Energy & Environment) and Dr. Anita Rajor Associate Professor (School of Energy & Environment).

The matter embodied in this thesis has not previously been submitted in part or full to any other university or institution for the award of any degree in India or abroad.

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CERTIFICATE

Certify that the thesis entitled **"Correlation and Source Profiling of Organic Tarry Matter and PAHs in Fine Particulate Matter in Urban Ambient Air"** which is submitted by **Er. Sandeep Garg**, in fulfillment of the requirement for the award of degree of **Doctor of Philosophy** in the School of Energy and Environment, Thapar Institute of Engineering and Technology, Patiala, is a record of candidate's own original and independent research work carried out by him under our supervision and guidance. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

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Executive Summary

In present era, urban air pollution has a serious health concern as the result of rapid urbanization, industrialization, population bloom, increasing automobiles and economic expansion. Air pollution episodes around the world like Meuse valley smog (1930), Donora smog (1948) and London smog (1952 & 1962) caused thousands of deaths due to high air pollution. As per an UNEP and WHO estimate, worldwide more than 500,000 deaths yearly worldwide are caused due to inhalation of particulate matter per annum. Particulate matter plays the significant role on human health in the presence of complex synergistic interrelationships among atmospheric processes such as visibility, precipitation, solar radiation, climate change, cloud formation and acidification. It also affects the features like ecosystems, vegetation and works of art & building materials. The epidemiological studies confirm that the adverse health effects are mainly due to particulate matter, especially smaller particles of $PM_{2.5}$ (<2.5μm in size)

Particulate matter is a complex mixture of organic and inorganic substances suspended in air as solids and liquids. Particulate aerosols are very diverse in size, shape and chemical composition depending on the source, meteorological conditions and geographical localization of the area. It is very essential to elaborate the emission sources of particulate matter in view of the air quality and human health perspectives. The implication of the preventive and control measures to minimize the mass levels of particulate matter is only possible when the emission sources are quantitatively characterized and identified. Source apportionment is based on the fact that the different emission sources of particular location have their characteristic chemical signature or source profile at that site such as potassium has strong association with biomass burning, while aluminum and silicon are strongly associated with crust material. The emissions of various industries are enriched in specific pollutants like iron from steel mills, calcium from cement plants and carbonaceous matter from diesel combustion. An elevation of only $10μg/m^3$ each in fine particulate matter is associated with approximately 4, 6 and 8% increased risk of cardiopulmonary, lung cancer and mortality respectively. Symptomatic or biological effects are determined by the chemical nature, site of deposition within lungs and physiologic responses of the deposited particulate matter. OC is suspected as carcinogenic and mutagenic, whereas EC causes tissue irritation and interferes in lung clearance mechanism. Polycyclic aromatic hydrocarbons (PAHs) among the organic compounds emitted by various combustion processes are likely to be carcinogenic and interferes the functioning of reproduction, hormone and immune systems.

So far much attention has been focused on source apportionment of particulate aerosols in India and abroad, however sources of $PM_{2.5}$ have not been characterized and identified in metropolitan region of Chandigarh (UT, India). This study presents mass levels, chemical characterization of PAHs and organic tarry matter, seasonal variation and source apportionment of $PM_{2.5}$ using three years data of summer and winter seasons from the metropolitan region of Chandigarh tri-city. The metropolitan region of Chandigarh Tricity includes Chandigarh-Mohali-Panchkula with over 2 million of population. Chandigarh is a union territory of India and serves as the combined capital of both states of Punjab and Haryana. Whereas Mohali and Panchkula are district head quarters of Punjab and Haryana states respectively. Chandigarh is located in the foothills of Shiwalik range of Himalayas and 162 miles (260 km) north of New Delhi, the national capital of India. The climate of Chandigarh is humid subtropical with varying temperature (−1 to 46 °C) and the annual average rainfall of 1110mm. Ambient air samples for particulate aerosols were collected from four location namely Sector 12 (Chandigarh), Sector 34 (Chandigarh), Sector 74 (Mohali) and Sector 12A (Panchkula). The present study focused on monitoring of fine particulate matter in ambient air of urban area and to source profile the ambient air and correlate with PAHs and organic tarry matter in fine particulate matter.

Particulate aerosols (PM_{10} and $PM_{2.5}$) were collected from the tricity of Chandigarh, Panchkula and Mohali during summer (April to May) and winter (December to January) seasons of 2013-14, 2014-15 and 2015-16. The mass levels of PM_{10} and $PM_{2.5}$ respectively varied from 69.2-187.5 $\mu g/m^3$ (average 116.4 $\mu g/m^3$) and 40.5-100.3 $\mu g/m^3$ (average 61.7 $\mu g/m^3$) in 2013-14, 79.8-198.0 $\mu g/m^3$ (average 138.9 $\mu g/m^3$) and 43.2-105.7 $\mu g/m^3$ (average 73.1 $\mu g/m^3$) in 2014-15 and 80.1-194.1 $\mu g/m^3$ (average 125.6 $\mu g/m^3$) and 42.4-103.8 $\mu g/m^3$ (average 66.4 $\mu g/m^3$) in 2015-16. The values of PM_{10} and $PM_{2.5}$ respectively exceeded to 24 hourly NAAQ standards of 100$\mu g/m^3$ and 60$\mu g/m^3$ during most of the sampling days which indicate the deteriorating air quality in this tricity. OTM contributes to $PM_{2.5}$ mass as 36.0% in 2013-14, 40.1% in 2014-15 and 35.7% in 2015-16 whereas OTM/OC ratio ranges from 1.57 to 1.71 indicates carbon as the largest component. The concentration of total PAHs (∑PAHs) varied from 5.16 to 72.59 ng/m^3 in 2013-14, 4.95-69.57 ng/m^3 in 2014-15 and 5.38-75.62 ng/m^3 in 2015-16 at the study area.

Presence of these polycyclic hydrocarbons indicates the emissions from combustion processes mainly associated to vehicles and biomass burning.

Markers of PAHs and their diagnostic ratio is used to categorize the anthropogenic and biogenic sources of emission. The ratio of IP/(IP+BghiP) as 0.42 under the range 0.37-0.70 and the ratio of BbF/BkF in the range 1.29-1.31 suggests the influence of diesel emissions whereas the ratio of BaA/BaP as 1.21 indicates the biomass burning. The ratio of BaA/(BaA+Chy) as 0.32 (0.20-0.35) indicates coal combustion in the study area. The diagnostic ratio performed in the study highlight the influence of multiple sources as vehicular emissions, coal combustion and Biomass burning as the main emission sources of PAHs in the study area. Pearson correlation shows higher coefficient among Acy, BghiP, BkF, dBahA, Fln, IP, Pery, Pyr, Chry, OC and EC as first group, high loading of Ant, BbF, BaA and NaP in second group and BaP, Flu, Ret and OTM in third group indicating similar and common sources of origin. Principal component analysis shows three contributory sources of particulate aerosols as vehicular emissions (44.03%), coal combustion (18.85%) and wood & biomass burning (15.88%).

The study describes existing air quality & source inventory in tricity of Chandigarh based on three years long data and it becomes a base to device an effective management plan for air pollution control and emission reduction strategies. The study recommends a comprehensive and regular monitoring of fine aerosols to understand the nature, strength, trend and potential health impacts of emission sources in the region.

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ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
Al	Aluminum
As	Arsenic
Ba	Barium
BC	Black Carbon
BIS	Bureau of Indian Standards
Br	Bromine
BSOM	Benzene Soluble Organic Matter
BTX	Benzene, Toluene and Xylene
°C	Degrees Celsius
Ca	Calcium
Ca^{2+}	Calcium Ion
Cd	Cadmium
CDM	Climatological Dispersion Model
Cl	Chlorine
Cl^{-}	Chloride Ion
CMB	Chemical Mass Balance
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
Cr	Chromium
Cu	Copper
EC	Elemental Carbon
EDXRF	Energy Dispersive X-Ray Fluorescence
F^{-}	Fluoride Ion
FA	Factor Analysis
Fe	Iron
GC-FID	Gas Chromatograph – Flame Ionization Detector
GEMS	Global Environmental Monitoring System
H	Hour
HC	Hydrocarbons

HNO_3	Mercury Nitric Acid
HPLC	High Performance Liquid Chromatography
HVS	High Volume Sampler
IC	Ion Chromatography
ICP	Inductively Coupled Plasma
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
ICP-ES	Inductively Coupled Plasma Emission Spectroscopy
IIT	Indian Institute of Technology
INAA	Instrumental Neutron Activation Analysis
INDOEX	Indian Ocean Experiment
INDOEX-FFP	Indian Ocean Experiment First Field Phase
INDOEX-IFP	Indian Ocean Experiment Intensive Field Phase
ISI	Indian Standard Institution
K^+	Potassium Ion
LPG	Liquefied Petroleum Gas
LPM	Liter per Minute
LRT	Long-range Transport
Mg	Magnesium
Mg^{2+}	Magnesium Ion
MMAD	Mass Median Aerodynamic Diameter
Mn	Manganese
Na	Sodium
Na^+	Sodium Ion
NAAQS	National Ambient Air Quality Standards
NAAQMS	National Ambient Air Quality Monitoring Series
NAMP	National Ambient Air Quality Monitoring Programme
NDIR	Non Dispersive Infrared
NEERI	National Environmental Engineering Research Institute
NH_3	Ammonia
NH_4^+	Ammonium Ion
Ni	Nickel

NMVOC	Non Methane Volatile Organic Compounds
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_3^-	Nitrate Ion
NO_X	Oxides of Nitrogen
O_3	Ozone
OTM	Organic Tarry Matter
PAH	Polycyclic Aromatic Hydrocarbon
PAN	Peroxyacetyle Nitrate
Pb	Lead
PCA	Principal Component Analysis
PCCs	Pollution Control Committees
PEM	Pollution Episodic Model
PIXE	Proton Induced X-Ray Emission
PM_{10}	Particulate Matter of Size ≤10µm in Aerodynamic Diameter
$PM_{2.5}$	Particulate Matter of Size ≤2.5µm in Aerodynamic Diameter
QA/QC	Quality Assurance /Quality Control
Rb	Rubidium
RH	Relative Humidity
RSPM	Respirable Suspended Particulate Matter
Se	Selenium
Sb	Antimony
SO_2	Sulphur Dioxide
SO_4^{2-}	Sulphate Ion
SPCB	State Pollution Control Board
SPM	Suspended Particulate Matter
Sr	Strontium
TC	Total Carbon
TEOM	Tapered Element Oscillating Microbalance
TERI	Tata Energy Research Institute
Temp	Temperature

Ti	Titanium
TNMVOC	Total Non-Methane Volatile Organic Compound
TOC	Total Organic Carbon
TOR	Thermo Optical Reflectance
TOT	Thermo Optical Transmittance
TSP	Total Suspended Particles
TSPM	Total Suspended Particulate Matter
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
UV	Ultra Violet
UV-VIS	Ultra Violet- Visible
V	Vanadium
VOC	Volatile Organic Compound
WHO	World Health Organization
WD	Wind Direction
WS	Wind Speed
WSOC	Water Soluble Organic Carbon
Zn	Zinc

LIST OF UNITS

cm/s	Centimeter per Second
mg/m^3	Milligram per Cubic Meter
m^3/min	Cubic Meter per Minute
ng/m^3	Nano Grams per Cubic Meter
ppbv	Parts per Billion by Volume
ppmv	Parts per Million by Volume
µm	Micron Meter or 10^{-6} Meter
$\mu g/m^3$	Microgram per Cubic Meter
µg/g	Micrograms per gram
%	Percentage

CHAPTER 1: INTRODUCTION

This chapter broadly covers the background of Particulate Matter and PAHs, their chemical characteristics and composition, followed by its source apportionment study and assessment of toxicity.

1.0 Background

In the present era, urban air pollution has a serious health concern as a result of rapid urbanization, industrialization, population bloom, increasing automobiles and economic expansion (Kothai et al., 2011). Air pollution episodes around the world like Meuse Valley Smog (1930), Donora Smog (1948) and London Smog (1952 & 1962) caused thousands of deaths due to high air pollution. As per UNEP and WHO estimate, worldwide more than 5,00,000 deaths are caused due to inhalation of particulate matter per annum. In India, most of the cities are highly polluted and millions of urban Indians are victims of deteriorating air quality due to the increased industrialization and fossil fuel demand (Dickerson et al., 2002).

Particulate matter poses significant impacts on human health in the presence of complex synergistic interrelationships among atmospheric parameters/processes such as visibility, precipitation, solar radiation, climate change, cloud formation, acidification of atmosphere (Revich and Shaposhnikov, 2010); and features like vegetation, ecosystems and art & buildings (Riga-Karandinos and Saitanis, 2005). As epidemiological studies have confirmed, airborne particles especially, smaller particles of $PM_{2.5}$ (<2.5μm in size) pose severe health hazards. Hence, $PM_{2.5}$ has been considered as most significant criteria pollutant of ambient air quality worldwide.

The six common air pollutants such as Particulate Matter (PM), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulphur dioxide (SO_2), ground level Ozone (O_3) and Lead (Pb) are known as criteria pollutants. Inhalation and frequent exposure to fine airborne particulate matter (PM_{10}/ $PM_{2.5}$ fractions) is a major cause of premature deaths and other chronic human health impacts worldwide. Even in fine particulate matter elevated levels of finer fractions (<$PM_{2.5}$ μm) are associated with more fatalities in comparison to coarse fraction (<PM_{10} μm). In general, as particle size becomes smaller or finer, their potential impact on human health is stronger because they can be easily inhaled deeply into lungs and even get into blood stream or tissues. For this reason, particulate matter is monitored and regulated by size as: (I) Coarse fraction ($\geq PM_{10}$), (II) Respirable fraction ($\leq PM_{10}$), (III) Fine fraction ($\leq PM_{2.5}$) and (IV) Ultrafine fraction ($\leq PM_{1.0}$).

United States Environment Protection Agency (USEPA) revised the PM standards in ambient air in 1987, replacing Total Suspended Particulate (Coarse fraction) with PM_{10}, while standard for $PM_{2.5}$ was published in 1997. It revised the standards again in 2006 and introduced stringent 24 hour standard mass limits of $PM_{2.5}$ from 65 to 35µg/m^3.

In India, taking a hint from international trends in regulation of fine particulate matter, standards for PM_{10} were laid down in 1994. In 2009, the NAAQ (National Ambient Air Quality) standards were again revised to incorporate standards for $PM_{2.5}$. A lot of work is therefore needed in the country to better understand about pollution from fine particulate matter and smaller fractions in it as $PM_{2.5}/PM_{1.0}$. Parallel to determining mass concentration of fine particulate matter, it is equally important to determine its toxic constituents due to reported association of exposure to fine particulate matter and diseases. In urban areas due to large scale burning of fossil fuels particularly in vehicles, it is prudent to develop data on organic tarry matter including particulate phase of PAHs (Polycyclic Aromatic Hydrocarbons) in fine fraction of air borne dust ($<PM_{2.5}$ µm). Organic tarry matter is a representative of organic air pollutants that include oxidized hydrocarbons carbons (aldehydes, ketones, oxyacids etc.), polycyclic aromatic hydrocarbons, dioxin and furans etc. Thus, the measurement of organic tarry matter and polycyclic aromatic hydrocarbons provides an accurate idea for anthropogenic emissions associated to combustion of fossil fuels and biomass.

1.1 Particulate Matter

Airborne particulate matter mainly comprises of organic and inorganic substances which are in the form of solids or liquids suspended in air. Particulate matter under the sampling conditions of atmosphere exists almost exclusively in solid phase, but liquid aerosols can also be there in the form of acidic fumes/mists and heavy compounds of diesel combustion. Particulate aerosols are very diverse in size, shape and chemical composition, emission of source and strength, meteorological conditions and geographical localization of the area (Miranda et al., 2002; Aneja et al., 2006).

Particle size is the key parameter which governs transport and removal of particles in the atmosphere as well as deposition of particles in the respiratory system. Particulate matter varies in size from a few nanometers (0.002µm) to around 100µm in aerodynamic diameter. However, significant size of particles in respect to physics, atmospheric chemistry and health hazards lies in the range 0.002 to10µm (CCPA, 2001). Particle size for spherical particles is simply defined as the diameter of particle; however the term "diameter" is not applicable for non-spherical particles such as a flake of material or a fiber. The size of particles having different shapes and densities is measured in terms of aerodynamic diameter. The aerodynamic diameter (da) refers to the diameter of the spherical particle which has unit density of 1.0gm/cm^3. USEPA has classified four categories of the particulate matter having different sizes as- (I) Ultra fine particles (<0.1µm), (II) fine particles (0.1-2.5µm), (III) coarse particles (2.5 to 10µm) and (IV) super coarse particles (10 to 100µm). Particle categorization is important because particulate matter is regulated and tested under these categories. A comparison of different particulate sizes with human hair has been illustrated in **Figure 1.1.**

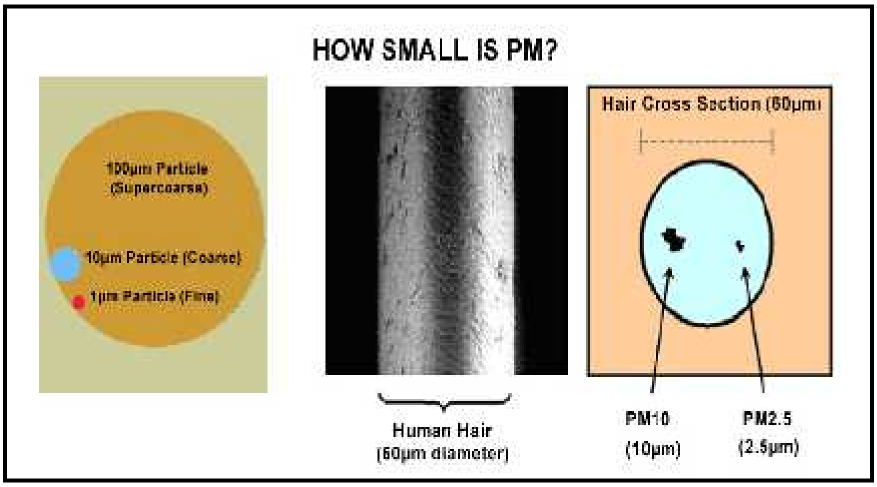

Fig. 1.1: A size wise comparison of particulate matter (CCPA, 2001)

Particulate matter is classified by number of ways depending upon its size, formation and health effects. Based on particle size, particulate matter is generally subdivided into a fine fraction $PM_{2.5}$ (<2.5µm) and a coarse fraction $PM_{2.5-10}$ (>2.5µm), reflecting typically bimodal distribution. The fine mode (<2.5µm) also known as accumulation mode associated with gas to particles conversion and subsequent agglomeration in the atmosphere.

The fine fraction of particulate aerosol (<2.5μm) differs from coarse fraction (>2.5μm) in chemistry and in origin. Fine fraction is generally composed of sulphate, nitrate, ammonium, carbonaceous compounds (organic and elemental), soil dust, acid fumes/mists, water droplets, metallic and volatile species. These aerosols are primarily of anthropogenic origin or secondary emission and tend to be acidic in nature. Forest fires are well known largest natural source and significantly contributes to the fine fraction airborne aerosols. The lifetime of these fine aerosols varies from days to weeks whereas travel distance varies in wide range of 100 kms to more than 1000 kms. Fine aerosols are solely responsible for decreased visibility in atmosphere and climate change.

The coarse fraction (>2.5μm) primarily consisting of crust material (oxides of iron, calcium, silicon and aluminum) is generally formed by natural and mechanical processes. Major sources include crushing and grinding, windblown dust, paved and unpaved roads, agriculture, industry, combustion of fossil fuels and construction & demolition activities. This size range is typically basic in nature. The coarse fraction being heavier in mass and size has shorter life span of minutes to hours and travel distance of less than 1km up to 10km. A few chemical species of nitrates, chlorides, sulphates and trace metals nickel, zinc, copper, manganese, vanadium, tin and antimony are variable and associated to coarse and fine fractions.

On the basis of formation mechanism, particulate matter contains primary components which are directly emitted into the atmosphere whereas the secondary components are formed in the atmosphere as the result of photo-chemical reactions of gaseous components by gas to particle conversion (Campos-Ramos et al., 2011). The emission of primary and secondary particulates depend upon the geographical location of the area and the atmospheric chemistry such as firewood burning and heating fuels during winters emits the particles which are primary in nature, while in summers the photochemical reaction attribute to secondary aerosols in the atmosphere.

The secondary reactions in the atmosphere include sulphur oxides, nitrogen oxides, ammonia and variety of organic and volatile compounds as precursors of secondary aerosols. The resulting secondary particulates include nitrates, sulphates and condensed organic compounds. Sometimes the distinction between the emissions from anthropogenic and natural sources is not possible. For example, emissions from biomass burning and fugitive dust cannot be differentiated due to variations in source emissions from different geographical areas. With reference to health impacts on humans, particulate matter is classified into four categories:

1.1.1 Inhalable Fraction

The inhalable fraction represents the mass fraction of particulate matter inhaled through the nose and/or mouth and which is expressed for air quality as:

$$E = 0.5 [1 + \exp(-0.06D) + 10^{-5} U^{.75} \exp(0.05D)]$$

Where -

D is the aerodynamic diameter of the particle.

U is the wind speed (up to 10 m/s).

1.1.2 Thoracic Fraction

Thoracic fraction of particulate matter (aerodynamic dia <10μm) represents the mass group and size fraction of inhaled particles. This fraction can deeply penetrate to human respiratory system even though beyond larynx.

1.1.3 Respirable Fraction

Respirable fraction comprises of the mass fraction of inhaled particles with median aerodynamic dia ≤ 4 μm. This fraction can penetrate deep into unciliated airways of our lungs

1.1.4 High Risk Respirable Fraction

High risk respirable fraction is the mass fraction of inhaled particles (median aerodynamic dia ≤ 2.5μm) which can cause sickness and/ or infirmity in children.

1.2 Chemical Characteristics of Particulate Matter

The behavior and fate of particulate matter in the atmosphere and within our respiratory system depend upon its physical and chemical properties. Physical characterization of particulate matter includes determination of shape and size; optical properties and molecular; elemental and isotopic structures. Most of epidemiological studies are based on the statistical investigation of mass concentrations and physical properties of PM_{10} and $PM_{2.5}$ with health effects. It is well established that chemical constituents of particulate matter influence the atmospheric processes and induce adverse health effects. Thus, the chemical characterization of particulate matter can help in better understanding of its behavior and influence. The chemical characterization can be divided into elemental, ionic and carbonic analysis.

The elemental composition of particulate matter is mainly contributed by crust sources consisting of the elements such as sodium, potassium, iron, aluminium, magnesium, calcium, manganese, silicon, and strontium. The combustion sources and industrial processes at high temperature emit cadmium, arsenic, chromium, nickel and lead in the vapor form which may quickly condense as the ambient air mixes with the hot exhaust gases. Elemental analysis generally refers to the measurements for total concentrations of 20 to 60 multi-elements. The energy dispersive X-ray fluorescence, proton induced X-ray emission spectroscopy and atomic absorption spectrophotometer are the effective techniques to determine the elements from sodium (Na_{11}) to uranium (U_{92}). Ionic species generally soluble in water are the important components of secondary aerosols which can often be used to distinguish the polluting sources.

Simple ions such as sodium, potassium, calcium and magnesium are best determined by atomic absorption spectrophotometer whereas polyatomic ions i.e. nitrate, sulphate, phosphate and ammonium along with chloride are best determined by ion chromatography and automated colorimetric techniques. Carbonaceous composition of particulate matter is determined in two categories – organic carbon and elemental carbon by thermal manganese oxidation, thermal/optical transmission and thermal/optical reflectance methods. Volatile organic fraction and polycyclic aromatic hydrocarbons are determined by Gas chromatograph with flame ionization detector (GC-FID) or mass spectrometry (GC-MS).

1.3 Chemical Composition of Particulate Matter

The chemical composition of atmospheric particles is very diverse with particle size varying both in space and time. Sulphates present in fine particles arise from the oxidation of SO_2 while silicon found in coarse particles usually arise from the resuspension of surface dusts and soils. Around the world, the particulate samples collected from urban areas typically have similar major components; however their proportions can be different according to the location of sampling sites (Harrison and Yin, 2000).

1.3.1 Sulphate

Particulate sulphate as a secondary component arises mainly from atmospheric oxidation of SO_2. Although sulphate arising from mineral matter such as gypsum or sea salt may be a primary component. The secondary sulphates in majority are found as a combination of ammonium bisulphate (NH_4HSO_4), ammonium sulphate [$(NH_4)_2SO_4$] and dihydrogen sulphate (H_2SO_4). Sulphur dioxide (SO_2) also undergoes change to form sulphate particles through aqueous and gaseous phase transformations. SO_2 reacts with hydroxyl radicals under the gas-phase pathway to form hydrogen sulphite in the atmosphere. The resulting species reacts rapidly with water vapor and oxygen to forming sulphuric acid gas. Under low vapor pressure conditions, this sulphuric acid gas condenses on existing particles and at high relative humidity it nucleates to form a sulphuric acid droplet. It becomes neutralized in the presence of ammonia gas to ammonium sulphate and/ or ammonium bisulphate.

Hydroxyl radical pathway as another gas-phase pathway also contributes significantly to a large extent. SO_2 present in atmosphere dissolved in droplets under aqueous reaction and reacts faster than gas-phase reactions when clouds and/ or fogs are present. Dissolved sulphur dioxide is oxidized quickly to sulphuric acid mist in the presence of hydrogen peroxide and ozone. The resulting sulphuric acid neutralizes to ammonium sulphate in the presence of ammonia and dissolves in the water droplets. When the clouds and/ or fogs evaporate and relative humidity decreases less than 100 per cent, then the resulting sulphate droplets contain a small fraction of liquid water. These sulphate droplets evaporate into small and solid sulphate particles when relative humidity further undergoes less than 70 per cent. The same reactions occur very fast in fog droplet and controlled by the presence of precursor gases and their rate of solubility. Aqueous transformation of sulphur dioxide to sulphate is 10 to 100 times faster than the gas-phase reactions.

1.3.2 Nitrate

Particulate nitrate arises from atmospheric oxidation of nitrogen dioxide (NO_2) as secondary pollutant. Particulate nitrate is normally present as ammonium nitrate (NH_4NO_3) resulting from neutralization of nitric acid (HNO_3) vapour by ammonia (NH_3). It can also be present as sodium nitrate ($NaNO_3$) resulting from chemical reaction of HNO_3 vapour by sodium chloride (NaCl). Nitric oxide (NO) is directly emitted into atmosphere and converted to nitrogen dioxide (NO_2) in presence of ozone. The nitrogen dioxide present in atmospheric principally undergoes to various gas-phase pathways as:

(1) In the presence of UV radiations, it can again convert to nitric oxide;

(2) It can get converted to radical species as precursor for another chemical reaction;

(3) Nitrogen dioxide can form peroxyacetyle nitrate and other organic nitrate species; and

(4) Can oxidize to nitric acid.

The hydroxyl radicals react with nitrogen dioxide and form nitric acid or convert the sulphur dioxide into sulphuric acid. The rapid deposition of nitric acid in the atmosphere is finally neutralized to ammonium nitrate in presence of ammonia. Nitrate formation also occurs during aqueous-phase transformations analogous to aqueous-phase transformation of sulphate during fogs and clouds. In aqueous phase or under moisture conditions, nitrogen dioxide changes to ammonium nitrate in the presence of dissolved ammonia or nitric acid in the presence of oxidants.

1.3.3 Ammonium

The occurrence of ammonium (NH_4^+) in the atmosphere takes place by the process of gas to particle conversion of ammonia (NH_3) gas (Adams et al., 1999). NH_3 is present in atmosphere as most abundance alkaline species. It comes from natural decomposition of nitrogenous organic matter/fertilizers, farming of animals, oceanic emissions and biomass burning (Tiwari et al., 2008). Ammonium rapidly reacts with acidic species sulphate and nitrate and forms salts of ammonium sulphate or ammonium nitrate in the atmosphere.

1.3.4 Sodium and Chloride

Sodium and chloride mainly originate from sea salt.

1.3.5 Carbonaceous Matter

Carbonaceous matter represents the complex mixture of variety of chemical substances consisting of carbon. Carbonaceous matter is generally classified as organic (OC) and elemental carbon (EC).

Organic Carbon

Organic carbon is emitted in to the atmosphere as primary as well as secondary emission sources through photo-chemical reactions of precursor organic species.

Elemental Carbon

Elemental carbon (EC) is usually known as inorganic, black or graphitic carbon. EC is primary in origin and product of incomplete combustion of fossil fuels and biomass burning. Elemental carbon is generally considered as the index of air pollution from diesel vehicles (Takahashi et al., 2008) and a primary light-absorbing species in the atmosphere which significantly affects the radiation balance and the climate of earth (Huang and Yu, 2007; Ramanathan and Carmichael, 2008).

1.3.6 Mineral (Crust) Material

Crust material originates from soil and rocks that is enriched in calcium, iron, silicon and aluminium. Crust material is generally present in coarse dust arising from windblown dust, entrainment processes, and anthropogenic sources such as quarrying, construction and demolition activities (Harrison et al.1997a, b).

1.3.7 Water

Water from atmosphere is absorbed as water vapour by airborne particles especially salts of ammonium nitrate (NH_4NO_3), ammonium sulphate [$(NH_4)_2SO_4$] and sodium chloride (NaCl). During higher conditions of relative humidity, these species are transformed from crystalline solids to droplets of liquid. This transformation occurs at deliquescence point (specific humidity) where dry crystals get exposed to highest level of humidity. As a result, even after drying at 40 to 50% relative humidity, particles sampled from the atmosphere retain airborne water that contribute significantly in particulate mass.

1.3.8 Trace Metals

Trace metals like zinc, nickel, chromium, cadmium, manganese, lead, and mercury are used in metallurgical processes, while others occur as additives or impurities in fuels. Industrial processes and products also contribute to emissions of these trace metals.

1.3.9 Trace Organic Compounds

Trace organic compounds comprises a significant part of particulate mass such as alkanes, alkenes, carboxylic acids, carbonyl, aromatic compounds (PAHs) and volatile organic compounds. These compounds originate either from primary sources as industrial and/or automotive or secondary emissions from the oxidation of volatile organics (VOCs). Generally, primary organics arise directly from fuel combustion and tend to have high hydrogen to carbon ratio. The secondary organics are more oxidized and often consist of poly-functional carbonyl and carboxylic acids.

In urban areas due to large scale burning of fossil fuels particularly in vehicles it is prudent to develop data on organic tarry matter including particulate phase of polycyclic hydrocarbons (PAHs) in the fine fraction. Organic tarry matter is a representative of organic air pollutants that include polycyclic hydrocarbons, oxidized hydrocarbons (ketones, aldehydes and oxyacids), dioxin and furan etc.

Airborne PAHs has been considered as major cause of adverse health impacts due to their carcinogenic (causing cancer) and mutagenic nature (Villalobos-Pietrini et al. 2007). These are complex organic compounds which have at least two benzene rings in their structure having carbon – hydrogen bond between them (Ravindra et al. 2008a&b). They originate mainly from anthropogenic activities associated to incomplete combustion of fossil fuels (oil, coal, petroleum) and pyrogenic sources as biomass burning (ATSDR 1995 and Takasuga et al. 2007)). In urban areas, the high vehicular density, industrial activities and low dispersion conditions of atmosphere are conducive for higher mass emissions of airborne Organic tarry species and PAHs (Caricchia et al. 1999). Emissions from vehicular exhaust contain most of the PAHs classified as carcinogens (Park et al. 2011). United States Environmental Protection Agency has included a total of sixteen PAHs in the list of 188 air pollutants of hazardous in nature (Ravindra et al. 2008a &b).

The classification of PAHs can be performed on the basis of their molecular weights as less than or equal to four aromatic rings called as low molecular weight (LMW) and four or more aromatic rings as high molecular weight (HMW) PAHs (Kaur et al. 2013). Various studies have showed PAHs of LMW category mainly from products of wood, oil and biomass combustion (Khalili et al. 1995 and Wilcke 2007) whereas PAHs of HMW arising from vehicular emissions and coal combustion (Khalili et al. 1995 and Marr et al. 1999). Hence, the source identification can be done by using ratios between PAHs of LMW and HMW. Sources are considered for the ratio <1 as pyrolytic sources, while the ratios >1as petrogenic sources (Mastral and Calle´n, 2000).

As per the global emission inventory of total sixteen PAHs in 2004, India ranks second with the mass emissions of PAHs as 90 giga grams per year (Gg/year) equals to 3.6% of the mass proportion of hazardous high molecular weight compounds than the global average (Zhang and Tao 2009). The PAHs show higher correlation with $PM_{2.5}$ than PM_{10} (Yang et al. 2012) and HMW fraction dominant over LMW (Aryal et al. 2011).

1.4 Source Apportionment of Particulate Matter

It is very essential to elaborate the emission sources of airborne particles in view of air quality status, human health and environmental perspectives. The implication of the preventive and control measures to minimize the mass levels of particulate matter is only possible when the emission sources are quantitatively characterized and identified (Viana et al., 2006). Source apportionment is factually based on different emission sources of particular location with their source profile and/ or characteristic signature at that site for example, potassium has strong association with biomass burning, while aluminium and silicon are strongly associated with crust material. The emissions of iron and steel mills are enriched in iron, cement plants emission enriched in calcium, while diesel emissions are enriched in carbonaceous matter. Signatures/markers for specific source are listed below in **Table 1.1**.

Table 1.1: Signatures/markers of source emissions

Source	Signature/Marker	Reference
Wood Burning	Al, BaP, Flu, Ret, Pb, Zn, stigma sterol	Larson & Baker 2003, Kulkarni et al. 2014, Lv et al. 2016, Dvorska et al. 2012
Coal Combustion	Ant, BbF, BaA, NaP, Picene, Se, As, SO_2	Larson and Baker 2003, Kulkarni et al. 2014, Lv et al. 2016; Gupta & Chakraborty 2010); Kumar et al. 2001
Biomass Burning	BaP, Flu, Ret, OTM, K,	Larson & Baker 2003, Kulkarni et al. 2014, Lv et al. 2016, Dvorska et al. 2012
Diesel Vehicle	Pyrene, Flu , BkF, EC, Mn, Fe	Yunker et al. 2002
Petrol Vehicles	Coronene, Acy, IP, Pery B(ghi)P, OC/EC, Ni, Na	Hoe et al. 2009; Guo et al. 2003; Ravindra et al. 2008a&b

Source apportionment of particulate aerosols from urban atmosphere is a complicated issue due to various reasons as (i) numerous source categories anthropogenic, natural and biogenic contributing to primary and secondary components (ii) inadequate characterization of all emission sources; and (iii) variability in emission pattern and sources due to different shapes, sizes, densities and lifetimes of pollutants, atmospheric chemistry, varying geographical and climatological conditions of the area.

1.5 Health Effects of Particulate Matter

Airborne particulate matter is a serious concern worldwide since it is linked with wide ranging health effects. Size, chemical nature and quantity of particulate matter in the atmosphere plays a vital role in human health. Notorious acute air pollution episodes like Meuse Valley smog (1930), Donora Smog (1948) and London Smog (1952, 1962) caused heavy mortality. These episodes clearly indicate that short-term elevated levels of particulate matter and sulphur dioxide are associated with various pulmonary disorders and mortality. As per UNEP and WHO estimate, about 5,00,000 people die each year due to inhalation of particulate matter worldwide among which 1,35,000 are victims of chronic asthma and rest die of heart or cardiovascular diseases. Suspended particulate matter dominated by 68% of respirable particulate matter ($<PM_{10}$) is associated with mortality of 9.5% (Samoli et al., 2001). An elevation of 10µg/m^3 each in fine fraction ($<PM_{2.5}$) is associated with increased risk of mortality, lung cancer and cardiopulmonary in approximate to 8, 6 and 4% (Pope III et al., 2002). In beginning of 20th century, lung cancer has been reported as a rare disease which has now become a leading cause of death in industrialized era of present world at a rate of 0.5% per annum accounted for about 13% of total deaths. As per physiological study, particulate matter in a range of 207 to 733µg/m^3 can increase pulmonary inflammation in rats (Clarke et al., 1999).

Symptomatic or biological effects are determined by the chemical nature, site of deposition within lungs and physiologic responses of the deposited particulate matter. The particulate components such as nitrate, sulphate, acidity, transition metals, organic carbon (OC) and black or elemental carbon (EC) are responsible for adverse health effects. OC is suspected as carcinogenic and mutagenic, whereas EC causes tissue irritation and interferes in lung clearance mechanisms.

Polycyclic aromatic hydrocarbons (PAHs) among the organic compounds emitted by various combustion processes are carcinogenic in nature and interfere with the functioning of reproduction, hormone and immune systems. Benzo[k] fluoranthene, benzo[j] fluoranthene, benzo[b] fluoranthene, benzo[a] pyrene and benzo[a] anthracene are directly mutagenic, whereas others are indirectly mutagenic in Salmonella (Mumtaz and George, 1995). Since PAHs emissions in the atmosphere are often associated with vehicular pollution, hence the population in urban areas experience higher exposure of petrochemical pollution and are under higher risk of lung cancer than the population of low pollution or rural areas (Yang et al., 1999).

In the atmospheric environment of India, particulate phase PAHs 22.91-190.96 ng/m^3 in Kolkata (Chattopadhyay et al., 1998) and 20-172 ng/m^3 in Coimbatore (Mohanraj and Azeez, 2004) are apparently higher than National Ambient Air Quality (NAAQ) Standards. Inorganic salts which serve as the reactive surface can enhance the deposition and condensation of harmful compounds. Toxic metals in association with particulate aerosols have a significant role in human health. The metallic species are derived from fossil fuel combustion; vehicular and industrial sources act as catalysts and activate biological processes.

1.6 Aim of the Study

So far, much attention has been focused on source apportionment of particulate aerosols in India and abroad, however sources of $PM_{2.5}$ have not been characterized and identified in metropolitan region of Chandigarh. This study presents mass levels, chemical characterization of PAHs and/ organic tarry matter, seasonal variability and source apportionment of $PM_{2.5}$ using three years data of summer and winter seasons from tri- city of Chandigarh-Mohali-Panchkula. The specific objectives of the study are described as to monitor airborne fine particulate matter in urban area and source profiling of ambient air, correlation of PAHs and organic tarry matter in fine particulate matter.

CHAPTER 2: REVIEW OF LITERATURE

This chapter summarizes substantive findings of evaluation and assessment of more than 300 scholarly articles published on the various aspects of research related to particulate aerosols and PAHs over a period of three decades, since 1990. The review has been conducted and compiled to synthesize historical research evidence to effectively support the key objectives of the study and provide a significant foundation for the research. Thus, this chapter helps us to understand the present state of affairs under research performed for chemical characterization and source apportionment of OTM and PAHs in Fine Particulate Matter and identify the potential research gaps to be filled up during the study, as per our objectives.

2.0 Standards of Particulate Matter

EPA Standards in United States of America

USEPA announced the first NAAQ (National Ambient Air Quality) standards with respect to PM_{10} (inhalable particles equal to or smaller than 10 micrometers) in 1987 as 24 hourly average standard of 150 micrograms per cubic meter ($\mu g/m^3$) and the annual average standard as $50\mu g/m^3$. In 1997, USEPA added $PM_{2.5}$ ($\leq 2.5\ \mu m$) as target particles and set the standards as annual average of $15\mu g/m^3$ and 24 hourly average of $65\mu g/m^3$. USEPA again revised 24 hourly average standard of $PM_{2.5}$ in 2006 from $65\mu g/m^3$ to $35\mu g/m^3$ whereas annual average standard remains same as $15\mu g/m^3$.

NAAQ Standards in India

In India, the air pollution standards were first laid down in 1981 when the Air (Prevention & Control of Pollution) Act 1981 was notified. The standards included measurement of Suspended Particulate Matter (SPM$\leq$100µm) only among various particulate fractions. These standards were amended in 1994 and notified for Respirable Particulate Matter (RSPM/PM_{10}) as per MoEF Notification: GSR 176 (E) April 2, 1996 prescribed for three categories as industrial, residential and sensitive areas. In 2009, NAAQ standards were amended with removal of SPM and addition of $PM_{2.5}$ under the area categorization as (I) Industrial area, Residential/ Rural area & others and (II) Sensitive area as per MoEF Notification: GSR 826 (E) Nov. 18, 2009 **(Table 1.2)**.

Table 1.2: National Ambient Air Quality Standards (NAAQS), 2009

Pollutant	**Time Weighted average**	**Concentration in Ambient Air**		**Methods of Measurement**
		Industrial, Residential, Rural and other area	**Ecologically sensitive area (Notified by Central Government)**	
Sulphur Dioxide SO_2 µg/m³	Annual *	50	20	o Improved West & Gaeke o Ultraviolet
	24 hours **	80	80	
Nitrogen Dioxide as NO_2 µg/m³	Annual*	40	30	o Modified Jacob & Hochheiser (Na-Arsenite) o Chemiluminescence
	24 hours **	80	80	
Particulate matter PM_{10} (≤10µm) µg/m³	Annual *	60	60	o Gravimetric o TOEM o Beta attenuation
	24 hours **	100	100	
Particulate matter $PM_{2.5}$ (≤2.5µm) µg/m³	Annual *	40	40	o Gravimetric o TOEM o Beta attenuation
	24 hours **	60	60	
Ozone (O_3) µg/m³	8 hours **	100	100	o UV photometric o Chemiluminescence o Chemical method
	I hour **	180	180	
Lead (Pb) µg/m³	Annual*	0.50	0.50	o AAS/ ICP method after sampling on EPM 2000 or equivalent filter paper o ED – XRF using Teflon filter
	24 hours **	1.0	1.0	
Carbon Monoxide mg /m³	8 hours **	02	02	o Non Dispersive Infra Red (NDIR) spectroscopy
	I hour **	04	04	
Ammonia (NH_3), µg/m³	Annual *	100	100	o Chemiluminescence o Indophenol blue method
	24 hours **	400	400	
Benzene (C_6H_6) µg/m³	Annual*	05	05	o Gas chromatography based continuous analyzer o Adsorption and desorption followed by GC analysis
Benzo(a) Pyrene – (BaP), ng/m³	Annual *	01	01	o Solvent extraction followed by HPLC/GC analysis
Arsenic (As) ng/m³	Annual *	06	06	AAS/ ICP method after sampling on EPM 2000 or equivalent filter paper
Nickel (Ni) ng/m³	Annual *	20	20	o AAS/ICP method after sampling on EPM 2000 or equivalent filter paper

Source: Central Pollution Control Board

2.1 Monitoring of Particulate Matter

In India, ambient air is being monitored under NAAQM (National Ambient Air Quality Monitoring) program in 25 States and 4 Union Territories (126 cities/towns) at 341 stations by National Environmental Engineering Research Institute (NEERI), State Pollution Control Boards (SPCBs), Pollution Control Committees (PCCs) and various other institutions in coordination with Central Pollution Control Board (CPCB).

