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REVIEW

Physico-Chemical Characteristics and Sources of Ambient Aerosol in India During 2001-2015: A Review

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From the last few decades, the studies related to source apportionment of airborne particulate matter (PM) have gain more attention among global scientific community including India. The outcomes from these studies are utilized for better and effective policy design to control pollution level. However, these source apportionment results have been shown much divergence for India due to differences in sampling technique, analytical methods, selection of source maker chemical species, and application of mathematical and statistical methods, *etc*. So, this review presents the trends and advancement of ambient $PM_{2.5}$ and PM_{10} particles source apportionment studies for special perspective of India for better understanding of these above highlighted issues. The ambient $PM_{2.5}$ and PM_{10} source investigations related earlier research articles and reports from various regulatory agencies which published between the years of 2000 to 2015 for India were selected and categorized into three plateau regions for review. Few studies were carried out with source apportionment centered objectives for ambient $PM_{2.5}$ and PM_{10} mass concentration and maximum reported studies were confined to address aerosol mass concentration and its chemical characterization to evaluate spatiotemporal variation. Higher number of data were reported for the Indo-Gangetic plain (IGP) region during the year of 2005 to 2007 with the annual average range from 56.2 to 136 μg m^{-3} and 134 to 306 μg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively. The annual average for ambient $PM_{2.5}$ and PM_{10} levels has been raised about 50 % and 14 %, respectively during the first fifteen years of 21st century in Indian environment. The carbonaceous matter (TC) has been found as the major component of PM mass in Indian environment. The carbonaceous matter was reported as major abundant species which was about > 50 % of $PM_{2.5}$ mass concentration with OC/EC ratio > 1. The distribution of different $PM_{2.5}$ chemical components were reported to be 7 ± 15 %, 1 ± 3 %, 46 ± 49 %, 34 ± 24 % and 12 ± 9%, for crustal elements (Al, Ca, Fe, Na, Mg, Si), trace elements (Cr, Zn, Ni, Cu, Cd and Pb), ionic (Na^+, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}) and carbonaceous matter fractions, respectively. The following six major contributing sources for ambient $PM_{2.5}$ pollution in India have been found during the assessment period *i.e*. road traffic emissions as the major contributor, followed by marine aerosols/sea salt, crustal, industrial emissions, secondary aerosols and biomass burning emissions.

Keywords: Particulate matter, Source apportionment, Elements, Spatiotemporal variation, India.

INTRODUCTION

Higher airborne particulate matter (PM) concentration is one of the key indicators of poor air quality in environment. According to the World Health Organization (WHO) ambient air pollution causes 72 % of outdoor air pollution-related premature deaths due to ischaemic heart disease and strokes, 14 % chronic obstructive pulmonary disease, and 14 % lung cancer [1]. Globally, three million premature deaths were estimated in 2012 by WHO among 88 % sharing from low and middle-income countries including India [1]. Particulate matter have shown strong association with adverse effects on susceptible biological receptors [2-7] and potential impact on local and global climate change [8-14]. Particulate matter affect both short term and long term, like coughing, wheezing, shortness of breath, heart impacts, including increased risk of heart attacks, decreased bronchitis, lung infection, aggravated asthma, and other respiratory illnesses and premature death in people with

heart or lung [15,16]. About 2-5 % increased health risk has been reported for 10 μg m^{-3} increase in the concentration of ambient PM [17,18]. Several comprehensive reviews have been conducted on the health effects of PM [19-21]. These health effects vary according to his physical and chemical properties of particulates [22,23]. For example, coarse inhalable particles (PM with aerodynamic diameter less than 10 μm) deposit in the upper respiratory tract while fine particles (PM with aerodynamic diameter less than 2.5 μm) travel deeper into the lungs and the smallest particles (less than 1 μm) can penetrate into the alveolar region.

The Central Pollution Control Board of Ministry of Environment and Forests (CPCB/MoEF) promulgates National Ambient Air Quality Standards (NAAQS) for particulate matter to address the air quality during last decade of 20th century and revised in the first decade of the 21st century. Primary PM standards are intended to mitigate adverse effects of particulate air pollution on public health [24,25]. In year 1994, NAAQS regulated SPM (suspended PM) and PM_{10} (particles with aerodynamic diameters less than 10 μm) with 24 h and annual average standards for SPM of 200 and 140.0 μg m^{-3} (residential areas) and PM_{10} of 100 and 60 μg m^{-3} (residential areas), respectively. Over the next 15 years, it was recognized that $PM_{2.5}$ along with PM_{10} was associated with short-term and long-term adverse health effects. In response, standards for $PM_{2.5}$ were enacted in year 2009. The 24 h and annual $PM_{2.5}$ standards were set at 60 and 40 μg m^{-3}, respectively. Standards have also been set for several specific components including lead, arsenic, nickel, benzene and benzo(*a*)pyrene but other individual chemical species associated with PM_{10}/$PM_{2.5}$ have not been included in NAAQS [24].