A size distribution study describes more than 85% aerosols are less than 12.5µm in size at industrial area in Mumbai (Sharma and Patil, 1991). Study on particle size distribution, reported fine particles < 2.1µm accounting for 45.4% and coarse particles >2.1µm accounting for 54.6% to TSPM at industrial area in Mumbai (Khemani et al., 1994), whereas smaller particles <2.0µm accounts for 52% to TSPM in Agra and 68% to PM_{10} mass in Delhi (Kulshrestha et al., 1995a). Another study on chemical characterization of airborne individual particles and its distribution in number and size of mineral aerosols, highlighted coarser particles more than 1.0µm during Asia-Dust Storm (ADS) while mineral particles less than 1.0µm were dominant in non-ADS collections. Respirable fraction (<2.5µm) accounts for 99% of the total particulate mass comprising of soot aggregates as the most abundant components, while fly ash (spherical particles) were enriched during summer season (March) and domestic coal-burning was indicated as predominant source of emission (Shi et al., 2003).

The study on air pollution and health indicate that the emissions of small particulates (PM_{10}) and SO_2 are responsible for 95% of the health damage in India (Khillare et al., 2004). Another study on events of dust storm and daily mortality in Taipei (Taiwan) reported that the dust storm increases risks of respiratory diseases by 7.66% after a day of event, risks of total deaths by 4.92% and risks of circulatory problems by 2.59% after two days of the event (Chen et al., 2004).

Moreno et al. (2007) demonstrated annual average mass levels of PM at urban traffic intersections, in European cities as high as 50-100% above the WHO standards. The situation exerted high urban $PM_{2.5}/PM_{10}$ ratio indicating predominance of finer fraction which when inhaled goes deeply in our lungs and has the potential of detrimental health impacts. Satsangi et al., (2007a) reports the mass concentrations for $PM_{2.5}$, PM_{10} and NO_2 as 2 to 3 times higher than the WHO standards, indicating deteriorated air quality in Agra and $PM_{2.5}/PM_{10}$ ratio suggests 54% of PM_{10} constituted by fine fraction of $PM_{2.5}$. A strong correlation of NO_2 with $PM_{2.5}$ and PM_{10} suggests road traffic as a common source and no correlation between $PM_{2.5}$ and PM_{10} shows both fractions originate from different sources.

Ostro et al. (2007) obtained daily data on mortality and $PM_{2.5}$ mass from 2000 to 2003. The study examined associations of $PM_{2.5}$ with mortality. It indicated that mortality, respiratory and cardiovascular disorders influence the age group > 65 years. The multiple mortality categories were found to be highly associated with $PM_{2.5}$ mass whereas cardiovascular deaths were more prone to $PM_{2.5}$ fraction. Thai et al., (2008) elucidated the health impacts associated with PM exposures in variety of land uses and in traffic dominated urban areas. During each of daily bicycle traverse, mass levels of PM_{10} and $PM_{2.5}$ varied between 26-77 and 7-34 $\mu g/m^3$ respectively. The study concluded that the factors significantly affecting exposures along the designated bicycle routes were associated to the proximity of traffic and land use pattern in the area. Measurement of PM_{10} and levels of Lead (Pb) over Madurai in Tamil Nadu presents the mass concentrations in the range of 88.1 to 226.9$\mu g/m^3$ and 0.21 to 1.18$\mu g/m^3$ respectively (Bhaskar et al., 2008).

A study estimated air quality for PM_{10}, CO, SO_2, O_3 and NO_2 from January 1997 to December 2006 in the Klang Valley of Malaysia and reported that the mass concentrations of PM_{10} and O_3 associated with meteorological factors especially of sunlight and air temperature, while other pollutants are more influenced by the number of automobiles (Azmi et al., 2009).

Brunekreef et al., (2009) reported increasing evidence of long-term exposures of air pollution which cause cardiopulmonary diseases and mortality deaths. This study also highlighted that the traffic induced air pollution at the local scale causes cardiopulmonary mortality. Díaz-Robles et al., (2009) found that the diesel particulate matter (DPM) in the size range of fine and ultra fine poses high cancer risk and great health concern. The annual DPM contribution to total $PM_{2.5}$ was reported as 3.7, 2.5 and 2.2% respectively in Atlanta, Nashville, and Birmingham. A study of elemental composition of particulate matter from Dar-Es-Salaam Tanzania during August 16 to September 16, 2010 (dry season) reported strong correlation among the most of elements in coarse mode, while weaker correlation in fine mode suggesting similarity in origin of sources (Mkoma et al., 2010). Houda et al. (2011) did exploratory study to estimate the low levels of particulate pollution. The study was based on vertical integrated optical measurements to facilitate PM_{10} monitoring by remote sensing observations to build relationship between Aerosol Optical Thickness (AOT) and particle mass concentration and it concluded that the strong correlation between AOT and PM_{10} was directly associated to the geographical location and the meteorological conditions of the area.

2.2 Chemical Characterization of Particulate Matter

2.2.1 Polycyclic Aromatic Hydrocarbons (PAH)

An intensive seasonal measurement campaign for particulate and vapor phase polycyclic hydrocarbons from urban locations in Birmingham (UK), using PCA followed by MLR technique, demonstrates the measurement of PAHs along with inorganic pollutants as the powerful tracer of source categories than PAHs alone (Harrison et al., 1996). Another study of non-methane hydrocarbons reports higher levels of C_2-C_5 hydrocarbons than C_6-C_{10} hydrocarbons and benzene concentration as 5 ppb in the proximity of a refinery in Mumbai. It suggested Principal Component Analysis as a significant tool for source identification of different hydrocarbons. A comparison between the ratios of hydrocarbon acetylene and benzene-toluene, elaborated industrial emissions to be predominant over vehicular emissions in the urban region (Mohan Rao et al., 1997).

In Kolkata, elevated levels of benzene and toluene are reported by Chattopadhyay et al. (1997), whereas benzene, toluene and xylene are measured in the range of 1,000 to 8,000μg/m^3, 100 to 1,200μg/m^3, and 60 to 120μg/m^3 respectively in winters during 1992-1994 (Samanta et al., 1998). Particulate phase VOCs were observed from Delhi, in the range of 1.3 to 32.5 ppm with peak values at 0900 hour during heavy traffic density, showing a wide temporal as well as seasonal variation attributing to the solar radiation intensity and meteorological conditions (Padhy and Varshney, 2000). The measurement of polycyclic hydrocarbons species from the atmospheric air of Calcutta (Chattopadhyay et al., 1998), Durg in Madhya Pradesh (Pandey et al., 1999) and Mumbai (Venkataraman et al., 1999; Kulkarni and Venkataraman, 2000; Sahu et al., 2001) shows the site specific contribution, whereas source quantification indicates oil combustion in industries and vehicles as primary sources of PAHs.

In 2008, a study was conducted in Mumbai, India in which PAHs in different sizes of aerosols were characterized and their dry deposition rate was estimated. It was indicated that dry deposition of PAHs was mainly due to gravitational settling of coarse particles. The results of the study identified that mostly PAHs were adsorbed on pre-existing aerosols associated with fine particles. (Sahu et al., 2008). In 2009, a study was conducted at Industrial area Agra, in which sixteen PAHs were identified in Total Suspended Particulate Matter (TSPM). Out of which, major high molecular weight PAHs included Benzo(a)pyrene, Benzo(ghi) Perylene, indeno(123cd) pyrene and Dibenzo(b) anthracene. The study concludes that BaP is considered as the most abundant PAH in urban area with average concentration lying between 0.7-176 ng/m^3. Diagnostic ratio was used as a tool to identify the potential sources of PAHs in aerosols. Vehicular influence is assessed from IP/(IP+BghiP) having value 0.29, BaP/(BaP+Chy) attributed to diesel emission with a value of 0.97 and the ratio of IP/BghiP with value 0.407 attributed to gasoline (Rajput et al., 2009). Similar study was conducted in Baoji, China where PAHs in PM_{10} were collected in 2008 during winter and spring seasons. The results of the study indicate that there is much increase in PAHs mass in winter due to increase in coal usage in house heating (Xie et al. 2009).

The investigation of polycyclic aromatic hydrocarbons from December 2005 to December 2006 at an urban and industrial site in Agra shows a significant seasonal variation with higher mass concentration in winter attributing to the changes in emissions rates and meteorology (Rajput and Lakhani, 2010). Shaofei et al. (2011) studied the characteristics of PAHs in various ash contents in the size range of PM_{10} fraction collected from iron smelt, coke production, heating station and stack emissions of power plants in Lianing Province, China. The total mass of PAHs varied from 290.2-7055.7 µg/g for 17 identified species and 140.3-3345.5 µg/g for carcinogenic species. The toxicity index of ash content was highest in coke production plants followed by coal based power plants, iron smelters and heating stations.

A study was conducted in 2012 in Agra, India where major industries use coal and coke as a fuel in cupola furnaces along with natural gas. Results of the study showed that HMW (High Molecular Weight) PAHs BghiP, DbA, IP &BaP were predominant in the area. The diagnostic ratios indicated that IP & BghiP were main source of diesel emissions because the ratio of IP/ (IP+BghiP) was found to be 0.72. BaP & BaA were associated as the source of gasoline, as the ratio of BaA/BaP was 0.50; whereas BbF & BkF were associated to be the sources of diesel emissions (BbF/BkF > 0.5). In 2012, study was conducted in Bogota where researchers prove that exposure and inhaling of PAHs and PM_{10} was due to heavy traffic flow in Bagota. It was recorded that emissions in case of bus was much higher when compared to Van. The study concludes that greater exposure to PAHs was due to poor maintenance of buses and also due to aggressive driving pattern of drivers (Pachon et al., 2013).

The study on characterization of PAHs in $PM_{2.5}$ & PM_{10} was conducted in 2012, in Tanngu district of China. The mass concentrations of PAHs varied from 8.47 - 113.94 ng/m^3 and 21.07 - 118.23 ng/m^3 for $PM_{2.5}$ and PM_{10} fractions respectively. The study showed that low molecular weight PAHs (2-3 rings) were dominant when compared to high molecular weight PAHs. Moreover, there was strong relationship between $PM_{2.5}$ and PAHs as compared to PM_{10}. Three factors were identified as the sources for emission, which includes coke production, pyrogenic sources and vehicular sources (Yang et al., 2012). In 2014, research on characterization and source identification of polycyclic aromatic hydrocarbon was done in Visakhapatnam, India. In which, researchers found sixteen particles bound to PAHs in industrial and residential areas. The dominating PAHs in that area were Acy, Ace, Phen, Pyr, B(a)P, B(k)F and B(ghi)P. It showed that concentration of these PAHs is almost twice in winter when compared to summer and 2.6 times as compared to monsoon seasons. Study also indicates that low molecular weight (2-3 rings) PAHs are predominant in these areas (Kulkarni et al., 2014). In August 2014, PAHs identification and characterization was performed in the Agra city where 3-4 rings PAHs were found in abundance as compared to other PAHs. The dominance of 3-4 ring PAHs showed the biomass combustion and vehicular emissions were the major sources. Health risk assessment was also performed on the basis of BaP equivalent (Dubey et al., 2014). Similarly in 2014, a research paper published on source apportionment of PAHs in New Delhi reported higher mass concentrations in winter as compared to other seasons due to combustion of fuel for household and space heating purposes. The emissions of PAHs were found to be associated to petrol/ diesel driven vehicles and diesel fumes of generator sets (Sharma et al., 2014).

Seasonal variations of PAHs were observed in Mexico in 2014 and the results indicated that 86-97% portion of PAHs comprised of vapor phase aerosols. Naphthalene was the most abundant PAH contributing around 84-93% of the total mass. On the other hand, BaP was found to be 7% in particle phase, while 0.2-1 % in gas phase. The overall study concluded that vehicular emissions along with diesel and gas combustion was the major contributors in PAH emissions. Also PAH concentration was 2-8 times higher in winter/cold season at industrial site as compared to other seasons. The carcinogenic effect of PAH was estimated by TEF (Toxicity Equivalent Factor) in which BaPeq concentrations were determined. The value of toxicity equivalent factor (TEF) was found to be much greater as compared to proposed standards that impose a health risk to the habitants of Mexico City (Mugica et al., 2012).

The researchers from university of Ghana performed a study at a toll booth on major highway & found a good correlation between PAH level and vehicular traffic. The most identified PAHs contained five rings, while low molecular weight PAHs was less in number. Analysis of diagnostic ratio identified that petrogenic sources like gasoline and diesel as the major pollutants for PAHs emission. BaP equivalent was calculated for estimating the lifetime lung cancer risk (LLCR) that attributes a very higher value than its limit given by WHO and USEPA (Safo-Adu et al., 2014). In the year 2015, determination and evaluation of PAHs in the city of Lahore, Pakistan were performed. The study indicates that among the total determined PAHs, Benzo (a) Anthracene was found to be in the highest concentration. Moreover, the average concentration of all PAHs were higher in winter in comparison to other seasons. The major identified sources of emissions were industrial emissions, vehicular emissions and incomplete combustion of organic matter (Kalim et al., 2015).

In the same year, a study on $PM_{2.5}$ bound PAHs in Mexico showed that PAHs with high molecular weight are abundant in atmosphere in comparison to low molecular weight PAHs. Source characterization of PAHs done with the help of diagnostic ratios and principal component analysis (PCA) reveals two major sources as coal burning and vehicular emissions. Also in this study, carcinogenic potential of BaP is calculated in terms of BaPE (equivalent index of BaP) which is attributed to an estimated concentration of $4.05 ng/m^3$ (Hugo et al., 2015). Another study on $PM_{2.5}$ bound PAHs in indoor and outdoor environments in Western Sierra Leone (Taylor et al., 2015) reported that the burning of wood and charcoal are the main sources of emission. The study concluded that kitchen has highest concentration, whereas living room has least concentration of PAHs in indoor atmosphere. High molecular weight PAHs (BaP & DbA) were found to be dominant in kitchens due to wood & charcoal burning as compared to living room and outdoor areas. A varying PAH profile with risk effect was reported with higher risks in kitchen when compared to outdoor and living areas.

In 2016, a size resolved PAH study was conducted in megacity Shanghai to understand the effects of PAH on human respiratory system. The results showed a bimodal distribution of size resolved PAHs. In this distribution, with the increase in the ring number, intensity of peak increased in fine mode while decreased in coarse mode. It is further used for calculating lifetime cancer risk (LCR). The major sources contributed to PAH emissions reported as vehicular emission (27%), coal combustion (25%) and biomass burning (27%) (lv et al., 2016). In the same year, research on PAH, Fe and Black Carbon was conducted in a Steel Industrial City, Central China where result trend showed that there were no relationship between Fe and other compounds. While PAH and black carbons were related to each other and the possible sources for their emissions were industrial production and vehicular emissions (Zhang et al., 2016).

In 2017, a research was reported (Study period October-December 2014) on identification of PAHs at industrial and traffic sites in the city of Mangalore, India. Seven PAHs were reported namely Flu, Ace, Chr, B (a) A, BaP, BbF, IP, Pyr. It was observed that average of TPAHs concentration at residential area was 70.2 ng/m^3 (ranging from 12-109 ng/m^3) and at industrial area was 109 ng/m^3 (varying from 39-252 ng/m^3). Also TPAH concentration was 1.8 times higher at traffic site as compared to industrial area. Source characterization was performed using PCA in which only two components were analyzed. The analysis indicated that the main sources of PAHs were vehicular emissions and fuel combustion other than gasoline/diesel (Kalaiarasan et al., 2017).

2.2.2 Diagnostic Ratio

Diagnostic Ratios indicated that B(k)F, B(ghi)P, IP were the sources of vehicular emissions. Anth, Flt, BghiP & Pyr were identified as the sources of wood combustion. Phen, Flt were tracers for coal combustion and BbF & BkF was the sources of heavy duty diesel vehicles. Diagnostic Ratios & PCA data indicated that coal combustion, oil burning, vehicular emission and diesel engines were the major sources of PAH (kulkarni et al., 2014). In January 2014, study was conducted on the size distribution pattern of PAH in

Japan and it was observed that high molecular weight PAH followed different size distribution in all the seasons with highest peak in fine particle size range of 1.1 µm, while low molecular weight PAH didn’t show much variation with particle size. Also carcinogenic potency of PAH mainly existed in the particle size range 1.1 µm. The emission source of PAH was identified as vehicular as well as anthropogenic (Wang et al., 2014).

2.2.3 Organic Species

A short term study of the carbon composition of particulate matter illustrates respirable suspended particulates (RSPM), total carbon (TC) and black carbon (BC) in the range of 72 to 702 µg/m^3, 28 to 341 µg/m^3 and 17 to 216 µg/m^3 respectively and a higher ratio of BC/TC (0.61) suggesting fossil fuel as predominant source over biomass (TERI, 2001). The INDOEX-IFP (Indian Ocean Experiment–Intensive Field Phase) program undertaken in Mumbai from January to March 1999 to determine the size distribution and chemical composition of PM_{10} reveals that carbonaceous and ionic constituents account for 30 and 20% to surface aerosols (Venkataraman et al., 2002). Another study in Mumbai during INDOEX programme from February to March 1999 demonstrates the ratio of BC/TC (0.42) and BC/OC (0.77) suggesting 60 to 80% aerosols from fossil fuel combustion, while 20 to 40% from biomass burning (Mayol-Bracero et al., 2002). In addition to INDOEX, various experimental researches over the Indian subcontinent have reported elevated aerosol loadings with variable aerosol characteristics over rural and urban areas (Carrico et al., 2003; Sumanth et al., 2004; Moorthy et al., 2005).

A study of the characterization of particulate aerosols for soluble and insoluble components (Kyotani and Iwatsuki, 2002) and particulate phase organic compounds (Sharma et al., 2003) suggests vehicular emissions, refuse waste and biomass burning significantly contribute in organic mass of $PM_{10.}$ Air quality for particulate aerosols, NO_X, CO and black carbon measured from June 1999 to May 2002 near busy road side in Athens, Greece shows the mass concentrations of $PM_{2.5}$ and PM_{10} are positively correlated with black carbon, CO and NO_X, whereas inversely correlated with wind speed (Chaloulakou et al., 2003). Another study reports the high molecular weight compounds (often named humic-like substances) from 0.3 to 1.6µg/m^3 corresponding to 9 to 30% per cent of the total organic carbon (Samburova et al., 2005). A characterization study on source characterization of $PM_{2.5}$ in Taiyuan, China reports that the mass levels of $PM_{2.5}$, OC, EC and OC/EC ratio are mainly affected by meteorology and the carbonaceous species are thought to be as key components in controlling particulate pollution in the city (Meng et al., 2007).

A study based on characterization of fine aerosols in Agra reports organic carbon (OC), elemental carbon (EC), SO_4^{2-} and NO_3^- as dominant species in $PM_{2.5}$ mass, whereas elemental, inorganic ionic and carbonaceous species contributed 32.3, 16.8 and 23.0% respectively (Saha et al., 2008). Another study based on carbonaceous composition of particulate aerosols from Tainjin, China shows the mass concentrations of elemental carbon (EC) and/ organic carbon (OC) accounting for 17.0 and 5.7% to $PM_{2.5}$ mass, while 16.1 and 4.9% to PM_{10} mass due to coal and biomass burning and vehicular emissions in the city. The chemical species showed a seasonal variability with higher mass levels in winter and fall in spring and summer attributed to the combined effect of variable emissions rates and meteorology (Gu et al., 2010).

Carbonaceous aerosols measured from suburban site of Agra accounts for 25.2% in total suspended particles (TSP) and high correlation coefficient for OC and EC suggests common source of origin, while high OC/EC ratio (8.1) suggests biomass burning as major source at the site (Satsangi et al., 2010). In 2006-07, a study was conducted on analysis of concentration of organic tarry matter in Patiala, Punjab. The analysis was performed during crop residue burning period (CRB) and non-crop residue burning period (NCRB). The results of the study indicate that OTM level is much higher during the period of CRB. Moreover higher level of concentration was observed in rice residue burning in comparison to wheat residue burning (Singh et al. 2012).

2.2.4 Elemental Species

Makkonen et al. (2010) determined elemental composition in PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ fractions during various wildfire episodes and different seasons in 2006. It was concluded that the most of toxic and trace metals such as arsenic, lead, nickel and cadmium contribute 70-80% to $PM_{1.0}$ (particles ≤ 1.0 µm in dia).

2.2.5 Ionic Species

Measurement of particulate sulphate from Mumbai during INDOEX reports largely a trimodal size distribution in condensation mode (MMAD of 0.6μm), droplet mode (MMAD of 1.9-2.4μm) and coarse mode (MMAD of 5.0μm) (Venkataraman et al., 2001). Ionic characterization of $PM_{2.5}$ shows NO_3^-, SO_4^{2-} and NH_4^+ as dominant species, whereas low NO_3^-/SO_4^{2-} ratio suggests stationary emissions as a dominant source of fine aerosols (Yao et al., 2002). Characterization of Inhalable particulate matter results, with the Scanning Electron Microscopy (SEM) analysis significantly yielded more information on elemental composition and morphology than direct examination of dust filters by SEM (Chong et al., 2002).

2.3 Seasonal, Temporal and Spatial Variations of Particulate Matter

Particulate aerosols show seasonal variations due to meteorological conditions, type of source, strength of emission and atmospheric chemistry. The influences of meteorology on air quality have been described in various environmental studies. A seasonal variability for different particulate size range observed from heavily polluted urban area of Hong Kong illustrates that the coarse size aerosols have apparent seasonal variation, whereas fine aerosols have insignificant variation suggesting fine aerosols mainly associated with local traffic sources (Chan and Kwok, 2001).

Spatial and temporal characterization of dust storms was reported from China and its surrounding by analyzing the reports for last 40 years. The meteorological conditions, nature and transport routes of dust storms and the Aeolian dust regions reveals Gobi and Taklimakan deserts as the major source of dust storms in China (Sun et al., 2001). Another investigation on dust contribution from the Sahara region to particulate aerosols in Spain reports high mass levels of total suspended particles (TSP) and PM_{10} during Saharan dust intrusions occurring from May to September. The study suggested that the mineral dust is considerably affected by the dust particulates in the areas, mostly affected by resuspended, windblown and long-range transportation of dust storms (Rodriguez et al., 2001). Various studies in Australia (Chan et al., 1999), Asia (Chen et al., 2004), North-America (Owega et al., 2004) and Europe (Koçak et al., 2004) have discussed the significant role of major desert events to particulate mass in the air. Estimation of spatio-temporal variations and sources of particulate trace metals from Levantine Basin of Eastern Mediterranean shows seasonal variability among crust elements (Al, Fe and Mn) in the order of transitional > summer > winter. It is all due to frequently and intensive dust storms during transitional period and washout effects during winter (Kocak et al., 2004).

A study on spatial and temporal variation of PM_{10} from four sites of the greater area of Athens by Andersen mass flow controlled high volume sampler, using quartz micro-fiber filters during June 2001 to May 2002, presents elevated mass concentrations of PM_{10} in cold period (16 October to 15 April) than warm period (16 April to 15 October). It is associated with the existence of additional sources such as domestic heating, starting of engines and the prevailing meteorological conditions favoring dispersion of pollutants in the cold period (Grivas et al., 2004). Another study on temporal and spatial variations in $PM_{10,}$ $PM_{2.5}$ and PM_1 observed from urban and rural sites of Austria show similar weather dependent mass patterns for these fractions of particulate matter suggesting similarity in sources (Gomiscek et al., 2004). A characterization study of fine aerosols from Finland during the wildfire episodes reports elevated levels of potassium and minor amount of calcium rich particles. It suggested that biomass burning from wildfires and large scale agricultural field substantially affects, the concentrations of $PM_{2.5}$ under unfavorable meteorological conditions, even at distances over 1000 kms from the burning areas (Niemi et al., 2004; Niemi et al., 2005).

Namedo et al. (2005) presented descriptive analysis of seasonal and temporal variation in PM_{10} and $PM_{2.5}$ mass fractions at urban (roadside and background) and rural locations. It was concluded that $PM_{2.5}$ and PM_{10} were positively correlated at urban locations. Both fractions were significant contributors to mortality, cardiovascular and respiratory disorders. The study further showed that $PM_{2.5}/PM_{10}$ ratio has diurnal variations and is influenced by vehicular emission. The higher ratio in winter than summer indicated longer residence and build-up time of finer fraction and wash down effect on coarse particles in winters as a result of fog.

The study conducted in Hong Kong presents a distinct seasonal variation in $PM_{2.5}$ and PM_{10} along with carbonaceous components with higher mass levels in winter than in summer. It suggested accumulation of pollutants in winters due to calm weathers and more dilutions and dispersions in summer due to hot air and higher mixing heights (Ho et al., 2006). A study of long range dust transport reveals four dust sources areas as Northerly sources, Northwesterly sources, Loess Plateau source and anthropogenic Southerly source contributing to higher mass loading of particulate pollution in China (Wang et al., 2006). Another study on temporal and spatial patterns of PM_{10} from the urban region of Finland presents the mass levels of PM_{10} from 11 to 24µg/m^3 with maximum seasonal variation in spring, strongly influenced by the traffic (Anttila and Salmi, 2006).

An overview of profile and influences of atmospheric aerosols in Belgrade reports seasonal variation to be higher in autumn (October) and winter (November to December) seasons. Higher mass levels were attributed to combustion of fossil fuels for space heating, higher traffic density and prevailing meteorological conditions during winters in the study area (Tasic et al., 2006). Another study elaborates a clear seasonality in mass levels of PM_{10}, inversely correlated with meteorological parameters, suggesting the increasing number of mobile and stationary sources, and the prevailing meteorology, responsible for variations in particulate mass levels in the urban environment (Dubey and Pervez, 2008).

Various studies have illustrated that the mass concentration of PM_{10}, $PM_{2.5}$ as well as the chemical species are higher in winter or cold season as compared to summer (Xuet al., 2011, Wang et al., 2012; Guoet al., 2014; Zhang and Cao, 2015; Zhang et al., 2015; Tang et al., 2016; Cai et al., 2017). The highest mass concentrations during winter were attributed to enhanced human activities such as burning of coal and bio-fuels for domestic, commercial cooking and space heating, along with higher exhaust emissions from automobiles and engine sets due to cold start in cold conditions. Stagnant atmosphere, temperature inversions, low mixing height and calm conditions were reported as conducive for the formation of particulate matter. A seasonal trend in mass levels of particulate aerosols in the order of winter > summer > monsoon has also been explored by various researchers (Xue et al., 2010; Cao et al., 2011; Perrino et al., 2011; Singh and Sharma 2012) as a result of stagnant conditions of the atmosphere in winter and chemical wash down effect in monsoon season.

2.4 Source Apportionment of Particulate Matter

Countable studies have estimated source apportionment of airborne particles in India, most of them focus on total suspended particulate matter (TSPM) and natural source as contributory sources to air pollution (Srivastava et al., 2005; Srivastava and Jain, 2007a&b; Kothai et al., 2008; Srivastava et al., 2008). However, at global level, much attention has been given to metal contents of the different fractions of TSPM specially fine and respirable aerosols ($PM_{2.5}$/PM_{10}) using different multivariate techniques (Christensen, 2004; Jones and Harrison, 2006; Song et al., 2006; Zhang et al., 2007; Harrison et al., 2008) wherein absence of long term database is a common problem (Wang et al., 2008). Various studies from Mumbai have confirmed the emissions of particulate aerosols from combustion sources, though authors are unable to differentiate industrial versus vehicular emissions (Negi et al., 1988; Sadasivan and Negi, 1990).

Aerosol samples were collected from an industrial area of Mumbai and analyzed using EDXRF, UV-visible photometry and ICP-AES techniques. Factor analysis applied for source identification reveals seven sources as ferrous and nonferrous industrial emissions; refuse burning, oil combustion, coal burning, secondary emissions and road transport as contributors to air pollution in the study area, while the association of soil elements with multiple factors shows co-linearity in the sources (Sharma and Patil, 1991). Another study from Mumbai based on particle size distribution represents windblown dust, vehicles and marine aerosols as sources, depending upon the emission of particle size by source type (Sharma and Patil, 1992a). Source apportionment of TSPM from industrial area of Mumbai using CMB model of US EPA, based on total of 19 elements, evaluates the model performance for seven sources at three sites. Unsatisfactory results of CMB model for highly polluted location of study area and the unsuitable resultant source profiles for the atmospheric conditions of India, suggest the need to evaluate the site specific source profiles (Sharma and Patil, 1994).

A size segregation aerosol study from the atmospheric air of Agra near Taj Mahal presents enrichment factors in two groups. Source apportionment using principal component analysis illustrated the higher loading of soil-derived elements as first factor, industrial processes as second factor, wood combustion as third factor and brick kilns as fourth factor. However, no factor of PCA was associated with vehicular emissions, despite the fact that Taj attracts the heavy traffic (Kulshrestha et al., 1995b). Another study determines air quality of industrial area in Agra using enrichment factor and correlation matrix analysis in which PCA shows road dust, foundry emissions, diesel engines (manufacturing and testing), electroplating and automobile exhausts as the contributory sources of air pollution (Khare et al., 1996).

A source estimation study by Factor analysis from Chembur, Mumbai reports four source categories contributing to PM_{10} aerosols: re-suspended soil dust, biomass burning, auto emissions and sea-salts. Particle size distribution shows the particles of larger size fraction are predominated by soil dust and the particles of smaller size fraction are predominated by auto-exhaust & refuse burning (Meenakshy et al., 1996). However, soil dust, biomass and refuse burning, smelter and vehicle emissions have been identified as five predominant sources contributing to air pollution in Chandigarh (Bandhu et al., 1998). Another source estimation study by CMB, TTFA and MLR methods from Brisbane, Australia shows that the contribution of PM_{10} includes soil/road dust (25%), EC and secondary aerosols (15%), Vehicles (13%), sea-salts (12%), Ti and Ca rich compounds (11%) and biomass burning (7%), whereas the contribution of $PM_{2.5}$ includes EC (24%), biomass burning (15%), secondary organics (21%) and secondary SO_4^{2-} (14%) (Chan et al., 1999).

A study, estimated chemical composition of particulate aerosols from commercial, industrial and clean zones of Chandigarh with EDXRF (Energy dispersive X-ray fluorescence) and PIXE (photon-induced X-ray emission) techniques. The source identification by principal component analysis reveals soil dust, refuse-burning, vehicular emissions, lead recycling and iron foundries as the sources of emissions (Bandhu et al., 2000). A multi-elemental source apportionment illustrates that the sea spray and soil contribute 60%, anthropogenic sources (smoke from biomass burning, wood fires and industrial sources) contribute 40% whereas sea salt as sodium chloride contributes 48% to the mass levels of fine aerosols (Cohen et al., 2000). A study, estimating source composition of PM_{10} aerosols from Los Angeles by CMB analysis, using source profiles derived from SAFER model shows the contribution from road dust 20 to $34\mu g/m^3$, secondary aerosols 17.75 to $31.40\mu g/m^3$, crustal sources 4.06 to $8.13\mu g/m^3$ and marine sources up to $2.50\mu g/m^3$. The study concluded that 80% of organic carbon (OC) is attributed to primary roadway sources and 32% of SO_4^{2-} is attributed to crustal, roadway and marine sources (Kim and Henry, 2000).

Indian Ocean Experiment (INDOEX) measured long range transportation of particulate aerosols from the Asian region of South and Southeast. The study indicated biomass burning and fossil fuel combustion as responsible for higher pollution load over Indian Ocean during January to March 1999 (Leilieveld et al., 2001 Another source apportionment study from two traffic junctions in Mumbai using factor analysis with multiple regression presents five sources of suspended particulate matter (SPM) as road dust (41%), marine aerosols (15%), vehicular emissions (15%), coal combustion (6%) and metal processing industries (6%) at Saki Naka traffic junction whereas, 33%, 18%, 15%, 8% and 11%, respectively at Gandhi Nagar traffic junction. The analyzed lead content of SPM is attributed to road dust (17%), vehicular emissions (62%), coal combustion (7%), metal processing industries (11%) and marine aerosols (3%) (Kumar et al. 2001).

A study on chemical characterization of $PM_{2.5}$ and PM_{10} from Yamanashi University, Kofu in Japan determined enrichment factor and source apportionment. Source investigation revealed soil, anthropogenic substances and vehicles as main source of emission in the region (Kyotani and Iwatsuki, 2002). A review study of air pollution and health impacts from Malaysia based on air quality monitoring for SO_2, NO_2, O_3, CO and suspended particulate matter (SPM) indicates NO_2 and SPM as the predominant pollutants. Land transportation, open burning and industrial emissions are reported as sources of air pollution with land transportation as the dominant source (Afroz et al., 2003).

A comprehensive characterization of fine aerosols estimated from January to December 2000, at national university of Singapore shows the higher mass concentrations of carbonaceous aerosols and nss-SO_4^{2-} (non-sea salts) associated to smoke haze. Principal Component Analysis (PCA) presents five source categories of soil dust, metallurgical industries, automobiles and biomass burning, sea salts and oil combustion (Balasubramanian et al., 2003). A characterization study demonstrates the mass levels of organic and elemental carbon in $PM_{2.5}$ higher in winter than summer. The comparison of carbonaceous species (OC/EC) with trace elemental species (Pb, As, K and Zn) reveals coal combustion as dominant source during winter, while vehicular and/or industrial emissions and biomass burning as the main sources of carbonaceous species in summer (Dan et al., 2004).

Air samples for $PM_{2.5}$ and PM_{10} aerosols were collected from traffic, industrial and residential sites in Beijing during summer and winter from 2002 to 2003. It identifies secondary aerosols, industrial and vehicular emissions, road and long range transported dust and coal burning as major sources of emission in Beijing. A clear spatial and seasonal variability shows higher mass concentrations of PM_{10} and $PM_{2.5}$ as well as chemical constituents in winter in comparison to summer (Sun et al., 2004). Source apportionment of $PM_{2.5}$ from three European cites by PCA and MLR shows six source categories as secondary aerosols (34%), traffic (30%), oil combustion (11%), industrial and incineration (9%), crustal matter (7%) and sea salts (2%) in Amsterdam, while four source categories as secondary aerosols (32%), traffic (32%), crustal matter (21%) and industrial activities (8%) at other sites (Vallius et al., 2005). Another study on PM_{10} source apportionment during cold and calm weather presents sea spray, vehicular emission, domestic heating and road dust as the main culprits of atmospheric pollutants (Senaratne et al., 2005).

A source apportionment study based on size-resolved particulate aerosols describes the natural sources including soil dust, Chinese aerosol and sea salts that account for 79%, anthropogenic emissions, coal and biomass burning account for 60% (to the fine fraction of 0.56 to 2.5µm), whereas diesel vehicles are responsible for about 52% (with primary aerosols in ultra-fine 0.07 to 0.56µm fraction) (Han et al., 2005). Another study determining the characteristics and sources of fine aerosols reports long-range transport (50 to 58%) and local traffic (41 to 45%) as the most important determinants, while soil dust, industrial emissions, oil combustion and sea salts as another source of $PM_{2.5}$ (Vallius, 2005). The estimation of particulate phase secondary organic carbon (SOC) in a long term study from 1998 to 2002, at Hong Kong by positive matrix factorization model reveals SOC as nearly half of the total carbonaceous aerosols, suggesting a clear seasonality with higher mass levels in winter than summer (Yuan et al., 2006).

Source apportionment of fine aerosols, by positive matrix factorization (PMF) during inhalation exposure studies in Detroit, USA elaborated major source categories as vehicles/road dust, coal combustion/or secondary sulphate, waste incinerator, oil combustion, iron/steal manufacturing and sewage sludge incineration responsible for $PM_{2.5}$ emissions (Morishita et al., 2006). Another study measures chemical characterization and source identification of size segregated aerosols from six European cities. Particulate aerosols were collected by high volume cascade impactor (HVCI). The particulate organic matter with mean mass levels of $1000ng/m^3$ was the largest component at all study sites. The total measured components accounted 79% to $PM_{2.5}$, while 77 to 96% to $PM_{2.5-10}$ (Sillanpaa, 2006). Another study collected $PM_{2.5}$ simultaneously from various receptors in Shanghai City for source apportionment. Total seven source categories were identified as vehicle exhaust, metallurgical industry, soil dust, diesel exhaust, coal and oil burning and motorcycle exhaust. Among the identified sources, metallurgical industry, coal combustion and automobile exhaust were recognized as the main culprits of $PM_{2.5}$ emissions in Shanghai City (Yue et al. 2006).

A study on multi-element analysis of particulate aerosols from the atmospheric air of Dhaka shows motor vehicles, fugitive emissions, sea spray and soil dusts as main culprits of air pollution in the city (Begum et al., 2006). Another source apportionment study from residential and industrial area of Kolkata reported the sources of PM_{10} as paved road (21%), coal combustion (42%), wood combustion (1%) and field burning (7%) at residential site, whereas coal combustion (34%), vehicular emissions (47%), metal industry (1%) and crust dust contributed (1%) at industrial site. The sources of total suspended particles were reported as diesel combustion (15%) at residential area, whereas coal combustion (17%), soil dust (36%), solid waste (17%), tyre abrasion (7%) and road dust (16%) at industrial area (Gupta et al., 2007).

A long term study on source apportionment of PM_{10} and $PM_{2.5}$ aerosols in Beijing illustrates six common sources as soil dust, vehicular emission, coal combustion, industrial emission, secondary aerosols and biomass burning with predominance of coal combustion to $PM_{2.5}$ and soil dust to PM_{10} aerosols (Wang et al., 2008). Another source apportionment study of PM_{10} aerosols from Kanpur, India shows road dust (15-47%) and secondary aerosols (21-26%) as the main culprits of particulate pollution in the city (Shukla and Sharma, 2008). Characterization of fine particulate ($PM_{2.5}$) aerosols was done, as collected by sequential sampler whereas principal component (PCA) and cluster analysis revealed anthropogenic emissions (traffic and industries) as a major source of fine particles (Ravindra et al., 2008a&b).

A composition profile of fine fraction ($PM_{2.5}$) and coarse fraction ($PM_{2.5-10}$) during 2004 to 2005 from highly polluted cities of Anshan, Shenyan, Jinzhou and Fushun in Northeast China and a site to site comparison using coefficient of divergence shows the similarity in elemental composition of $PM_{2.5}$. Whereas principal component analysis presents crust, coal combustion, vehicles and iron or other metallurgical activities as common sources of particulate matter in China (Han et al., 2009). Another source apportionment study from Lahore reports six sources as – secondary aerosols, two-stroke vehicle exhaust, diesel emissions, industrial sources, coal combustion and biomass burning, whereas the quantification of sources indicated two-stroke and diesel vehicles

(36%), coal combustion (13%) and biomass burning (15%) towards $PM_{2.5}$ in the city (Raja et al., 2009).

A study demonstrated the sources of ultra-fine particles ($PM_{1.0}$) from Kanpur and suggested that the metallic composition of $PM_{1.0}$ associates with anthropogenic origin while vehicular emission is the most significant source of these aerosols (Chakraborty and Gupta, 2009 & 2010). $PM_{2.5}$ and PM_{10} aerosols from a residential area of Vashi, Navi Mumbai were analyzed for elemental composition using PIXE technique and PCA reveal common sources as soil, fuel combustion and sea salts for both the fractions with industries as additional source to fine particles (Kothai et al., 2009). Quantitative estimation of the emission sources of airborne aerosols in urban atmosphere has been a significant issue with various anthropogenic sources including traffic emission, industrial processes and biomass burning (Godoy et al., 2009; Heo et al., 2009).

Shao et al., (2009) investigated mass levels, size distribution and morphology of $PM_{2.5}$ and PM_{10} aerosols during the Olympic Games at Beijing in summer 2008. They reported the mass levels of PM_{10} and $PM_{2.5}$ as 81.6 and 54.6 $\mu g/m^3$ respectively meeting with air quality standards in China. They further investigated the morphology and size distribution of individual particles in PM_{10} and $PM_{2.5}$. Microscopic morphology identified four categories of particles as soot aggregates, minerals, spherical and unresolved particles in which spherical and unresolved particles were reported as predominant components. The results of size distribution studies showed average $PM_{2.5}$ and PM_{10} ratio as 0.63 indicating the dominance of the mass fraction of PM_{10} (Coarse) to $PM_{2.5}$ (fine). Karnae et al., (2011) used Positive Matrix Factorization (PMF) technique to quantify the emission sources of fine particulate matter in South Texas. Study reveals regional transport and local emissions significantly contribute to fine aerosols ($PM_{2.5}$) in the region. Positive matrix factorization identified total eight source categories as secondary sulphates (30.4%), biomass burning (12.7%), aged sea salt (18.5%), fresh sea salt (8.1%), traffic emission (9.7%), crustal dust (10.1%), industrial sources (6%) and oil and diesel combustion (4.6%) with distinct seasonal variability in mass and source categories.

A characterization study for the sources of fine and coarse particulates from Lahore examines organic and elemental carbon, ionic species, organic species, elemental species, water soluble species and biological matter using macro-phase ROS assay method. It suggested crustal components dominant in coarse mode while carbonaceous components dominant in fine mode. Elemental composition subjected to principal component analysis shows industries, vehicles, re-suspended soil and secondary aerosols as the main source (Schneidemesser et al., 2010). A short term study used the combination of semi-continuous measurements and single particle mass spectrometry to estimate source apportionment of $PM_{2.5}$ aerosols. Total six source categories were identified as marine aerosols (14%), vehicular traffic (23%), long-range transport (13%), domestic solid fuel burning (5%), power generation (11%) and shipping vessels (1.5%) accounting to $PM_{2.5}$ emissions in Cork Harbor, Ireland (Healy et al., 2010).

The source apportionment study using EF and CMB model from Harbin, China presented traffic emissions, road dusts, petrochemical plants and coal burning as major sources having spatial as well as seasonal variability (Huang et al., 2010). Another source apportionment study from a major European Airport of El Prat, Barcelona reveals major attributions of crust material by 38%, total carbon (OC and EC) by 25%, secondary aerosols by 20% and sea-salts by 6% to PM_{10} (Amato et al., 2010) whereas Singh and Sharma (2012) reported natural, vehicular, industrial and secondary sources as main culprits to contribute PM_{10} in Agra, India.

2.5 Gap Analysis in Literature

It is evident from the various studies and research trends that the accelerated investigations are going all over the world to better understand the atmospheric pollutants: how particulate aerosols are emitted into the atmosphere, how are they transformed from gaseous and secondary pollutants, how are they transported on local and regional scale, how are the people getting exposed to them, how much and to what extent health impacts are being experienced by people due to the exposures of fine aerosols ($PM_{2.5}$).

So far, the main constituents of particulate matter being studied are elemental, inorganic carbon (Boldo et al., 2006), other inorganic constituents such as sulphates, nitrates (Shao et al., 2009) and elemental composition (Yue et al., 2006, Makkonen et al., 2010). However, the studies have also been initiated to study organic solvent soluble fractions including oxidized hydrocarbons as ketones, aldehydes, oxyacids, polycyclic aromatic hydrocarbons (PAHs), dioxins and furans etc. (CPCB, 2006, Dasgupta et al., 2008, Makkonen et al., 2010, Shaofei et al., 2011).

The majority of above studies are however limited to PM_{10} fraction. In India, standard for $PM_{2.5}$ has been notified just few years ago though the countable studies have focused on $PM_{2.5}$ however, no study is evident in literature from Chandigarh region, Therefore, it is a dire need to understand the characterization and source profile of fine particulate aerosols in different geographical and meteorological settings. Among the measurement of various constituents of these fine aerosols, organic tarry matter and PAHs are of particular relevance in urban ambient air.

CHAPTER 3: MATERIALS AND METHODS

This chapter broadly explains the material and methods utilized for implementation of the study including details of Study Area (Sampling Locations, Site Selection & Meteorology), Sampling of PM_{10} and $PM_{2.5,}$ Gravimetric Analysis of PM_{10} and $PM_{2.5,}$ Chemical Analysis (Organic Tarry Matter, Organic carbon, Elemental Carbon and Polycyclic Aromatic Hydrocarbons), Quality Assurance & Control (QA/QC) and Statistical Analysis (Correlation Analysis and Source Apportionment) for source profiling.

3.1 Study Area

The study was conducted in the metropolitan region of Chandigarh tricity including Chandigarh-Mohali-Panchkula with over 2 million of population. Chandigarh the Union Territory of India, serves as a combined capital of Haryana and Punjab. It is located in the foothills of Shiwalik range of Himalayas and 162 miles (260 km) north of New Delhi, the national capital of India. The climate of Chandigarh is humid subtropical with varying temperature (−1 to 46°C) and the annual average rainfall of 1110 mm. Mohali and Panchkula are district head quarters of Punjab and Haryana states respectively.

Mohali has emerged as one of the most important cities in Punjab and in the rest of northern India. It is developing rapidly as an IT Hub of the state. The city has many places of importance including international sports venues like a magnificent cricket stadium, hockey stadium, indoor stadium, golf course area and an International Airport. The city has a sub-tropical continental monsoon climate. The average temperature varies from -1 to 44°C.

Panchkula is approximately 4 km (2.4 miles) southeast of Chandigarh, 105 km (65 miles) southwest of Shimla and 259 km (162 miles) northeast of New Delhi, the national capital of India. The city hosts the Chandimandir Cantonment, the headquarters of the Western Command of the Indian Army. This area also receives winter rains from the western disturbance.

3.1.1 Sampling Locations

Ambient air samples for particulate aerosols (PM_{10} and $PM_{2.5}$) were collected from four locations namely Sector 12 (Chandigarh), Sector 34 (Chandigarh), Sector 74 (Mohali) and Sector 12A (Panchkula) as per details shown in **Table 3.1.**

Table 3.1: Details of sampling locations in the study area

Sampling Location	Site Description	Location Code	Location Coordinate
Sector 12 (Chandigarh)	Educational Institute	Site ST0	N 30°42.997'; E 76°45.856'
Sector 34 (Chandigarh)	Residential Cum Commercial Area	Site ST1	N 30°42.986'; E 76°45.884'
Sector 74 (Mohali)	Industrial Area	Site ST2	N 30°42.617'; E 76°41.326'
Sector 12A (Panchkula)	Residential Area	Site ST3	N 30°41.071'; E 76°51.136'

The study area experiences prominent wind direction from north-west and thus the station in this direction should have least impacts from anthropogenic and urban activities of the tricity. Hence, one station ST_0 (Sector 12, Chandigarh) is proposed in north-west in a green belt beyond Sarangpur in Chandigarh as a background station. Furthermore, there is little habitation in this location with the presence of Shiwalik hills in the background **(Figure 3.1)**.

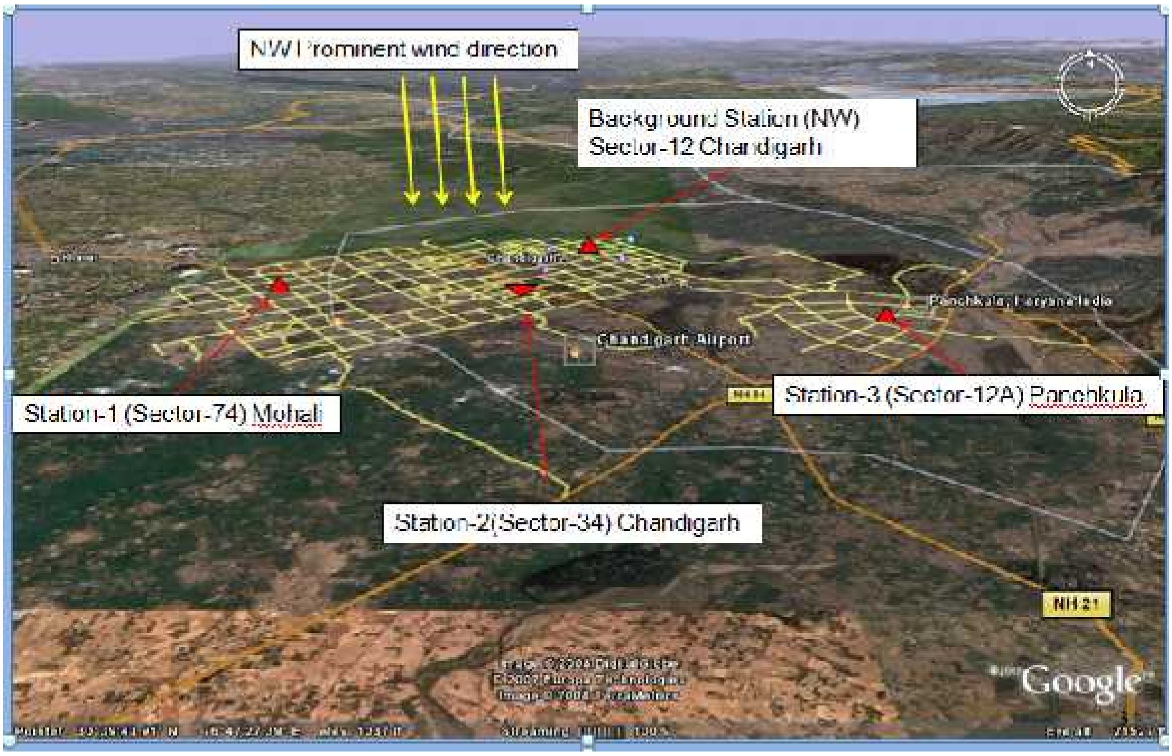

Fig 3.1: Location map of the study area

Sector 74 (Mohali) represents the industrial area comprising engineering, electrical, electronics, pharmaceuticals, IT, hospitals and healthcare, office automation and stationery type of industries. Sector 34 (Chandigarh) is a commercial cum residential area in the downwind direction of city. Sector 12A (Panchkula) is purely a residential area. Among these three cities, Chandigarh city has the highest vehicle to population ratio.

3.1.2 Site Selection

The site selection is based on the importance of emission sources, sensitivity of receptors, predominant local activities and wind directions in the study area. Four sampling locations namely Sector 12 Chandigarh (Educational Institute – Sensitive Zone), Sector 34 Chandigarh (Residential cum Commercial Zone), Sector 74 Mohali (Industrial Zone) and Sector 12A Panchkula (Residential Zone) were selected for representative sampling from each category of zone classification as defined by CPCB. The sampling stations were installed at two storey buildings for suitable heights of 3 to 10 meters from ground level as per guidelines of IS: 5182 (Part 14) 2000 and CPCB guidelines.

Sampling guidelines of CPCB were followed in site selection at each location as per zone area classification as sites were chosen with open spaces from all sides, unrestricted airflow, absence of obstructions (trees, balcony, corners or walls) and source (s) of direct emissions (like furnace, incinerator, process duct, domestic chimney, wood burning, unpaved roads and streets etc.).

3.1.3 Sampling Duration and Frequency

The air sampling was done on 24 hourly basis with the frequency of twice a week during summer (April-May) and winter (December-January) for three consecutive years of 2013-14, 2014-15 and 2015-16 at each location. A total of 384 samples [2 (twice a week)*16 (8 weeks in April-May plus 8weeks in December-January)*3 (three years)*4 (No. of locations)] each of $PM_{2.5}$ and PM_{10} was collected from each location.

3.1.4 Meteorology

To assess the influence of origin, dispersion and migration of particulate aerosols, the meteorological data of study area was obtained from continuous weather monitoring station operated by Eco Laboratories and Consultants Private Limited located near sampling location in Sector 74, Industrial Area, Mohali. Meteorological parameters considered were wind direction (degree), wind speed (m/s), temperature (ºC), relative humidity (%) and precipitation (mm) on hourly basis, during the entire study period. Data was collected from March 2013 to January 2016 and wind rose diagram was plotted for representation of predominant wind direction from Northwest (NW) in the study area.

Meteorological data was collected using permanent fixed weather monitoring system (Model: WDL 1002; Virtual Electronics Company, Roorkee, UK). The system is operated by self contained battery and solar panel. The data is collected in data logger on hourly basis and transferred from data logger to computer system through data shuttle. Meteorological data were interpreted and arranged as per input requirement of WR Plot (Environment Lakes).

Weather Monitoring Station

3.2 Materials

3.2.1 Filter paper

PM_{10} samples collected on Whatman glass fiber filters GF/A (size A4 / 8x10 inches) and $PM_{2.5}$ samples collected on Whatman Quartz Filter papers (circular & 47 mm in diameter).

PM2.5 Filter paper

PM10 Filter Paper

3.2.2 Instruments and Equipments

Weighing Balance

Micro Balance used is from M/s Denver Instrument, USA having least count of 0.001 mg.

Fine Particulate Sampler

$PM_{2.5}$ sampler used for the sampling is manufactured by M/S Envirotech Instruments Pvt. Ltd., Delhi (India), Model-APM550 capable to set Flow rate 16.67 liter per minute (lpm).

	
Fine Particulate Sampler ($PM_{2.5}$)	**Respirable Dust Sampler (PM_{10})**

Respirable Dust Sampler

PM_{10} sampler manufactured by M/S Envirotech Instruments Pvt. Ltd., Delhi (India), Model-AAS 217NL maintains the sampling flow rate @ 1.13 m^3/min.

Gas chromatograph

Agilent- 7890, Equipped with Flame ionization detector (Capable to detect Tridecane <1.4 pg) and column oven (Dimension 28 x 31 x 16cm) has been used to accommodate a capillary column up to 100 m and Software to compute the Peak Signal response (Chem Station software).

Capillary column (Stationary Phase): Agilent, DB-5, L-25 m, Column ID 0.20 mm, Film thickness 0.33 µm.

Organic Carbon and Elemental Carbon Analyzer

OC-EC Aerosol Analyzer manufactured by M/S Sunset Laboratory Inc. (USA), has been used, which is based on working principle of National Institute for Occupational Safety and Health (NIOSH method 5040). Testing of OC/EC was conducted at Atmospheric Particle Technology Lab, Centre for Environmental Science and Engineering, IIT-Kanpur.

Other equipment: Soxhlet Apparatus, Ultra sonicator, Rotary Evaporator, Steam Bath

		
Ultra-sonicator	**Rotatory Vacuum Evaporator**	**GC-FID**

3.2.3 Reagents

- Toluene, ultra-residue grade.
- Cyclohexane, ultra-residue grade.
- Solid PAHs Compounds, high purity
- Activated Silica Gel
- Carrier Gas (Helium/Nitrogen)
- Fuel Gases (Hydrogen & Zero air)

3.2.4 Software

Statistical Package for Social Sciences (SPSS) Version 22 was used for basic statistical analysis, Pearson Correlation Analysis and Principal Component Analysis (PCA) for source apportionment (quantification and identification) of $PM_{2.5}$ emission sources.

3.3 Methodology

3.3.1 Sampling of PM_{10} and $PM_{2.5}$

Air particulate samples for PM_{10} were collected on Whatman glass fiber filters using respirable dust sampler (APM460, Envirotech) whereas samples for $PM_{2.5}$ were collected on Whatman Quartz filter papers (47 mm dia) using fine particulate sampler (APM550, Envirotech). During sampling a laminar flow was maintained at 16.7 liter per min (~0.167 m^3/ min) for $PM_{2.5}$ and 1.13m^3/min for PM_{10} as per guidelines of IS: 5182 (Part 14) 2000 and CPCB.

The air sampling was done on 24 hourly basis with the frequency of twice a week during summer (April-May) and winter (December-January) at four locations for three consecutive years of 2013-14, 2014-15 and 2015-16. Monsoon season was not considered during the study, as the associated mass levels of $PM_{2.5}$ are in very low range during that period and could not serve the purpose of meaningful analysis of organic tarry matter. A total of 384 samples [2 (twice a week)*16 (8 weeks in April-May plus 8weeks in December-January)*3 (three years)*4 (No. of locations)] each of $PM_{2.5}$ and PM_{10} were collected for three consecutive years at all sampling locations. Sampling flow rate was checked on hourly basis through manometer, and the pump flow of the equipment was calibrated with the frequency of once in a month.

3.3.2 Gravimetric Analysis of PM_{10} and $PM_{2.5}$

In gravimetric analysis, the mass concentration is calculated by dividing the net mass of filter papers weight difference, by the volume of air sampled. The exposed filter papers of PM_{10} and $PM_{2.5}$ along with field blanks were kept in desiccators containing active and fresh silica gel. The conditioning was done for 24 hours in a room with controlled environment, at a temperature of 25±5ºC, and relative humidity of 45±5%, before and after sampling. The net mass of particulate matter is determined by weighing the filter papers with a pre-calibrated electronic balance of 0.1µg precision as per the standard method of USEPA (USEPA—Method IO-3.1 1999). The obtained mass concentrations of dust particles are expressed in terms of particle numbers by weight in per cubic meter of air.

Calculations for Mass Concentration of PM_{10} and $PM_{2.5}$

a) Volume of Air Sampled

$$V\ (m^3) = QT$$

Where:

V = Volume of air sampled in cubic meter (m^3)

Q = Average flow rate in cubic meter per min (m^3/min)

T = Total sampling time in minute (min)

b) Mass Concentration

$$PM\ (\mu g/m^3) = \frac{(W_f - W_i) \times 10^6}{V}$$

Where:

PM = Mass concentration in micrograms per cubic meter ($\mu g/m^3$)

W_i = Initial weight of filter paper in grams (g)

W_f = Final weight of filter paper in grams (g)

V = Volume of air sampled in cubic meter (m^3)

10^6 = conversion of grams (g) to micrograms (µg)

The obtained mass concentrations of dust particles are expressed in terms of particle numbers by weight in per cubic meter of air. Weighing of laboratory and field blank filter papers was also done to ensure accuracy of balance. The accuracy of microbalance (scale and reading) was checked regularly with standard weights.

3.3.3 Chemical Analysis

3.3.3.1 Organic Tarry Matter (OTM)

Soxhlet extraction was applied using organic solvents as customized procedure to determine organic tarry matter. Halved part of all sampled filter papers for $PM_{2.5}$ (384 Nos.) were extracted in 150 ml Organic solvent sequentially for 8 hours at 80^{o}c. The steam bath treatment reduced the solvent to 5 ml. The resulting extract was filtered using Whatman filter and transferred in to amber vials (chromatographic). After drying at room temperature, their weight was determined using microbalance (précised to 0.1ug).

3.3.3.2 Organic Carbon (OC) and Elemental Carbon (EC)

All sampled filter papers of $PM_{2.5}$ (384 Nos.) were analyzed by NIOSH method using OC/EC aerosol analyzer. A standard sized (1.5 sq cm) punch of filter sample was placed in a quartz oven purged with helium. Oven temperature was rose to 870˚C by thermal desorption of organic compounds for pyrolysing them to manganese dioxide.

Carbon fragments flowing through manganese dioxide in oven are finally converted to CO_2 gas. CO_2 is swept out by helium stream and hydrogen gas. This mixture was converted to methane gas when passed through the heated catalyst of nickel. The resulting methane gas was determined by flame ionization detector. Flow stream was switched to helium/oxygen mixture after cooling the temperature to 550˚C and the second ramp of temperature was initiated. EC is then oxidized from the filter paper and determined as per the same procedure of OC.

3.3.3.3 Polycyclic Aromatic Hydrocarbons (PAHs)

All 384 samples of $PM_{2.5}$ were analyzed using standard method of IS: 5182 Part 12: 2004 (methods for measurement of air pollution- polynuclear aromatic hydrocarbons in air particulate matter). Halved part of each $PM_{2.5}$ filter paper was extracted in 100ml toluene into a 200ml Erlenmeyer flask. The solution was ultra sonicated (Ultrasonic Processor of Citizen) at 30 min and 20 Hz. The extract was filtered using Whatman filter paper No. 41 (20) in the evaporated flask of 250 ml. The extraction was repeated twice and the extracts were combined.

Rotary evaporator with temperature not exceeding 40°C was used for the evaporation of toluene extract until its volume was reduced to 1-2 ml. The wall of evaporation flask was rinsed by using 2.0 ml toluene and the extract was transferred to a beaker of 5 ml capacity. To clean up the impurities, silica gel column (length 200mm, and inner diameter 0.5 cm) was used. 3g slurry in cyclohexane of deactivated silica gel (60-120 mesh size) was taken and poured into the column. Conditioning of column was done as the toluene eluted by cyclohexane through the column. The sample extract was passed through the silica column and the resulting PAH fraction was collected within 5ml of cyclohexane. Finally 30ml of cyclohexane was added to elute all organics of interest through the column. The PAH fraction was collected in the flask (reduced to about 1ml) and transferred to 5ml capacity vials (stored in a dark and cool place).

The identification of PAHs was carried out using Gas Chromatography consisting of a capillary column (Dimension 28 x 31 x 16cm) and flame ionization detectors (FID) in a split less mode. The temperatures of detector and injection were set 320°C. The carrier gas was N2 @ 30ml/min. The GC calibration was performed by known standard of Dr. Ehrenstorfer GmbH containing sixteen analyte in acetonitrile. The concentrations were made in three levels from the original mixture. On the basis of retention times, the peaks were identified and the amount of analyte was calculated.

Chromatography grade solvents were used in the analysis. Total of sixteen PAHs were investigated as Anthracene, Acenaphthylene, Benzo(a)pyrene, Benzo(a)Anthracene, Benzo(ghi)perylene, Benzo(b)fluroanthene, Benzo(K)fluoranthene, Chrysene, Dibenz(a,h) anthracene, Fluorene, Fluroanthene, Indeno(1,2,3-c,d)pyrene, Naphthalene, Pyrene, Perylene and Retene. Nomenclature of these Polycyclic Aromatic Hydrocarbons (PAHs) species is presented in **Table 3.2**.

Table 3.2: Nomenclature of Polycyclic Aromatic Hydrocarbons (PAHs)

PAH	Abbreviation	Molecular weight	Chemical formula
Acenaphthylene	Acy	152	$C_{12}H_8$
Anthracene	Ant	178	$C_{14}H_{10}$
Benzo(a) Anthracene	BaA	252	$C_{18}H_{12}$
Benzo(a)pyrene	BaP	252	$C_{20}H_{12}$

Benzo(b) Fluroanthene	BbF	252	$C_{20}H_{12}$
Benzo(ghi)perylene	BghiP	276	$C_{22}H_{12}$
Benzo(K)fluoranthene	BkF	252	$C_{20}H_{12}$
Chrysene	Chry	228	$C_{18}H_{12}$
Dibenz(a,h) anthracene	dBahA	278	$C_{22}H_{14}$
Fluroanthene	Fln	202	$C_{16}H_{10}$
Fluorene	Flu	165	$C_{13}H_{10}$
Indeno(1,2,3-c,d)Pyrene	IP	276	$C_{22}H_{12}$
Naphthalene	Nap	128	$C_{10}H_{8}$
Perylene	Pery	252	$C_{20}H_{12}$
Pyrene	Pyr	202	$C_{16}H_{10}$
Retene	Ret	234	$C_{18}H_{18}$

Calculations for the Mass Concentration of OTM, OC, EC & PAHs

a) Volume of Air Sampled

$$V\ (m^3) = QT$$

Where:

V = Volume of air sampled in cubic meter (m^3)

Q = Average flow rate in cubic meter per min (m^3/min)

T = Total sampling time in minute (min)

b) Mass Concentration

$$C\ (\mu g/m^3) = \frac{(\text{Cs-Cb in } \mu g/mL)\ (\text{Volume of extraction, mL})\ (S_{F/P})}{E_{F/P} \times V\ (m^3)}$$

Where:

C = Concentration of analyte in air (in µg/m^3)

Cs-Cb = Difference of analyte concentration determined by instrument in sample and blank (µg/ml)

$S_{F/P}$ = Area of exposed/sampled filter paper (in cm^2)

$E_{F/P}$ = Area of filter paper used in extraction (cm^2)

V = Volume of air sampled through filter paper (m^3)

3.4 Quality Assurance & Quality Control (QA/QC)

3.4.1 Quality Assurance

To maintain the accuracy and precision during sampling and analysis, intensive quality control was adopted and the following quality assurance procedures were taken into account as -

- Regular maintenance of the sampling and analysis equipments.
- Regular check-up and setting of water level at zero in manometer and cleaning of cyclone and dust cup before sampling
- Cleaning of jet pipes, oil well, inlet and application of silicon oil wet filter paper in impactor of $PM_{2.5}$
- Proper labeling & numbering of filter papers, sampling location, date, time and environmental conditions
- Routine calibration of the pump flow rate and timer for accurate measurements
- Filter handling with non-serrated clean forceps to avoid finger moisture and salt contamination
- Monitoring and recording of sampler flow at hourly basis for accurate sampling
- Use of filters, glass wares, chemical reagents and solvents of standard quality and grade
- Conditioning of filters in desiccators with silica for 24 hours at controlled room conditions
- Storage of exposed filters papers in refrigerator with sealed plastic containers until lab analysis

- Quality control using field and control blanks, flow audit, spot check and duplicate weighing and analysis

3.4.2 Quality Control in Carbonaceous Analysis

The accuracy for analytical results was periodically checked using standard reference materials (SRMs). Methane as internal standard was used to check the accuracy of carbon results (Pachauri et al. 2013). The minimum detection limits of OC/EC analyzer were observed as 1.01µg/m^3 for OC and 0.21µg/$m^3$for EC with the maximum analytical error of 15% (Hegde et al. 2016). The measured concentrations were reported after correction of field blanks. Uncertainty was calculated by fixing the Method Detection Limit (MDL) as (5/6) x MDL in case the analytic concentration was ≤MDL and as under root (Error Fraction + concentration)^2 + (0.05MDL)^2 in case the analytic concentration was >MDL (Huang et al. 2017).

NIST 8785 as SRM 1649 was also used to determine the analytical accuracy of OC and EC as 15% and 10%, respectively (Murillo et al., 2013). Total five replicates of this SRM were analyzed as the results depicted in Table 2. As per t-test performed for median comparison, no significant difference was observed between reference and obtained results at 95% confidence level.

3.4.3 Quality Control in PAHs Analysis

The accuracy for analysis was periodically checked using standard reference materials (SRMs). All sampled filter papers were stored at 4ºC temperature after sampling. Based on retention times and peak areas of samples and standards, the mass concentrations of PAHs were calculated. Blanks samples were also used for the accuracy of analysis. The detection limit of GC was determined using serial dilution of standard in a range of 0.008 - 0.020 ng/ml.

3.5 Statistical Analysis

3.5.1 Basic Statistic

The basic statistical analysis was performed for minimum, maximum, mean and standard deviations for PM_{10}, $PM_{2.5}$, carbonaceous species and polynuclear aromatic hydrocarbons. The basic statistics included daily 24 hours, seasonal as well as the annual, minimum, maximum, mean, and standard deviation of each variable. Statistical analysis was performed by the use of Statistical Package for Social Sciences (SPSS Version22).

3.5.2 Correlation Analysis

Pearson Correlation Coefficient Analysis was performed among PAHs, Organic tarry matter, OC and EC. The Pearson Correlation Coefficient measure the relationship between two variables, gives an idea about how much the chemical species are correlated in terms of their origin and source. Pearson Correlation Analysis was performed by the use of Statistical Package for Social Sciences (SPSS Version22).

3.5.3 Factor Analysis for Source Apportionment

Factor analysis, a statistical technique that is used to investigate whether the variables of interest i.e Y_1, Y_2,…,Y_n, and the unobservable factors i.e. F_1,F_2,…, F_n are linearly related. Each Y variable and two factors are assumed to be linearly related to each other as follows:

$$Y_1 = \beta_{10} + \beta_{11}F_1 + \beta_{12}F_2 + E_1 \quad (1)$$

$$Y_2 = \beta_{20} + \beta_{21}F_1 + \beta_{22}F_2 + E_2 \quad (2)$$

$$Y_3 = \beta_{30} + \beta_{31}F_1 + \beta_{32}F_2 + E_3 \quad (3)$$

E_1, E_2, and E_3 as error terms that indicate the hypothesized relationship is not exact. The parameter βij is referred as loading as per the vocabulary of factor analysis. As illustrated in above example, β_{12} represents the loading for the variable Y_1 on factor $F_{2.}$

The main objective of PCA using factor analysis is to set smaller set of factors by reducing the large number of variables which retain most of the information or original data set (Marcazzanet al., 2003; Karar and Gupta(2007).

Factor Analysis/PCA produces small number of independent correlated variables by replacing the set of multiple variables. Orthogonal transformations are achieved computing eigen-values and eigen vectors and diagonalizing correlation matrix of variables (Salvador et al., 2003). Each factor describes maximum total variance for similar data set which is totally uncorrelated with the other data set. After varimax rotation obtained, each factor loading gives significant correlation between factors and variables. Thus, each factor contains the chemical species of higher loading which represents fingerprint of the emission source. The bilinear model used in the study for factor analysis is expressed as:

$$C_{it} = \sum L_{ij} \times S_{jt} + E_{it}$$

Where,

C_{it} = Standardized value for the mass levels of i^{th} species in t^{th} sample,

S_{jt} = Factor/ common score for j^{th} factor in t^{th} sample,

L_{ij} = Factor loading for i^{th} species in j^{th} source

E_{it} = Residual of i^{th} species for t^{th} sample which is not in account by the j factor or source.

Principal component analysis was performed by selecting factor analysis option in Statistical Package for Social Sciences (SPSS Version 22).

3.6 Assessment of Toxicity

BaP is considered as the most powerful tool as reference chemical/ indicator for estimating the risk level imposed by PAHs. BaP equivalent (BaP_{eq}) is calculated by multiplying the concentration of each compound with its corresponding TEF value and then summing up the obtained results as per USEPA guidelines. To assess the health impacts of particulate aerosols, Benzo(a) pyrene equivalent (BaP_{eq}) and Toxic Equivalency factor (TEF) were calculated using mathematical expression defined as

BaP equivalent (BaP_{eq}) = $\sum Conc_{.} * TEF$

Where
Conc = Concentration of Individual PAH,
TEF = Toxic Equivalency factor

CHAPTER 4: RESULT AND DISCUSSION

This chapter broadly discusses the results and their interpretation for meteorology, mass concentration of Particulate Matter (PM_{10} and $PM_{2.5}$), mass concentration of Organic Tarry Matter (OTM), Organic Carbon (OC), Elemental Carbon (EC) and mass concentration of Polycyclic Aromatic Hydrocarbons (PAHs). It also focuses on the seasonal variation in Particulate Aerosols during the study period, correlation among PAHs, Organic Tarry Matter, Organic & Elemental Carbon in terms of Diagnostic Ratio, Pearson Correlation and OC/EC ratio, Source apportionment using Principal Components Analysis has been presented.

4.1 Meteorology of the Study Area

To assess the influence of origin, dispersion and migration of particulate aerosols, the meteorological data of study area was obtained from a continuous weather monitoring station operated by Eco Laboratories and consultants private limited located nearby our sampling location in ST_2 (Sector 74, Industrial area), Mohali. Meteorological parameters considered are wind direction (degree), wind speed (m/s), temperature (°C), relative humidity (%) and precipitation (mm) on hourly basis during entire study period. Wind rose diagram was plotted as presented in **Figure 4.1** and predominant wind direction from Northwest (NW) was reported for study period.

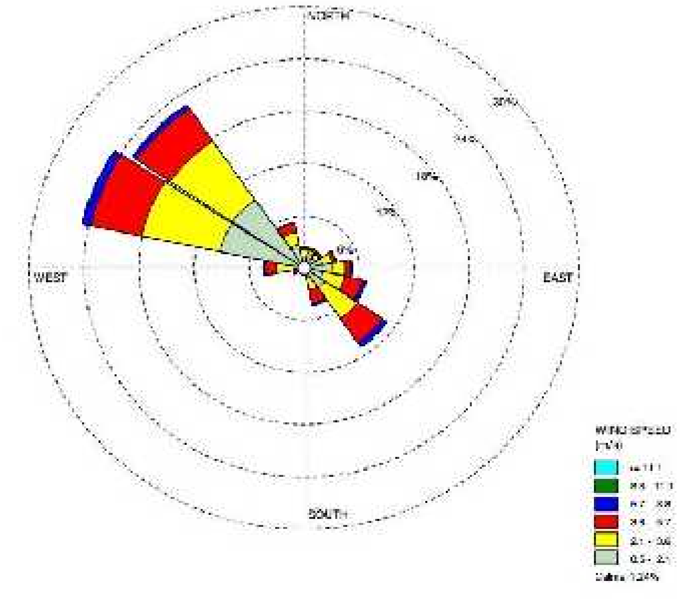

Fig. 4.1: Wind Rose showing Meteorology of Study Area (April 2013 - January 2016)

4.2 Mass Concentration of Particulate Matter (PM_{10} and $PM_{2.5}$)

Air samples for PM_{10} (particle size <10µm in aerodynamic diameter) and $PM_{2.5}$ (particle size <2.5µm in aerodynamic diameter) were collected from the tricity of Chandigarh-Mohali-Panchkula during summer season (March to April) and winter season (December to January) in 2013-14, 2014-15 and 2015-16.

The sampling was carried out twice a week at four locations namely Sector 12 Chandigarh (ST_0), Sector 34 Chandigarh (ST_1), Sector 74 Mohali (ST_2) and Sector 12A Panchkula (ST_3). Total 384 Nos. of samples [2 (twice a week)*16 (8 weeks in April-May plus 8weeks in December-January)*3(three years)*4(No. of locations)] each for PM_{10} and $PM_{2.5}$ were collected from all locations during the study period of three years. The daily average mass concentrations of PM_{10} and $PM_{2.5}$ are presented in **Table 4.1(a) - 4.1(l)** as enclosed in **Annexure-1** and year wise statistical summary of PM_{10} and $PM_{2.5}$ is depicted in **Table 4.2(a-c).**

Particulate Matter in 2013-14

As illustrated in **Table 4.2a** and **Figure 4.2a & 4.3a**, the mass concentrations of PM_{10} and $PM_{2.5}$ respectively varied from 69.2-162.2 µg/m^3 (average 108.1 µg/m^3) and 40.5-84.5 µg/m^3 (average 57.1 µg/m^3) at ST_0, 79.8-173.6 µg/m^3 (average 119.7 µg/m^3) and 41.8-91.2 µg/m^3 (average 62.1 µg/m^3) at ST_1, 80.6-187.5 µg/m^3 (average 124.1 µg/m^3) and 42.4-100.3 µg/m^3 (average 65.7 µg/m^3) at ST_2 and 82.6-171.1 µg/m^3 (average 116.8 µg/m^3) and 45.5-91.3 µg/m^3 (average 61.8 µg/m^3) at ST_3.

Particulate Matter in 2014-15

PM_{10} and $PM_{2.5}$ respectively varied from 84.2-177.1 µg/m^3 (average 125.7 µg/m^3) and 43.2-90.5 µg/m^3 (average 65.7 µg/m^3) at ST_0, 82.9-191.2 µg/m^3 (average 140.1 µg/m^3) and 44.7-99.5 µg/m^3 (average 73.6 µg/m^3) at ST_1, 84.8-198.0 µg/m^3 (average 148.9 µg/m^3) and 47.8-105.7 µg/m^3 (average 78.8 µg/m^3) at ST_2 and 79.8-193.0 µg/m^3 (average 142.9 µg/m^3) and 43.7-101.1 µg/m^3 (average 74.1 µg/m^3) at ST_3 (**Table 4.2b** and **Figure 4.2b & 4.3b**).

Table 4.2(a): Statistical summary of ambient air quality at study area during 2013-14 (PAHs in ng/m^3 & rest in µg/m^3)

Location	ST$_0$				ST$_1$				ST$_2$				ST$_3$			
Parameter	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD
PM$_{10}$	69.2	162.2	108.1	25.8	79.8	173.6	119.7	31.2	80.6	187.5	124.1	33.0	82.6	171.1	116.8	24.7
PM$_{2.5}$	40.5	84.5	57.1	12.5	41.8	91.2	62.1	15.5	42.4	100.3	65.7	17.0	45.5	91.3	61.8	12.8
Acy	0.15	1.93	0.72	0.55	0.19	2.44	0.91	0.70	0.21	2.74	1.02	0.78	0.17	2.22	0.83	0.64
Ant	0.22	1.45	0.73	0.40	0.28	1.83	0.92	0.51	0.31	2.05	1.03	0.57	0.26	1.67	0.83	0.46
BaA	0.53	3.45	1.73	0.96	0.67	4.36	2.19	1.21	0.75	4.89	2.45	1.36	0.61	3.97	1.99	1.10
BaP	0.32	2.43	1.35	0.55	0.41	3.08	1.70	0.70	0.46	3.45	1.91	0.78	0.37	2.80	1.55	0.63
BbF	0.80	5.81	2.61	1.29	1.01	7.34	3.30	1.63	1.15	8.23	3.69	1.83	0.92	6.68	3.00	1.48
BghiP	0.29	5.39	1.60	1.18	0.37	6.81	2.02	1.49	0.41	7.63	2.26	1.67	0.34	6.19	1.84	1.35
BkF	0.50	4.12	1.92	0.89	0.63	5.21	2.43	1.13	0.71	5.83	2.72	1.26	0.58	4.74	2.21	1.02
Chry	0.58	10.69	3.34	2.81	0.74	13.53	4.22	3.56	0.83	15.15	4.73	3.99	0.67	12.30	3.84	3.24
dBahA	0.27	1.61	0.77	0.41	0.34	2.04	0.97	0.51	0.38	2.29	1.09	0.58	0.31	1.85	0.89	0.47
Fln	0.24	2.59	0.68	0.55	0.30	3.28	0.86	0.69	0.34	3.67	0.97	0.77	0.27	2.98	0.78	0.63
Flu	0.14	1.01	0.56	0.23	0.17	1.28	0.71	0.29	0.19	1.44	0.79	0.33	0.16	1.17	0.64	0.26
IP	0.30	2.02	1.25	0.48	0.38	2.55	1.58	0.60	0.43	2.86	1.77	0.67	0.35	2.32	1.44	0.55
Nap	0.38	2.76	1.24	0.61	0.48	3.50	1.57	0.78	0.54	3.92	1.76	0.87	0.44	3.18	1.43	0.70
Pery	0.23	4.44	1.01	1.03	0.29	5.61	1.28	1.31	0.33	6.28	1.43	1.47	0.27	5.10	1.16	1.19
Pyr	0.10	0.73	0.31	0.20	0.12	0.92	0.39	0.25	0.14	1.03	0.44	0.28	0.11	0.83	0.35	0.23
Ret	0.11	0.81	0.45	0.18	0.14	1.03	0.57	0.23	0.15	1.15	0.64	0.26	0.12	0.93	0.52	0.21
OTM	4.98	37.31	20.63	8.45	5.94	41.79	22.47	7.31	7.24	45.42	23.71	8.26	6.41	40.22	22.08	6.42
OC	3.03	32.46	11.71	7.56	2.88	30.80	12.02	7.83	2.57	33.65	11.98	7.28	3.45	22.65	12.81	5.50
EC	0.82	5.00	2.39	1.26	0.70	4.28	2.05	1.08	0.80	5.96	2.53	1.63	0.90	6.68	2.84	1.83
∑PAHs	5.16	51.24	20.25	12.32	6.53	64.82	25.62	15.59	7.34	72.59	28.70	17.47	5.94	5.92	23.29	14.17

Note: Min – Minimum, Max – Maximum, Avg – Average, SD – Standard deviation

Table 4.2(b): Statistical summary of ambient air quality at study area during 2014-15 (PAHs in ng/m^3 & rest in µg/m^3)

Location	ST_0				ST_1				ST_2				ST_3			
Parameter	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD
PM_{10}	84.2	177.1	125.7	29.8	82.9	191.2	140.1	34.5	84.8	198.0	148.9	36.1	79.8	193.0	142.9	37.3
$PM_{2.5}$	43.2	90.5	65.7	15.1	44.7	99.5	73.6	17.4	47.8	105.7	78.8	19.3	43.7	101.1	74.1	18.3
Acy	0.15	1.85	0.69	0.53	0.18	2.34	0.88	0.67	0.21	2.62	0.98	0.75	0.17	2.13	0.80	0.61
Ant	0.21	1.39	0.70	0.39	0.27	1.76	0.88	0.49	0.30	1.97	0.99	0.55	0.24	1.60	0.80	0.44
BaA	0.51	3.31	1.66	0.92	0.64	4.18	2.09	1.16	0.72	4.68	2.35	1.30	0.58	3.80	1.90	1.06
BaP	0.31	2.33	1.29	0.53	0.39	2.95	1.63	0.67	0.44	3.30	1.83	0.75	0.36	2.68	1.48	0.61
BbF	0.76	5.56	2.50	1.23	0.97	7.04	3.16	1.56	1.11	7.88	3.54	1.76	0.88	6.40	2.87	1.42
BghiP	0.28	5.16	1.53	1.13	0.35	6.53	1.93	1.43	0.40	7.31	2.17	1.60	0.32	5.94	1.76	1.30
BkF	0.48	3.95	1.84	0.85	0.61	4.99	2.33	1.08	0.68	5.59	2.61	1.21	0.55	4.54	2.12	0.98
Chry	0.56	10.25	3.20	2.70	0.71	12.96	4.05	3.41	0.79	14.52	4.53	3.82	0.64	11.78	3.68	3.10
dBahA	0.25	1.55	0.74	0.39	0.32	1.96	0.93	0.49	0.36	2.19	1.05	0.55	0.29	1.78	0.85	0.45
Fln	0.23	2.48	0.65	0.52	0.29	3.14	0.83	0.66	0.32	3.52	0.93	0.74	0.26	2.86	0.75	0.60
Flu	0.13	0.97	0.54	0.22	0.16	1.23	0.68	0.28	0.18	1.38	0.76	0.31	0.15	1.12	0.62	0.25
IP	0.29	1.93	1.20	0.46	0.37	2.44	1.51	0.58	0.41	2.74	1.70	0.65	0.33	2.22	1.38	0.52
Nap	0.36	2.65	1.19	0.59	0.46	3.35	1.50	0.74	0.52	3.75	1.68	0.83	0.42	3.05	1.37	0.68
Pery	0.22	4.25	0.97	0.99	0.28	5.38	1.23	1.25	0.32	6.02	1.37	1.40	0.26	4.89	1.11	1.14
Pyr	0.09	0.70	0.30	0.19	0.12	0.88	0.37	0.24	0.13	0.99	0.42	0.27	0.11	0.80	0.34	0.22
Ret	0.10	0.78	0.43	0.18	0.13	0.98	0.54	0.22	0.15	1.10	0.61	0.25	0.12	0.89	0.49	0.20
OTM	6.85	51.30	25.28	10.41	7.49	56.11	28.44	12.12	7.99	59.85	31.83	12.94	7.78	58.29	31.76	12.71
OC	3.78	40.45	14.24	9.92	4.23	45.26	15.67	10.99	3.65	47.85	18.31	11.74	4.96	32.55	18.42	7.90
EC	0.97	5.87	2.80	1.48	0.84	5.08	2.43	1.28	0.90	6.70	2.85	1.83	1.07	8.00	3.40	2.19
∑PAHs	4.95	49.10	19.41	11.81	6.26	62.11	24.53	14.94	7.03	69.57	27.50	16.74	5.69	56.47	22.32	13.58

Note: Min – Minimum, Max – Maximum, Avg – Average, SD – Standard deviation

Table 4.2(c): Statistical summary of ambient air quality at study area during 2015-16 (PAHs in ng/m^3 & rest in µg/m^3)