Some reviews [26-31] have also been conducted on this topic with different objectives and area of interest, but no one has explained the physico-chemical characteristics and spatio-temporal variation throughout the years from 2001 to 2015. The divergence on characteristics and concentrations of PM can be usually observed in previously reported literature for different Indian regions. It happens due to differences in several facts like (a) In India, few of analysis is conduct to village area and there is a gap in terms of national-level assessment of PM concentrations and composition analysis; (b) PM concentration influencing sources, geology, geography, seasonality, timely advancement in measurement and chemical characterization techniques, *etc*. So, it is very difficult to understand concentration trends and advancements on PM research for overall Indian environments; and also, important for future research directions and/or to design effective national level mitigation plan. This review was conducted to investigate the spatiotemporal variation of ambient $PM_{2.5}$ mass with its associated chemical component and relative source contributions in the different plateau of Indian peninsula during year 2001-2015.

Methodology: The Indian peninsula covers between latitudes 8º4′-37º6′ north, longitudes 68º7′-97º25′ east, separated from mainland Asia by the Himalayas with population of 1,210, 854,977 [32]. The country is surrounded by Bay of Bengal in the east, Indian Ocean to the south and Arabian Sea in the west. Due to the large variation in climatic conditions, demography and geographic details across the different locations of India, the whole country has been divided into three geographical regions namely: Indo-gangetic plateau (IGP), central peninsula plateau (CPP) and coastal plateau (CP) for the purpose of this review study (Fig. 1). Two additional regions, namely; the Himalayan region and Indian Thar desert were also included in IGP due to few reported publications on ambient $PM_{2.5}$ for these regions during the assessment period. Temporal variation in mass and chemical component and associated source apportionment results of ambient $PM_{2.5}$ have been addressed for whole Indian and as well as for three defined regions. Web of Science, Science Direct and Google scholar search engines, Journals of American Chemical Society and UGC-Inflbnet e-consortium portals were used, with *keywords*: ambient air, $PM_{2.5}$, fine particulates, Source Apportionment, India, to sketch the research publications on ambient $PM_{2.5}$ in Indian sub-continent, published during the period of 2001-2015. Apart from this, ambient $PM_{2.5}$ measurements from Indian regulatory body in different locations of India were recorded from the web portal of CPCB, Ministry of Environment, Forests and Climate Change, Government of India.

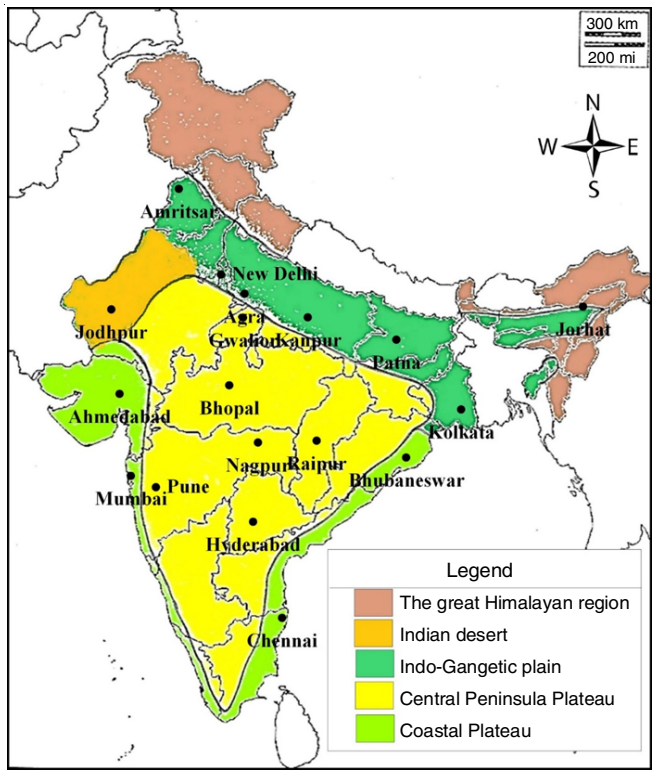

Fig. 1. Map showing the different geographical region in India

Due to lognormal distribution pattern associated to air pollution, geometric mean and standard deviations of $PM_{2.5}$ mass along with associated chemical component measured in different monitoring sites, located in a specific plateau, were used to determine associated temporal variation during the assessment period. Most of the reported measurement data for different locations of India were available during 2002 to 2013 and used to evaluate temporal variation during the assessment period. Comparison of year wise geomean values of mass measurements, reported for different locations of India in published research articles, CPCB and NAAQS report was also

investigated to address the differentiability between research outcomes and measurements by regulatory agencies in India and causes behind any possible variations (Fig. 2; Tables 1 and 2). For this evaluation, overall geomean of mass values, reported for different locations in published research papers for a specific year were used to compare with the overall geomean of reported annual averaged mass concentrations by CPCB for different locations for similar yearly period.