Location	ST_0				ST_1				ST_2				ST_3			
Parameter	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD
PM_{10}	80.1	159.4	116.0	23.0	81.0	184.7	124.2	28.8	89.1	188.6	132.4	28.6	89.3	194.1	129.8	28.8
$PM_{2.5}$	44.4	83.1	61.4	11.5	42.4	99.3	65.5	15.1	46.6	100.8	69.9	14.9	46.3	103.8	68.7	15.0
Acy	0.16	2.01	0.75	0.58	0.20	2.55	0.95	0.73	0.22	2.85	1.07	0.82	0.18	2.31	0.87	0.66
Ant	0.23	1.51	0.76	0.42	0.29	1.91	0.96	0.53	0.33	2.14	1.07	0.59	0.27	1.74	0.87	0.48
BaA	0.55	3.59	1.80	1.00	0.70	4.55	2.28	1.26	0.78	5.09	2.55	1.41	0.63	4.13	2.07	1.15
BaP	0.34	2.53	1.40	0.57	0.43	3.21	1.77	0.73	0.48	3.59	1.99	0.81	0.39	2.91	1.61	0.66
BbF	0.83	6.05	2.71	1.34	1.05	7.65	3.43	1.70	1.20	8.57	3.85	1.91	0.96	6.96	3.12	1.54
BghiP	0.30	5.61	1.66	1.23	0.39	7.10	2.10	1.55	0.43	7.95	2.36	1.74	0.35	6.45	1.91	1.41
BkF	0.52	4.29	2.00	0.93	0.66	5.43	2.53	1.17	0.74	6.08	2.84	1.32	0.60	4.93	2.30	1.07
Chry	0.61	11.14	3.48	2.93	0.77	14.09	4.40	3.71	0.86	15.78	4.93	4.15	0.70	12.81	4.00	3.37
dBahA	0.28	1.68	0.80	0.42	0.35	2.13	1.01	0.54	0.39	2.38	1.14	0.60	0.32	1.93	0.92	0.49
Fln	0.25	2.70	0.71	0.57	0.31	3.42	0.90	0.72	0.35	3.83	1.01	0.81	0.29	3.11	0.82	0.65
Flu	0.14	1.06	0.58	0.24	0.18	1.34	0.74	0.30	0.20	1.50	0.83	0.34	0.16	1.21	0.67	0.27
IP	0.32	2.10	1.30	0.50	0.40	2.66	1.65	0.63	0.45	2.98	1.84	0.70	0.36	2.42	1.50	0.57
Nap	0.40	2.88	1.29	0.64	0.50	3.64	1.64	0.81	0.56	4.08	1.83	0.90	0.45	3.31	1.49	0.73
Pery	0.24	4.62	1.05	1.08	0.31	5.84	1.33	1.36	0.34	6.55	1.49	1.53	0.28	5.31	1.21	1.24
Pyr	0.10	0.76	0.32	0.21	0.13	0.96	0.41	0.26	0.14	1.07	0.46	0.29	0.12	0.87	0.37	0.24
Ret	0.11	0.84	0.47	0.19	0.14	1.07	0.59	0.24	0.16	1.20	0.66	0.27	0.13	0.97	0.54	0.22
OTM	12.95	30.94	21.96	5.15	15.90	38.61	24.18	5.69	16.69	36.58	25.49	5.61	12.69	36.75	23.12	6.44
OC	9.01	18.69	13.97	2.60	8.94	20.00	14.11	3.25	9.98	23.64	15.77	3.79	7.69	21.90	13.90	4.00
EC	0.92	3.91	2.20	0.76	0.78	3.57	1.88	0.80	0.85	3.55	2.03	0.78	1.01	4.21	2.18	0.88
∑PAHs	5.38	53.57	21.10	12.84	6.80	67.52	26.69	16.24	7.64	75.62	29.89	18.20	6.18	61.38	24.26	14.76

Note: Min – Minimum, Max – Maximum, Avg – Average, SD – Standard deviation

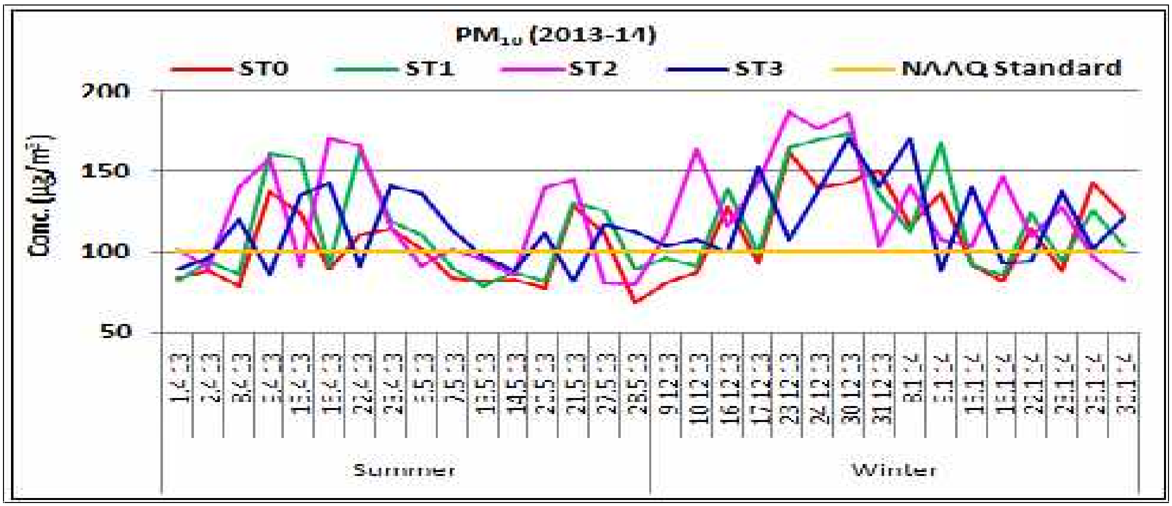

Fig. 4.2a: Air quality profile of PM$_{10}$ at study area during 2013-14

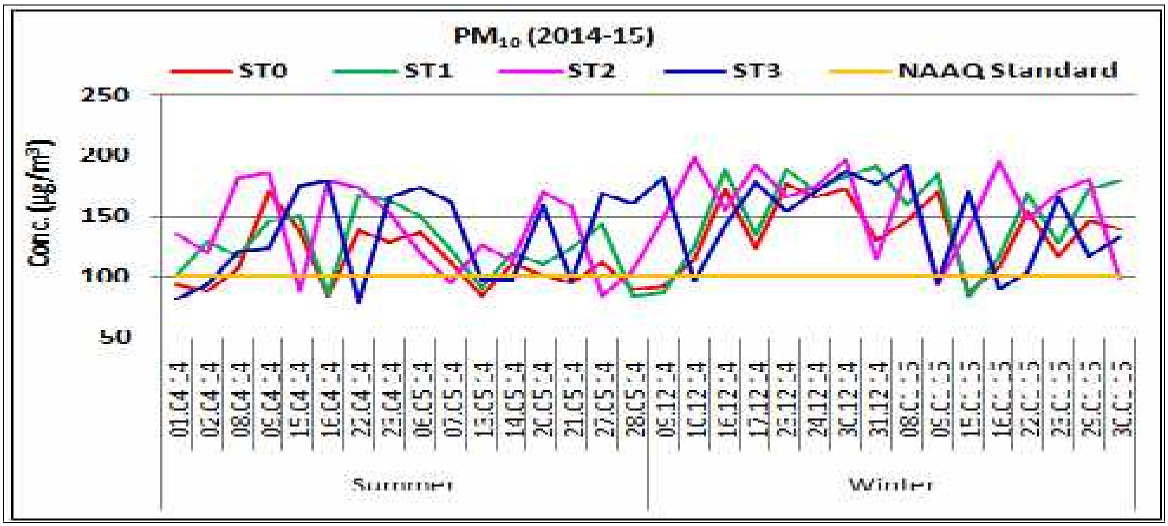

Fig. 4.2b: Air quality profile of PM$_{10}$ at study area during 2014-15

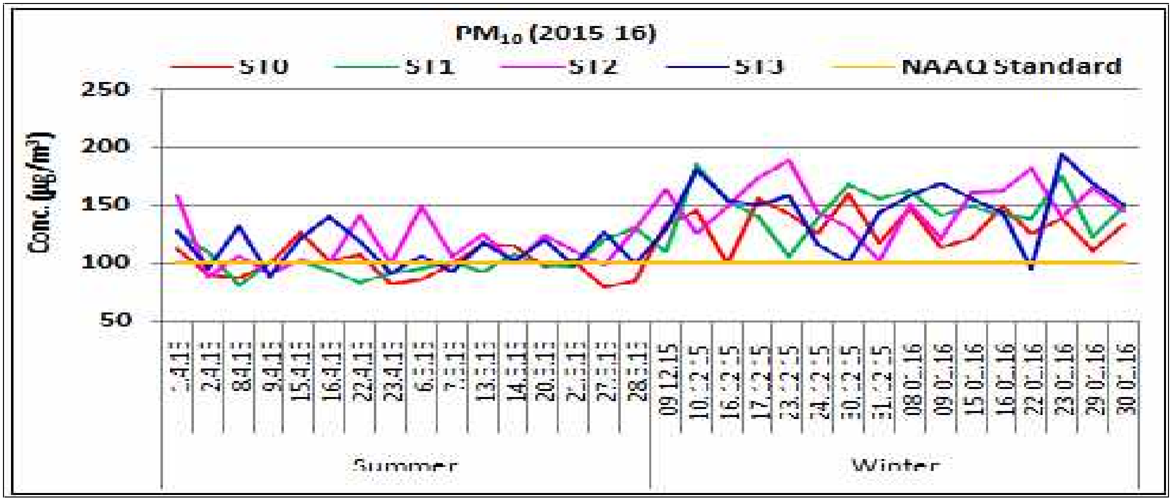

Fig. 4.2c: Air quality profile of PM$_{10}$ at study area during 2015-16

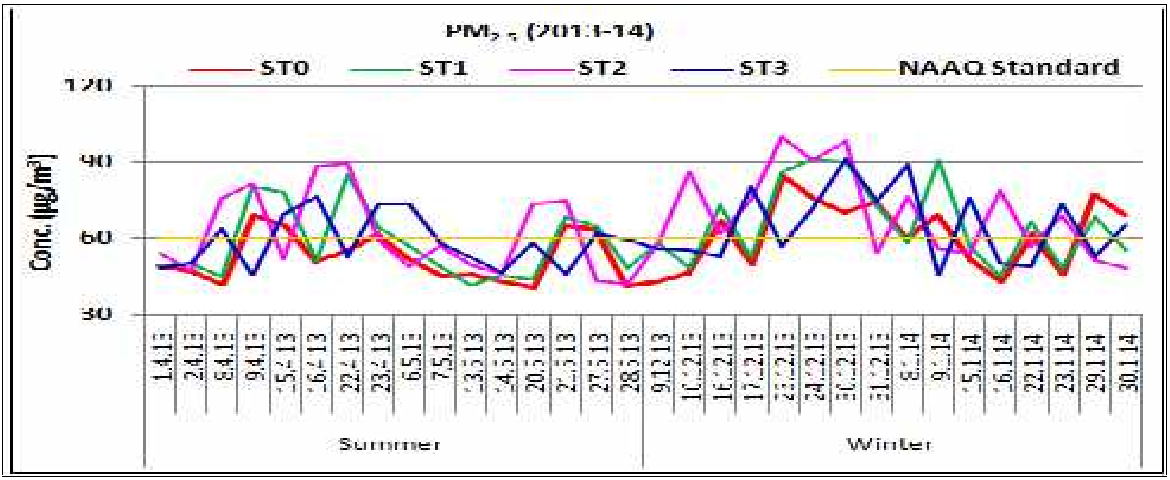

Fig. 4.3a: Air quality profile of $PM_{2.5}$ at study area during 2013-14

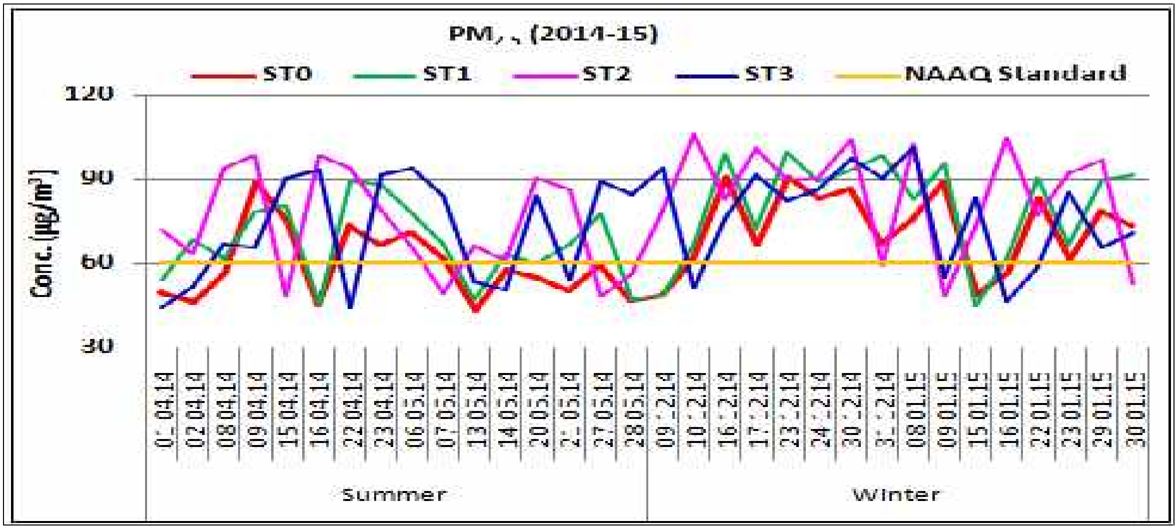

Fig. 4.3b: Air quality profile of $PM_{2.5}$ at study area during 2014-15

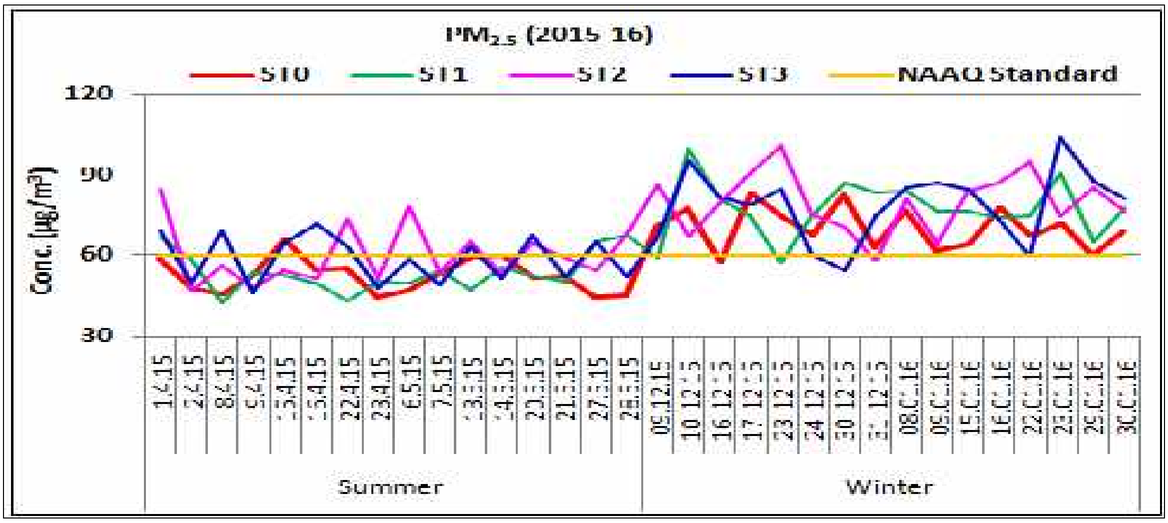

Fig. 4.3c: Air quality profile of $PM_{2.5}$ at study area during 2015-16

Particulate Matter in 2015-16

PM_{10} and $PM_{2.5}$ respectively varied from 80.1-159.4 µg/m^3 (average 116.0 µg/m^3) and 44.4-83.1 µg/m^3 (average 61.4 µg/m^3) at ST_0, 81.0-184.7 µg/m^3 (average 124.2 µg/m^3) and 42.4-99.3 µg/m^3 (average 65.5 µg/m^3) at ST_1, 89.1-188.6 µg/m^3 (average 132.4 µg/m^3) and 46.6-100.8 µg/m^3 (average 69.9 µg/m^3) at ST_2 and 89.3-194.1 µg/m^3 (average 129.8 µg/m^3) and 46.3-103.8 µg/m^3 (average 68.7 µg/m^3) at ST_3 (**Table 4.2c** and **Figure 4.2c & 4.3c)**.

PM_{10} and $PM_{2.5}$ exceed to respective 24 hourly NAAQ standards of 100 µg/m^3 and 60 µg/m^3 during most of sampling days. The results clearly indicate that the airborne PM is a critical air pollutant which not only deteriorates air quality but also causes secondary concerns. Literature studies also indicate that increase in PM_{10} by 10 µg/m^3 leads to daily mortality of 0.2–0.6% (Samoli et al. 2008) and increase in $PM_{2.5}$ by 10 µg/m^3 leads to a long tern risk of cardiopulmonary mortality of 6–13% (Krewski et al. 2009; Beelen et al. 2008; Pope et al. 2002).

The higher mass concentrations of these particulate aerosols in the study period may be attributed to various sources such as combustion of fossil fuels in stationary, mobile sources, trans-boundary migrations and crop residue burning after rice and wheat harvesting periods in the region which are in agreement with previous studies (Gupta et al. 2017 and Lohan et al. 2018). PM_{10} & $PM_{2.5}$ levels were also reported to be higher during the events of crop residue burning in rural area of Patiala (Awasthi et al. 2011). Another study reported similar pattern of mass concentration of PM_{10} and $PM_{2.5}$ during crop residue burning periods at three urban locations at Amritsar, Ludhiana and Mandi Gobindgarh in Punjab (Gupta et al. 2016).

The obtained mass levels of $PM_{2.5}$ and PM_{10} showed spatial and temporal variation as depicted in **Figure 4.4**. The average concentrations of PM_{10} were reported as 116.6 µg/m^3 at ST_0, 127.0 µg/m^3 at ST_1, 135.1 µg/m^3 at ST_2 and 129.2 µg/m^3 at ST_3 whereas average concentrations of $PM_{2.5}$ were reported as 61.4 µg/m^3 at ST_0, 67.1 µg/m^3 at ST_1, 71.5 µg/m^3 at ST_2 and 68.2 µg/m^3 at ST_3. The mass values of PM_{10} and $PM_{2.5}$ varied as $ST_2>ST_3>ST_1>ST_0$.

The highest mass concentrations of $PM_{2.5}$ and PM_{10} were observed at ST_2 Sector 74 (Mohali). ST_2 is an industrial area comprising various types of industries. Road dust, diesel generators and heavy vehicles, boilers running on wood, rice husk and coal contributed to highest mass of PM at the site. ST_3 in Sector 12A Panchkula represents residential area and ST_1 in Sector 34 Chandigarh represents residential cum commercial areas which experience less pollution than industrial site. ST_0 in Sector 12 of Chandigarh is located in green belt region in north-west of tricity with little habitation and presence of Shiwalik hills in background. Thus this site has least impacts from the anthropogenic activities of tricity due to prominent wind direction from north-west in the region.

The average mass concentrations of PM_{10} and $PM_{2.5}$ respectively were reported as 116.4 µg/m^3 and 61.7 µg/m^3 in 2013-14, 138.9 µg/m^3 and 73.1 µg/m^3 in 2014-15 and 125.6 µg/m^3 and 66.4 µg/m^3 in 2015-16. The data showed temporal variation as 2013-14 <2015-16 <2014-15 during the three year study. The data of first two years shows increasing trend while the third year data indicates slight down fall in PM values which could be the reason of increasing awareness among public and enforcement of government regulations to curb the environmental hazards due to residual crop burning by farmers in the vicinity of study locations. The results clearly indicate that airborne PM is a critical air pollutant which is adversely affecting the air quality of this tricity.

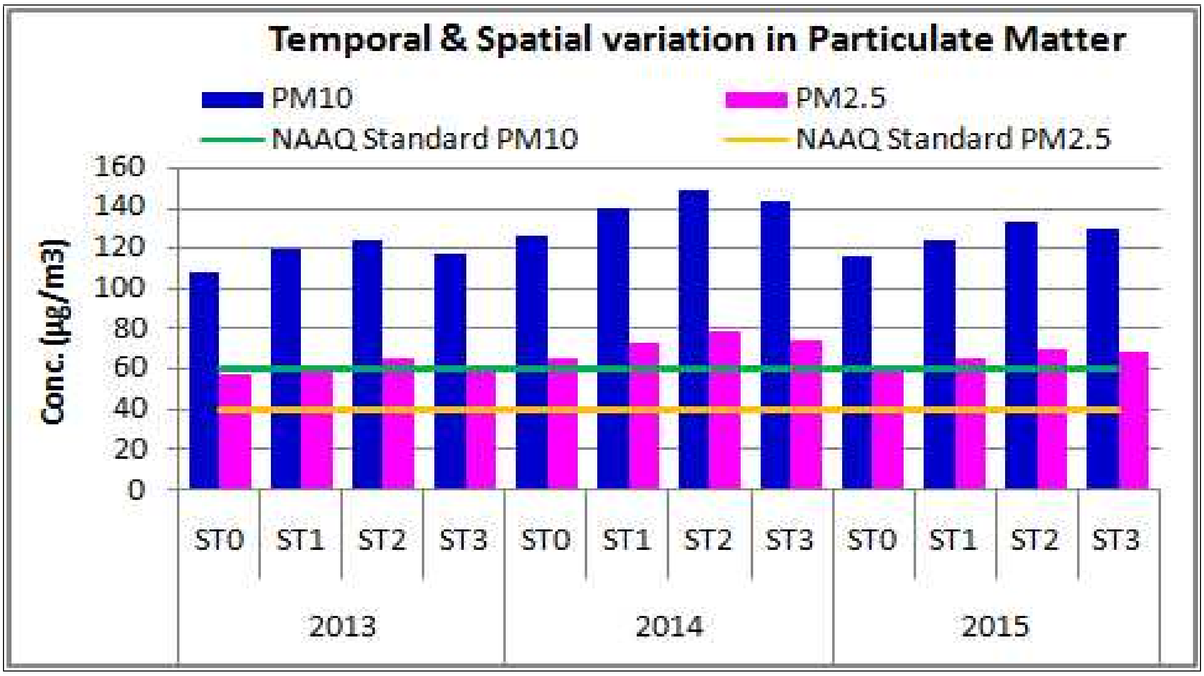

Fig. 4.4: Temporal and spatial variation in PM_{10} & $PM_{2.5}$ at study area

4.3 Mass concentration of Organic Tarry Matter (OTM)

Carbonaceous matter includes organic compounds (such as alkanes, alkenes, carboxylic acids, carbonyls, aromatic compounds and volatile organic compounds) and inorganic/elemental compounds. Organic tarry matter represents oxidized hydrocarbons (ketones, aldehydes and oxyacids), aromatics (PAHs) and dioxins and furans. These compounds originate either primarily from industrial and/or automotive sources or secondarily from oxidation of VOCs (volatile organics). In urban areas, these carbonaceous compounds are largely associated to burning of fossil fuels particularly in vehicles.

Organic Tarry Matter in 2013-14

As illustrated in **Table 4.2a** and **Figure 4.5a**, the mass concentrations of OTM varied from 4.98-37.31 $\mu g/m^3$ (average 20.63 $\mu g/m^3$) at ST_0, 5.94-41.79 $\mu g/m^3$ (average 22.47 $\mu g/m^3$) at ST_1, 7.24-45.42 $\mu g/m^3$ (average 8.26 $\mu g/m^3$) at ST_2 and 6.41-40.22 $\mu g/m^3$ (average 22.08 $\mu g/m^3$) at ST_3.

Organic Tarry Matter in 2014-15

The mass concentrations of OTM varied from 6.85-51.30 $\mu g/m^3$ (average 25.28 $\mu g/m^3$) at ST_0, 7.49-56.11 $\mu g/m^3$ (average 28.44 $\mu g/m^3$) at ST_1, 7.99-59.85 $\mu g/m^3$ (average 31.83 $\mu g/m^3$) at ST_2 and 7.78-58.29 $\mu g/m^3$ (average 31.76 $\mu g/m^3$) at ST_3 (**Table 4.2b** and **Figure 4.5b)**.

Organic Tarry Matter in 2015-16

The mass concentrations of OTM varied from 12.95-30.94 $\mu g/m^3$ (average 21.96 $\mu g/m^3$) at ST_0, 15.90-38.61 $\mu g/m^3$ (average 24.18 $\mu g/m^3$) at ST_1, 16.69-36.58 $\mu g/m^3$ (average 25.49 $\mu g/m^3$) at ST_2 and 12.69-36.75 $\mu g/m^3$ (average 23.12 $\mu g/m^3$) at ST_3 (**Table 4.2c** and **Figure 4.5c)**.

OTM among the largest in composition contributes to $PM_{2.5}$ as 36.0% in 2013-14, 40.1% in 2014-15 and 35.7% in 2015-16 at the study area. The results were consistent with the previous finding (Ichikawa and Naito, 2017). The results indicate OTM as the main component of $PM_{2.5}$ aerosols and largely associated to burning of fossil fuels particularly in vehicles, crop residue and biomass burning in and around the study area. Like $PM_{2.5}$, the average mass concentrations of OTM were also highest at ST_2 (27.0 µg/m^3) followed by ST_3 (25.7 µg/m^3), ST_1 (25.0 µg/m^3) and ST_0 (22.6 µg/m^3) as presented in **Figure 4.4a-c**. The highest mass concentrations at ST_2 (industrial area) may be associated to diesel generators, heavy vehicles, boilers running on wood, rice husk/ coal and construction activities in the area. ST_1 in Chandigarh is residential cum commercial and ST_3 in Panchkula is purely residential site which experiences less pollution than ST_2 industrial site of Mohali. ST_0 in Chandigarh represents educational institute and is located in green belt region in north-west of tricity with little habitation and presence of Shiwalik hills in background experiences least pollution in the region.

4.4 Mass concentration of Organic Carbon (OC) and Elemental Carbon (EC)

OC and EC in 2013-14

OC and EC respectively varied from 3.03-32.46 µg/m^3 (average 11.71 µg/m^3) and 0.82-5.00 µg/m^3 (average 2.39 µg/m^3) at ST_0, 2.88-30.80 µg/m^3 (average 12.02 µg/m^3) and 0.70-4.28 µg/m^3 (average 2.05 µg/m^3) at ST_1, 2.57-33.65 µg/m^3 (average 11.98 µg/m^3) and 0.80-5.96 µg/m^3 (average 2.53 µg/m^3) at ST_2 and 3.45-22.65 µg/m^3 (average 12.81 µg/m^3) and 0.90-6.68 µg/m^3 (average 2.84 µg/m^3) at ST_3 (**Table 4.2a** and **Figure 4.5a)**.

OC and EC in 2014-15

OC and EC respectively varied from 3.78-40.45 µg/m^3 (average 14.24 µg/m^3) and 0.97-5.87 µg/m^3 (average 2.80 µg/m^3) at ST_0, 4.23-45.26 µg/m^3 (average 15.67 µg/m^3) and 0.84-5.08 µg/m^3 (average 2.43 µg/m^3) at ST_1, 3.65-47.85 µg/m^3 (average 18.31 µg/m^3) and 0.90-6.70 µg/m^3 (average 2.85 µg/m^3) at ST_2 and 4.96-32.55 µg/m^3 (average 18.42 µg/m^3) and 1.07-8.00 µg/m^3 (average 3.40 µg/m^3) at ST_3 (**Table 4.2b** and **Figure 4.5b)**.

OC and EC in 2015-16

OC and EC respectively varied from 9.01-18.69 µg/m^3 (average 13.97 µg/m^3) and 0.92-3.91 µg/m^3 (average 2.20 µg/m^3) at ST_0, 8.94-20.00 µg/m^3 (average 14.11 µg/m^3) and 0.78-3.57 µg/m^3 (average 1.88 µg/m^3) at ST_1, 9.98-23.64 µg/m^3 (average 15.77 µg/m^3) and 0.85-3.55 µg/m^3 (average 2.03 µg/m^3) at ST_2 and 7.69-21.90 µg/m^3 (average 13.90 µg/m^3) and 1.01-4.21 µg/m^3 (average 2.18 µg/m^3) at ST_3 (**Table 4.2c** and **Figure 4.5c)**.

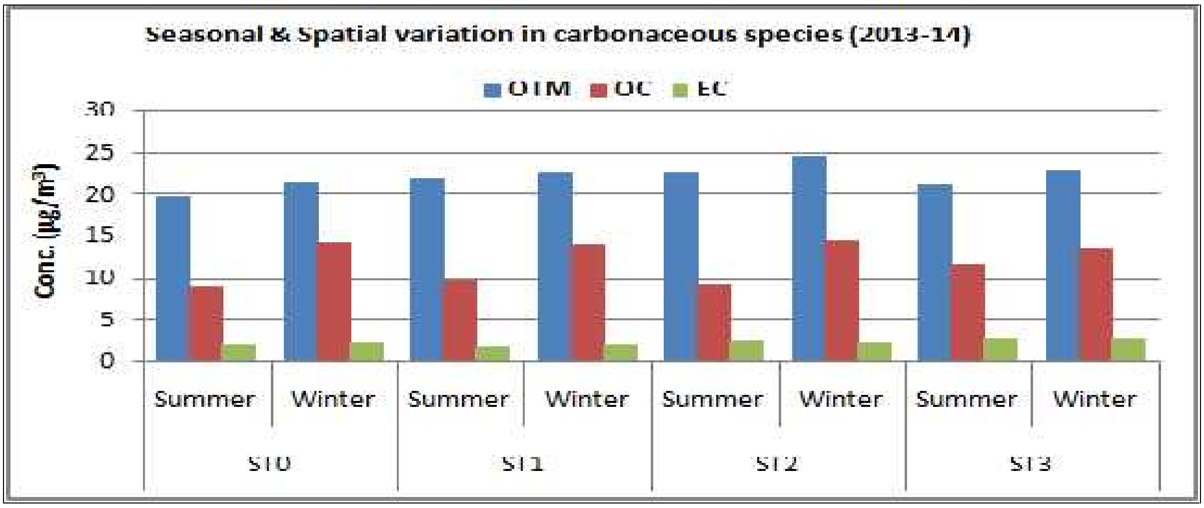

Fig. 4.5a: Seasonal and spatial variation in carbonaceous species during 2013-14

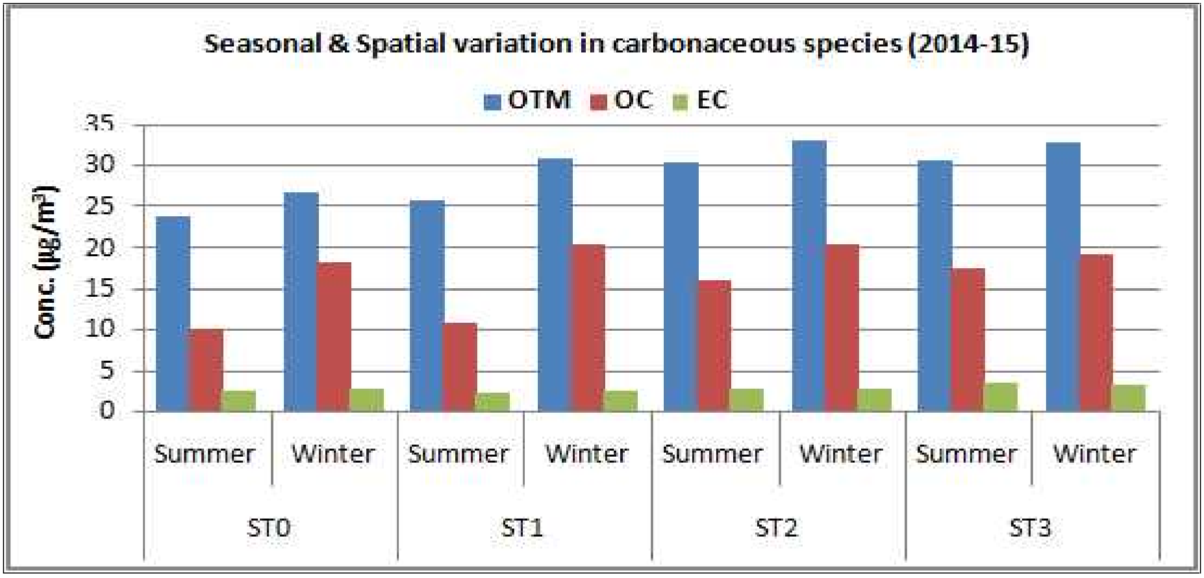

Fig. 4.5b: Seasonal and spatial variation in carbonaceous species during 2014-15

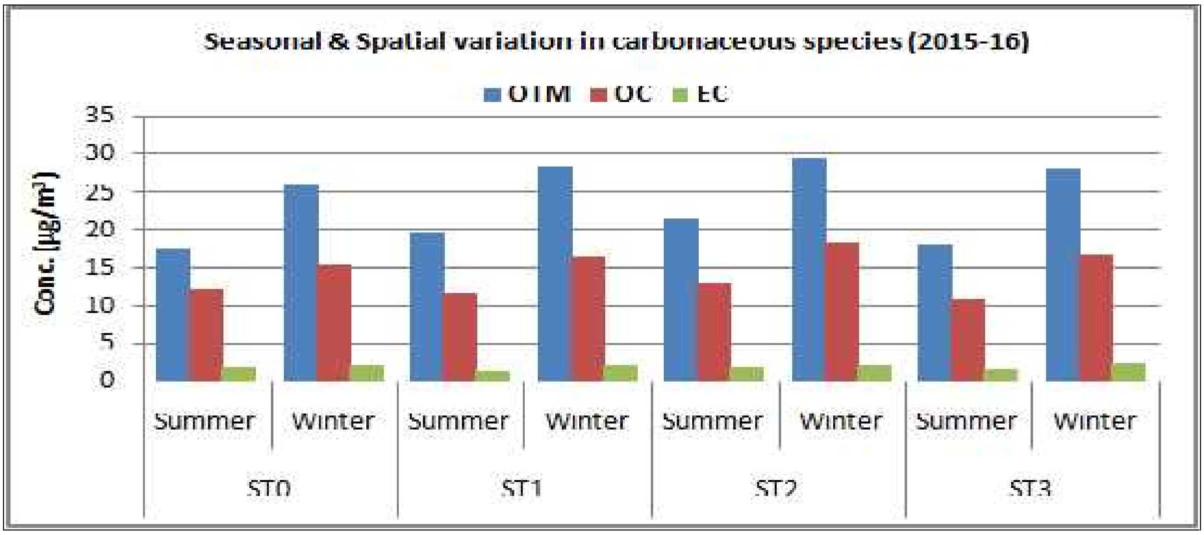

Fig. 4.5c: Seasonal and spatial variation in carbonaceous species during 2015-16

The average mass concentrations of OC and EC were highest at ST_2 followed by ST_3, ST_1 and ST_0 as presented in **Figure 4.5a-c**. The highest mass concentrations at ST_2 (industrial area) may be associated to diesel generators, heavy vehicles, boilers running on wood, rice husk/ coal and construction activities in the area. Many organic-related factories located in this area can emit considerable organic pollutants during operation. ST_1 in Chandigarh is residential cum commercial and ST_3 in Panchkula is purely residential site which experiences less pollution than ST_2 industrial site of Mohali. ST_0 in Chandigarh represents educational institution area experiences least pollution in the region. OC and EC also varied in same manner of $PM_{2.5}$ and contribute nearly half to OTM mass. Trends of seasonal variation in OC & EC were also observed similar to $PM_{2.5}$ as being higher when $PM_{2.5}$ was high and lower during $PM_{2.5}$ levels were low. The relative abundance of carbonaceous species is presented in **Figure 4.6.**

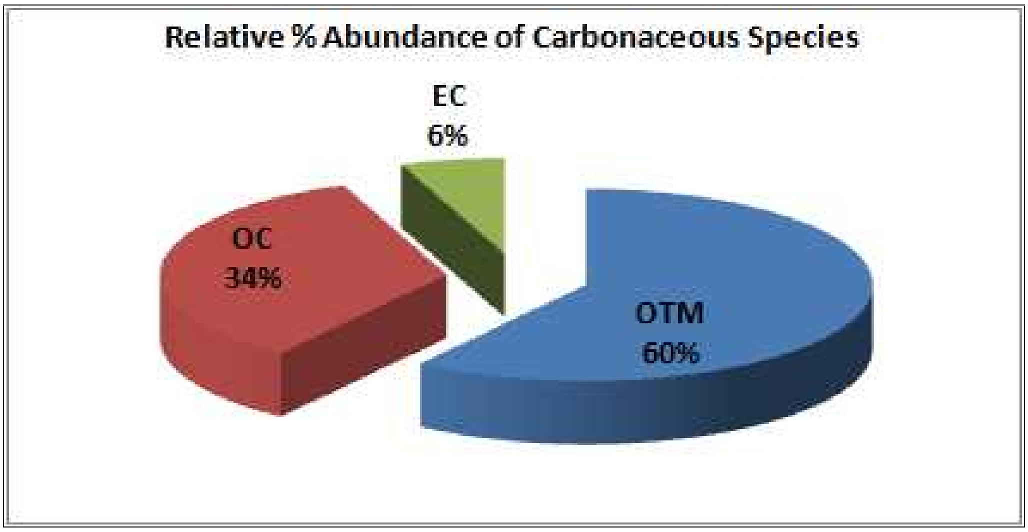

Fig. 4.6: Relative abundance of carbonaceous components

4.5 Mass concentration of Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are emitted by combustion processes that are associated with vehicles and biomass burning. Study depicted that People living in urban areas experience high level of exposure of petrochemical pollutants and is under high risk of lung cancer in comparison to those living in low pollution areas (Yang et al., 1999). A total of sixteen PAHs named Anthracite, Acenaphthylene, Benzo(a) anthracene, Benzo(b) fluroanthene, Benzo(a) pyrene, Benzo(K) fluoranthene, Benzo(ghi) perylene, Chrysene, Dibenzo(a,h) anthracene, Fluorene, Fluroanthene, Indeno(1,2,3-c,d) pyrene, Naphthalene, Perylene, Pyrene and Retene were determined in $PM_{2.5}$. A statistical summary of the individual PAH is presented **Table 4.2a-c.**

PAHs in 2013-14

As illustrated in **Table 4.2a**, the mass concentrations of total PAHs (∑PAHs) varied from 5.16-51.24 ng/m^3 (average 20.25 ng/m^3) at ST$_0$, 6.53-64.82 ng/m^3 (average 25.62 ng/m^3) at ST$_1$, 7.34-72.59 ng/m^3 (average 28.70 ng/m^3) at ST$_2$ and 5.94-58.92 ng/m^3 (average 23.29 ng/m^3) at ST$_3$.

PAHs in 2014-15

The mass concentrations of total PAHs (∑PAHs) varied from 4.95-49.10 ng/m^3 (average 19.41 ng/m^3) at ST$_0$, 6.26-62.11 ng/m^3 (average 24.55 ng/m^3) at ST$_1$, 7.03-69.57 ng/m^3 (average 27.50 ng/m^3) at ST$_2$ and 5.69-56.47 ng/m^3 (average 22.32 ng/m^3) at ST$_3$ (**Table 4.2b)**.

PAHs in 2015-16

The mass concentrations of total PAHs (∑PAHs) varied from 5.38-53.57 ng/m^3 (average 21.10 ng/m^3) at ST$_0$, 6.80-67.52 ng/m^3 (average 26.69 ng/m^3) at ST$_1$, 7.64-75.62 ng/m^3 (average 29.89 ng/m^3) at ST$_2$ and 6.18-61.38 ng/m^3 (average 24.26 ng/m^3) at ST$_3$ (**Table 4.2c)**.

In present study, the mass levels of all sixteen PAHs especially Benzo(a) pyrene (BaP) reported in the range of 0.31-3.59 ng/m^3 (average 1.36 ng/m^3) were higher than the NAAQ standard of BaP as 1 ng/m^3. The higher mass results of PAHs indicate the potency and toxicity causing adverse health impacts in the study area. The obtained values of particulate phase PAHs were consistent with 22.91-190.96 ng/m^3 in Kolkata (Chattopadhyay et al., 1998) and 20-172 ng/m^3 in Coimbatore (Mohanraj and Azeez, 2004).

The mass concentrations of PAHs also showed spatial and temporal variation as ST$_2$>ST$_3$>ST$_1$>ST$_0$. The highest mass concentrations at ST$_2$ Sector 74 (Mohali) are mainly associated to industrial activities, diesel generators, and heavy vehicles, boilers running on wood, rice husk and coal. ST$_3$ and ST$_1$ are located in residential areas and experiences less pollution than industrial site ST$_{2.}$ ST$_0$ is least polluted. The mass levels of PAHs also showed temporal variation as 2013-14<2015-16<2014-15. Relative abundance of individual PAHs species is presented in **Figure 4.7.**

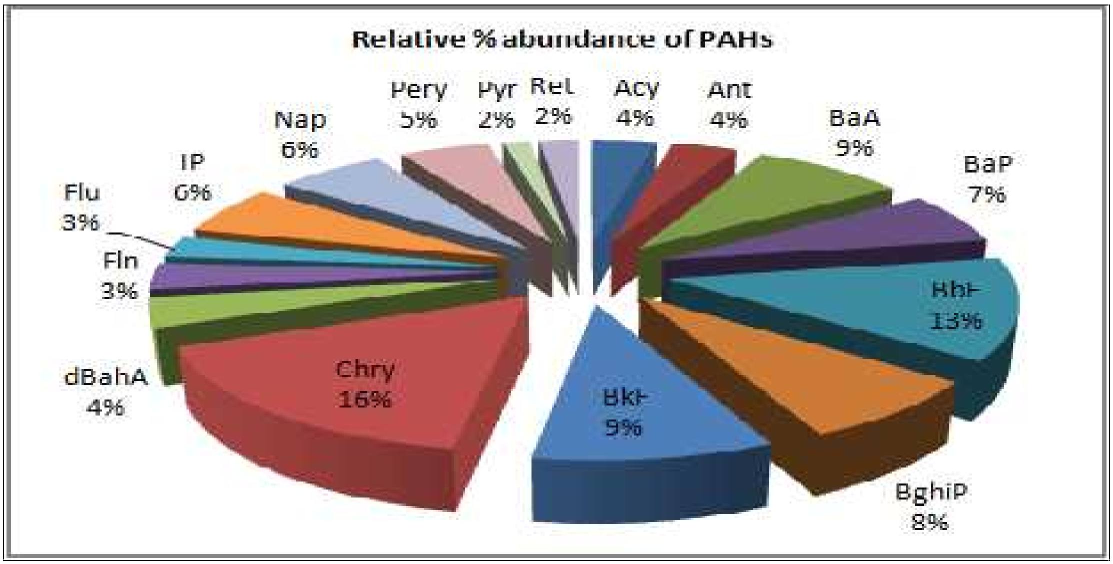

Fig. 4.7: Relative percent abundance of PAHs species

Presence of low molecular weight (LMW) PAHs i.e. Flu and Ant indicates industrial oil, wood and grass combustion as a probable source (Wilcke 2007; Khalili et al. 1995). The presence of HMW PAHs i.e. Fln, Pyr, Chry, BaA, BbF, BkF, BghiP, BaP, Pery, dBahA, and IP is mainly due to vehicular emissions (Marr et al. 1999; Khalili et al. 1995), coal combustion (Ravindra et al. 2007, 2008a&b; Smith and Harrison 1998; Khalili et al. 1995) and industrial sources (Daisey et al. 1986).

Like $PM_{2.5}$, the mass levels of PAHs species show temporal and spatial variation as highest at ST_2 followed by ST_3, ST_1 and ST_0 as presented in **Figure 4.8**. The highest mass concentrations at ST_2 (industrial area) are associated to diesel generators, heavy vehicles, boilers running on wood, rice husk, coal and construction activities whereas least mass levels at ST_0 in Chandigarh, an educational institute located in green belt region and foothills of Shiwalik hills.