To address the spatiotemporal variation in chemical components of ambient $PM_{2.5}$, measured species were grouped in four different fractions, namely crustal (Al, Ca, Fe, Na, Mg, Si), trace elements (Cr, Zn, Ni, Cu, Cd, Pb), ions (Na^+, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}) and carbonaceous matter (OC, EC). Temporal variation in relative strengths of selected chemical fractions

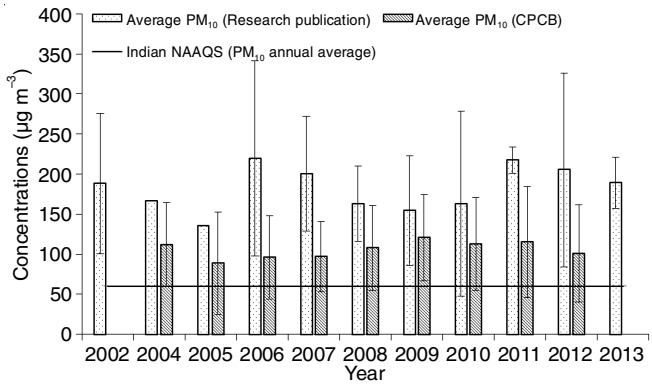

Fig. 2. Comparison of year wise average of reported PM_{10} levels in different research publications with those reported by regulatory body (CPCB) during the assessment period

TABLE-1
CPCB REPORT PM_{10} MASS CONCENTRATION (μg m^{-3}) OF DIFFERENT YEAR AND CITIES

State	Cites	(CPCB 2012)	(CPCB 2011b)	(CPCB 2010)	(CPCB 2009)	(CPCB 2008)	(CPCB 2007)	(CPCB 2006)	(CPCB 2005)	(CPCB 2004)
Andhra Pradesh	Hyderabad	67.95	74	81	80	87	77	77.19	72.61	67.53
	Visakhapatnam	60.97	80	69	97	87	95	99.68	91.25	87.43
	Vijayawada	96.98	90	98	80	91	85	86.32	84	-
Bihar	Patna	163.87	158	165	146	120	123	111.39	106.55	81.5
Chandigarh	Chandigarh	109.4	102	–	–	–	–	15.24	93.73	105.49
Chhattisgarh	Raipur	264.3	310	–	–	–	–	150.79	201.47	283.37
	Durg– Bhilainagar	97.1	104	–	–	–	–	121.53	131.72	126.59
Delhi	Delhi	234.73	222	259	243	198	159	151.43	96.82	146.81
Jharkhand	Jamshedpur	149.5	152	154	172	172	166	154	166.44	167.93
	Dhanbad	175.09	207	112	164	131	107	109	121	129
	Ranchi	202	165	–	–	–	–	–	95	138
Karnataka	Bangalore	108.92	91	94	122	90	63	68.47	64.98	71.03
Kerala	Kochi	68.46	38	36	40	40	46	65.86	58.9	59.22
	Kozhikode	55.48	46	–	–	–	–	32.31	67.5	56.48
	Thrissur	73	33	–	–	–	–	–	–	–
	Mallapuram	36	30	–	–	–	–	–	–	–
	Thiruvananthapuram	54.37	58	–	–	–	–	73.21	82.81	101.38
	Kollam	40.95	53	–	–	–	–	–	–	–
Madhya Pradesh	Indore	142.55	132	120	183	174	108	115.92	136.44	137.07
	Bhopal	169.13	170	116	115	93	84	64.01	57.03	54.61
	Jabalpur	75	73	107	136	136	107	81	82	69
	Gwalior	328.56	311	–	–	–	–	137.74	–	–
Maharashtra	Mumbai	118	116	94	109	132	92	82.8	81.55	77.52
	Pune	91.49	113	65	82	99	109	130.97	99.25	111.55
	Nagpur	99.27	108	86	99	98	99	73.37	67.75	68.61
	Nashik	95.23	96	79	89	80	45	82	101.97	80.27
	Aurangabad	79.09	83	–	–	–	–	66.05	–	–
Punjab	Ludhiana	226.47	221	229	254	251	201	244.71	234.85	246.63
	Amritsar	201.84	210	218	190	209	–	–	–	–
Rajasthan	Jaipur	178.79	139	171	151	112	98	121.1	–	119.29
	Jodhpur	184	168	–	–	–	–	127.11	107.61	110.13
	Kota	155.8	139	–	–	–	–	119.21	107.69	95.58
Tamil Nadu	Chennai	51.17	92	59	70	48	37	57.64	64.34	94.94
	Coimbatore	67.76	102	75	74	55	45	40.47	46.31	62.16
	Madurai	48.27	44	47	42	41	43	37.52	57.03	94.87
Uttar Pradesh	Kanpur	201.14	183	208	211	209	193	183.67	186.42	186.1
	Ghaziabad	247.48	231	163	154	139	–	250.97	337.68	156.92
	Agra	194.43	155	156	185	184	167	221.82	192	190.43
	Varanasi	137.99	127	–	125	106	114	106.77	102	111
	Meerut	129	123	170	118	115	120			
	Allahabad	315.58	258	218	160	128	159	–	–	–
	Lucknow	210.74	189	204	197	186	187	121.22	191.93	172.24
West Bengal	Kolkata	132.17	113	98	187	–	99	101.21	102.39	132.84
	Asansol	110.84	145	140	163	135	112	132	126	120
Gujrat	Ahmedabad	81.37	–	96	95	80	86	105.48	25.54	143.88
	Surat	96.58	–	77	91	81	87	123.58	25.91	123.38
	Vadodara	96.88	–	94	86	57	114	–	26.92	137.08
	Rajkot	96.55	–	97	105	89	76	104.49	17.66	220.00

TABLE-2
AMBIENT PARTICULATE FRACTIONS (PM_{10} AND $PM_{2.5}$) IN DIFFERENT LOCATIONS OF INDIA DURING THE PERIOD OF 2002-2015 (IGP-INDO-GANGETIC PLAIN, CP-COASTAL PLATEAU, CPP-CENTRAL PENINSULA PLATEAU)

Year	Geographical region	City	Average concentration (μg m^{-3})		Ref.
			$PM_{2.5}$	PM_{10}	
2002	IGP	New Delhi	–	260.4	[71]
	CP	Mumbai	–	136.3	[65]
2004	IGP	Kolkata	–	166.1	[70]
2005	CPP	Hyderabad	–	135.1	[33]
2006	IGP	Delhi	–	372.6	[65]
		Agra	71.7	133.8	[36]
	CPP	Raipur	–	211.37	[72]
2007	IGP	Agra	79.62	141.2	[36]
		North India	97	219	[73]
		Delhi	103	–	[65]
		Delhi	136	306	[62]
	CP	Ahmadabad	56	171	[34]
2008	IGP	Lucknow	101.05	204	[41]
		Agra	135.33	206.19	[36]
		Agra	–	155.47	[42]
		Kanpur	197.89	–	[59]
	CP	Mumbai	44.03	107.85	[35]
2009	IGP	Agra	140.29	222.99	[46]
		Agra	78.18	257.28	[47]
		Delhi	–	178.2	[44]
		Agra	72	113.8	[46]
		Delhi	76.75	–	[48]
	CPP	Rajnandgaon	–	108	[38]
		Raipur	185.9	–	[74]
2010	CPP	Nagpur	80.43	–	[51]
		Raipur	150.9	270.5	[75]
		Durg	135	–	[43]
		Durg	–	253.5	[40]
	CP	Tiruchirappalli	63.4	–	[39]
2011	IGP	Delhi	149.6	–	[76]
		Agra	108.54	236.47	[51]
		Delhi	123	208	[27]
		Udaipur	46.78	109.32	[51]
		Jabalpur	43.65	87.88	[51]
2012	IGP	Udaipur	53.72	127.24	[51]
		Jabalpur	45.31	107.14	[51]
		Lucknow	89.3	–	[77]
	CPP	Dhanbad Balko	–	354.6	[78]
		Bhilai	215	–	[55]
		Bhopal	79	–	[79]
		Pune	72.3	113.8	[50]
2013	IGP	Lucknow	97.3	–	[77]
		Delhi	118.3	232.1	[52]
		Delhi	186.25	–	[54]
		Delhi	117.6	191	[53]
	CPP	Dhanbad	–	155.04	[49]
	CP	Bhubaneswar	60.72	–	[54]
2015	IGP	Delhi	153	–	[80]
		Patana	149	–	[80]
		Kanpur	93	–	[80]
		Amritsar	92	–	[80]
		Agra	88	–	[80]
		Jodhpur,	75.88	253.4	[81]
	CPP	Gwalior	144	–	[80]
	CP	Ahmedabad	100	–	[80]

was evaluated for the period of 2007-2014 due to lack of available studies on chemical characterization of ambient $PM_{2.5}$ before 2007 in India.

Source apportionment studies has emerged as the major issue in significant numbers of reviewed papers, published during the assessment period, to address the source contributions to ambient $PM_{2.5}$. Different source apportionment techniques including receptor modeling [Effective Variance-Chemical Mass Balance (EV-CMB 8.2), Positive Matrix Factorization (PMF), UNMIX], factor analysis and simple mass balance approaches have been used to address source contribution estimates. Apart from this, different measurement techniques, sampler and analytical instrumentation and naming of specific sources were used in reported studies due to multi-complexity exist in type and location of specific source of $PM_{2.5}$. In the light of above facts, a qualitative comparison of reported relative source contribution to ambient $PM_{2.5}$ has been carried out by clubbing-up similar types of sources to a specific source category. Six major and common source categories of ambient $PM_{2.5}$ (biomass burning, crustal origin, road traffic emissions, industrial emissions, secondary aerosols and marine aerosols/sea salts) were identified (Table-3) and average values of reported contribution estimates (in percentage) from different sources, grouped in defined source categories, to ambient $PM_{2.5}$ during the assessment period (2001-2015) has been depicted in Fig. 3.

Spatiotemporal trend of ambient $PM_{2.5}$: Out of the 55 studies conducted across 24 cities in India, 62 % of the publications are related to IGP and 27 % and 10 % research articles are related to CPP and CP of India, respectively. As far as city based measurements are concerned, half of the studies are associated to Delhi (IGP), Agra (IGP) and Raipur cities (CPA). Geometric mean and geometric standard deviations of $PM_{2.5}$ values, described in studies grouped for different years (2001-2015), were plotted to address the associated average temporal variation in Indian ambient $PM_{2.5}$. Similar plots were also determined for three different plateau regions (Indo-Gangetic, Central peninsula plateau and coastal) to understand variability in PM concentrations across the country.