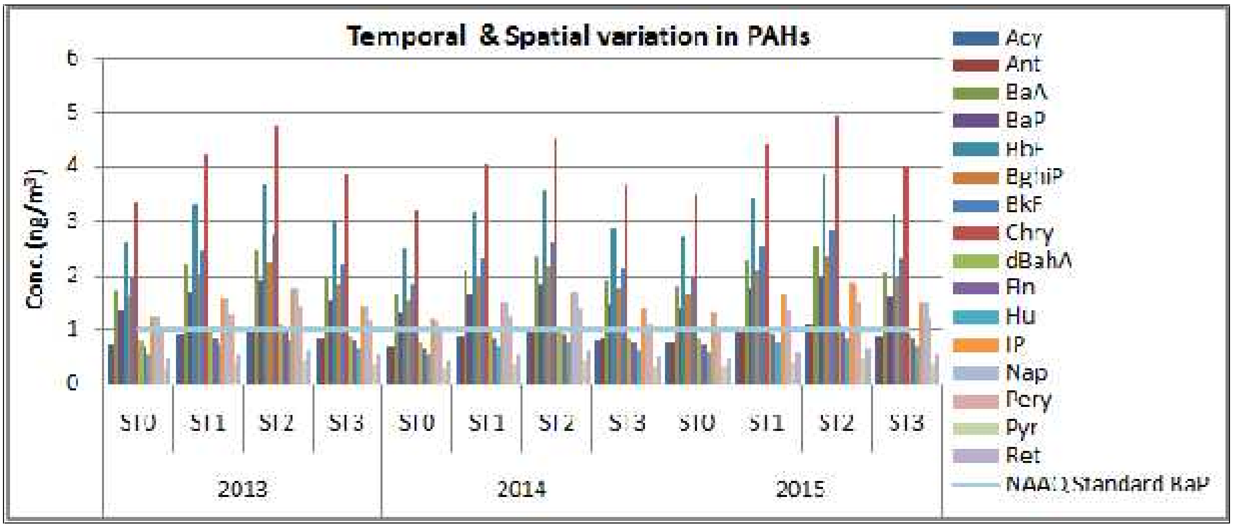

Fig. 4.8: Temporal and spatial variation in PAHs at study area

4.6 Seasonal Variation in Particulate Aerosols

Particulate aerosols show seasonal variation due to meteorological conditions, type of source, strength of emission and atmospheric chemistry (Cai et al. 2017; Guo et al. 2014; Tang et al. 2016; Wang et al. 2012, Xu et al. 2011; Zhang et al. 2015; Zhang and Cao, 2015). The mass concentration of particulate matter PM_{10} and $PM_{2.5}$ (**Figure 4.9a-c),** carbonic species (**Figure 4.5a-c),** and total PAHs (**Figure 4.10a-c)** were higher in winter than summer at all the sites.

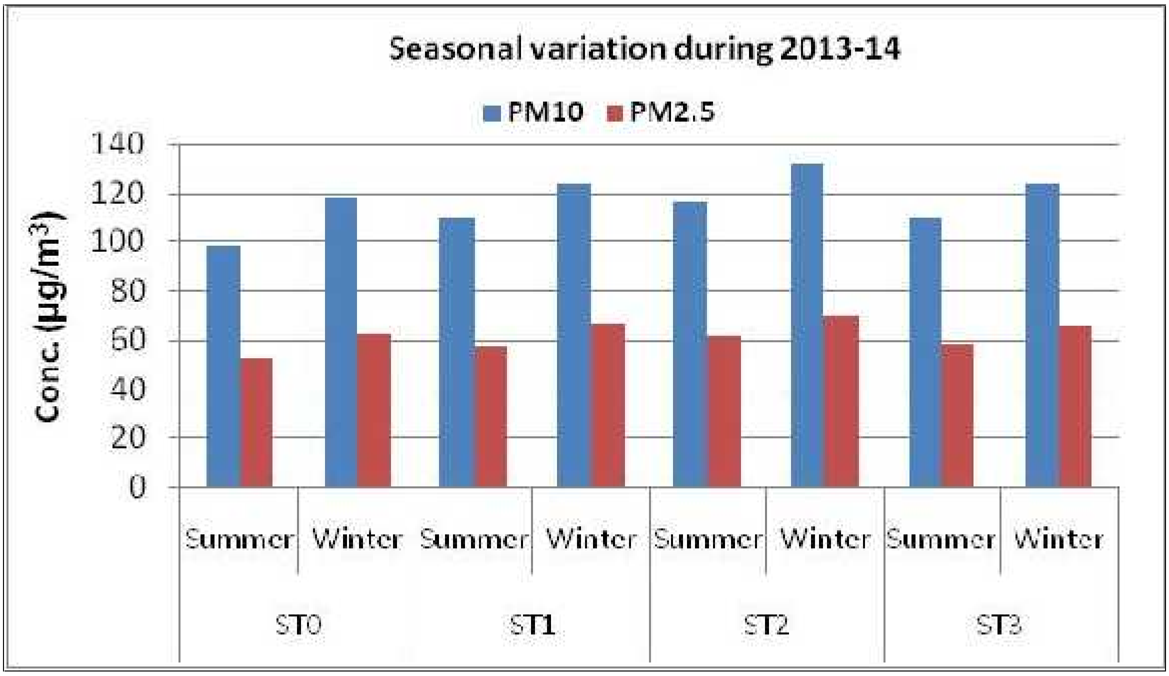

Fig. 4.9a: Seasonal variation in Particulate Matter during 2013-14

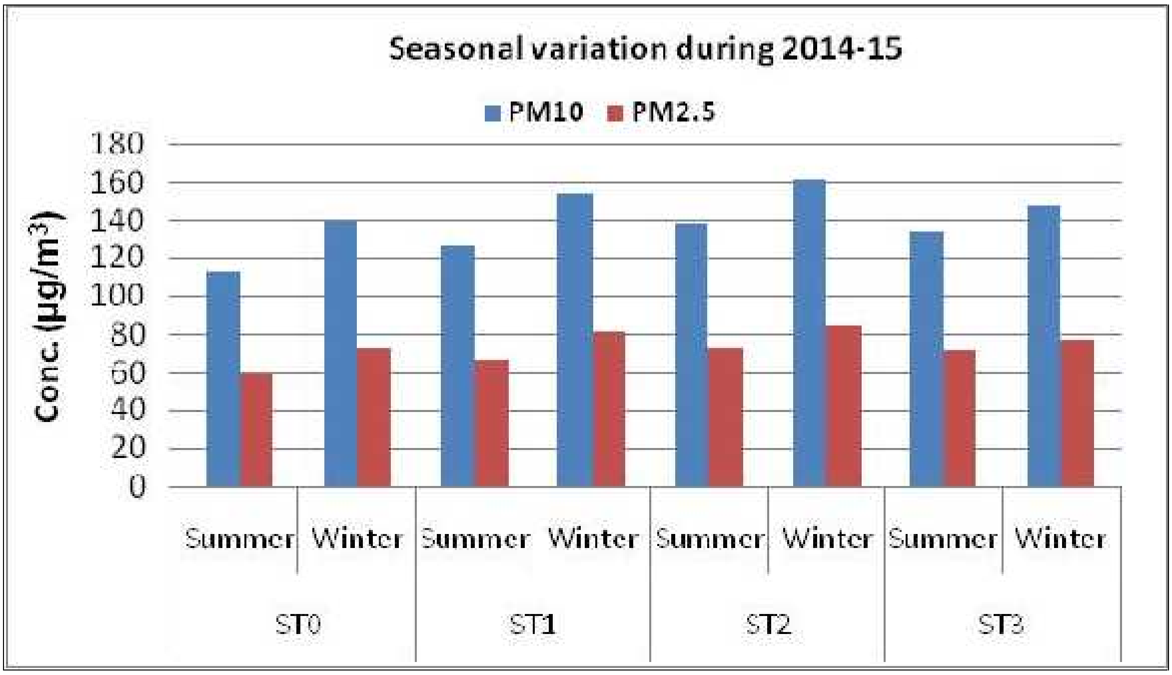

Fig. 4.9b: Seasonal variation in Particulate Matter during 2014-15

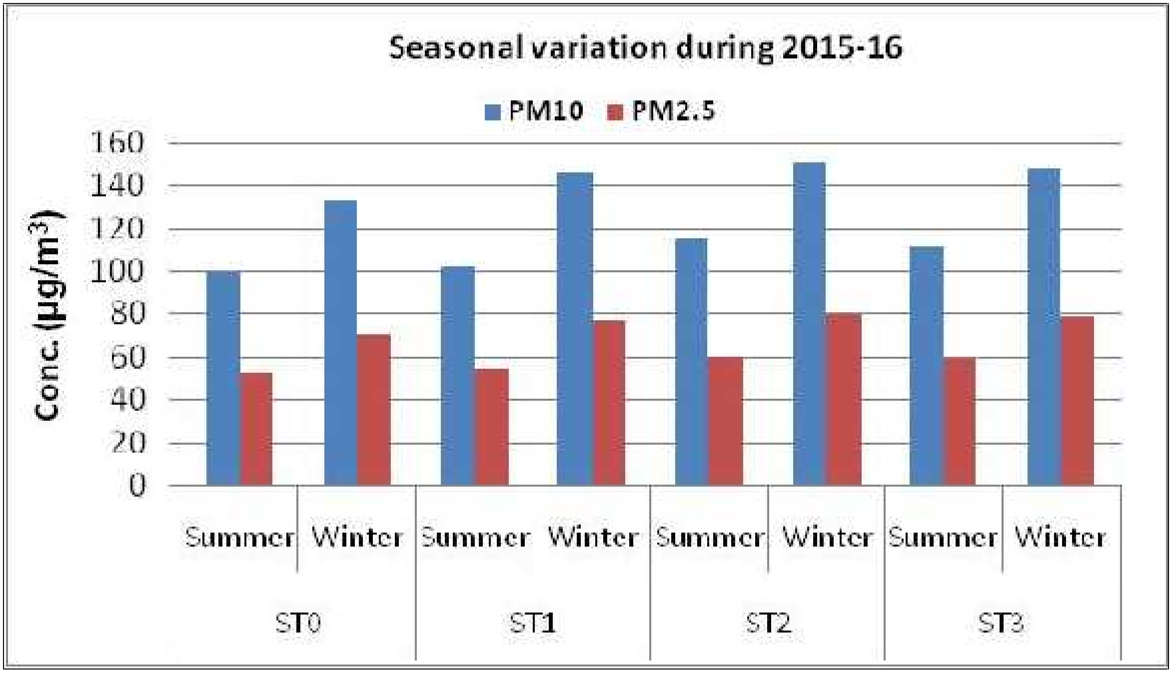

Fig. 4.9c: Seasonal variation in Particulate Matter during 2015-16

The higher mass concentrations during winter can be attributed to enhanced anthropogenic activities including burning of coal and bio fuels for domestic and commercial cooking and space heating plus higher exhaust emissions from automobiles and engine sets due to cold start in cold conditions (Chakraborty and Gupta, 2010; Tang et al. 2016).

Moreover, in winters, stagnant atmosphere, temperature inversions, low mixing height and calm conditions may be other causes for enhanced concentrations (Bressi et al. 2013; Zhao et al. 2012).

Apart from the above, crop stubble burning after rice harvesting period in October-November could be another reason (Awasthi et al. 2011). Various studies have reported the similar trends in Patiala (Awasthi et al. 2011), Agra (Singh and Sharma, 2012), Udaipur (Yadav et al. 2014) in India, Nanjing (Chen et al. 2016), Jinan (Yang et al. 2012), Wuhan (Xu et al. 2017); north to south region (Wang et al. 2015), Beijing, Shijiazhuang, Tianjin, Shangdianzi and Chengde (Zhao et al. 2013) in China and Riyadh (Modaihsh et al. 2015) in Saudi Arabia.

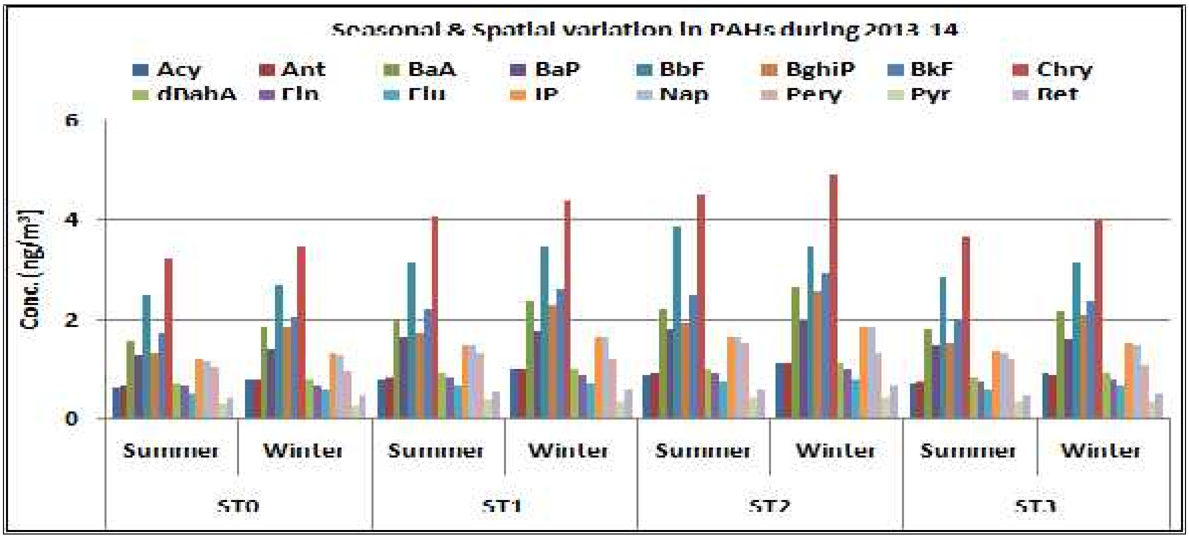

Fig. 4.10a: Seasonal & spatial variation in PAHs at study area during 2013-14

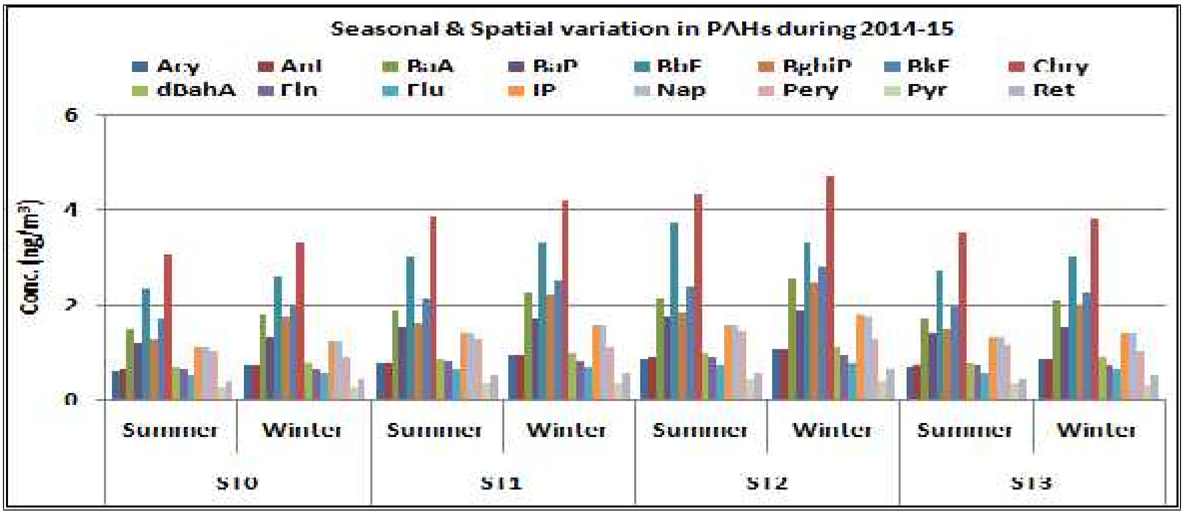

Fig. 4.10b: Seasonal & spatial variation in PAHs at study area during 2014-15

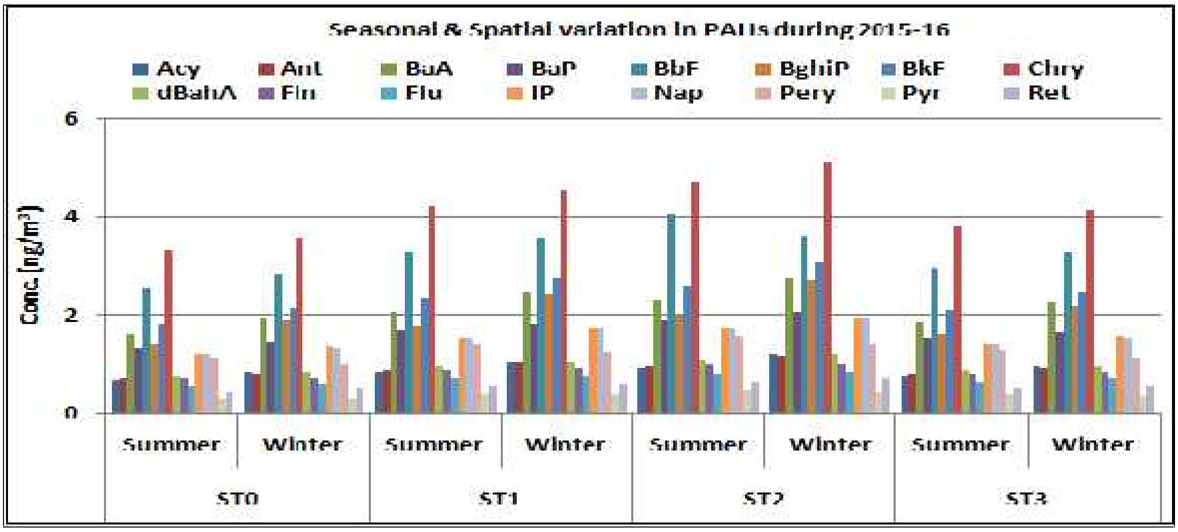

Fig. 4.10c: Seasonal & spatial variation in PAHs at study area during 2015-16

4.7 Correlation Analysis

Correlation analysis is the statistical tool that predicts correlation coefficient of one variable with other two or more variables. The correlation coefficient (between zero to one) describes a better correlation in dependent variables with higher value of one or near to one and no correlation in independent variables with zero or lesser value.

4.7.1 Diagnostic Ratio

PAHs and other semi volatile organic compounds are used to identify their emission sources. Diagnostic ratios can be used to categorize anthropogenic and biogenic sources of emission. Despite from these facts, ratios act as a fingerprint of emission sources and can be used to differentiate between various PAHs and their potency of having carcinogenic and mutagenic effects. The emission sources can be determined by comparing the values of this study with the values given in literature as predicted source range of PAHs (Kulkarni et al., 2014, Wang et al., 2007, and Rajput et al., 2009).

The diagnostic ratios calculated for IP/(IP+BghiP), BaA/(BaA+Chy), BaA/BaP, BbF/BkF are presented in **Table 4.3**. The ratio of IP/(IP+BghiP) as 0.42 under the range 0.37-0.70 and the ratio of BbF/BkF in the range 1.29-1.31 suggests the influence of diesel emissions (Kulkarni et al., 2014, Hugo et al., 2015, Mohanraj et al., 2012). The ratio of BaA/BaP as 1.21 indicates biomass burning (Lakhani et al., 2012) and the ratio of

BaA/(BaA+Chy) as 0.32 (0.20-0.35) indicates coal combustion (Tobiszewski et al., 2014) in the study area. The diagnostic ratios performed in the study highlight the influence of multiple sources as vehicular emissions and coal and biomass burning as the main source of PAHs.

Table 4.3: Diagnostic ratio with source, range and reference studies

Diagnostic Ratios	Present Study	Range	Sources	Conclusion	References
IP/(IP+BghiP)	0.42	0.18-0.20 0.37-0.70 0.56 0.62	Gasoline Diesel Coal Wood	Oil Combustion	Kulkarni et al., 2014, Hugo et al., 2015
BaA/BaP	1.21	0.90-1.70 0.5-0.70 1.0-1.5	Diesel Gasoline Wood	Wood Combustion	Lakhani et al., 2012
BaA/(BaA+Chy)	0.32	0.38-0.64 0.20-0.35	Diesel Coal	Coal Combustion	Tobiszewski et al., 2014
BbF/BkF	1.29	>0.5	Diesel	Diesel Combustion	Kulkarni et al., 2014, Mohanraj et al., 2012

4.7.2 Pearson Correlation

Pearson correlation was applied for the mass concentration of carbonaceous and PAHs species for a total number of 384 data sets as depicted in **Table 4.4**. Correlation was significant at 0.01 levels and 0.05 levels (2-tailed) with a confidence level of 95%. The higher correlation coefficient among Acy, BghiP, BkF, dBahA, Fln, IP, Pery, Pyr, Chry, OC and EC indicates similarity in source of origin. The high loading of Ant, BbF, BaA and NaP shows another source of emission. The higher correlations among BaP, Flu, Ret and OTM indicates third source of emission.

Table 4.4: Pearson correlation among mass concentration of OTM, OC, EC and PAHs species

	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
Acy	1.000																		
Ant	-0.029	1.000																	
BaA	-0.028	**1.000****	1.000																
BaP	.232**	-0.074	-0.074	1.000															
BbF	.184**	**.459****	**.460****	0.075	1.000														
BghiP	**.872****	0.043	0.044	.323**	.248**	1.000													
BkF	**.905****	-0.016	-0.015	.305**	.180**	**.929****	1.000												
Chry	.351**	-.429**	-.429**	.422**	-0.052	.324**	.306**	1.000											
dBahA	**.943****	-0.030	-0.030	.264**	.199**	**.839****	**.896****	.470**	1.000										
Fln	**.842****	-0.011	-0.011	.269**	.208**	**.908****	**.830****	.207**	**.714****	1.000									
Flu	.232**	-0.075	-0.075	**1.000****	0.074	.323**	.305**	.423**	.264**	.269**	1.000								
IP	**.786****	0.027	0.027	.330**	.190**	**.814****	**.884****	**.482****	**.913****	**.597****	.330**	1.000							
Nap	.124*	**.802****	**.802****	-0.019	**.582****	.228**	.160**	-.462**	0.085	.240**	-0.020	0.089	1.000						
Pery	**.890****	-.152**	-.152**	0.080	.102*	**.747****	**.790****	.193**	**.804****	**.782****	0.080	**.633****	0.045	1.000					
Pyr	**.962****	-0.074	-0.073	.256**	.174**	**.895****	**.915****	.344**	**.929****	**.894****	.256**	**.809****	.111*	**.907****	1.000				
Ret	.232**	-0.073	-0.073	**1.000****	0.076	.323**	.305**	.422**	.264**	.269**	**1.000****	.330**	-0.018	0.080	.256**	1.000			
OTM	0.033	-0.042	-0.042	**.590****	-0.013	0.086	0.075	.224**	0.041	0.024	**.591****	.105*	-0.060	-0.081	0.007	**.589****	1.000		
OC	**.597****	-0.071	-0.071	0.065	0.072	**.541****	**.569****	.279**	**.569****	**.473****	0.065	**.518****	-0.004	**.485****	**.546****	0.065	.195**	1.000	
EC	**.651****	-0.088	-0.088	.114*	0.063	**.602****	**.595****	.248**	**.624****	**.562****	.114*	**.529****	0.002	**.579****	**.643****	.114*	.154**	**.721****	1.000

Note: **-Correlation is significant at the 0.01 level (2-tailed), *-Correlation is significant at the 0.05 level (2-tailed), N=384

4.7.3 OC/EC ratio

The average OC/EC ratio indicates higher concentrations of OC in comparison to EC **(Figure 5).** OC contributes second largest to $PM_{2.5}$ after OTM. OC varies in the order of ST_2 (industrial site) followed by ST_1 (Commercial and residential area), ST_3 (residential area) and ST_0 (institutional area). The higher mass concentrations OC and EC at ST_2 and ST_1 may be associated to the heavy vehicular and industrial activities. Presence of organic-related factories at ST2 can emit considerable organic pollutants. Emissions of boilers, process ducts, DG sets and construction activities may be another source. The results of OTM/OC ratio in the range of 1.57 to 1.71 indicate combustion sources, which are agreement with the previous findings of a study carried out in Agra, India (Pachauri et al., 2013).

4.8 Source Apportionment using Principal Components Analysis

The main objective of PCA using factor Analysis is to produce small number of independent correlated variables by replacing the set of multiple variables. Orthogonal transformations are achieved by computing eigen-values and eigenvectors and diagonalizing correlation matrix of variables (Salvador et al., 2003). Each factor describes maximum total variance for similar data set which is totally uncorrelated with the set of other data. After varimax rotation, each factor loadings gives significant correlation between factors and variables. Thus, each factor contains the chemical species of higher loading which represents fingerprint of the emission source. Principal component analysis was performed by selecting factor analysis option in Statistical Package for Social Sciences (SPSS Version 22). PCA with varimax rotation was applied to determine the sources of PAHs in the study area (**Table 4.5**).

The first factor represents high loading of Acy, BghiP, BkF, dBahA, Fln, IP, Pery, Pyr, Chry, OC and EC with a total variance of 44.03%. Various studies have reported BghiP, BkF, dBahA and IP in vehicular emissions (Kulkarni & Venkataraman 2000, Bostrom et al. 2002, Ravindra et al. 2008a&b, Kulkarni et al. 2014) whereas BkF as the marker for diesel emissions (Khalili et al 1995, Yunker et al. 2002) and Acy, IP and Pery as the markers for gasoline emissions (Guo et al. 2003, Ravindra et al. 2008a&b). These species show higher correlation and represent vehicular emission as source of origin.

The second factor represents a total variance of 18.85%. The high loading of Ant, BbF, BaA and NaP indicates coal combustion as the source (Larson and Baker 2003, Kulkarni et al. 2014, Lv et al. 2016).

The third factor represents a total variance of 15.88%. The high loading of BaP, Flu, Ret and OTM indicates biomass and wood burning as the source (Khalili et al. 1995, Larson and Baker 2003, Kulkarni et al. 2014, Lv et al. 2016). Various researchers have indicated the marker of biomass and wood burning as Ret (Dvorska et al. 2012, Alves et al. 2015), BaP and Flu (Kulkarni and Venkataraman 2000). Remaining variance of 21.24 is unknown and may be attributed to non-identifiable sources present in the study area.

Table 4.5: Source apportionment using PCA

Component	Factor 1	Factor 2	Factor 3
Acy	**.945**	.153	-.143
Ant	-.070	**.736**	.594
BaA	-.069	**.736**	.593
BaP	.434	-.579	**.665**
BbF	.205	**.473**	.428
BghiP	**.931**	.157	.018
BkF	**.943**	.126	-.052
Chry	**.460**	**-.574**	-.084
dBahA	**.935**	.098	-.112
Fln	**.858**	.174	-.041
Flu	.434	-.580	**.664**
IP	**.870**	.048	.010
Nap	.101	**.748**	.546
Pery	**.822**	.166	-.317
Pyr	**.955**	.127	-.151
Ret	.434	-.578	**.665**
OTM	.186	-.471	**.560**
OC	**.636**	.065	-.209
EC	**.696**	.065	-.210
Eigen value	8.37	3.58	3.02
Variance (%)	44.03	18.85	15.88
Cumulative (%)	44.03	62.88	78.76
Source	Vehicular Emission	Coal Combustion	Wood & Biomass Burning

Principal component analysis (PCA) as shown in **Figure 4.9** identified the emission sources of $PM_{2.5}$ aerosols in the study area as vehicular emissions (44.03%), coal combustion (18.85%) and wood & biomass burning (15.88%).

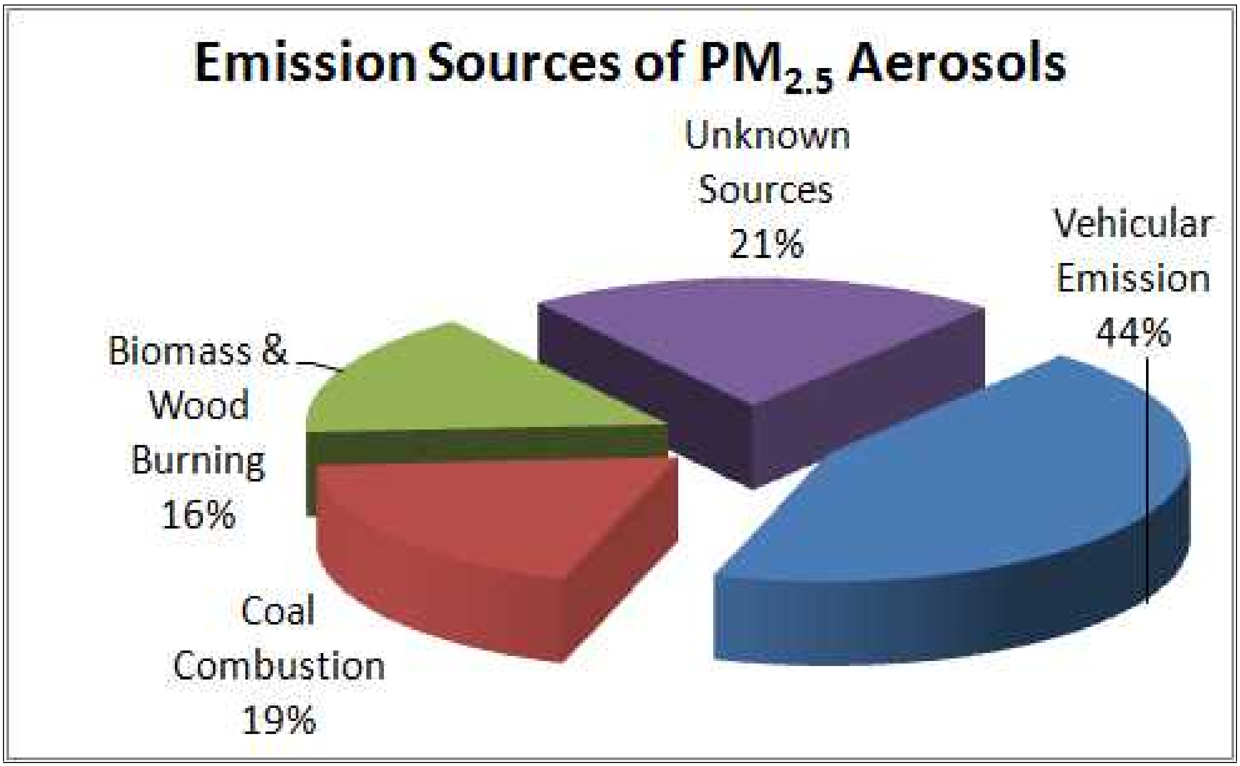

Fig. 4.11: Source of $PM_{2.5}$ aerosols identified by PCA

4.9 Toxicity Assessment of Particulate Aerosols

Among the PAHs studied, BaP is considered as the most powerful tool as reference chemical/ indicator for estimating the risk level imposed by all PAHs because of their well characterized toxicity. BaP equivalent (BaPeq) is calculated by multiplying the concentration of each compound with its corresponding TEF value given in **Table 4.6** (Halek et al., 2008 and Petry et al., 1996) and then summing up the obtained results. TEF or RPF from the EPA were taken into account as reference values in present study.

Table 4.6: PAHs and their toxic equivalency factor

S. No.	PAH Compound	Toxic Equivalency factor
1	Acenaphthylene (Acy)	-----
2	Anthracene (Ant)	-----
3	Benzo(g,h,i)perylene (BghiP)	0.01
4	Benzo(a)anthracene (BaA)	0.1
5	Benzo(a)pyrene (BaP)	1
6	Benzo(k)fluoranthene (BkF)	0.01
7	Benzo(b)fluoranthene (BbF)	0.1
8	Chrysene (Chy)	0.001
9	Dibenzo(a,h)anthracene (dBahA)	0.1
10	Fluoranthene (Fln)	0.001
11	Fluorene (Flu)	-----
12	Indeno(1,2,3)pyrene (IP)	0.1
13	Naphthalene (Nap)	-----
14	Pyrene (Pyr)	0.001
15	Perylene (Pery)	-----
16	Retene (Ret)	-----

In present study, the mass levels of all sixteen PAHs especially Benzo(a) pyrene (BaP) reported in the range of 0.31-3.59 ng/m^3 (average 1.36 ng/m^3) were higher than the NAAQ standard of BaP as 1 ng/m^3. The higher mass results of PAHs indicate the potency and toxicity causing adverse health impacts in the study area.

CHAPTER 5: CONCLUSION

Conclusion

Particulate aerosols (PM_{10} and $PM_{2.5}$) were collected from tricity of Chandigarh, Panchkula and Mohali during summer (April to May) and winter (December to January) seasons of 2013-14, 2014-15 and 2015-16. The mass levels of PM_{10} and $PM_{2.5}$ respectively varied from 69.2-187.5 µg/m^3 (average 116.4 µg/m^3) and 40.5-100.3 µg/m^3 (average 61.7 µg/m^3) in 2013-14, 79.8-198.0 µg/m^3 (average 138.9 µg/m^3) and 43.2-105.7 µg/m^3 (average 73.1 µg/m^3) in 2014-15 and 80.1-194.1 µg/m^3 (average 125.6 µg/m^3) and 42.4-103.8 µg/m^3 (average 66.4 µg/m^3) in 2015-16. Exceeding mass levels of PM_{10} and $PM_{2.5}$ to NAAQ standards during most of sampling days indicates deteriorating air quality in the study area. OTM contributes to $PM_{2.5}$ as 36.0% in 2013-14, 40.1% in 2014-15 and 35.7% in 2015-16 whereas ratio of OTM/OC ranging from 1.57 to 1.71 indicates carbon as the largest component. The presence of PAHs in the range of 5.16-72.59 ng/m^3 in 2013-14, 4.95-69.57 ng/m^3 in 2014-15 and 5.38-75.62 ng/m^3 in 2015-16 indicates combustion processes associated to vehicles and biomass burning in study area.

PM_{10} and $PM_{2.5}$ were higher in winter season in comparison to summer season during all three years at all sampling locations mainly associated to increased fuel demand for domestic and space heating. Moreover, calm, stagnant and stable weather conditions in winter limit the dilution and dispersions whereas cold start of engines enhanced accumulation of air pollutants.

Diagnostic ratio of IP/(IP+BghiP) as 0.42 in the range 0.37-0.70 and BbF/BkF in the range 1.29-1.31 indicates diesel emissions, BaA/BaP as 1.21 indicates biomass burning and BaA/(BaA+Chy) as 0.32 in the range of 0.20-0.35 indicates coal combustion as the source. Principal component analysis shows three contributory sources of particulate aerosols as vehicular emissions (44.03%), coal combustion (18.85%) and wood & biomass burning (15.88%). PM as well as carbonic species showed seasonal and temporal variations as higher in winters attributed to enhanced domestic and commercial activities and poor dispersion conditions.

Future Recommendations

The study describes profiling & source inventory of $PM_{2.5}$ in tricity of Chandigarh based on three year long data that becomes a base to device an effective management plan to control air pollution. Though the study mainly focused on chemical characterization of carbonaceous species but trace metallic and ionic species were lacking. The study recommends a comprehensive and regular monitoring of fine aerosols to understand the nature, strength, trend and potential health impacts in the region.

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ANNEXURE-1

Table 4.1(a): Status of ambient air quality at ST_0 during 2013-14 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM_{10}	$PM_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.13	83.8	49.7	0.16	0.53	1.26	1.18	1.86	0.31	0.53	3.42	0.28	0.28	0.49	0.32	0.88	0.40	0.10	0.39	18.02	3.23	0.87
2.4.13	89.1	47.1	0.36	0.24	0.56	1.24	1.81	0.78	2.16	0.62	0.44	0.51	0.52	0.97	0.86	0.65	0.22	0.41	19.08	7.26	1.37
8.4.13	79.8	41.8	0.20	0.65	1.55	1.45	1.99	0.31	0.62	3.36	0.32	0.40	0.60	0.69	0.95	0.40	0.16	0.48	22.26	4.03	1.00
9.4.13	137.5	69.1	1.33	0.65	1.55	1.48	1.97	2.90	2.95	7.15	1.29	1.13	0.62	2.02	0.94	1.77	0.52	0.49	22.70	16.61	4.00
15.4.13	124.2	64.9	1.38	0.87	2.07	1.90	3.22	2.90	3.02	3.42	1.49	1.19	0.79	2.02	1.53	1.77	0.62	0.63	29.19	17.65	4.62
16.4.13	90.1	51.4	0.32	1.45	3.45	0.35	3.73	0.62	1.24	0.68	0.44	0.51	0.14	0.89	1.78	0.56	0.21	0.12	5.30	6.45	1.37
22.4.13	111.0	55.3	1.77	0.47	1.12	1.27	2.17	2.95	3.28	3.23	1.61	1.19	0.53	2.02	1.03	4.44	0.73	0.42	19.46	15.48	5.00
23.4.13	114.6	61.6	0.65	0.41	0.98	1.45	2.04	2.85	2.57	9.01	0.97	0.85	0.60	2.02	0.97	0.98	0.41	0.48	22.26	12.97	3.00
6.5.13	102.0	52.6	0.24	0.65	1.55	1.87	4.97	0.36	0.89	0.87	0.36	0.40	0.78	0.77	2.37	0.44	0.16	0.62	28.62	4.84	1.12
7.5.13	84.4	45.6	0.28	0.53	1.26	1.31	2.25	0.36	1.12	2.02	0.44	0.45	0.55	0.81	1.07	0.44	0.21	0.44	20.14	5.64	1.37
13.5.13	82.5	46.0	0.15	0.50	1.19	1.10	1.74	0.29	0.50	3.22	0.27	0.27	0.46	0.30	0.83	0.38	0.10	0.37	16.94	3.03	0.82
14.5.13	83.1	43.3	0.34	0.22	0.53	1.17	1.70	0.73	2.03	0.58	0.42	0.48	0.49	0.91	0.81	0.61	0.20	0.39	17.93	6.82	1.29
20.5.13	78.8	40.5	0.19	0.61	1.45	1.36	1.87	0.29	0.58	3.16	0.30	0.37	0.57	0.64	0.89	0.38	0.15	0.45	20.92	3.79	0.94
21.5.13	128.7	65.2	1.25	0.61	1.45	1.39	1.86	2.73	2.78	6.72	1.21	1.06	0.58	1.90	0.88	1.67	0.49	0.46	21.34	15.01	3.76
27.5.13	112.0	63.5	1.30	0.82	1.95	1.79	3.03	2.73	2.83	3.22	1.40	1.11	0.75	1.90	1.44	1.67	0.58	0.60	27.44	16.99	4.35
28.5.13	69.2	41.1	0.30	1.36	3.24	0.32	3.51	0.58	1.17	0.64	0.42	0.48	0.14	0.83	1.67	0.53	0.19	0.11	4.98	6.06	1.29
9.12.13	81.6	43.3	0.41	1.26	3.01	0.46	4.75	1.44	1.71	0.65	0.66	0.35	0.19	1.27	2.26	0.35	0.17	0.15	6.99	8.16	2.05
10.12.13	87.5	46.3	0.46	0.26	0.62	1.14	0.87	1.53	1.77	2.96	0.66	0.40	0.48	1.30	0.41	0.35	0.20	0.38	17.49	9.19	2.05
16.12.13	128.1	67.0	0.29	1.24	2.95	2.13	2.56	1.12	1.58	0.84	0.40	0.26	0.89	1.15	1.22	0.25	0.14	0.71	32.64	5.76	1.25
17.12.13	93.5	49.7	0.40	1.20	2.85	1.37	4.28	1.30	1.65	0.75	0.58	0.32	0.57	1.18	2.04	0.32	0.14	0.46	20.98	7.92	1.79
23.12.13	162.2	84.5	1.21	1.18	2.80	1.47	3.46	1.61	2.15	5.04	1.12	0.60	0.61	1.44	1.65	0.70	0.36	0.49	22.59	24.17	3.48
24.12.13	141.0	75.6	0.62	0.28	0.67	2.43	1.01	1.58	1.94	10.69	0.86	0.52	1.01	1.44	0.48	0.38	0.26	0.81	37.31	12.48	2.68
30.12.13	143.7	70.0	1.62	0.30	0.73	1.16	2.32	3.83	3.17	4.11	1.15	2.25	0.48	1.50	1.10	2.69	0.69	0.39	17.84	32.46	3.57
31.12.13	151.5	74.5	1.93	1.26	3.01	2.17	5.81	5.39	4.12	1.68	1.27	2.59	0.90	1.61	2.76	2.95	0.73	0.72	33.30	21.64	3.93
8.1.14	116.5	60.0	1.29	0.35	0.83	0.39	1.58	1.70	2.41	4.85	1.15	0.60	0.16	1.47	0.75	2.45	0.42	0.13	5.95	25.78	3.57
9.1.14	136.6	69.1	1.55	0.33	0.78	1.40	1.45	1.96	2.79	4.67	1.15	1.01	0.58	1.47	0.69	2.68	0.52	0.47	21.40	18.94	3.57
15.1.14	92.2	51.8	0.38	1.16	2.77	0.42	4.37	1.32	1.57	0.60	0.61	0.32	0.17	1.17	2.08	0.32	0.16	0.14	6.44	7.51	1.89
16.1.14	82.3	42.8	0.42	0.24	0.57	1.05	0.80	1.40	1.63	2.72	0.61	0.37	0.44	1.19	0.38	0.32	0.19	0.35	16.09	8.46	1.89
22.1.14	114.7	61.3	0.26	1.14	2.72	1.96	2.36	1.03	1.46	0.77	0.37	0.24	0.82	1.06	1.12	0.23	0.13	0.65	30.03	5.30	1.15
23.1.14	88.9	46.1	0.36	1.10	2.62	1.26	3.94	1.19	1.52	0.69	0.53	0.29	0.52	1.09	1.88	0.29	0.13	0.42	19.31	7.29	1.64
29.1.14	143.7	77.2	1.11	1.08	2.58	1.36	3.18	1.48	1.98	4.64	1.03	0.56	0.56	1.32	1.52	0.64	0.33	0.45	20.79	22.24	3.20
30.1.14	123.6	69.2	0.57	0.26	0.62	2.24	0.93	1.46	1.78	9.84	0.79	0.48	0.93	1.32	0.44	0.35	0.24	0.75	34.32	11.48	2.46