The percentage changes (increase or decrease) in mass during the assessment period (2001-2015) is evaluated using trend line, plotted in the associated graph of temporal variation (Fig. 4). The mass values (Y-axis), corresponding to right-end of trend line was subtracted from those corresponding to left-end of trend line on year 2001. The difference value was divided by mass value corresponding to left-end of trend line and resultant was multiplied by hundred to determine the percentage of increasing or decreasing throughout the assessment period. Results indicate a sharply increasing trend in average ambient $PM_{2.5}$ concentration between 2001 and 2015 in the Indian subcontinent (Fig. 5). About 50 % increment was observed for average ambient $PM_{2.5}$ concentration levels when comparing concentrations in 2001 and 2015 and for the same period, PM_{10} concentrations increased by 14 %. Average values of ambient $PM_{2.5}$ described in published research papers were compared with values reported by Indian regulatory agencies (CPCB and State Pollution Control Boards) to evaluate consistency in results. Concentrations reported in research studies were found to be consistently higher than those reported by regulatory agencies

TABLE-3
DESCRIPTION OF DIFFERENT SOURCE CATEGORIES USING REPORTED SOURCES

Source categories	Reported sources*
Road traffic emission (RTE)	Vehicular emissions and road dust, tyre wear, diesel combustion, traffic emission, traffic induced crustal source, Automobile, brake wear.
Crustal origin (CO)	Resuspended dust, soil, fugitive emission, soil and crustal origin emission.
Industrial emissions (IE)	Industrial Coal combustion, metal processing industries, industrial composite, brick kiln, Industrial coal combustion.
Biomass & solid waste combustion (B&SWC)	Solid waste/refuse burning, agricultural waste burning, waste incineration, wood combustion, cow dung burning,
Secondary aerosols (SA)	Secondary inorganic aerosols
Marine aerosols & sea salt (MA&SS)	Marine aerosols, Sea salt

*Name of sources, used in reviewed publications

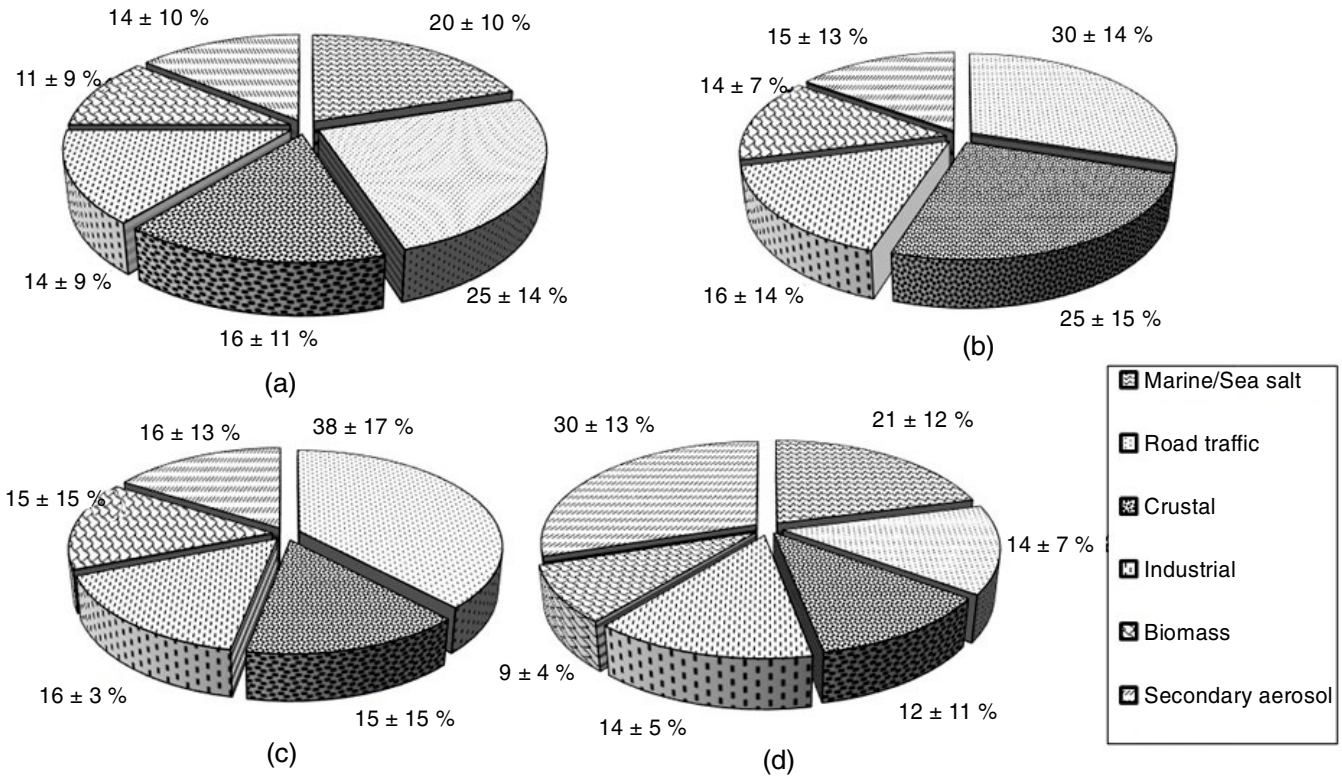

Fig. 3. 15 Year's average percentage source apportionment results of ambient $PM_{2.5}$ in (a) whole India, (b) Indo-Gangetic plain, (c) central plain and (d) coastal plain of India

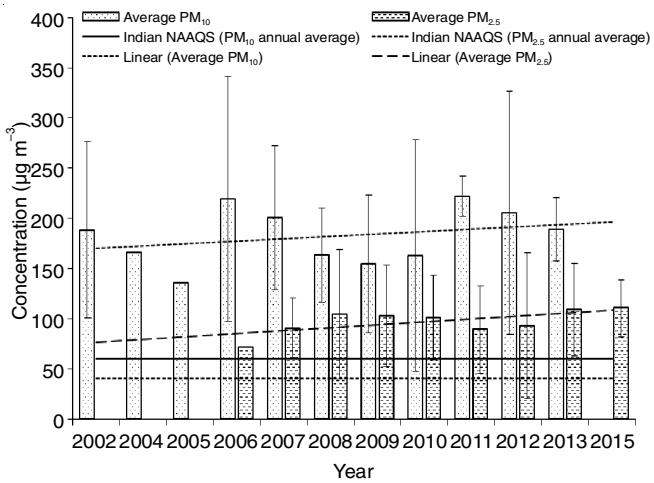

Fig. 4. Temporal variation in year wise average of different reported ambient $PM_{2.5}$ and PM_{10} levels across the India during the assessment period (2001-2015)

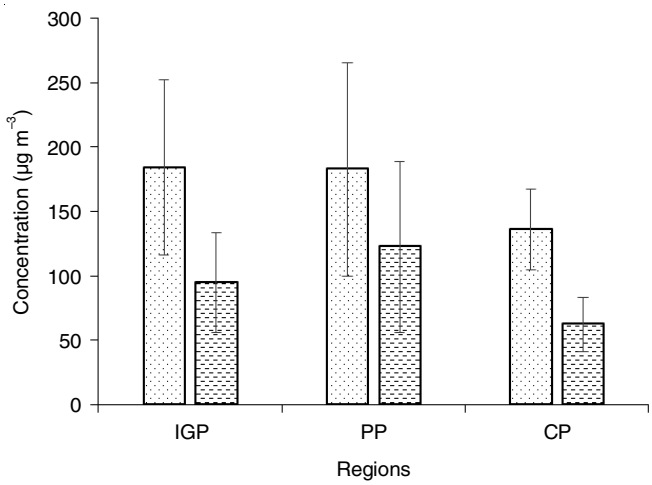

Fig. 5. Comparison of mean values of reported ambient $PM_{2.5}$ and PM_{10} for defined regions (IGP, CPP, CP) during the whole assessment period of 15 years (2001-2015)

(Fig. 2). On an average, 42 % lower annual ambient PM_{10} has been quantified by regulatory agencies compared to those measured in different research studies since year 2004.

Although $PM_{2.5}$ standards were established in year 2009, research oriented ambient $PM_{2.5}$ monitoring was started earlier in year 2006 and extended to different parts of India till 2015. However, few studies were reported for earlier periods. During 2005-2007, most of the studies were reported in the region of IGP with annual $PM_{2.5}$ ranges from 56.2 μg m^{-3} to 136 μg m^{-3} and annual PM_{10} range from 134 μg m^{-3} to 306 μg m^{-3} [33,34]. Further, in three years (2008-2010), particulate fractions have shown increasing trend with the ranges of 63.4-198 μg m^{-3} ($PM_{2.5}$) and 107 - 271 μg m^{-3} (PM_{10}) [35-48]. Between 2011 and 2015, the ranges of ambient $PM_{2.5}$ and PM_{10} were found to be 43.7- 215 μg m^{-3} and 87.9-355 μg m^{-3}, respectively [27, 34,49-57]. On giving attention to different plateau regions of India (Fig. 5), significant spatial variability has been observed. IGP and CPA have shown comparable 15 years averaged ambient particulate fractions with 30.3 % higher $PM_{2.5}$ in CPP compared to those found for IGP. Locations of a number of coal-fired mineral-based industrial zones in central India might be the major reason behind higher ambient $PM_{2.5}$ in CPP. Coastal plateau (CP) has shown 33.6 % and 49.0 % lower 15 years averaged $PM_{2.5}$ compared to IGP and CPP, respectively. Similarly, 15 years averaged PM_{10} was also found 25.6 % and 25.5 % lower in CP compared to IGP and CPP.