Table 4.1(b): Status of ambient air quality at ST_1 during 2013-14 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM_{10}	$PM_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.13	81.7	49.9	0.20	0.67	1.60	1.49	2.35	0.39	0.67	4.33	0.36	0.36	0.62	0.41	1.12	0.51	0.13	0.50	20.18	3.06	0.75
2.4.13	94.6	50.1	0.46	0.30	0.71	1.57	2.29	0.98	2.73	0.79	0.56	0.64	0.66	1.22	1.09	0.82	0.28	0.52	21.37	6.89	1.18
8.4.13	86.6	45.3	0.26	0.82	1.96	1.84	2.52	0.39	0.79	4.25	0.41	0.50	0.77	0.87	1.20	0.51	0.20	0.61	24.93	3.83	0.86
9.4.13	162.0	80.4	1.68	0.82	1.96	1.87	2.50	3.67	3.74	9.05	1.63	1.43	0.78	2.55	1.19	2.24	0.66	0.62	25.43	15.25	3.43
15.4.13	158.5	78.2	1.75	1.10	2.62	2.41	4.07	3.67	3.82	4.33	1.89	1.50	1.00	2.55	1.94	2.24	0.79	0.80	32.69	16.24	3.96
16.4.13	91.4	51.6	0.41	1.83	4.36	0.44	4.72	0.79	1.57	0.87	0.56	0.64	0.18	1.12	2.25	0.71	0.26	0.15	5.94	6.12	1.18
22.4.13	163.4	85.0	2.24	0.60	1.42	1.61	2.75	3.74	4.15	4.09	2.04	1.50	0.67	2.55	1.31	5.61	0.92	0.54	21.79	19.66	4.28
23.4.13	119.3	64.1	0.82	0.52	1.24	1.84	2.58	3.61	3.25	11.40	1.22	1.07	0.77	2.55	1.23	1.23	0.52	0.61	24.93	12.30	2.57
6.5.13	111.0	57.2	0.31	0.82	1.96	2.36	6.29	0.46	1.12	1.10	0.46	0.50	0.98	0.97	2.99	0.56	0.20	0.79	32.05	4.59	0.96
7.5.13	90.5	48.9	0.36	0.67	1.60	1.66	2.85	0.46	1.41	2.56	0.56	0.57	0.69	1.02	1.36	0.56	0.26	0.55	22.55	5.36	1.18
13.5.13	79.8	41.8	0.19	0.63	1.50	1.40	2.21	0.37	0.63	4.07	0.34	0.34	0.58	0.38	1.05	0.48	0.12	0.47	18.97	2.88	0.70
14.5.13	88.2	45.9	0.43	0.28	0.67	1.48	2.15	0.92	2.56	0.74	0.53	0.60	0.62	1.15	1.02	0.77	0.26	0.49	20.09	6.47	1.11
20.5.13	82.3	44.0	0.24	0.77	1.84	1.73	2.36	0.37	0.74	3.99	0.38	0.47	0.72	0.82	1.13	0.48	0.18	0.58	23.43	3.60	0.81
21.5.13	131.1	68.5	1.58	0.77	1.84	1.76	2.35	3.45	3.51	8.51	1.53	1.34	0.73	2.40	1.12	2.11	0.62	0.59	23.90	23.73	3.22
27.5.13	126.0	64.6	1.64	1.03	2.46	2.26	3.83	3.45	3.59	4.07	1.77	1.41	0.94	2.40	1.82	2.11	0.74	0.75	20.73	14.66	3.73
28.5.13	89.4	48.3	0.38	1.72	4.10	0.41	4.44	0.74	1.48	0.81	0.53	0.60	0.17	1.05	2.11	0.67	0.25	0.14	15.58	11.75	1.11
9.12.13	96.1	58.5	0.52	1.60	3.80	0.58	6.01	1.82	2.16	0.83	0.84	0.44	0.24	1.60	2.86	0.44	0.22	0.19	17.83	11.74	1.76
10.12.13	91.5	48.4	0.58	0.33	0.79	1.44	1.10	1.93	2.24	3.74	0.84	0.51	0.60	1.64	0.52	0.44	0.26	0.48	19.59	8.72	1.76
16.12.13	139.2	72.9	0.36	1.57	3.74	2.69	3.24	1.42	2.00	1.06	0.51	0.33	1.12	1.46	1.54	0.32	0.18	0.90	36.56	5.46	1.07
17.12.13	99.2	52.8	0.50	1.52	3.61	1.73	5.42	1.64	2.09	0.94	0.73	0.40	0.72	1.49	2.58	0.40	0.18	0.58	23.50	7.51	1.53
23.12.13	165.3	86.1	1.53	1.49	3.54	1.86	4.38	2.04	2.73	6.37	1.42	0.77	0.78	1.82	2.09	0.88	0.46	0.62	25.31	22.93	2.98
24.12.13	170.5	91.2	0.79	0.36	0.85	3.08	1.28	2.00	2.45	13.53	1.09	0.66	1.28	1.82	0.61	0.48	0.33	1.03	41.79	11.84	2.30
30.12.13	173.6	90.0	2.05	0.39	0.92	1.47	2.93	4.85	4.01	5.19	1.46	2.84	0.61	1.89	1.40	3.41	0.87	0.49	19.98	30.80	3.06
31.12.13	136.0	72.9	2.44	1.60	3.80	2.75	7.34	6.81	5.21	2.12	1.60	3.28	1.14	2.04	3.50	3.73	0.92	0.92	17.20	11.50	3.37
8.1.14	112.8	58.1	1.63	0.44	1.05	0.49	2.00	2.15	3.05	6.14	1.46	0.77	0.20	1.86	0.95	3.10	0.54	0.16	6.66	24.46	3.06
9.1.14	168.0	90.8	1.96	0.41	0.98	1.77	1.84	2.48	3.53	5.90	1.46	1.28	0.74	1.86	0.87	3.39	0.66	0.59	23.97	29.35	3.06
15.1.14	92.6	57.0	0.47	1.47	3.50	0.53	5.53	1.68	1.99	0.76	0.77	0.40	0.22	1.47	2.63	0.40	0.20	0.18	17.21	12.12	1.62
16.1.14	86.1	44.8	0.53	0.30	0.72	1.33	1.01	1.78	2.06	3.44	0.77	0.47	0.55	1.51	0.48	0.40	0.23	0.44	18.02	8.02	1.62
22.1.14	124.6	66.6	0.34	1.44	3.44	2.48	2.98	1.31	1.84	0.98	0.47	0.30	1.03	1.34	1.42	0.29	0.17	0.83	33.64	5.03	0.99
23.1.14	94.3	48.8	0.46	1.39	3.32	1.59	4.99	1.51	1.92	0.87	0.67	0.37	0.66	1.37	2.37	0.37	0.17	0.53	21.62	6.91	1.41
29.1.14	126.5	68.3	1.41	1.37	3.26	1.71	4.03	1.88	2.51	5.86	1.31	0.70	0.71	1.68	1.92	0.81	0.42	0.57	23.28	21.10	2.75
30.1.14	103.8	55.4	0.73	0.33	0.78	2.83	1.17	1.84	2.26	12.44	1.01	0.60	1.18	1.68	0.56	0.44	0.30	0.94	18.44	10.89	2.11

Table 4.1(c): Status of ambient air quality at ST$_2$ during 2013-14 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.13	102.4	54.2	0.51	0.33	0.80	1.76	1.23	1.10	3.05	0.88	0.63	0.72	0.73	1.37	1.22	0.91	0.31	0.59	23.23	6.83	1.79
2.4.13	91.0	47.6	0.29	0.92	2.19	2.06	3.63	0.44	0.88	4.76	0.46	0.56	0.86	0.97	1.34	0.57	0.22	0.69	27.10	2.73	1.28
8.4.13	140.4	75.9	1.89	0.92	2.19	2.10	6.07	4.11	4.19	10.14	1.83	1.60	0.87	2.86	1.33	2.51	0.73	0.70	27.64	15.50	4.26
9.4.13	158.3	81.3	1.96	1.23	2.93	2.70	4.90	4.11	4.27	4.85	2.11	1.68	1.12	2.86	2.17	2.51	0.88	0.90	27.54	15.50	5.11
15.4.13	91.6	52.2	0.46	2.05	4.89	0.49	1.43	0.88	1.76	0.97	0.63	0.72	0.20	1.26	2.52	0.80	0.29	0.16	16.45	5.46	1.70
16.4.13	170.8	88.5	2.51	0.67	1.59	1.80	3.28	4.19	4.65	4.58	2.29	1.68	0.75	2.86	1.47	6.28	1.03	0.60	23.69	25.96	5.96
22.4.13	166.5	89.5	0.92	0.59	1.39	2.06	8.23	4.04	3.64	12.77	1.37	1.20	0.86	2.86	1.38	1.38	0.59	0.69	27.10	25.05	3.41
23.4.13	116.0	59.8	0.34	0.92	2.19	2.64	2.24	0.51	1.26	1.23	0.51	0.56	1.10	1.09	3.35	0.63	0.22	0.88	34.84	3.19	1.28
6.5.13	91.5	49.4	0.40	0.75	1.79	1.86	2.06	0.51	1.58	2.87	0.63	0.64	0.78	1.14	1.52	0.63	0.29	0.62	24.52	3.19	1.70
7.5.13	102.1	57.0	0.21	0.71	1.68	1.56	6.33	0.41	0.71	4.56	0.38	0.38	0.65	0.43	1.18	0.54	0.14	0.52	20.62	2.57	0.80
13.5.13	95.5	49.7	0.48	0.31	0.75	1.66	1.15	1.04	2.87	0.83	0.59	0.68	0.69	1.29	1.15	0.86	0.29	0.55	21.83	6.42	1.68
14.5.13	86.5	46.2	0.27	0.86	2.06	1.93	3.41	0.41	0.83	4.47	0.43	0.53	0.81	0.91	1.26	0.54	0.21	0.64	25.47	2.57	1.20
20.5.13	140.9	73.3	1.77	0.86	2.06	1.97	5.71	3.87	3.93	9.53	1.72	1.50	0.82	2.68	1.25	2.36	0.69	0.66	15.20	13.10	4.00
21.5.13	145.2	74.8	1.84	1.16	2.76	2.54	4.61	3.87	4.02	4.56	1.99	1.58	1.06	2.68	2.04	2.36	0.83	0.85	14.90	11.20	4.81
27.5.13	81.5	43.3	0.43	1.93	4.59	0.46	1.34	0.83	1.65	0.91	0.59	0.68	0.19	1.18	2.37	0.75	0.28	0.15	10.06	8.70	1.60
28.5.13	80.6	42.4	0.23	0.75	1.79	1.66	6.73	0.44	0.75	4.85	0.40	0.40	0.69	0.46	1.25	0.57	0.15	0.55	21.94	2.73	0.85
9.12.13	110.7	58.6	0.65	0.37	0.88	1.62	2.56	2.16	2.51	4.19	0.94	0.57	0.67	1.84	0.58	0.49	0.29	0.54	21.29	13.41	1.66
10.12.13	164.0	85.9	0.41	1.76	4.19	3.02	2.82	1.59	2.24	1.19	0.57	0.37	1.26	1.63	1.73	0.36	0.20	1.01	39.74	9.87	1.18
16.12.13	116.2	61.8	0.56	1.70	4.04	1.94	2.80	1.84	2.34	1.06	0.82	0.45	0.81	1.67	2.89	0.45	0.20	0.65	25.55	11.38	1.18
17.12.13	144.2	75.1	1.71	1.67	3.97	2.09	4.56	2.29	3.05	7.14	1.59	0.86	0.87	2.04	2.34	0.99	0.51	0.70	27.51	14.17	2.98
23.12.13	187.5	100.3	0.88	0.40	0.95	3.45	5.29	2.24	2.75	15.15	1.22	0.73	1.44	2.04	0.68	0.54	0.37	1.15	45.42	13.91	2.13
24.12.13	176.9	90.8	2.30	0.43	1.03	1.65	3.08	5.43	4.49	5.82	1.63	3.18	0.69	2.12	1.56	3.82	0.98	0.55	21.72	33.65	5.68
30.12.13	186.8	98.2	2.74	1.79	4.26	3.08	2.89	7.63	5.83	2.38	1.80	3.67	1.28	2.29	3.92	4.17	1.03	1.03	30.10	22.20	5.96
31.12.13	104.0	54.4	1.83	0.49	1.18	0.55	7.04	2.41	3.41	6.87	1.63	0.86	0.23	2.08	1.07	3.47	0.60	0.18	7.24	14.93	3.48
8.1.14	141.7	76.6	2.19	0.46	1.10	1.98	3.19	2.77	3.95	6.61	1.63	1.43	0.82	2.08	0.98	3.79	0.73	0.66	26.06	17.20	4.26
9.1.14	108.0	56.3	0.53	1.65	3.92	0.59	2.42	1.88	2.23	0.85	0.86	0.45	0.25	1.65	2.95	0.45	0.23	0.20	19.50	11.64	1.31
15.1.14	104.1	54.2	0.60	0.34	0.81	1.49	2.36	1.99	2.31	3.85	0.86	0.53	0.62	1.69	0.54	0.45	0.26	0.50	19.59	12.34	1.52
16.1.14	146.9	78.5	0.38	1.62	3.85	2.77	2.59	1.46	2.06	1.09	0.53	0.34	1.16	1.50	1.59	0.33	0.19	0.92	36.57	9.08	1.09
22.1.14	110.4	57.2	0.52	1.56	3.72	1.78	2.57	1.69	2.16	0.97	0.75	0.41	0.74	1.54	2.66	0.41	0.19	0.59	23.51	10.47	1.09
23.1.14	127.7	68.7	1.58	1.53	3.65	1.92	4.20	2.10	2.81	6.57	1.46	0.79	0.80	1.88	2.15	0.91	0.47	0.64	25.31	13.03	2.74
29.1.14	97.2	51.2	0.81	0.37	0.88	3.17	4.86	2.06	2.53	13.94	1.13	0.68	1.32	1.88	0.63	0.50	0.34	1.06	19.10	12.80	1.96
30.1.14	83.0	48.4	0.58	1.79	4.26	0.65	2.63	2.04	2.42	0.93	0.94	0.49	0.27	1.80	3.21	0.49	0.24	0.22	8.52	12.65	1.42

Table 4.1(d): Status of ambient air quality at ST_3 during 2013-14 (PAHs in ng/m^3 & rest in $\mu g/m^3$)

Date	PM_{10}	$PM_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.13	89.5	48.3	0.35	1.57	3.73	0.37	4.03	0.67	1.34	0.74	0.48	0.55	0.16	0.96	1.92	0.61	0.22	0.12	13.50	8.05	1.79
2.4.13	96.2	50.1	0.19	0.61	1.45	1.35	2.13	0.36	0.61	3.93	0.32	0.32	0.56	0.37	1.02	0.46	0.12	0.45	19.42	3.67	0.95
8.4.13	120.4	63.7	0.42	0.27	0.65	1.43	2.08	0.89	2.48	0.72	0.51	0.58	0.60	1.11	0.99	0.74	0.25	0.48	20.57	14.87	2.00
9.4.13	86.9	45.5	0.23	0.75	1.78	1.67	2.29	0.36	0.71	3.86	0.37	0.45	0.70	0.79	1.09	0.46	0.18	0.56	24.00	4.28	1.43
15.4.13	135.9	69.2	1.53	0.75	1.78	1.70	2.27	3.34	3.40	8.23	1.48	1.30	0.71	2.32	1.08	2.04	0.60	0.57	24.48	20.38	4.77
16.4.13	143.0	76.1	1.59	1.00	2.38	2.19	3.70	3.34	3.47	3.93	1.72	1.36	0.91	2.32	1.76	2.04	0.72	0.73	23.47	20.81	5.72
22.4.13	91.4	53.3	0.37	1.67	3.97	0.40	4.29	0.72	1.43	0.79	0.51	0.58	0.17	1.02	2.04	0.65	0.24	0.13	15.20	10.60	1.91
23.4.13	141.1	73.3	2.04	0.54	1.29	1.46	2.50	3.40	3.77	3.72	1.85	1.36	0.61	2.32	1.19	5.10	0.83	0.49	20.98	22.65	6.68
6.5.13	136.5	73.4	0.75	0.48	1.13	1.67	2.35	3.28	2.96	10.37	1.11	0.97	0.70	2.32	1.12	1.12	0.48	0.56	24.00	17.75	3.82
7.5.13	113.3	58.4	0.28	0.75	1.78	2.15	5.72	0.42	1.02	1.00	0.42	0.45	0.89	0.88	2.72	0.51	0.18	0.72	30.85	6.12	1.43
13.5.13	97.4	52.7	0.32	0.61	1.45	1.51	2.59	0.42	1.29	2.33	0.51	0.52	0.63	0.93	1.23	0.51	0.24	0.50	21.71	7.71	1.91
14.5.13	88.8	46.6	0.17	0.57	1.37	1.27	2.01	0.34	0.58	3.70	0.31	0.31	0.53	0.35	0.95	0.44	0.11	0.42	18.26	3.45	0.90
20.5.13	112.2	58.4	0.39	0.26	0.61	1.34	1.95	0.84	2.33	0.67	0.48	0.55	0.56	1.05	0.93	0.70	0.24	0.45	19.33	13.98	1.88
21.5.13	82.6	46.2	0.22	0.70	1.67	1.57	2.15	0.34	0.67	3.63	0.35	0.43	0.65	0.74	1.02	0.44	0.17	0.52	22.56	4.03	1.34
27.5.13	117.8	62.1	1.44	0.70	1.67	1.60	2.13	3.14	3.19	7.73	1.39	1.22	0.67	2.18	1.02	1.92	0.56	0.53	23.01	19.16	4.48
28.5.13	112.5	59.3	1.49	0.94	2.24	2.06	3.48	3.14	3.26	3.70	1.61	1.28	0.86	2.18	1.66	1.92	0.67	0.69	19.20	11.10	5.38
9.12.13	104.0	56.3	0.66	0.30	0.71	2.57	1.07	1.68	2.05	11.31	0.91	0.55	1.07	1.52	0.51	0.40	0.27	0.86	17.50	12.31	2.19
10.12.13	107.7	55.6	0.47	1.45	3.46	0.52	5.47	1.66	1.97	0.75	0.76	0.40	0.22	1.46	2.60	0.40	0.20	0.17	19.20	11.80	1.59
16.12.13	100.3	53.1	0.53	0.30	0.72	1.31	1.00	1.76	2.04	3.40	0.76	0.46	0.55	1.49	0.47	0.40	0.23	0.44	18.85	12.24	1.85
17.12.13	153.2	80.2	0.33	1.43	3.40	2.45	2.94	1.29	1.82	0.97	0.46	0.30	1.02	1.32	1.40	0.29	0.17	0.82	35.19	10.93	1.32
23.12.13	107.8	57.3	0.46	1.38	3.28	1.57	4.93	1.49	1.90	0.86	0.66	0.36	0.66	1.36	2.35	0.36	0.17	0.52	22.62	11.41	1.32
24.12.13	137.4	71.6	1.39	1.35	3.22	1.69	3.98	1.85	2.48	5.79	1.29	0.70	0.71	1.66	1.90	0.80	0.42	0.56	24.36	14.86	3.34
30.12.13	170.7	91.3	0.72	0.33	0.78	2.80	1.16	1.82	2.23	12.30	0.99	0.60	1.17	1.66	0.55	0.44	0.30	0.93	40.22	13.38	2.38
31.12.13	141.3	74.4	1.87	0.35	0.83	1.34	2.67	4.40	3.64	4.72	1.32	2.58	0.56	1.72	1.27	3.10	0.79	0.45	19.23	21.86	6.36
8.1.14	171.1	89.2	2.22	1.45	3.46	2.50	6.68	6.19	4.74	1.93	1.46	2.98	1.04	1.85	3.18	3.39	0.83	0.83	29.90	20.42	6.68
9.1.14	88.9	45.8	1.48	0.40	0.95	0.45	1.82	1.95	2.77	5.58	1.32	0.70	0.19	1.69	0.87	2.82	0.49	0.15	6.41	16.61	3.89
15.1.14	140.3	75.8	1.78	0.38	0.89	1.61	1.67	2.25	3.21	5.37	1.32	1.16	0.67	1.69	0.79	3.08	0.60	0.54	23.08	19.24	4.77
16.1.14	93.8	50.6	0.43	1.34	3.18	0.48	5.03	1.52	1.81	0.69	0.70	0.37	0.20	1.34	2.39	0.37	0.18	0.16	16.50	10.86	1.46
22.1.14	94.3	49.1	0.49	0.28	0.66	1.21	0.92	1.61	1.88	3.13	0.70	0.43	0.50	1.37	0.44	0.37	0.21	0.40	17.35	11.26	1.71
23.1.14	137.2	73.4	0.30	1.31	3.13	2.25	2.71	1.19	1.68	0.89	0.43	0.27	0.94	1.22	1.29	0.27	0.15	0.75	32.38	10.06	1.22
29.1.14	102.4	53.1	0.42	1.27	3.02	1.45	4.53	1.37	1.75	0.79	0.61	0.34	0.60	1.25	2.16	0.34	0.15	0.48	20.81	10.50	1.22
30.1.14	121.7	65.4	1.28	1.24	2.96	1.56	3.66	1.71	2.28	5.33	1.19	0.64	0.65	1.52	1.74	0.74	0.38	0.52	22.41	13.68	3.07

Table 4.1(e): Status of ambient air quality at ST$_0$ during 2014-15 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
01.04.14	94.1	49.5	0.15	0.51	1.21	1.13	1.78	0.30	0.51	3.28	0.27	0.27	0.47	0.31	0.85	0.39	0.10	0.38	24.77	4.02	1.03
02.04.14	88.6	45.8	0.35	0.23	0.54	1.19	1.73	0.75	2.07	0.60	0.43	0.49	0.50	0.93	0.82	0.62	0.21	0.40	16.10	9.04	1.62
08.04.14	107.6	56.3	0.19	0.62	1.48	1.39	1.91	0.30	0.60	3.22	0.31	0.38	0.58	0.66	0.91	0.39	0.15	0.46	30.60	5.02	1.17
09.04.14	171.0	88.6	1.28	0.62	1.48	1.42	1.89	2.78	2.83	6.86	1.24	1.08	0.59	1.93	0.90	1.70	0.50	0.47	31.21	23.15	4.70
15.04.14	139.2	74.9	1.33	0.83	1.98	1.82	3.09	2.78	2.89	3.28	1.43	1.14	0.76	1.93	1.47	1.70	0.60	0.61	20.10	14.20	5.43
16.04.14	85.3	45.0	0.31	1.39	3.31	0.33	3.58	0.60	1.19	0.66	0.43	0.49	0.14	0.85	1.70	0.54	0.20	0.11	7.29	8.04	1.62
22.04.14	138.3	73.3	1.70	0.45	1.08	1.22	2.08	2.83	3.15	3.10	1.55	1.14	0.51	1.93	0.99	4.25	0.70	0.41	26.76	14.20	5.87
23.04.14	129.1	66.3	0.62	0.40	0.94	1.39	1.96	2.73	2.47	8.64	0.93	0.81	0.58	1.93	0.93	0.94	0.40	0.46	30.60	16.16	3.52
06.05.14	137.7	71.0	0.23	0.62	1.48	1.79	4.76	0.35	0.85	0.83	0.35	0.38	0.75	0.73	2.27	0.43	0.15	0.60	39.35	6.03	1.32
07.05.14	113.0	61.1	0.27	0.51	1.21	1.26	2.16	0.35	1.07	1.94	0.43	0.43	0.52	0.77	1.03	0.43	0.20	0.42	27.69	7.03	1.62
13.05.14	84.2	43.2	0.15	0.48	1.14	1.06	1.67	0.28	0.48	3.08	0.25	0.25	0.44	0.29	0.80	0.36	0.09	0.35	23.29	3.78	0.97
14.05.14	110.6	57.6	0.33	0.21	0.51	1.12	1.63	0.70	1.94	0.56	0.40	0.46	0.47	0.87	0.78	0.58	0.20	0.37	24.66	8.50	1.52
20.05.14	102.2	54.7	0.18	0.59	1.39	1.31	1.79	0.28	0.56	3.03	0.29	0.36	0.54	0.62	0.85	0.36	0.14	0.44	28.77	4.72	1.10
21.05.14	95.8	50.1	1.20	0.59	1.39	1.33	1.78	2.62	2.66	6.44	1.16	1.02	0.56	1.82	0.85	1.60	0.47	0.44	19.20	11.50	4.42
27.05.14	113.1	59.3	1.25	0.78	1.86	1.71	2.90	2.62	2.72	3.08	1.34	1.07	0.71	1.82	1.38	1.60	0.56	0.57	23.10	20.30	5.11
28.05.14	90.1	46.8	0.29	1.31	3.11	0.31	3.36	0.56	1.12	0.62	0.40	0.46	0.13	0.80	1.60	0.51	0.19	0.10	6.85	7.55	1.52
09.12.14	92.3	48.4	0.39	1.21	2.88	0.44	4.56	1.38	1.64	0.63	0.63	0.33	0.18	1.21	2.17	0.33	0.17	0.15	9.62	10.17	2.41
10.12.14	115.4	61.1	0.44	0.25	0.60	1.09	0.83	1.46	1.70	2.83	0.63	0.39	0.46	1.24	0.40	0.33	0.19	0.36	24.05	11.45	2.41
16.12.14	172.8	90.5	0.28	1.19	2.83	2.04	2.45	1.08	1.52	0.80	0.39	0.25	0.85	1.10	1.17	0.24	0.14	0.68	44.88	7.18	1.47
17.12.14	124.4	66.2	0.38	1.15	2.73	1.31	4.11	1.24	1.58	0.72	0.55	0.30	0.55	1.13	1.96	0.30	0.14	0.44	28.85	9.87	2.10
23.12.14	177.1	90.2	1.16	1.13	2.68	1.41	3.32	1.55	2.06	4.83	1.08	0.58	0.59	1.38	1.58	0.67	0.35	0.47	31.07	30.11	4.09
24.12.14	166.2	83.1	0.60	0.27	0.65	2.33	0.97	1.52	1.86	10.25	0.83	0.50	0.97	1.38	0.46	0.36	0.25	0.78	51.30	15.55	3.15
30.12.14	173.5	86.3	1.56	0.29	0.70	1.11	2.22	3.67	3.04	3.93	1.10	2.15	0.46	1.44	1.06	2.58	0.66	0.37	24.53	40.45	4.20
31.12.14	130.8	66.8	1.85	1.21	2.88	2.08	5.56	5.16	3.95	1.61	1.21	2.48	0.87	1.55	2.65	2.82	0.70	0.69	22.10	19.30	4.61
08.01.15	146.8	75.7	1.24	0.33	0.79	0.37	1.52	1.63	2.31	4.65	1.10	0.58	0.15	1.41	0.72	2.35	0.41	0.12	8.18	32.12	4.20
09.01.15	170.0	88.8	1.48	0.31	0.75	1.34	1.39	1.88	2.67	4.47	1.10	0.97	0.56	1.41	0.66	2.57	0.50	0.45	29.43	38.54	4.20
15.01.15	87.2	48.7	0.36	1.11	2.65	0.40	4.19	1.27	1.51	0.58	0.58	0.30	0.17	1.12	2.00	0.30	0.15	0.13	8.85	9.35	2.22
16.01.15	108.5	56.5	0.41	0.23	0.55	1.01	0.76	1.35	1.56	2.61	0.58	0.36	0.42	1.14	0.36	0.30	0.18	0.34	22.12	10.54	2.22
22.01.15	154.8	82.8	0.25	1.09	2.61	1.88	2.26	0.99	1.40	0.74	0.36	0.23	0.78	1.02	1.07	0.22	0.13	0.63	41.29	6.60	1.35
23.01.15	118.2	61.2	0.35	1.06	2.51	1.21	3.78	1.14	1.46	0.66	0.51	0.28	0.50	1.04	1.80	0.28	0.13	0.40	26.55	9.08	1.93
29.01.15	146.3	78.2	1.07	1.04	2.47	1.30	3.05	1.42	1.90	4.44	0.99	0.53	0.54	1.27	1.45	0.61	0.32	0.43	28.58	27.70	3.76
30.01.15	139.8	73.4	0.55	0.25	0.59	2.15	0.89	1.40	1.71	9.43	0.76	0.46	0.89	1.27	0.42	0.34	0.23	0.72	27.30	14.30	2.89

Table 4.1(f): Status of ambient air quality at ST_1 during 2014-15 (PAHs in ng/m^3 & rest in $\mu g/m^3$)

Date	PM_{10}	$PM_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
01.04.14	102.5	53.9	0.20	0.64	1.53	1.42	2.25	0.38	0.65	4.15	0.34	0.34	0.59	0.39	1.07	0.49	0.13	0.47	27.10	4.50	0.89
02.04.14	129.2	68.4	0.44	0.29	0.68	1.51	2.19	0.94	2.61	0.75	0.54	0.62	0.63	1.17	1.04	0.78	0.26	0.50	28.69	10.12	1.40
08.04.14	117.3	61.4	0.24	0.79	1.87	1.76	2.41	0.38	0.75	4.07	0.39	0.48	0.73	0.83	1.15	0.49	0.19	0.59	33.47	5.62	1.02
09.04.14	146.2	78.3	1.61	0.79	1.87	1.79	2.39	3.52	3.58	8.67	1.56	1.37	0.75	2.44	1.14	2.15	0.63	0.60	24.20	17.10	4.07
15.04.14	151.1	80.1	1.68	1.05	2.51	2.31	3.90	3.52	3.66	4.15	1.81	1.44	0.96	2.44	1.86	2.15	0.75	0.77	29.30	21.20	4.70
16.04.14	86.3	45.1	0.39	1.76	4.18	0.42	4.52	0.75	1.51	0.83	0.54	0.62	0.17	1.08	2.15	0.68	0.25	0.14	7.97	8.99	1.40
22.04.14	167.3	89.3	2.15	0.57	1.36	1.54	2.63	3.58	3.98	3.92	1.96	1.44	0.64	2.44	1.25	5.38	0.88	0.51	29.26	19.47	5.08
23.04.14	163.6	88.0	0.79	0.50	1.19	1.76	2.47	3.46	3.12	10.93	1.17	1.03	0.73	2.44	1.18	1.18	0.50	0.59	33.47	18.08	3.05
06.05.14	150.2	77.4	0.29	0.79	1.87	2.26	6.03	0.44	1.08	1.06	0.44	0.48	0.94	0.93	2.87	0.54	0.19	0.75	43.04	6.75	1.14
07.05.14	123.0	66.5	0.34	0.64	1.53	1.59	2.73	0.44	1.35	2.45	0.54	0.55	0.66	0.98	1.30	0.54	0.25	0.53	30.28	7.87	1.40
13.05.14	91.7	47.0	0.18	0.61	1.44	1.34	2.11	0.35	0.61	3.90	0.32	0.32	0.56	0.37	1.01	0.46	0.12	0.45	25.47	4.23	0.84
14.05.14	120.5	62.8	0.41	0.27	0.64	1.42	2.06	0.89	2.46	0.71	0.51	0.58	0.59	1.10	0.98	0.74	0.25	0.47	26.97	9.51	1.31
20.05.14	111.4	59.6	0.23	0.74	1.76	1.65	2.27	0.35	0.71	3.83	0.37	0.45	0.69	0.78	1.08	0.46	0.18	0.55	31.46	5.28	0.96
21.05.14	124.2	66.3	1.52	0.74	1.76	1.69	2.25	3.31	3.37	8.15	1.47	1.29	0.70	2.30	1.07	2.02	0.59	0.56	16.60	12.50	3.82
27.05.14	143.9	77.7	1.58	0.99	2.36	2.17	3.67	3.31	3.44	3.90	1.70	1.35	0.90	2.30	1.75	2.02	0.71	0.72	18.60	13.30	4.42
28.05.14	84.3	46.8	0.37	1.65	3.93	0.39	4.25	0.71	1.42	0.78	0.51	0.58	0.16	1.01	2.03	0.64	0.24	0.13	7.49	8.45	1.31
09.12.14	87.5	48.7	0.49	1.53	3.65	0.55	5.76	1.75	2.07	0.79	0.80	0.42	0.23	1.54	2.74	0.42	0.21	0.18	10.52	11.38	2.09
10.12.14	125.4	66.4	0.56	0.32	0.75	1.38	1.05	1.85	2.15	3.58	0.80	0.49	0.58	1.57	0.50	0.42	0.24	0.46	26.30	12.81	2.09
16.12.14	188.6	98.7	0.35	1.51	3.58	2.58	3.10	1.36	1.92	1.02	0.49	0.31	1.08	1.40	1.48	0.31	0.17	0.86	49.09	8.03	1.27
17.12.14	135.3	72.0	0.48	1.45	3.46	1.66	5.19	1.57	2.00	0.90	0.70	0.38	0.69	1.43	2.47	0.38	0.17	0.55	31.56	11.04	1.82
23.12.14	189.6	99.5	1.46	1.43	3.39	1.79	4.20	1.96	2.61	6.11	1.36	0.73	0.74	1.75	2.00	0.84	0.44	0.60	33.98	33.69	3.54
24.12.14	172.0	89.1	0.76	0.34	0.82	2.95	1.22	1.92	2.35	12.96	1.05	0.63	1.23	1.75	0.58	0.46	0.31	0.98	56.11	17.40	2.72
30.12.14	184.0	93.2	1.97	0.37	0.88	1.41	2.81	4.64	3.84	4.98	1.40	2.72	0.59	1.82	1.34	3.26	0.84	0.47	26.83	45.26	3.63
31.12.14	191.2	98.5	2.34	1.53	3.65	2.63	7.04	6.53	4.99	2.04	1.54	3.14	1.10	1.96	3.35	3.57	0.88	0.88	30.20	23.10	3.99
08.01.15	160.1	82.5	1.56	0.42	1.01	0.47	1.92	2.06	2.92	5.88	1.40	0.73	0.20	1.78	0.91	2.97	0.51	0.16	8.94	35.94	3.63
09.01.15	185.0	95.6	1.88	0.40	0.94	1.69	1.76	2.37	3.38	5.66	1.40	1.22	0.71	1.78	0.84	3.25	0.63	0.56	32.19	43.13	3.63
15.01.15	82.9	44.7	0.46	1.41	3.35	0.51	5.30	1.61	1.91	0.73	0.74	0.39	0.21	1.41	2.52	0.39	0.19	0.17	9.68	10.47	1.92
16.01.15	118.0	61.4	0.51	0.29	0.69	1.27	0.97	1.70	1.98	3.30	0.74	0.45	0.53	1.45	0.46	0.39	0.22	0.42	24.20	11.79	1.92
22.01.15	168.8	90.3	0.32	1.38	3.30	2.37	2.86	1.25	1.77	0.94	0.45	0.29	0.99	1.28	1.36	0.28	0.16	0.79	45.16	7.39	1.17
23.01.15	128.6	66.6	0.44	1.34	3.18	1.53	4.78	1.45	1.84	0.83	0.64	0.35	0.64	1.32	2.28	0.35	0.16	0.51	29.03	10.16	1.67
29.01.15	173.1	89.5	1.35	1.31	3.12	1.64	3.86	1.80	2.40	5.62	1.25	0.67	0.68	1.61	1.84	0.78	0.40	0.55	31.26	31.00	3.26
30.01.15	179.2	91.2	0.70	0.32	0.75	2.71	1.12	1.77	2.16	11.92	0.96	0.58	1.13	1.61	0.54	0.42	0.29	0.90	51.62	16.01	2.51

Table 4.1(g): Status of ambient air quality at ST_2 during 2014-15 (PAHs in ng/m^3 & rest in $\mu g/m^3$)

Date	PM_{10}	$PM_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
01.04.14	136.0	72.0	0.49	0.32	0.76	1.69	1.18	1.06	2.93	0.84	0.60	0.69	0.70	1.31	1.17	0.88	0.30	0.56	30.60	9.71	2.01
02.04.14	119.9	62.8	0.27	0.88	2.10	1.97	3.48	0.42	0.84	4.56	0.44	0.54	0.82	0.93	1.29	0.55	0.21	0.66	35.70	3.89	1.44
08.04.14	183.0	93.6	1.81	0.88	2.10	2.01	5.82	3.94	4.01	9.71	1.75	1.53	0.84	2.74	1.28	2.41	0.70	0.67	36.42	36.26	4.79
09.04.14	186.0	98.4	1.88	1.18	2.81	2.58	4.70	3.94	4.09	4.65	2.03	1.61	1.08	2.74	2.08	2.41	0.84	0.86	46.82	36.26	5.74
15.04.14	89.1	47.8	0.44	1.97	4.68	0.47	1.37	0.84	1.69	0.93	0.60	0.69	0.20	1.20	2.41	0.77	0.28	0.16	8.50	7.77	1.91
16.04.14	179.2	98.1	2.41	0.64	1.53	1.72	3.15	4.01	4.46	4.39	2.19	1.61	0.72	2.74	1.40	6.02	0.99	0.57	31.21	36.91	6.70
22.04.14	175.1	93.4	0.88	0.56	1.34	1.97	7.88	3.87	3.49	12.24	1.31	1.15	0.82	2.74	1.32	1.32	0.56	0.66	35.70	35.62	3.83
23.04.14	153.0	78.9	0.33	0.88	2.10	2.53	2.15	0.49	1.20	1.18	0.49	0.54	1.06	1.04	3.21	0.60	0.21	0.84	45.90	4.53	1.44
06.05.14	120.5	65.1	0.38	0.72	1.72	1.78	1.97	0.49	1.52	2.75	0.60	0.61	0.74	1.09	1.45	0.60	0.28	0.59	32.30	4.53	1.91
07.05.14	95.3	48.9	0.21	0.68	1.61	1.50	6.07	0.40	0.68	4.37	0.36	0.36	0.62	0.41	1.13	0.51	0.13	0.50	27.17	3.65	0.90
13.05.14	126.9	66.1	0.46	0.30	0.72	1.59	1.11	0.99	2.75	0.79	0.57	0.65	0.66	1.24	1.10	0.82	0.28	0.53	28.77	9.13	1.89
14.05.14	114.0	61.0	0.26	0.83	1.97	1.85	3.27	0.40	0.79	4.29	0.41	0.50	0.77	0.87	1.21	0.51	0.20	0.62	33.56	3.65	1.35
20.05.14	170.1	90.0	1.70	0.83	1.97	1.89	5.47	3.71	3.77	9.13	1.65	1.44	0.79	2.57	1.20	2.26	0.66	0.63	34.23	34.09	4.50
21.05.14	158.6	86.4	1.76	1.11	2.64	2.43	4.42	3.71	3.85	4.37	1.90	1.51	1.01	2.57	1.96	2.26	0.79	0.81	24.10	20.10	5.40
27.05.14	84.8	48.1	0.41	1.85	4.40	0.44	1.29	0.79	1.58	0.87	0.57	0.65	0.18	1.13	2.27	0.72	0.26	0.15	7.99	7.30	1.80
28.05.14	106.5	56.1	0.22	0.72	1.72	1.60	6.45	0.42	0.72	4.65	0.38	0.38	0.66	0.44	1.20	0.55	0.14	0.53	28.90	3.89	0.96
09.12.14	149.1	78.9	0.62	0.35	0.84	1.55	2.45	2.07	2.41	4.02	0.90	0.55	0.65	1.76	0.56	0.47	0.27	0.52	28.05	19.07	1.86
10.12.14	198.0	105.7	0.39	1.69	4.01	2.89	2.70	1.53	2.15	1.14	0.55	0.35	1.20	1.56	1.66	0.34	0.20	0.96	52.36	14.03	1.33
16.12.14	155.9	83.0	0.54	1.63	3.87	1.86	2.68	1.76	2.25	1.01	0.78	0.43	0.77	1.60	2.77	0.43	0.20	0.62	33.66	16.19	1.33
17.12.14	192.8	100.4	1.64	1.60	3.80	2.00	4.37	2.19	2.92	6.84	1.53	0.82	0.83	1.96	2.24	0.95	0.49	0.67	36.24	20.15	3.35
23.12.14	166.6	89.7	0.85	0.38	0.92	3.30	5.07	2.15	2.63	14.52	1.17	0.70	1.38	1.96	0.65	0.52	0.35	1.10	59.85	19.79	2.39
24.12.14	174.1	90.1	2.20	0.41	0.99	1.58	2.95	5.20	4.30	5.57	1.56	3.05	0.66	2.03	1.50	3.66	0.94	0.53	28.61	47.85	6.38
30.12.14	197.6	103.8	2.62	1.72	4.08	2.95	2.77	7.31	5.59	2.28	1.72	3.52	1.23	2.19	3.75	4.00	0.99	0.98	33.20	29.30	6.70
31.12.14	114.5	59.0	1.75	0.47	1.13	0.53	6.75	2.31	3.27	6.59	1.56	0.82	0.22	1.99	1.02	3.32	0.57	0.18	9.54	21.23	3.91
08.01.15	189.5	102.4	2.10	0.44	1.06	1.90	3.05	2.66	3.79	6.33	1.56	1.37	0.79	1.99	0.94	3.64	0.70	0.63	34.34	24.46	4.79
09.01.15	93.5	47.9	0.51	1.58	3.76	0.57	2.32	1.80	2.14	0.82	0.83	0.43	0.24	1.58	2.83	0.43	0.22	0.19	10.32	16.55	1.47
15.01.15	140.2	73.0	0.57	0.33	0.78	1.42	2.26	1.91	2.22	3.69	0.83	0.50	0.59	1.62	0.52	0.43	0.25	0.47	25.81	17.54	1.71
16.01.15	195.8	104.7	0.36	1.55	3.69	2.66	2.48	1.40	1.98	1.05	0.50	0.32	1.11	1.44	1.52	0.32	0.18	0.89	48.18	12.91	1.22
22.01.15	148.2	76.8	0.49	1.50	3.56	1.71	2.47	1.62	2.07	0.93	0.72	0.40	0.71	1.47	2.55	0.40	0.18	0.57	30.97	14.89	1.22
23.01.15	170.8	91.8	1.51	1.47	3.50	1.84	4.02	2.01	2.69	6.29	1.40	0.76	0.77	1.80	2.06	0.87	0.45	0.61	33.34	18.53	3.08
29.01.15	181.0	96.3	0.78	0.35	0.84	3.04	4.66	1.98	2.42	13.36	1.08	0.65	1.27	1.80	0.60	0.47	0.32	1.01	55.06	18.20	2.20
30.01.15	99.6	52.4	0.55	1.72	4.08	0.62	2.52	1.96	2.32	0.89	0.90	0.47	0.26	1.72	3.07	0.47	0.23	0.21	11.22	17.99	1.60

Table 4.1(h): Status of ambient air quality at ST$_3$ during 2014-15 (PAHs in ng/m^3 & rest in μg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
01.04.14	82.7	43.7	0.33	1.50	3.57	0.36	3.87	0.64	1.29	0.71	0.46	0.53	0.15	0.92	1.84	0.58	0.21	0.12	7.78	11.58	2.15
02.04.14	93.4	51.7	0.18	0.59	1.39	1.29	2.04	0.34	0.59	3.77	0.31	0.31	0.54	0.36	0.97	0.44	0.11	0.43	28.15	5.28	1.14
08.04.14	122.2	66.3	0.40	0.26	0.62	1.37	1.99	0.86	2.38	0.69	0.49	0.56	0.57	1.07	0.95	0.71	0.24	0.46	29.81	21.38	2.40
09.04.14	124.7	65.3	0.22	0.72	1.70	1.60	2.19	0.34	0.68	3.70	0.36	0.44	0.67	0.76	1.04	0.44	0.17	0.53	34.78	6.16	1.71
15.04.14	176.2	90.4	1.47	0.72	1.70	1.63	2.18	3.20	3.26	7.88	1.42	1.24	0.68	2.22	1.04	1.96	0.57	0.54	35.47	29.30	5.71
16.04.14	180.1	93.2	1.52	0.96	2.28	2.10	3.55	3.20	3.32	3.77	1.64	1.31	0.87	2.22	1.69	1.96	0.69	0.70	45.61	29.91	6.86
22.04.14	79.8	44.2	0.36	1.60	3.80	0.38	4.11	0.69	1.37	0.75	0.49	0.56	0.16	0.98	1.96	0.62	0.23	0.13	8.28	12.32	2.29
23.04.14	167.1	91.4	1.96	0.52	1.24	1.40	2.39	3.26	3.62	3.57	1.78	1.31	0.58	2.22	1.14	4.89	0.80	0.47	30.40	32.55	8.00
06.05.14	174.5	93.5	0.71	0.46	1.08	1.60	2.25	3.14	2.84	9.93	1.07	0.93	0.67	2.22	1.07	1.08	0.46	0.53	34.78	25.52	4.57
07.05.14	162.9	84.0	0.27	0.72	1.70	2.06	5.48	0.40	0.98	0.96	0.40	0.44	0.86	0.84	2.61	0.49	0.17	0.69	44.71	8.80	1.71
13.05.14	98.4	53.4	0.31	0.59	1.39	1.45	2.48	0.40	1.23	2.23	0.49	0.50	0.60	0.89	1.18	0.49	0.23	0.48	31.46	11.09	2.29
14.05.14	97.6	50.1	0.17	0.55	1.31	1.22	1.92	0.32	0.55	3.54	0.29	0.29	0.51	0.33	0.92	0.42	0.11	0.41	26.46	4.96	1.07
20.05.14	160.6	83.6	0.38	0.24	0.58	1.29	1.87	0.81	2.23	0.64	0.46	0.53	0.54	1.00	0.89	0.67	0.23	0.43	28.02	20.10	2.26
21.05.14	96.1	53.7	0.21	0.67	1.60	1.50	2.06	0.32	0.64	3.48	0.33	0.41	0.63	0.71	0.98	0.42	0.16	0.50	32.69	5.79	1.61
27.05.14	169.5	88.9	1.38	0.67	1.60	1.53	2.05	3.01	3.06	7.41	1.34	1.17	0.64	2.09	0.97	1.84	0.54	0.51	33.34	27.54	5.37
28.05.14	160.7	84.7	1.43	0.90	2.14	1.97	3.34	3.01	3.12	3.54	1.55	1.23	0.82	2.09	1.59	1.84	0.64	0.66	38.87	28.12	6.44
09.12.14	183	93.6	0.63	0.29	0.68	2.47	1.02	1.61	1.97	10.84	0.88	0.53	1.03	1.46	0.49	0.39	0.26	0.82	53.63	17.69	2.63
10.12.14	96.3	50.7	0.45	1.39	3.31	0.50	5.24	1.59	1.89	0.72	0.73	0.38	0.21	1.40	2.49	0.38	0.19	0.17	10.93	16.97	1.90
16.12.14	143.5	75.9	0.51	0.29	0.69	1.26	0.96	1.68	1.96	3.26	0.73	0.44	0.52	1.43	0.45	0.38	0.22	0.42	27.32	17.60	2.22
17.12.14	179	91.2	0.32	1.37	3.26	2.35	2.82	1.24	1.75	0.93	0.44	0.29	0.98	1.27	1.34	0.28	0.16	0.78	51.00	15.71	1.59
23.12.14	154.7	82.3	0.44	1.32	3.14	1.51	4.72	1.43	1.82	0.82	0.63	0.35	0.63	1.30	2.25	0.35	0.16	0.50	32.79	16.40	1.59
24.12.14	171	86.4	1.33	1.30	3.09	1.62	3.81	1.78	2.37	5.55	1.24	0.67	0.68	1.59	1.82	0.77	0.40	0.54	35.30	21.37	4.00
30.12.14	188	97.3	0.69	0.31	0.74	2.68	1.11	1.75	2.14	11.78	0.95	0.57	1.12	1.59	0.53	0.42	0.29	0.89	58.29	19.23	2.86
31.12.14	177	90.0	1.79	0.34	0.80	1.28	2.55	4.22	3.49	4.52	1.27	2.48	0.53	1.65	1.22	2.97	0.76	0.43	27.87	31.42	7.62
08.01.15	193	101.1	2.13	1.39	3.31	2.39	6.40	5.94	4.54	1.85	1.40	2.86	1.00	1.78	3.05	3.25	0.80	0.80	41.10	20.10	8.00
09.01.15	94.9	54.7	1.42	0.38	0.91	0.43	1.74	1.87	2.65	5.35	1.27	0.67	0.18	1.62	0.83	2.70	0.47	0.14	9.29	23.88	4.67
15.01.15	170	83.3	1.70	0.36	0.86	1.54	1.60	2.16	3.07	5.14	1.27	1.11	0.64	1.62	0.76	2.95	0.57	0.51	33.44	27.65	5.71
16.01.15	90.4	46.4	0.41	1.28	3.05	0.46	4.82	1.46	1.73	0.66	0.67	0.35	0.19	1.28	2.29	0.35	0.18	0.15	10.06	15.61	1.75
22.01.15	104.2	58.6	0.47	0.27	0.63	1.16	0.88	1.55	1.80	3.00	0.67	0.41	0.48	1.31	0.42	0.35	0.20	0.39	25.14	16.19	2.04
23.01.15	167	85.0	0.29	1.26	3.00	2.16	2.60	1.14	1.61	0.85	0.41	0.26	0.90	1.17	1.24	0.26	0.15	0.72	46.92	14.45	1.46
29.01.15	117.2	65.4	0.40	1.21	2.89	1.39	4.34	1.31	1.68	0.76	0.58	0.32	0.58	1.20	2.07	0.32	0.15	0.46	30.17	15.09	1.46
30.01.15	133.3	70.6	1.23	1.19	2.84	1.49	3.51	1.64	2.18	5.11	1.14	0.61	0.62	1.46	1.67	0.71	0.37	0.50	32.48	19.66	3.68

Table 4.1(i): Status of ambient air quality at ST$_0$ during 2015-16 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.15	112.2	59.0	0.17	0.55	1.32	1.22	1.93	0.32	0.55	3.56	0.29	0.29	0.51	0.34	0.92	0.42	0.11	0.41	19.07	14.25	2.24
2.4.15	89.9	47.5	0.38	0.25	0.59	1.30	1.88	0.81	2.25	0.65	0.46	0.53	0.54	1.01	0.90	0.67	0.23	0.43	15.00	11.48	1.48
8.4.15	87.3	45.7	0.21	0.68	1.61	1.51	2.07	0.32	0.65	3.50	0.34	0.41	0.63	0.71	0.99	0.42	0.16	0.50	17.44	11.41	0.99
9.4.15	99.1	52.7	1.39	0.68	1.61	1.54	2.06	3.02	3.08	7.45	1.34	1.18	0.64	2.10	0.98	1.85	0.54	0.51	18.16	12.01	1.37
15.4.15	126.5	65.9	1.44	0.91	2.16	1.98	3.35	3.02	3.14	3.56	1.55	1.23	0.83	2.10	1.60	1.85	0.65	0.66	25.74	14.03	2.44
16.4.15	102.4	54.8	0.34	1.51	3.59	0.36	3.89	0.65	1.29	0.71	0.46	0.53	0.15	0.92	1.85	0.59	0.22	0.12	18.97	12.26	2.35
22.4.15	107.3	55.6	1.85	0.49	1.17	1.32	2.26	3.08	3.42	3.37	1.68	1.23	0.55	2.10	1.08	4.62	0.76	0.44	18.72	14.28	1.93
23.4.15	82.7	44.5	0.68	0.43	1.02	1.51	2.13	2.97	2.68	9.39	1.01	0.88	0.63	2.10	1.01	1.02	0.43	0.50	14.48	11.10	2.02
6.5.15	85.6	46.9	0.25	0.68	1.61	1.94	5.18	0.38	0.92	0.91	0.38	0.41	0.81	0.80	2.47	0.46	0.16	0.65	13.88	10.55	1.13
7.5.15	99.5	53.8	0.29	0.55	1.32	1.37	2.34	0.38	1.16	2.11	0.46	0.47	0.57	0.84	1.12	0.46	0.22	0.46	17.32	12.57	2.12
13.5.15	115.9	59.4	0.16	0.52	1.24	1.15	1.82	0.30	0.52	3.35	0.28	0.28	0.48	0.32	0.86	0.39	0.10	0.38	19.76	15.29	3.53
14.5.15	115.4	60.1	0.36	0.23	0.55	1.22	1.77	0.76	2.11	0.61	0.43	0.50	0.51	0.95	0.84	0.63	0.21	0.41	20.45	13.41	2.35
20.5.15	97.0	51.9	0.20	0.64	1.51	1.42	1.95	0.30	0.61	3.29	0.32	0.39	0.59	0.67	0.93	0.39	0.15	0.47	17.82	12.52	2.47
21.5.15	101.4	52.5	1.30	0.64	1.51	1.45	1.93	2.84	2.89	7.00	1.26	1.11	0.60	1.97	0.92	1.74	0.51	0.48	17.82	12.31	1.88
27.5.15	80.1	44.4	1.35	0.85	2.03	1.86	3.15	2.84	2.95	3.35	1.46	1.16	0.78	1.97	1.50	1.74	0.61	0.62	15.28	9.28	0.92
28.5.15	84.2	45.1	0.32	1.42	3.38	0.34	3.65	0.61	1.22	0.67	0.43	0.50	0.14	0.87	1.74	0.55	0.20	0.11	12.95	9.01	1.46
09.12.15	134.2	70.6	0.43	1.32	3.13	0.48	4.95	1.50	1.78	0.68	0.69	0.36	0.20	1.32	2.36	0.36	0.18	0.16	22.62	15.85	3.06
10. 12.15	145.6	77.0	0.48	0.27	0.65	1.19	0.90	1.59	1.85	3.08	0.69	0.42	0.50	1.35	0.43	0.36	0.21	0.40	25.58	18.33	3.91
16. 12.15	98.8	57.7	0.30	1.29	3.08	2.22	2.67	1.17	1.65	0.87	0.42	0.27	0.92	1.20	1.27	0.26	0.15	0.74	26.27	15.56	2.72
17. 12.15	156.2	83.1	0.41	1.25	2.97	1.43	4.46	1.35	1.72	0.78	0.60	0.33	0.59	1.23	2.13	0.33	0.15	0.48	30.94	17.86	2.48
23. 12.15	142.9	74.4	1.26	1.23	2.92	1.53	3.61	1.68	2.24	5.25	1.17	0.63	0.64	1.50	1.72	0.73	0.38	0.51	28.79	13.36	2.11
24. 12.15	126.3	67.5	0.65	0.29	0.70	2.53	1.05	1.65	2.02	11.14	0.90	0.54	1.06	1.50	0.50	0.40	0.27	0.84	25.96	13.83	1.60
30. 12.15	159.4	82.6	1.69	0.32	0.76	1.21	2.41	3.99	3.30	4.28	1.20	2.34	0.50	1.56	1.15	2.81	0.72	0.40	30.46	16.04	2.94
31. 12.15	117.3	63.0	2.01	1.32	3.13	2.26	6.05	5.61	4.29	1.75	1.32	2.70	0.94	1.68	2.88	3.07	0.76	0.75	26.06	11.01	1.33
08.01.16	148.7	76.7	1.34	0.36	0.86	0.40	1.65	1.77	2.51	5.05	1.20	0.63	0.17	1.53	0.79	2.55	0.44	0.13	25.67	16.66	2.75
09.01.16	114.1	61.7	1.61	0.34	0.81	1.45	1.51	2.04	2.90	4.86	1.20	1.05	0.61	1.53	0.72	2.79	0.54	0.48	24.23	12.94	1.11
15.01.16	121.2	64.2	0.39	1.21	2.88	0.44	4.56	1.38	1.64	0.63	0.63	0.33	0.18	1.21	2.17	0.33	0.17	0.15	29.01	17.69	2.19
16.01.16	149.4	77.8	0.44	0.25	0.60	1.09	0.83	1.46	1.70	2.83	0.63	0.39	0.46	1.24	0.40	0.33	0.19	0.36	25.86	18.69	3.46
22.01.16	126.1	67.4	0.28	1.19	2.83	2.04	2.45	1.08	1.52	0.80	0.39	0.25	0.85	1.10	1.17	0.24	0.14	0.68	22.52	15.40	2.20
23.01.16	139.3	72.2	0.38	1.15	2.73	1.31	4.11	1.24	1.58	0.72	0.55	0.30	0.55	1.13	1.96	0.30	0.14	0.44	25.94	15.34	2.98
29.01.16	111.7	60.1	1.16	1.13	2.68	1.41	3.32	1.55	2.06	4.83	1.08	0.58	0.59	1.38	1.58	0.67	0.35	0.47	26.37	17.15	1.99
30.01.16	133.5	68.8	0.60	0.27	0.65	2.33	0.97	1.52	1.86	10.25	0.83	0.50	0.97	1.38	0.46	0.36	0.25	0.78	23.71	15.50	2.73

Table 4.1(j): Status of ambient air quality at ST$_1$ during 2015-16 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.15	127.6	67.2	0.21	0.70	1.67	1.55	2.44	0.41	0.70	4.51	0.37	0.37	0.65	0.43	1.16	0.53	0.14	0.52	21.73	16.90	1.81
2.4.15	110.2	58.3	0.48	0.31	0.74	1.64	2.38	1.02	2.84	0.82	0.58	0.67	0.68	1.28	1.13	0.85	0.29	0.55	21.93	11.07	1.28
8.4.15	81.0	42.4	0.27	0.86	2.04	1.91	2.62	0.41	0.82	4.43	0.43	0.52	0.80	0.90	1.25	0.53	0.20	0.64	16.00	10.00	1.71
9.4.15	101.0	53.7	1.75	0.86	2.04	1.95	2.60	3.83	3.89	9.43	1.70	1.49	0.81	2.66	1.24	2.34	0.68	0.65	19.02	12.08	1.03
15.4.15	101.2	52.7	1.82	1.15	2.73	2.51	4.24	3.83	3.97	4.51	1.97	1.56	1.05	2.66	2.02	2.34	0.82	0.84	18.14	14.17	1.45
16.4.15	93.4	49.9	0.43	1.91	4.55	0.46	4.92	0.82	1.64	0.90	0.58	0.67	0.19	1.17	2.34	0.74	0.27	0.15	16.84	12.90	0.86
22.4.15	83.0	43.0	2.34	0.62	1.48	1.67	2.86	3.89	4.32	4.26	2.13	1.56	0.70	2.66	1.36	5.84	0.96	0.56	15.90	9.61	1.52
23.4.15	91.8	50.4	0.85	0.54	1.30	1.91	2.69	3.76	3.39	11.88	1.28	1.12	0.80	2.66	1.28	1.29	0.55	0.64	18.03	8.94	1.17
6.5.15	94.8	49.8	0.32	0.86	2.04	2.46	6.55	0.48	1.17	1.15	0.48	0.52	1.02	1.01	3.12	0.58	0.20	0.82	17.74	10.11	0.78
7.5.15	101.2	54.7	0.37	0.70	1.67	1.73	2.96	0.48	1.47	2.67	0.58	0.60	0.72	1.06	1.41	0.58	0.27	0.58	21.42	10.17	0.95
13.5.15	92.8	47.6	0.20	0.66	1.57	1.46	2.30	0.39	0.66	4.24	0.35	0.35	0.61	0.40	1.09	0.50	0.13	0.49	18.45	11.17	1.25
14.5.15	107.0	55.7	0.45	0.29	0.70	1.54	2.24	0.96	2.67	0.77	0.55	0.63	0.64	1.20	1.07	0.80	0.27	0.51	21.12	11.49	0.95
20.5.15	98.3	52.6	0.25	0.80	1.91	1.80	2.46	0.39	0.77	4.16	0.40	0.49	0.75	0.85	1.17	0.50	0.19	0.60	21.52	10.40	1.34
21.5.15	97.1	50.3	1.65	0.80	1.91	1.83	2.45	3.60	3.66	8.86	1.60	1.40	0.76	2.50	1.16	2.20	0.64	0.61	18.20	11.44	1.00
27.5.15	120.6	64.8	1.71	1.08	2.56	2.36	3.99	3.60	3.74	4.24	1.85	1.47	0.98	2.50	1.90	2.20	0.77	0.79	26.66	12.41	1.42
28.5.15	131.4	67.7	0.40	1.80	4.27	0.43	4.62	0.77	1.54	0.85	0.55	0.63	0.18	1.10	2.20	0.70	0.26	0.14	23.36	15.47	2.69
09.12.15	109.7	59.3	0.54	1.66	3.96	0.60	6.26	1.90	2.25	0.86	0.87	0.46	0.25	1.67	2.98	0.46	0.23	0.20	24.63	13.36	1.99
10. 12.15	184.7	99.3	1.46	1.43	3.39	1.79	4.20	1.96	2.61	6.11	1.36	0.73	0.74	1.75	2.00	0.84	0.44	0.60	38.61	17.68	3.15
16. 12.15	154.8	81.1	0.38	1.64	3.89	2.81	3.37	1.48	2.09	1.11	0.53	0.34	1.17	1.52	1.61	0.33	0.19	0.94	27.01	17.76	3.16
17. 12.15	140.7	74.8	0.52	1.58	3.76	1.80	5.65	1.71	2.18	0.98	0.76	0.42	0.75	1.56	2.69	0.42	0.19	0.60	24.29	20.00	1.88
23. 12.15	106.3	57.1	1.59	1.55	3.69	1.94	4.56	2.13	2.84	6.64	1.48	0.80	0.81	1.90	2.17	0.92	0.48	0.65	24.05	16.13	2.19
24. 12.15	139.1	74.4	0.82	0.37	0.89	3.21	1.33	2.09	2.55	14.09	1.14	0.68	1.34	1.90	0.63	0.50	0.34	1.07	24.33	18.30	2.96
30. 12.15	168.0	87.1	2.14	0.40	0.96	1.53	3.05	5.05	4.17	5.41	1.52	2.96	0.64	1.97	1.45	3.55	0.91	0.51	29.24	19.29	3.57
31. 12.15	155.5	83.6	2.55	1.66	3.96	2.86	7.65	7.10	5.43	2.21	1.67	3.42	1.19	2.13	3.64	3.88	0.96	0.95	31.38	17.11	2.45
08.01.16	163.3	84.2	1.70	0.46	1.09	0.51	2.09	2.24	3.17	6.39	1.52	0.80	0.21	1.94	0.99	3.23	0.56	0.17	30.82	15.63	3.03
09.01.16	141.4	76.5	2.04	0.43	1.02	1.84	1.91	2.58	3.67	6.15	1.52	1.33	0.77	1.94	0.91	3.53	0.68	0.61	28.18	17.27	2.00
15.01.16	149.2	76.5	0.49	1.53	3.65	0.55	5.76	1.75	2.07	0.79	0.80	0.42	0.23	1.54	2.74	0.42	0.21	0.18	25.41	16.87	2.97
16.01.16	141.7	73.8	0.56	0.32	0.75	1.38	1.05	1.85	2.15	3.58	0.80	0.49	0.58	1.57	0.50	0.42	0.24	0.46	28.02	14.80	2.74
22.01.16	139.3	74.5	0.35	1.51	3.58	2.58	3.10	1.36	1.92	1.02	0.49	0.31	1.08	1.40	1.48	0.31	0.17	0.86	29.95	12.49	1.86
23.01.16	175.4	90.9	0.48	1.45	3.46	1.66	5.19	1.57	2.00	0.90	0.70	0.38	0.69	1.43	2.47	0.38	0.17	0.55	34.47	19.04	2.21
29.01.16	122.9	65.1	0.61	0.34	0.82	1.50	1.14	2.01	2.34	3.90	0.87	0.53	0.63	1.71	0.54	0.46	0.27	0.50	26.03	12.86	1.49
30.01.16	150.0	77.3	0.76	0.34	0.82	2.95	1.22	1.92	2.35	12.96	1.05	0.63	1.23	1.75	0.58	0.46	0.31	0.98	31.20	14.55	1.37

Table 4.1(k): Status of ambient air quality at ST$_2$ during 2015-16 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.15	158.9	84.6	0.54	0.35	0.83	1.84	1.28	1.15	3.18	0.92	0.65	0.75	0.77	1.43	1.27	0.95	0.32	0.61	26.92	14.11	2.16
2.4.15	89.1	46.6	0.30	0.96	2.28	2.14	3.78	0.46	0.92	4.96	0.48	0.58	0.89	1.01	1.40	0.60	0.23	0.71	18.22	10.96	1.27
8.4.15	105.8	56.3	1.96	0.96	2.28	2.19	6.32	4.28	4.36	10.56	1.90	1.67	0.91	2.98	1.39	2.62	0.77	0.73	21.10	10.73	1.84
9.4.15	91.9	47.8	2.04	1.28	3.05	2.81	5.11	4.28	4.45	5.05	2.20	1.75	1.17	2.98	2.26	2.62	0.92	0.94	19.80	9.98	0.85
15.4.15	101.6	54.3	0.48	2.14	5.09	0.51	1.49	0.92	1.83	1.01	0.65	0.75	0.21	1.31	2.62	0.83	0.31	0.17	19.99	12.09	1.23
16.4.15	99.3	51.4	2.62	0.70	1.66	1.87	3.42	4.36	4.84	4.77	2.38	1.75	0.78	2.98	1.53	6.55	1.07	0.62	16.69	13.89	1.72
22.4.15	141.6	73.3	0.96	0.61	1.45	2.14	8.57	4.21	3.80	13.30	1.43	1.25	0.89	2.98	1.43	1.44	0.61	0.71	19.86	14.72	2.72
23.4.15	99.2	51.1	0.36	0.96	2.28	2.75	2.34	0.54	1.31	1.29	0.54	0.58	1.15	1.13	3.49	0.65	0.23	0.92	19.78	12.11	1.73
6.5.15	149.4	78.3	0.42	0.78	1.87	1.94	2.14	0.54	1.65	2.99	0.65	0.67	0.81	1.19	1.58	0.65	0.31	0.65	21.20	17.23	3.34
7.5.15	105.4	54.1	0.22	0.74	1.75	1.63	6.59	0.43	0.74	4.75	0.39	0.39	0.68	0.45	1.23	0.56	0.14	0.54	19.99	13.53	1.57
13.5.15	125.2	65.2	0.50	0.33	0.78	1.73	1.20	1.08	2.99	0.86	0.62	0.70	0.72	1.34	1.19	0.89	0.30	0.58	23.76	13.18	2.32
14.5.15	99.0	52.9	0.28	0.90	2.14	2.01	3.55	0.43	0.86	4.66	0.45	0.55	0.84	0.95	1.31	0.56	0.22	0.67	17.88	14.27	1.34
20.5.15	124.6	64.6	1.85	0.90	2.14	2.05	5.94	4.03	4.10	9.92	1.79	1.57	0.86	2.80	1.30	2.46	0.72	0.68	20.11	16.61	2.61
21.5.15	111.1	59.3	1.92	1.21	2.87	2.64	4.80	4.03	4.18	4.75	2.07	1.64	1.10	2.80	2.13	2.46	0.86	0.88	26.24	12.73	1.64
27.5.15	98.4	54.5	0.45	2.01	4.79	0.48	1.40	0.86	1.72	0.95	0.62	0.70	0.20	1.23	2.47	0.78	0.29	0.16	24.14	11.31	0.98
28.5.15	129.1	68.0	0.24	0.78	1.87	1.73	7.02	0.46	0.79	5.05	0.42	0.42	0.72	0.48	1.30	0.60	0.15	0.58	27.63	11.75	1.55
09.12.15	163.7	86.6	0.68	0.39	0.92	1.68	2.67	2.25	2.62	4.36	0.98	0.60	0.70	1.91	0.61	0.51	0.30	0.56	36.58	14.64	2.55
10. 12.15	126.3	66.6	0.43	1.83	4.36	3.14	2.93	1.66	2.34	1.24	0.60	0.38	1.31	1.70	1.80	0.37	0.21	1.05	26.66	15.59	2.99
16. 12.15	149.1	79.3	0.58	1.77	4.21	2.02	2.91	1.91	2.44	1.10	0.85	0.47	0.84	1.74	3.01	0.47	0.21	0.67	31.87	15.17	1.88
17. 12.15	174.4	90.8	1.78	1.74	4.13	2.17	4.75	2.38	3.18	7.44	1.66	0.89	0.91	2.13	2.43	1.03	0.54	0.72	31.31	19.18	3.55
23. 12.15	188.6	100.8	0.92	0.42	0.99	3.59	5.51	2.34	2.86	15.78	1.28	0.77	1.50	2.13	0.71	0.56	0.38	1.20	34.79	23.64	3.38
24. 12.15	144.8	75.0	2.40	0.45	1.07	1.72	3.20	5.65	4.68	6.06	1.70	3.32	0.72	2.21	1.63	3.97	1.02	0.57	24.32	17.23	3.34
30. 12.15	130.6	70.2	2.85	1.86	4.44	3.20	3.01	7.95	6.08	2.48	1.87	3.83	1.34	2.38	4.08	4.35	1.07	1.07	25.26	15.69	1.82
31. 12.15	102.3	57.7	1.90	0.51	1.22	0.57	7.34	2.51	3.55	7.16	1.70	0.89	0.24	2.17	1.11	3.61	0.62	0.19	20.65	18.56	1.04
08.01.16	150.1	81.2	2.28	0.48	1.15	2.06	3.32	2.89	4.11	6.89	1.70	1.49	0.86	2.17	1.02	3.95	0.77	0.69	25.25	23.31	1.82
09.01.16	121.4	64.3	0.55	1.72	4.08	0.62	2.52	1.96	2.32	0.89	0.90	0.47	0.26	1.72	3.07	0.47	0.23	0.21	26.88	20.65	1.24
15.01.16	160.9	83.8	0.62	0.35	0.84	1.55	2.45	2.07	2.41	4.02	0.90	0.55	0.65	1.76	0.56	0.47	0.27	0.52	28.22	22.33	1.16
16.01.16	162.7	87.0	0.39	1.69	4.01	2.89	2.70	1.53	2.15	1.14	0.55	0.35	1.20	1.56	1.66	0.34	0.20	0.96	31.14	18.51	2.13
22.01.16	182.8	94.7	0.54	1.63	3.87	1.86	2.68	1.76	2.25	1.01	0.78	0.43	0.77	1.60	2.77	0.43	0.20	0.62	34.36	21.63	2.08
23.01.16	140.1	74.8	1.64	1.60	3.80	2.00	4.37	2.19	2.92	6.84	1.53	0.82	0.83	1.96	2.24	0.95	0.49	0.67	33.61	18.56	2.49
29.01.16	165.1	85.1	0.85	0.38	0.92	3.30	5.07	2.15	2.63	14.52	1.17	0.70	1.38	1.96	0.65	0.52	0.35	1.10	31.51	17.27	3.07
30.01.16	145.3	76.5	0.60	1.86	4.44	0.67	2.74	2.13	2.52	0.96	0.98	0.51	0.28	1.87	3.34	0.51	0.26	0.22	29.85	13.56	1.55

Table 4.1(l): Status of ambient air quality at ST$_3$ during 2015-16 (PAHs in ng/m^3 & rest in µg/m^3)

Date	PM$_{10}$	PM$_{2.5}$	Acy	Ant	BaA	BaP	BbF	BghiP	BkF	Chry	dBahA	Fln	Flu	IP	Nap	Pery	Pyr	Ret	OTM	OC	EC
1.4.15	127.8	69.0	1.66	1.04	2.48	2.28	3.86	3.48	3.61	4.10	1.79	1.42	0.95	2.42	1.84	2.13	0.75	0.76	15.32	10.59	1.23
2.4.15	95.2	49.7	0.19	0.64	1.51	1.41	2.22	0.37	0.64	4.10	0.34	0.34	0.59	0.39	1.06	0.48	0.12	0.47	16.28	9.92	1.23
8.4.15	132.2	69.3	0.43	0.28	0.67	1.49	2.17	0.93	2.58	0.75	0.53	0.61	0.62	1.16	1.03	0.77	0.26	0.50	21.68	13.27	2.45
9.4.15	89.3	46.3	0.24	0.78	1.85	1.74	2.38	0.37	0.74	4.02	0.39	0.47	0.72	0.82	1.13	0.48	0.19	0.58	16.34	10.01	1.43
15.4.15	121.4	64.7	1.56	0.98	2.33	2.14	3.63	3.27	3.40	3.85	1.68	1.33	0.89	2.27	1.73	2.00	0.70	0.71	21.37	13.42	2.27
16.4.15	140.1	71.6	0.36	1.63	3.88	0.39	4.20	0.70	1.40	0.77	0.50	0.57	0.16	1.00	2.00	0.64	0.23	0.13	22.75	14.22	3.29
22.4.15	119.4	63.3	0.39	1.74	4.13	0.41	4.47	0.75	1.49	0.82	0.53	0.61	0.17	1.06	2.13	0.68	0.25	0.14	19.53	13.66	2.40
23.4.15	91.9	47.7	2.13	0.57	1.35	1.52	2.60	3.54	3.93	3.88	1.93	1.42	0.63	2.42	1.24	5.31	0.87	0.51	12.69	9.05	1.14
6.5.15	106.5	58.4	0.78	0.50	1.18	1.74	2.44	3.42	3.08	10.80	1.16	1.01	0.72	2.42	1.16	1.17	0.50	0.58	14.44	10.12	1.03
7.5.15	92.6	49.2	0.29	0.78	1.85	2.24	5.95	0.43	1.06	1.04	0.43	0.47	0.93	0.92	2.84	0.53	0.19	0.75	16.40	7.69	1.01
13.5.15	118.1	63.2	0.34	0.64	1.51	1.57	2.70	0.43	1.34	2.42	0.53	0.54	0.66	0.97	1.28	0.53	0.25	0.52	20.56	12.56	1.39
14.5.15	101.6	51.6	0.18	0.60	1.42	1.32	2.09	0.35	0.60	3.85	0.32	0.32	0.55	0.36	0.99	0.45	0.12	0.44	17.94	10.77	2.04
20.5.15	120.5	67.7	0.41	0.27	0.63	1.40	2.04	0.88	2.43	0.70	0.50	0.57	0.58	1.09	0.97	0.73	0.25	0.47	17.53	9.08	1.42
21.5.15	97.9	51.9	0.23	0.73	1.74	1.63	2.24	0.35	0.70	3.78	0.36	0.44	0.68	0.77	1.07	0.45	0.18	0.54	19.87	8.74	1.50
27.5.15	126.7	65.1	1.50	0.73	1.74	1.67	2.22	3.27	3.33	8.06	1.45	1.27	0.69	2.27	1.06	2.00	0.58	0.56	22.73	12.31	1.32
28.5.15	98.7	52.0	1.59	0.78	1.85	1.77	2.36	3.48	3.54	8.57	1.55	1.35	0.74	2.42	1.13	2.13	0.62	0.59	15.62	10.84	2.10
09.12.15	129.9	66.9	0.69	0.31	0.74	2.68	1.11	1.75	2.14	11.78	0.95	0.57	1.12	1.59	0.53	0.42	0.29	0.89	26.29	12.48	2.02
10. 12.15	180.7	95.1	0.49	1.51	3.60	0.55	5.69	1.73	2.05	0.78	0.79	0.41	0.23	1.52	2.71	0.41	0.21	0.18	32.92	19.58	3.43
16. 12.15	154.8	81.9	0.55	0.31	0.75	1.37	1.04	1.83	2.13	3.54	0.79	0.48	0.57	1.55	0.49	0.41	0.24	0.46	32.66	15.22	3.00
17. 12.15	150.4	78.7	0.35	1.49	3.54	2.55	3.07	1.35	1.90	1.01	0.48	0.31	1.06	1.38	1.46	0.30	0.17	0.85	27.32	16.69	2.55
23. 12.15	158.7	84.4	0.47	1.44	3.42	1.64	5.13	1.55	1.98	0.89	0.69	0.38	0.68	1.41	2.44	0.38	0.17	0.55	28.86	21.14	2.09
24. 12.15	116.2	60.5	1.45	1.41	3.35	1.77	4.15	1.93	2.58	6.04	1.35	0.72	0.74	1.73	1.97	0.83	0.43	0.59	18.85	14.76	2.39
30. 12.15	101.2	54.1	0.75	0.34	0.81	2.91	1.21	1.90	2.32	12.81	1.04	0.62	1.21	1.73	0.58	0.46	0.31	0.97	19.51	11.45	2.21
31. 12.15	143.8	74.5	1.94	0.37	0.87	1.39	2.78	4.59	3.80	4.92	1.38	2.69	0.58	1.79	1.32	3.23	0.83	0.46	25.32	15.88	3.38
08.01.16	158.4	85.2	2.31	1.51	3.60	2.60	6.96	6.45	4.93	2.01	1.52	3.11	1.08	1.93	3.31	3.53	0.87	0.87	27.85	20.44	3.58
09.01.16	169.3	87.3	1.54	0.42	0.99	0.46	1.90	2.04	2.88	5.81	1.38	0.72	0.19	1.76	0.90	2.93	0.51	0.15	29.68	18.99	2.64
15.01.16	156.6	84.7	1.85	0.39	0.93	1.67	1.74	2.35	3.34	5.59	1.38	1.21	0.70	1.76	0.83	3.21	0.62	0.56	34.01	16.02	2.53
16.01.16	143.5	73.6	0.45	1.39	3.31	0.50	5.24	1.59	1.89	0.72	0.73	0.38	0.21	1.40	2.49	0.38	0.19	0.17	27.59	14.66	1.28
22.01.16	95.3	59.9	0.51	0.29	0.69	1.26	0.96	1.68	1.96	3.26	0.73	0.44	0.52	1.43	0.45	0.38	0.22	0.42	22.84	12.68	1.45
23.01.16	194.1	103.8	0.32	1.37	3.26	2.35	2.82	1.24	1.75	0.93	0.44	0.29	0.98	1.27	1.34	0.28	0.16	0.78	36.75	21.31	3.71
29.01.16	168.7	87.4	0.44	1.32	3.14	1.51	4.72	1.43	1.82	0.82	0.63	0.35	0.63	1.30	2.25	0.35	0.16	0.50	27.48	21.90	4.21
30.01.16	150.4	80.9	1.33	1.30	3.09	1.62	3.81	1.78	2.37	5.55	1.24	0.67	0.68	1.59	1.82	0.77	0.40	0.54	30.98	15.33	2.08

LIST OF PUBLICATIONS

- Seasonal and Spatial Variation of Particulate Aerosols and Carbonaceous Species in $PM_{2.5}$ in the Periphery of Chandigarh, India. MAPAN (2018), DOI: https://doi.org/10.1007/s12647-018-0280-6 **(Copy Enclosed).**

- Source apportionment of $PM_{2.5}$ bound Polycyclic Aromatic Hydrocarbons from a Tri-city in the foothills of Himalayas in Northern India. International J. of Engineering & Applied Sciences, International Journal of Engineering and Applied Sciences, Volume-5, Issue-8, pp-20-25, August 2018 **(Copy Enclosed).**

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ORIGINAL PAPER

Seasonal and Spatial Variation of Particulate Aerosols and Carbonaceous Species in $PM_{2.5}$ in the Periphery of Chandigarh, India

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Abstract: Present study highlights the seasonal and spatial variation of particulate aerosols (PM_{10} and $PM_{2.5}$) and carbonaceous species (organic tarry matter, organic and elemental carbon) in $PM_{2.5}$. The ambient air samples for particulate aerosols were collected from tricity of Chandigarh, Mohali and Panchkula in India during summer (April'15–May'15) and winter (December'15–January'16). The mass levels of particulate aerosols and carbonaceous species show significant variation both seasonally and spatially. Average mass levels reported as higher in winter than summer were attributed to stagnant atmospheric and poor dispersion conditions. The mass levels were also found to be higher in industrial area as compared to residential and commercial areas. Average mass levels varying from 107.6 to 137.8 $\mu g\ m^{-3}$ for PM_{10} and 46.6–59.5 $\mu g\ m^{-3}$ for $PM_{2.5}$ during the study period indicate alarming situation of particulate aerosols in this tricity. Carbonaceous species contributing as 42.5–47.5% OTM, 25.4–29.9% OC and 3.4–4.7% EC in $PM_{2.5}$ indicate larger in fraction at all sites during both summer and winter.

Keywords: Elemental carbon; Fine particulate matter; Organic carbon; Organic tarry matter; Seasonal and temporal variation

1. Introduction

Air pollution is critical and serious health issue in urban areas. Various studies have highlighted the significance of airborne particulate matter (PM) for human health and environment depending on the particle size and their surface area [1–3]. PM is classified into respirable (PM_{10}), fine ($PM_{2.5}$) and ultrafine (PM_1) fractions. Epidemiological studies suggest that fine particles exert more adverse health effects than coarse particles in addition to its chemical composition and mass concentration [4–7]. The fine fraction ($PM_{2.5}$) generally contributes to respirable fraction (PM_{10}) as 55–64% in Patiala, India [8] and 0.62–0.68% in Wuhan, Central China [9]. Airborne particulate matter (PM_{10}/$PM_{2.5}$) shows seasonal variability as higher in winter season (cold conditions) and spatial variability as higher at industrial locations than others observed in Patiala [8], Agra [10], Udaipur [11] in India, Wuhan [9], Nanjing [12], north to south region [13] in china and Riyadh and Wuhan [14] in Saudi Arabia. These variations are associated to meteorology, source type and emission strength and atmospheric chemistry [15–17].

The fine particles ($PM_{2.5}$) contain anthropogenic and secondary aerosols from combustion process, re-condensation and gas to particle conversions [18–20]. Organic tarry matter (OTM) as the major part of primary carbonaceous matter in airborne particles comprises of polycyclic aromatic hydrocarbons, aliphatic hydrocarbons, alkanols and fatty acids. The particulate phase of carbonaceous matter generally classified as organic carbon (OC) and elemental (black or soot) carbon (EC) and play significant role inhuman health and atmospheric chemistry [21]. EC released directly from incomplete combustion of carbon-contained materials (coal, diesel, gasoline and biomass) whereas, OC can either be released directly from

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*Corresponding author, E-mail: consulteco@yahoo.com combustion sources (fossil fuels, vehicular exhaust, biomass burning and cooking) or formed through atmospheric reactions. Particulate matter comprising of OC and EC act as the agent of global warming and ultimately affect global climate [22]. Organic compounds such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dioxins and furans (PCDD/Fs) are mutagenic and/or carcinogenic. Keeping in the view of limited research work in Chandigarh region, present study attempts to obtain quality and quantitative information on carbonaceous and $PM_{2.5}$ aerosols.

2. Materials and Methods

2.1. Sampling Site

The metropolitan region of Chandigarh Tricity includes Chandigarh–Mohali–Panchkula with over 2 million of population. Chandigarh is a union territory of India and serves as the combined capital of both states of Punjab and Haryana. Mohali and Panchkula are district head quarters of Punjab and Haryana states, respectively. Chandigarh is located in the foothills of Sivalik range of Himalayas and 162 miles (260 km) north of New Delhi, the national capital of India. The climate of Chandigarh is humid subtropical with varying temperature (− 1 to 46 °C) and the annual average rainfall of 1110 mm.

Ambient air samples for particulate aerosols were collected from four location namely Sector 12 (Chandigarh), Sector 34 (Chandigarh), Sector 74 (Mohali) and Sector 12A (Panchkula) as per details shown in Table 1. One station (Sector 12, Chandigarh) is proposed in north-west in a green belt beyond Sarangpur in Chandigarh as background station. The prominent wind direction in the study area is north-west and thus the station in this direction shall have least impacts from the anthropogenic and urban activities of this tricity. Furthermore, there is little habitation in this location with the presence of Shiwalik hills in the background (Fig. 1). Sector 74 (Mohali) represents the industrial area comprising engineering, electrical, electronics, pharmaceuticals, IT, hospitals and healthcare, office automation and stationery type of industries. Sector 34 (Chandigarh) is a commercial cum residential are in the downwind direction of city. Sector 12A (Panchkula) is purely a residential area. Among these three cities, Chandigarh city has the highest vehicle to population ratio. The sampling stations were selected at two story buildings at suitable heights of 3–10 m from ground level as per guidelines of IS: 5182 (Part 14) 2000 and CPCB.

Table 1 Details of sampling locations in the study area

Sampling Location	Site description	Location Code	Location coordinates
Sector 12 (Chandigarh)	Background station (Institute)	Site ST0	N 30°42.997′; E 76°45.856′
Sector 34 (Chandigarh)	Residential and commercial area	Site ST1	N 30°42.986′; E 76°45.884′
Sector 74 (Mohali)	Industrial area	Site ST2	N 30°42.617′; E 76°41.326′
Sector 12A (Panchkula)	Residential area	Site ST3	N 30°41.071′; E 76°51.136′

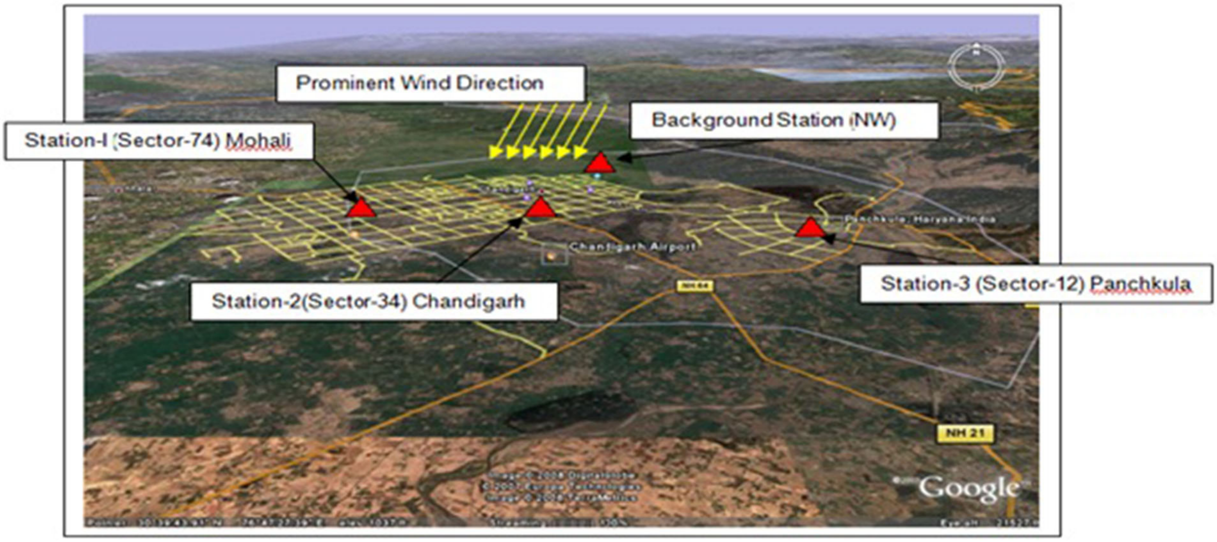

Fig. 1 Location map of the study area

2.2. Sampling of PM_{10} and $PM_{2.5}$

Air particulate samples for PM_{10} were collected on Whatman glass fiber filters using respirable dust sampler (APM460, Envirotech) whereas samples for $PM_{2.5}$ were collected on Whatman Quartz filter papers (47 mm diameter) using fine particulate sampler (APM550, Envirotech). During sampling a laminar flow was maintained as 16.7 L min^{-1} (1.0 m^3 h^{-1}) for $PM_{2.5}$ and 1.13 m^3 min^{-1} for PM_{10}. The air sampling was done on 24 hourly basis with the frequency of twice a week during summer (April'15–May'15) and winter (December'15–January'16) at four locations. The monsoon season was not considered as the associated mass levels of $PM_{2.5}$ in very low range could not serve the purpose of meaningful analysis of organic tarry matter. Total of 128 samples (32 × 4) each for $PM_{2.5}$ and PM_{10} were collected from four sampling locations with the sampling frequency of twice a week for 2 months in summer and 2 months in winter season.