Spatiotemporal variation in chemical components associated to ambient $PM_{2.5}$: About 23 out of 55 published research articles during 2001-2015 reported $PM_{2.5}$ chemical speciation results. Table-4 has summarized the concentration of selected chemical species associated to ambient $PM_{2.5}$ of different Indian locations during the period of years 2001-2015. Chemical components crustal elements, trace elements, ions, and carbonaceous matter (OC, EC), of ambient $PM_{2.5}$, were used to address associated spatiotemporal variation during the study period. The major component of PM is carbonaceous aerosols. Total carbonaceous matter (TC) (sum of OC and EC) accounted for > 50 % of $PM_{2.5}$ emissions in most of the research articles with OC/EC ratio > 1 [54,58-62] attributed to the fact that Indian ambient carbonaceous matter contains larger content of primary and secondary organic carbon. A 15 years averaged concentration of selected chemical components of ambient $PM_{2.5}$ in India (Fig. 6) was evaluated to be: 7 ± 15 % (crustal), 1 ± 03 % (trace elements), 46 ± 49 % (ions), 34 ± 24 % (OC) and 12 ± 9 % (EC). About 25 % of total studies on chemical characterization of ambient $PM_{2.5}$ was reported for CPP region, whereas IGP and CP regions have shown 60 % and 19 % of the total studies, respectively. The ionic components have shown the highest contribution to mass in year 2008 (50 %), followed by carbonaceous matter with 43 % contribution. Crustal and trace species have shown small contribution with 2 % and 5 % contributions, respectively. Lower variability associated with 15 years averaged concentration of Indian ambient $PM_{2.5}$ carbonaceous matter compared to other components attributed the higher degree of uniformity and similar source origin associated with carbonaceous matter. As far as temporal variation in the relative association of chemical component with ambient $PM_{2.5}$ is a concern (Fig. 7), the ionic component has shown 19 % lesser association, which was found to be compensated by carbonaceous matter

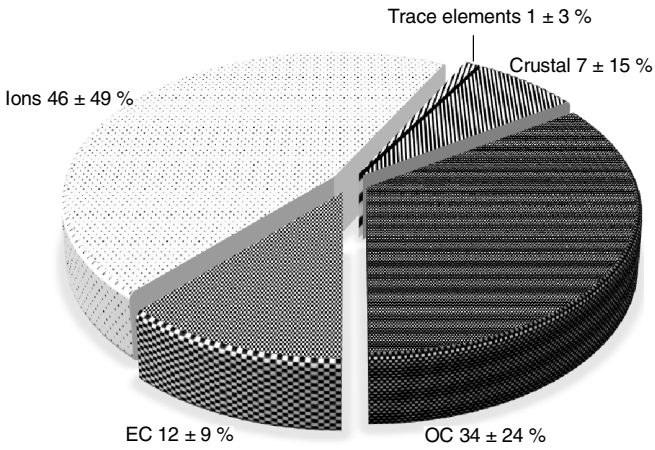

Fig. 6. 15-year averaged ambient $PM_{2.5}$ chemical components (crustal, traces, ionics and carbonaceous matter) in Indian atmosphere

TABLE-4
CONCENTRATION OF SELECTED CHEMICAL SPECIES ASSOCIATED TO AMBIENT $PM_{2.5}$ OF DIFFERENT INDIAN LOCATIONS DURING THE PERIOD OF 2001-2015

Year	City	Different elements concentration (ng.m^{-3}) of $PM_{2.5}$																			Ref.
		Al	Ca	Fe	Na	Si	Mn	Cr	Ni	Cu	Zn	Cd	Pb	OC	EC	Na^+	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}	
2001	Mumbai	–	–	–	–	–	–	–	–	–	–	–	–	21067	12075	–	–	–	–	–	[82]
	Delhi	–	–	–	–	–	–	–	–	–	–	–	–	51775	10500	–	–	–	–	–	[82]
	Kolkata	–	–	–	–	–	–	–	–	–	–	–	–	47725	5833	–	–	–	–	–	[82]
	Chandigarh	–	–	–	–	–	–	–	–	–	–	–	–	9500	3700	–	–	–	–	–	[82]
2005	Hyderabad	–	–	216	–	–	24	7	9	19	134	37	271	–	–	–	–	–	–	–	[82]
2006	Delhi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8380	5090	–	–	–	[62]
2007	Ahmedabad	668	–	283	–	–	36	11	3	12	93	2	153	–	–	–	–	–	–	–	[34]
	North–East	815	411	427	500	1015	92.15	15.73	41.1	23.6	25.435	25.2	24	–	–	–	–	–	–	–	[83]
	Kanpur	263	3418	360	2339	3393	176	85	10	819	222	72	606	38553	11593	2339	15213	1742	16192	27079	[59]
2008	Delhi	–	581	624	463	1095	–	18	8	–	332	–	123	–	–	–	–	–	–	–	[35]
2009	Nagpur	852.5	–	219	–	555	35	12	15	222	178	18	43	23180	9003	584	6514	910	7044	8501	[51]
	Gual pahri Delhi)	–	–	–	–	–	–	–	–	–	–	–	–	28450	4575	587	18955	3140	12217	22792	[48]
	Delhi	–	–	1900	–	–	100	600	200	200	–	500	400	–	–	–	–	–	–	–	[47]
2011	Ahmedabad	–	–	–	–	–	–	–	–	–	–	–	–	–	–	240	4700	2600	5000	5700	[84]
	Hyderabad	–	–	–	–	–	–	–	–	–	–	–	–	21150	10050	–	–	–	–	–	[85]
	Agra	–	–	–	–	–	–	–	–	–	–	–	–	22800	3400	–	–	–	–	–	[61]
2012	Bhubaneswar	–	–	–	–	–	–	–	–	–	–	–	–	16500	8020	–	–	–	–	–	[54]
	Hyderabad	–	–	–	–	–	–	–	–	–	–	–	–	16500	9700	–	–	–	–	–	[51]
	Dhanbad, Bokaro	6740	–	8340	510	2050	250	390	60	1580	840	70	190	19510	–	–	–	560	550	3470	[56]
	Pune	1300	2060	1310	6880	–	110	270	910	100	280	80	110	–	–	–	–	–	–	–	[50]
	Delhi	–	–	–	–	–	–	–	–	–	–	–	–	37730	7790	–	–	–	12740	22470	[52]
2013	Bhubaneswar	–	–	–	–	–	–	–	–	–	–	–	–	11160	6000	–	–	–	–	–	[54]
	Delhi, Nurpur	–	–	–	–	–	–	–	–	–	–	–	–	25600	13700	–	–	–	–	–	[30]
	Delhi, Nurpur	–	–	–	–	–	–	–	–	–	–	–	–	29600	12800	–	–	–	–	–	[30]
2014	Delhi	1270	945	930	–	1835	55	10	7	45	420	–	340	61000	27035	525	19570	14990	18585	18035	[78]