To assess the influence of origin, dispersion and migration of particulate aerosols, wind data for the period of April 2015 to March 2016 were used. The meteorological data were obtained from Eco Laboratories (a continuous weather station) located nearby our sampling location in Sector 74, Industrial area, Mohali. The data were interpreted and incorporated in the form of wind rose diagram as shown in Fig. 2.

2.3. Determination of PM Concentration

Sampled filters (total 128 each for $PM_{2.5}$ and PM_{10}) were kept in vacuum desiccators in environment controlled room (temperature 25 ± 5 °C and relative humidity 45 ± 5%) for a period of 24 h before and after the sampling for dryness. After sampling, each of loaded filters were wrapped in aluminium foil for transportation and kept in refrigerator at 4 °C inside sealed plastic bags until laboratory analysis. Mass levels were calculated gravimetrically by dividing weight difference with volume of air sampled.

2.4. Analysis of Organic Tarry Matter (OTM)

Soxhlet extraction using benzene was applied as customized procedure to determine organic tarry matter based on various used practices. All sampled filter papers for $PM_{2.5}$ were extracted in 150 mL benzene (Merck) sequentially for 8 h. The steam bath treatment reduced the

Fig. 2 Wind rose of the study area

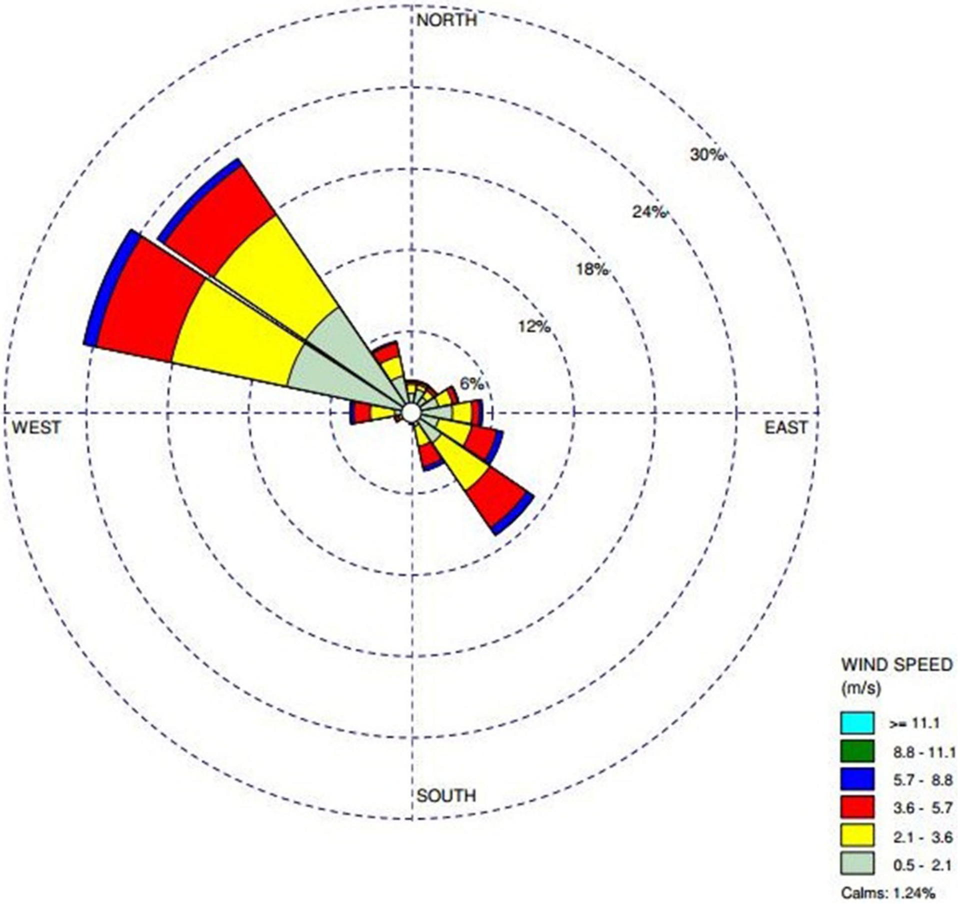

Table 2 Results of reference material (SRM 8785) in percentage for OC and EC analysis

	Obtained values		Reference values (SRM 8785)	
	Average	Standard deviation	Average	Standard deviation
Organic carbon (%)	0.106	0.047	0.111	0.085
Elemental carbon (%)	0.108	0.023	0.110	0.034
Total carbon (%)	0.214	0.026	0.221	0.029

solvent to 5 mL. The resulting extract filtered using Whatman filter and transferred into amber vials (chromatographic). After drying at room temperature, weight was determined using microbalance (précised to 0.1 µg).

2.5. Analysis of OC and EC

All sampled filters for $PM_{2.5}$ were analyzed by NIOSH method using OC/EC aerosol analyzer (Sunset Laboratory Inc.) as per the instrumental details provided elsewhere [23, 24]. A standard sized (1.5 sq cm) punch of filter sample was placed in a quartz oven purged with helium. Oven temperature rose to 870 °C by thermally desorbing organic compounds and pyrolysis to manganese dioxide. Carbon fragments flowing through manganese dioxide oven finally converted to CO_2 gas. CO_2 swept out by helium stream and hydrogen gas. This mixture was converted to methane gas when passed through the heated catalyst of nickel. The resulting methane gas was determined by flame ionization detector. After cooling temperature to 550 °C and switching the flow stream to helium/oxygen mixture, the second ramp in temperature was initiated. EC then oxidized off the filter and determined the same as OC.

2.6. Quality Assurance/Control (QA/QC) in Carbonaceous Analysis

The accuracy for analytical results was periodically checked using standard reference materials (SRMs). Methane as internal standard was used to check the accuracy of carbon results [25]. The minimum detection limits of OC/EC analyzer were observed as 1.01 µg m^{-3} for OC and 0.21 µg m^{-3} for EC with the maximum analytical error of 15% [26]. The measured concentrations were reported after correction of field blanks. Uncertainty was calculated by fixed fraction of method detection limit (MDL) as (5/6)xMDL in case the analytic concentration was $\leq$ MDL and as under root (Error Fraction + concentration)2 + (0.05MDL)2 in case the analytic concentration was > MDL [27].

NIST 8785 as SRM 1649 was also used to determine the analytical accuracy of OC and EC as 15 and 10%, respectively [28]. Total five replicates of this SRM were analyzed as the results depicted in Table 2. As per *t* test performed for medians comparison, no significant difference was observed between reference and obtained results at 95% confidence level.

3. Results and Discussion

3.1. Mass Levels of Particulate Aerosols

The mass values of PM_{10} and $PM_{2.5}$ observed at Sector 12 Chandigarh (ST_0), Sector 34 Chandigarh (ST_1), Sector 74 Mohali (ST_2), and Sector 12A Panchkula (ST_3) are presented in Figs. 2 and 3, respectively. The mass concentration of PM_{10} varied from 77.9 to 155.1 µg m^{-3} (average 107.6 µg m^{-3}) at ST0, 81.9–168.3 µg m^{-3} (average 128.4 µg m^{-3}) at ST1, 94.2–206.4 µg m^{-3} (average 137.8 µg m^{-3}) at ST2 and 75.2–154.9 µg m^{-3} (average 108.4 µg m^{-3}) at ST3.

The mass concentration of $PM_{2.5}$ varied from 31.1 to 60.9 µg m^{-3} (average 46.6 µg m^{-3}) at ST0, 32.1–72.7 µg m^{-3} (average 55.6 µg m^{-3}) at ST1, 36.9–91.3 µg m^{-3} (average 59.5 µg m^{-3}) at ST2 and 33.5–65.5 µg m^{-3} (average 48.7 µg m^{-3}) at ST3. As illustrated in Table 3, out of total 32 sampling days, PM_{10} exceeds to NAAQ standard of 100 µg m^{-3}at all four locations. $PM_{2.5}$ exceeds to NAAQ standard of 60 µg m^{-3}during almost half of sampling days at ST1, ST2 and ST3. The results clearly indicate that the airborne PM is a critical air pollutant which does not only deteriorate air quality but also cause serious health impacts. Literature studies also indicate that increase in PM_{10} by 10 µg/m^3 leads to daily mortality of 0.2–0.6% [29] and increase in $PM_{2.5}$ by 10 µg/m^3 leads to a long tern risk of cardiopulmonary mortality of 6–13% [30–32].

The higher mass concentrations of particulate aerosols in the study period may be attributed to various sources such as combustion of fossil fuels in stationary/mobile sources, trans-boundary migrations and crop residue burning after rice and wheat harvesting periods in the region, which are in agreement with previous studies [33, 34]. Further, a study reported PM_{10} & $PM_{2.5}$ respectively, 97 and 57 µg m^{-3} as back ground levels and up to 51–66 and 43–78% as increased levels during the events of

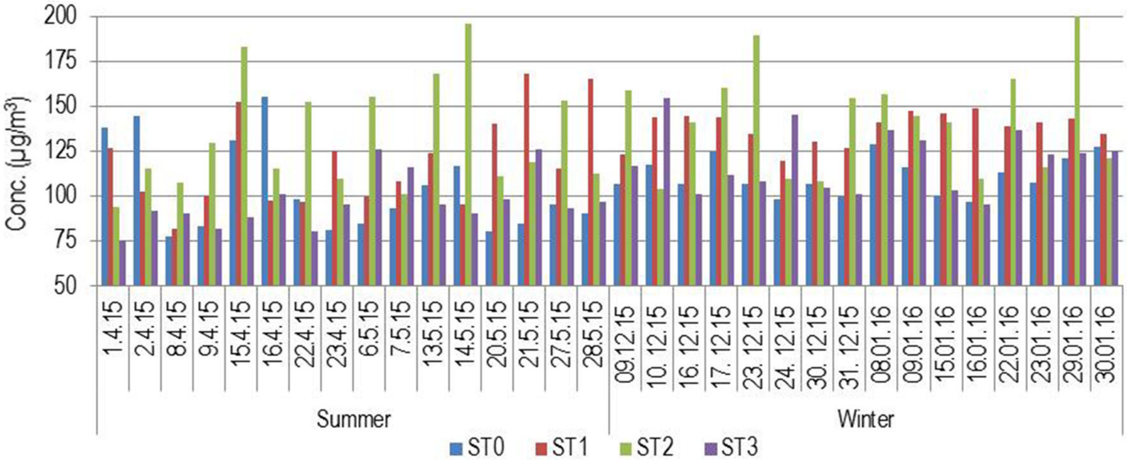

Fig. 3 Mass concentrations of PM_{10} at the study area

Table 3 Percent of days during PM exceeding to NAAQ limits

Location	Percent of days (PM exceeding NAAQ limits)	
	PM_{10}	$PM_{2.5}$
Chandigarh Sector 12 (ST_0)	59	3
Chandigarh Sector 34 (ST_1)	84	44
Mohali Sector 74 (ST_2)	97	44
Panchkula Sector 12A (ST_3)	59	19

crop residue burning in rural area of Patiala [8]. Another study reported mass concentration of PM_{10} and $PM_{2.5}$ as 71–167 and 43–107 µg m^{-3} respectively, during crop residue burning periods at three urban locations at Amritsar, Ludhiana and Mandi Govindgarh in Punjab [35].

3.2. Spatial Variation in PM

The mass values of PM_{10} and $PM_{2.5}$ varied as $ST_2 > ST_1 > ST_3 > ST_0$. Highest concentrations were observed at ST_2 Sector 74 (Mohali). This is an industrial area comprising engineering, electrical, electronics, pharmaceuticals, IT, hospitals and healthcare, office automation and stationery type of industries. Road dust, diesel generators, heavy vehicles, boilers running on wood, rice husk and coal contribute to highest mass of PM at this site. ST_1 Sector 34 (Chandigarh) representing commercial cum residential site with high traffic density. These two sites are also located in downwind of the city experiencing high pollution load as evident in location map (Fig. 1) and wind rose of study (Fig. 2). ST_3 Sector 12A (Panchkula) is a residential site and located in crosswind direction, hence experiences less pollution than industrial site. ST_0 Sector 12, (Chandigarh) is located in green belt region in north-west (upwind) of tricity with little habitation and presence of Shiwalik hills in background. Hence the site has least impacts from the anthropogenic activities of tricity as justified by location map and wind rose diagram.

3.3. Spatial Variation in OTM, OC and EC

OTM among the largest in composition contributes 42.8–47.5% (w/w) to $PM_{2.5}$ during the study period at all the sites. The mass levels of OTM varied from 12.9 to 30.9 µg m^{-3} (average 22.0 µg m^{-3}) at ST0, 15.9–38.6 µg m^{-3} (average 24.2 µg m^{-3}) at ST1, 16.7–36.6 µg m^{-3} (average 25.5 µg m^{-3}) at ST2 and 12.7–36.7 µg m^{-3} (average 23.1 µg m^{-3}) at ST3 (Fig. 4). Results indicate that OTM content depends on aerosols concentrations in the study area during monitoring periods. OC and EC also varied in same manner and contribute nearly half of OTM mass. Like $PM_{2.5}$ concentrations, average concentrations of OTM were also highest at ST_2 followed by ST_1, $ST_3$and ST_0, respectively. Highest mass concentrations at ST_2 (industrial area) may be associated to diesel generators, heavy vehicles, boilers running on wood, rice husk and coal and construction activities in the area. ST_1 representing commercial cum residential site and ST_3 as residential site experiences less pollution than industrial site. ST_0 located in green belt region in north-west of tricity with little habitation and presence of Shiwalik hills in background experiences least pollution in the region.

3.4. Seasonal Variation

Particulate aerosols show seasonal variation due meteorological conditions, type of source, strength of emission and atmospheric chemistry [6, 15–17, 36]. As illustrated in Figs. 3, 4 and 5, the mass concentration of particulate matter (PM_{10} and $PM_{2.5}$) and carbonic species are higher in winter when compared to summer at all the sites. The

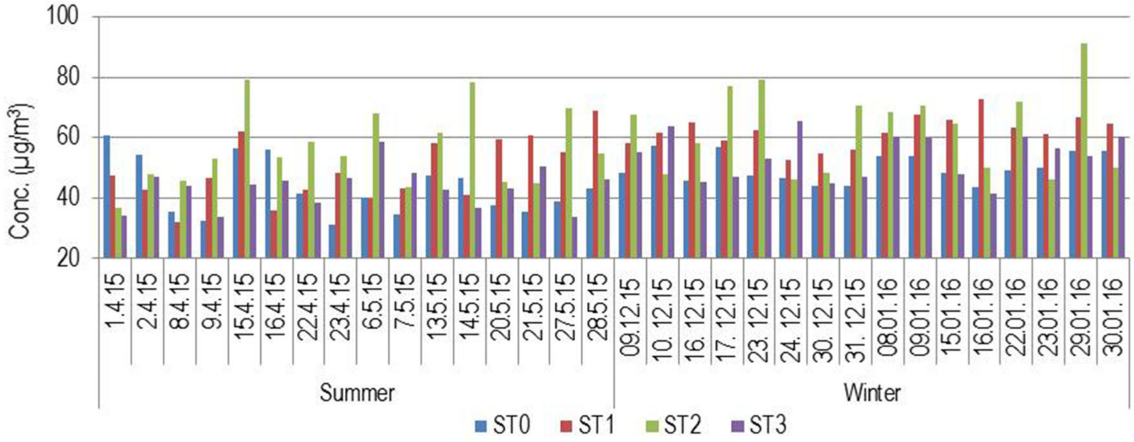

Fig. 4 Mass concentrations of $PM_{2.5}$ at the study area

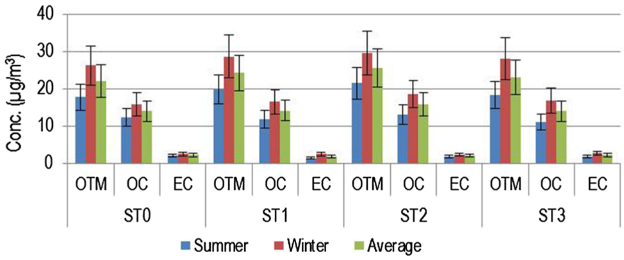

Fig. 5 Mass concentrations of carbonaceous species in $PM_{2.5}$ at the study area

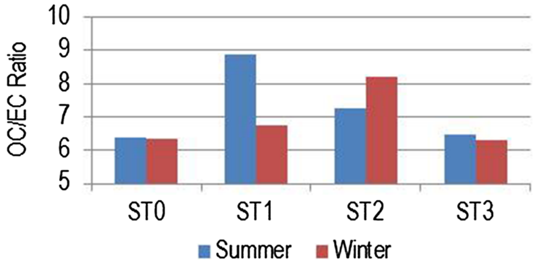

Fig. 6 Ratio of OC/EC in $PM_{2.5}$ mass at the study area

highest mass concentrations during winter can be attributed to enhanced human activities such as burning of coal and bio fuels for domestic and commercial cooking and space heating plus higher exhaust emissions from automobiles and engine sets due to cold start in cold conditions [37, 38]. In winters, stagnant atmosphere, temperature inversions, low mixing height and calm conditions are conducive for the accumulation of particulate matter [39, 40]. Apart from the above, crop stubble burning after rice harvesting period (October–November) is usually more pronounced than wheat harvesting period (March–April) [8, 34]. Various studies have reported the similar trend in Patiala [8], Agra [10], Udaipur [11] in India, Wuhan [9], Nanjing [12], north to south region [13], Jinan [41], Beijing, Shijiazhuang, Tianjin, Shangdianzi and Chengde [42] in china and Riyadh [14] in Saudi Arabia.

3.5. OC/EC Ratio

As illustrated in Fig. 6, the seasonal average OC/EC ratio indicates higher mass of OC than EC in the study area in the order of ST2 (industrial site) followed by ST1 Commercial area, residential and background sites. This might be related to the heavy vehicular and industrial activities at ST2 and ST1. Presence of organic-related factories in this area can emit considerable organic pollutants during operation. Emissions from nearby ongoing construction activities may be another factor. The obtained ratio of OTM/OC ranging from 1.57 to 1.71 was similar to the findings in Agra, India [25].

4. Conclusion

Particulate aerosols (PM_{10} and $PM_{2.5}$) were collected from tricity of Chandigarh, Panchkula and Mohali during April to May 2015 (summer) and December 2015 to January 2016 (winter). Daily 24 h average mass values of PM_{10} and $PM_{2.5}$ considerably higher than NAAQ standards indicate deteriorating air quality in this tricity. OTM contributes 42.8–47.5% (w/w) in $PM_{2.5}$ whereas ratio of OTM/OC ranges from 1.57 to 1.71 indicating carbon as the largest component.PM as well as carbonic species showed seasonal and temporal variations. The high mass loading in winter attributed to enhanced domestic and commercial activities and poor dispersion conditions. The results of present study can be utilized to evaluate existing air quality and to devise more efficient emission reduction strategies. A comprehensive physico-chemical analysis and source apportionment is required to understand the type and strength of emission sources and to device and establish suitable control measures for air pollution.

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Source apportionment of $PM_{2.5}$ bound Polycyclic Aromatic Hydrocarbons from a Tricity in the foothills of Himalayas in Northern India

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***Abstract*— This study highlights variability in mass levels and source identification of $PM_{2.5}$ bound polycyclic aromatic hydrocarbons (PAHs) in the tricity of Chandigarh, Mohali and Panchkula in India. The samples of $PM_{2.5}$ were collected from industrial and residential and sensitive receptor sites during summer (April-May 2015) and winter (December 2015-January 2016) season. Sampling was done using medium volume sampler and chemical analysis was done using gas-chromatography technique. The average mass levels of $PM_{2.5}$ varied from 31 to 91 µg m^{-3} exceeding to NAAQ standard of 60µg m^{-3} and total PAHs varied from 5.76 to 75.62 ngm^{-3} with a seasonal variability as higher in winter than in summer season. The positive correlation between $PM_{2.5}$ & TPAHs suggested similarity in source and origin. Diagnostic ratio and principal components analysis suggested vehicular emissions, coal combustion, wood and biomass burning as the main source of PAHs in the study area for potential health hazards.**

***Index Terms*— Source identification, polycyclic aromatic hydrocarbons, Diagnostic ratio, Principal components analysis, Seasonal variability, Health hazards**

I. INTRODUCTION

Airborne PAHs have been considered as major cause of adverse health impacts due to their carcinogenic (causing cancer) and mutagenic nature [1]. These are complex organic compounds which have at least two benzene rings in their structure having carbon – hydrogen bond between them [2]. They originate mainly from anthropogenic activities, such as incomplete combustion of coal, petroleum products, and biomass (pyrogenic sources) [3-4]. In the urban areas due to high vehicular density and low dispersion conditions, the mass concentration of atmospheric PAHs is generally very high [5]. Emissions from vehicular exhaust contain most of the PAHs classified as carcinogens [6].

United States Environmental Protection Agency has included a total of sixteen PAHs in the list of 188 Hazardous Air Pollutants [2].

The classification of PAHs can be performed on the basis of their molecular weights as less than or equal to four aromatic rings called as LMW and four or more aromatic rings as HMW PAHs [7]. PAHs of HMW are dominant over LMW. Various studies have showed LMW PAHs are considered as the products of wood, biomass and oil combustion [8-9] whereas HMW PAHs are associated with coal combustion and vehicular emissions [8], [10]. Therefore, source identification can be done by using ratios between PAHs of LMW and HMW. Sources are considered for the ratio <1 as pyrolytic sources, while the ratios>1as petrogenic sources [11]. Based on global atmospheric emission inventory of 16PAHs for the year 2004, India ranks 2nd with emissions of 90 Gg/year and also has higher proportion (3.6%) of hazardous high molecular weight (HMW) PAHs emissions than global average [12]. The PAHs show higher correlation with $PM_{2.5}$ than PM_{10} [13] and HMW fraction dominant over LMW [14].

As per literature, studies on airbone PAHs are reported through wordwide but limited to few cities of Delhi [15, 16], Mumbai [17], Ahmedabad [18] and Visakhapatnam [19] in India. No such study is evident in northern India particular to Chandigarh region. The present study focuses on the qualitative and quantitative data analysis and source identification of $PM_{2.5}$ bound PAHs from a tricity of Chandigarh, Mohali and Panchkula region of Northern India.

II. MATERIAL AND METHODS

A. Sampling Site

The metropolitan region of Chandigarh Tricity includes Chandigarh-Mohali-Panchkula with over 2 million of population. Chandigarh is a union territory of India and serves as the combined capital of both states of Punjab and Haryana. Mohali and Panchkula are district head quarters of Punjab and Haryana states, respectively. Chandigarh is located in the foothills of Sivalik range of Himalayas and 162 miles (260 km) north of New Delhi, the national capital of India. The climate of Chandigarh is humid subtropical with varying temperature (−1 to 46 °C) and the annual average rainfall of 1110mm.

Ambient air samples for $PM_{2.5}$ were collected at four sites, namely Sector 12 (Chandigarh), Sector 34 (Chandigarh), Sector 74 (Mohali) and Sector 12 A (Panchkula) (Fig.1). The location of Sector 12 (Chandigarh) is located in north-west of Chandigarh city in a green belt area. In the study area, NW is the prominent wind direction thus this station shall have least impacts from the anthropogenic and urban activities of this tricity. Furthermore, there is little habitation in this location with the presence of Shiwalik hills in the background. Sector 74 (Mohali) represents an industrial area comprising of various type of industries as engineering works, electrical/electronics, stationery, IT, pharmaceuticals and healthcare. Sector 34 (Chandigarh) represents a mix type of commercial cum residential areas in the downwind direction of city whereas Sector 12A (Panchkula) is purely a residential area. Among these three cities, Chandigarh city has the highest vehicle to population ratio.

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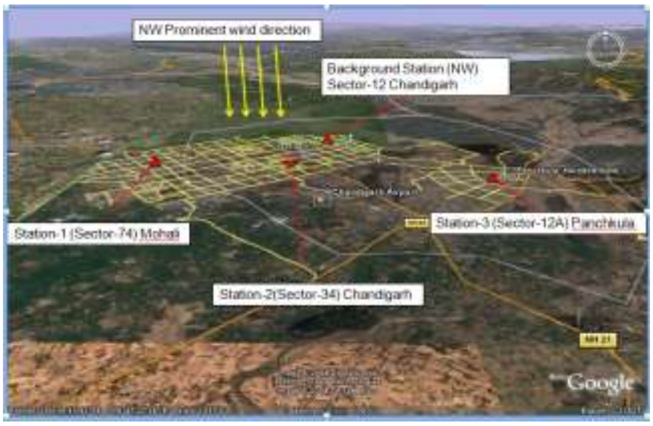

Figure 1: Location map of the study area

B. Sampling Procedure

The sampling was carried out as per CPCB guidelines (NAAQS) for 24h twice in a week over the summer season (April-May 2015) and winter season (December 2015-January 2016) for one year. The stations were located at suitable height >3m as per IS: 5182 (P-14) 2000. The laminar flow rate of the ambient air was 16.7 L/min ($1m^3$/hr). Quartz filter paper having 47 mm diameter was used for sampling of $PM_{2.5}$. For removal of moisture content in the sample paper, it is mandatory to keep it in vacuum desiccators for 24 hour before and after the sampling. The monitoring and analysis was undertaken as per in NAAQS Monitoring and Analysis Guidelines Volume-1 (Guidelines for determination of $PM_{2.5}$ in ambient air). A total of sixteen samples of $PM_{2.5}$ were collected from each site using fine particulate sampler (Envirotech APM 550). After sampling to the extraction of PAHs, the filter papers were wrapped in aluminum foil and kept refrigerated (4°C) inside sealed plastic bags.

C. Analysis Procedure

A total of 64 samples of $PM_{2.5}$ (sixteen from each location) were analyzed using standard method of IS: 5182 Part 12: 2004 (Methods for Measurement of Air Pollution-Polynuclear Aromatic Hydrocarbons in Air Particulate Matter). Each $PM_{2.5}$ filter paper was extracted in 100ml toluene into a 200ml Erlenmeyer flask. The solution was ultra sonicated (Citizon Ultrasonic Processor) for 30 min at 20 Hz. The extract was filtered with the help of Whatman filter paper No. 41 (20) in the evaporated flask of 250 ml. The extraction was repeated twice and the extracts were combined. Rotary evaporator with temperature not exceeding 40°C was used for the evaporation of toluene extract until its volume was reduced to 1-2 ml. Added 2.0 ml of toluene to rinse the wall of evaporation flask and transfer the extract in to a beaker of 5 ml capacity. To clean up the impurities, silica gel column (length 200mm, and inner diameter 0.5 cm) was used. 3g slurry in cyclohexane of deactivated silica gel (60-120 mesh size) was taken and poured into the column. Toluene was eluted by cyclohexane through the column for conditioning. The sample extract was passed through the silica column and the resulting PAH fraction was collected within 5ml of cyclohexane. Finaly 30ml of cyclohexane was added to the column to elute all organics of interest. The PAH fraction was collected in to the flask (reduced to about 1ml) and transferred in to 5ml capacity vials (stored in a dark and cool place).

The identification of PAHs was carried out using Gas Chromatography (Agilent) consisting of a capillary column (DB-5), 25m x 0.2 mm inner diameter (ID) and flame ionization detectors (FID) in a split less mode. The injection and detector temperatures were 320°C. The carrier gas was N_2 @ 30ml/min. The calibration of GC was performed by known standard of Dr. Ehrenstorfer GmbH containing 14 analytes in acetonitrile. Three levels of concentrations were made from the original mixture. The peaks were identified on the basis of retention times and the amount of analyte was calculated.

HPLC grade solvents were used in the analysis. Total of sixteen PAHs were investigated, i.e., Acenaphthylene, Anthracene, Benzo(a) Anthracene, Benzo(a)pyrene, Benzo(b)fluroanthene, Benzo(ghi)perylene, Benzo(K)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluroanthene, Fluorene, Indeno(1,2,3-c,d) pyrene, Naphthalene, Perylene, Pyrene and Retene

D. Quality assurance in analysis

The accuracy for analysis was periodically checked using standard reference materials (SRMs). All sampled filter papers were stored at 4°C temperature after sampling. PAHs concentrations were calculated using retention times and peak areas of samples and standards. Blanks samples were also used for the accuracy of analysis. The detection limit of GC was determined using serial dilution of standard in a range of 0.008 to 0.020 ng/ml.

E. Principal components analysis using positive matrix factorization

PCA or PMF as a useful tool for source apportionment of PAHs was applied to multivariate data analysis [44], [47]. A number of data is reduced to small independent variables and each extracted factor corresponds to the specific source of PAHs. The factor loadings were carried out using SPSS after the varimax rotation to obtained correlation between factors and variables. Data with eigenvalue >1 for the factor were included in the matrix.

III. RESULTS AND DISCUSSION

A. Mass levels

As presented in figure 2, the mass levels of $PM_{2.5}$ varied from 31 to 91 µg m^{-3} exceeding NAAQ standard of 60µg m^{-3}. The results indicate $PM_{2.5}$ as critical and serious concern which is affecting the air quality of this tricity.

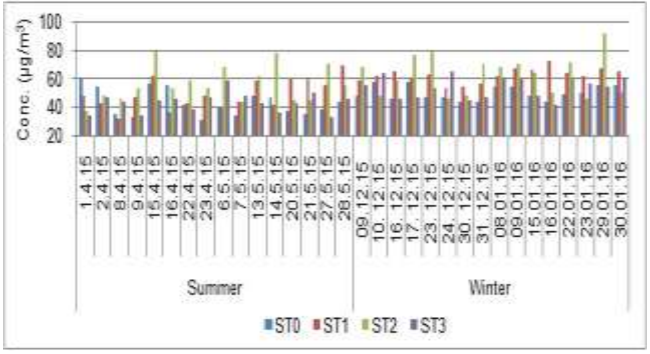

Figure 2: Mass levels of $PM_{2.5}$ in the study area

A total of sixteen PAHs named Acenaphthylene, Anthracene, Benzo(a) Anthracene, Benzo(a)pyrene, Benzo(b)fluroanthene, Benzo(ghi)perylene, Benzo(K)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluroanthene, Fluorene, Indeno(1,2,3-c,d) pyrene, Naphthalene, Perylene, Pyrene and Retene were determined in $PM_{2.5}$ samples. A statistical summary of the individual PAH is presented Table I

Table I: Mass levels of polycyclic aromatic hydrocarbons (ng/m^3) in the study area

PAH	Annual				Summer				Winter			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Acy	1.04	0.17	2.85	0.77	0.84	0.17	2.62	0.73	1.23	0.30	2.85	0.76
Ant	0.89	0.25	2.14	0.52	0.81	0.25	2.14	0.41	0.96	0.27	1.86	0.61
BaA	2.11	0.59	5.09	1.24	1.93	0.59	5.09	0.99	2.30	0.65	4.44	1.45
BaP	1.74	0.36	3.59	0.73	1.70	0.36	2.81	0.57	1.78	0.40	3.59	0.87
BbF	3.40	0.90	8.57	1.77	3.35	1.28	8.57	1.68	3.46	0.90	7.65	1.88
BghiP	2.25	0.32	7.95	1.69	1.81	0.32	4.36	1.57	2.70	1.17	7.95	1.70
BkF	2.62	0.55	6.08	1.24	2.31	0.55	4.84	1.34	2.93	1.65	6.08	1.06
Chry	4.41	0.65	15.78	3.58	4.25	0.65	13.30	3.42	4.56	0.68	15.78	3.77
dBahA	1.05	0.29	2.38	0.54	0.96	0.29	2.38	0.65	1.13	0.42	1.87	0.40
Fln	0.99	0.27	3.83	0.80	0.87	0.29	1.75	0.45	1.12	0.27	3.83	1.03
Flu	0.72	0.15	1.50	0.30	0.71	0.15	1.17	0.24	0.74	0.17	1.50	0.36
IP	1.66	0.34	2.98	0.64	1.57	0.34	2.98	0.85	1.74	1.20	2.38	0.29
Nap	1.62	0.43	4.08	0.84	1.56	0.90	3.49	0.64	1.68	0.43	4.08	1.01
Pery	1.57	0.26	6.55	1.51	1.49	0.42	6.55	1.55	1.65	0.26	4.35	1.48
Pyr	0.44	0.11	1.07	0.27	0.42	0.11	1.07	0.27	0.46	0.15	1.07	0.27
Ret	0.58	0.12	1.20	0.24	0.57	0.12	0.94	0.19	0.59	0.13	1.20	0.29
∑PAHs	27.09	5.76	75.62	16.68	25.16	6.78	64.06	15.55	29.03	9.06	70.47	17.21

The concentration of Total PAHs (∑PAHs) varied from 5.76 to 75.62 ngm^{-3} in the study area. Presence of LMW PAHs i.e. Flu and Ant indicates wood, grass and industrial oil combustion as a probable source [8], [19].

Table II: Comparison of mass levels and measurement techniques for polycyclic aromatic hydrocarbons [19].

Country	City	Extraction /Analysis	Mean/Range of TPAH (ng/m^3)	Samples collected	Site Description
India	Visakhapatnam	Acetonitrile-water/HPLC	57	PM_{10}	Industrial/Residential
India	Agra	DCM /GC-FID	40 - 2500	SPM	Industrial
India	Delhi	DCM /GC-MS	33.1- 81.5	PM_{10}	Roadside/ Residential
India	Tiruchirapalli	DCM: methanol/HPLC	232.7	$PM_{2.5}$	Residential
Hong kong	Kwun Tong	DCM / GC-FID	2- 269	PM_{10}	Industrial/Residential
Taiwan	Taichung	DCM /GC-MS	180.62	$PM_{2.5}$	Residential
Greece	Elefsina	Acetonitrile/HPLC	0.6- 38.3	PM_{10}	Industrial
Turkey	Zonguldak province	Hexane -acetone/HPLC	28	PM_{10}	Industrial
Present Study	Chanidigarh-Mohali-Panchkula	DCM / GC-FID	5.76 - 75.62	$PM_{2.5}$	Industrial, residential & Educational

The presence of HMW PAHs i.e. Fln, Pyr, Chry, BaA, BbF, BkF, BghiP, BaP, Pery, dBahA, and IP is mainly due to vehicular emissions [8], [10], industrial sources [20] and coal combustion [2], [8] ,[21] , [22].

B. Seasonal Variations

Particulate aerosols show a significant seasonal variability mainly associated to meteorological conditions, type and strength of source and atmospheric chemistry [23-27]. As illustrated in Figures, the mass concentration of PM2.5 and its associated PAHs are observed as higher in winter than summer [28-29]. The higher concentrations in winter may associated to increased coal and bio fuels burning plus higher exhaust emissions from automobiles and engine sets due to cold start [30-31]. Stagnant atmosphere and calm conditions in winters are conductive for the formation of particulate aerosols [32-33]. Crop stubble burning in October-November after rice harvesting and in March-April after wheat harvesting could be another reason [34].

C. Diagnostic Ratios

PAHs and other semi volatile organic compounds were used as tracers to identify diverse sources. Diagnostic ratios of PAHs can be used to categorize anthropogenic and biogenic sources of emission. Despite from these facts, ratios act as a fingerprint of emission sources and can be used to differentiate between various PAHs and their potency of having carcinogenic and mutagenic effects. The emission sources can determine by comparing the values of present study with the values given by various authors, who established possible ranges indicating the source of emission of various PAHs [19], [35], [36].

In this study, the diagnostic ratios were calculated for IP/(IP+BghiP), BaA/(BaA+Chy), BaA/BaP, BbF/BkF are presented in Table III. The ratio of IP/(IP+BghiP) as 0.42 under the range 0.37-0.70 and the ratio of BbF/BkF in the range 1.29-1.31 suggests the influence of diesel emissions [19], [37], [38]. The ratio of BaA/BaP as 1.21 indicates biomass burning [39] and the ratio of BaA/(BaA+Chy) as 0.32 (0.20-0.35) indicates coal combustion [40] in the study area. The diagnostic ratios performed in the study highlight the influence of multiple sources as vehicular emissions, coal and Biomass burning as the main source of PAHs in the study area.

Table III: Diagnostic ratio with source, range and reference studies

Diagnostic Ratios	Present Study	Range	Sources	Conclusion	References
IP/(IP+BghiP)	0.42	0.18-0.20 0.37-0.70 0.56 0.62	Gasoline Diesel Coal Wood	Oil Combustion	[19] [37]
BaA/BaP	1.21	0.90-1.70 0.5-0.70 1.0-1.5	Diesel Gasoline Wood	Wood Combustion	[39]
BaA/(BaA+Chy)	0.32	0.38-0.64 0.20-0.35	Diesel Coal	Coal Combustion	[40]
BbF/BkF	1.29	>0.5	Diesel	Diesel Combustion	[19],[38]

D. Principal component analysis (PCA)

PCA with varimax rotation was applied to determine the sources of PAHs in the study area of a tri-city.

Table IV: Source identification and factor analysis using PCA technique

PAH	Factor 1	Factor 2	Factor 3
Acy	**.941**	-.070	-.223
Ant	-.042	**.919**	-.199
BaA	-.042	**.919**	-.199
BaP	.392	.258	**.874**
BbF	.207	**.606**	-.078
BghiP	**.936**	.106	-.099
BkF	**.958**	.003	-.131
Chry	.402	**.477**	.403
dBahA	**.929**	-.113	-.157
Fln	**.862**	.098	-.132
Flu	.393	.256	**.875**
IP	**.854**	-.055	-.024
Nap	.135	**.900**	-.183
Pery	**.827**	-.200	-.332
Pyr	**.962**	-.088	-.189
Ret	.390	.259	**.875**
Eigenvalue	**7.31**	3.38	2.84
Variance (%)	45.70	21.14	17.76
Cumulative (%)	45.70	66.84	84.60
Source	Vehicular Emission	Coal Combustion	Wood & Biomass Burning

The first factor represents high loading of Acy, Ant, BghiP, BkF, dBahA, Fln, IP, Pery and Pyr with a total variance of 45.70%. Various studies have reported BghiP, BkF, dBahA and IP in vehicular emissions [2], [19], [41], [42] as BkF is the marker for diesel emissions [8], [43] whereas the Acy Pery and IP are the tracers of gasoline emissions [2], [29].

The second factor represents a total variance of 21.14%. The high loading of Ant, BaA, BbF, Chry and NaP indicates coal combustion as the source [19], [44], [45].

The third factor represents a total variance of 17.76%. The high loading of BaP, Flu and Ret indicates biomass and wood burning as the source [8], [19], [44], [45]. Various researchers have indicated the marker of biomass and or wood burning as Ret [46] BaP and Flu [41].

E. Evaluation of health risks

Among the PAHs studied, BaP is considered as the most powerful tool as reference chemical/ indicator for estimating the risk level imposed by all PAHs because of their well characterized toxicity. A toxic equivalency factor(TEF) also called as relative potency factor (RPF) was taken for each compound by multiplying the concentration of each compound with its corresponding TEF value given in table below and then summing up the results for BaP equivalent (BaP_{eq}). TEF or RPF from the EPA were taken into account as reference values in present study.

The mathematical expression for calculation of BaP equivalent (BaP_{eq}) is defined as $\sum Conc_n * TEF_n$

Where,

$Conc._n$= Concentration of Individual PAH

TEF_n= Toxic Equivalency factor

Table V: PAHs and their toxic equivalency factor

S. No.	PAH Compound	TEF- Toxic Equivalency factor
1	Acenaphthylene (Acy)	-----
2	Anthracene(Ant)	-----
3	Benzo(a)pyrene (BaP)	1
4	Benzo(a)anthracene (BaA)	0.1
5	Benzo(b)fluoranthene (BbF)	0.1
6	Benzo(k)fluoranthene (BkF)	0.01
7	Benzo(g.h,i)perylene (BghiP)	0.01
8	Chrysene (Chy)	0.001
9	Dibenzo(a,h)anthracene (dBahA)	0.1
10	Fluoranthene (Fln)	0.001
11	Fluorene (Flu)	-----
12	Indeno(1,2,3)pyrene (IP)	0.1
13	Napthalene (Nap)	-----
14	Pyrene (Pyr)	0.001
15	Perylene (Pery)	-----
16	Retene (Ret)	-----

In present study, the total Bap_{eq} concentration reported as 2.61 ng/m^3 was higher than BaP standard of 1 ng/m^3. The result indicates that PAHs can impose adverse impacts on human health in the study area.

IV. Conclusion

In present study, the average mass levels of $PM_{2.5}$ varied from 31 to 91 µg m^{-3} exceeding NAAQ standard of 60µg m^{-3} indicating alarming situation of air quality in the region. The average concentration of TPAHs varied from 5.76 to 75.62 ngm^{-3} during entire study period. The mass levels of $PM_{2.5}$ and total PAHs show seasonal variability as higher in winter than in summer season. The positive correlation between $PM_{2.5}$ & total PAHs suggested similarity in source and origin. PCA suggested vehicular emissions, coal combustion, wood and biomass burning as the main source of PAHs in the study area.

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