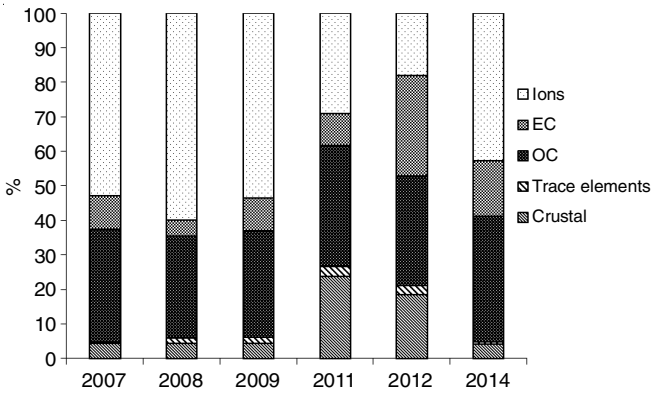

Fig. 7. Temporal variation of annual averaged Indian ambient $PM_{2.5}$ chemical components (crustal, traces, ionic and carbonaceous matter) during the period of 2007-2014

with 17.3 % increased association with ambient $PM_{2.5}$. On evaluating the ionic/carbonaceous matter ratio, the value was decreased from 1.13 to 0.82 during year 2007-2013. On contrary, trace elements and crustal content have shown uniform association (4 %) to ambient $PM_{2.5}$.

Spatial variability in ambient $PM_{2.5}$ chemical components has been evaluated using reported measurements in three different plateau regions of India; Indo-Gangetic, central peninsula plateau and coastal plain. Except for EC and trace species, all other components were observed to be higher in IGP compared to other regions. Higher EC and trace species in CPP might be due to emissions resulting from a large number of coal-fired mineral-based industrial units, located in CPP. Organic carbon (OC) concentration associated to ambient $PM_{2.5}$ of CP has found 38 % and 27 % lower compared to those found in IGP and CPP, respectively.

Ambient PM source apportionment studies: Source apportionment (SA) of ambient $PM_{2.5}$ has been reported to be carried out using different approaches; factor analysis, principal component analysis (PCA), chemical mass balance using positive matrix factorization (PMF-CMB), Effective variance (EV-CMB) and UNMIX in various Indian air quality studies, since from year 2007. About 25 % of the total reported studies on ambient air quality, during the assessment period, have shown findings of source apportionment using various receptor modeling approaches. Six major contributing source categories of Indian ambient $PM_{2.5}$, during the assessment period, have been observed. Road traffic emissions have been observed to be the major contributor to Indian ambient $PM_{2.5}$, followed by marine aerosols/sea salt, crustal, industrial emissions, secondary aerosols and biomass burning emissions. Lower variability associated with road traffic and marine aerosols/sea salt, compared to those associated to other source categories addresses the higher relative consistency of these source categories in contributing to ambient $PM_{2.5}$, measured in different locations, across the India. As far as defined regions are concern, the order of mean contribution estimates from selected source categories to ambient $PM_{2.5}$ is observed to be: RTE > CO > IE > SA > B&SWC (IGP), RTE > SA= IE > B&SWC = CO (CPP) and SA > MA&SS > RTE = IE > CO > B&SWC (CP). Upon comparing the variability associated with the contribution of emissions resulting from biomass burning source category to ambient $PM_{2.5}$ of selected three plateau regions, two-fold higher variability associated to CPP than those found in IGP and CP has been observed. Similarly, RTE has shown about two- and three-fold higher contribution to ambient $PM_{2.5}$ of IGP and CPP, respectively, compared to those evaluated for CP region. As far as apportionment of IE to ambient $PM_{2.5}$ is concern, about similar contribution to ambient $PM_{2.5}$ has been observed in all defined plateau regions. Additionally, lowest associated variability observed in CPP region, compared to those observed in IGP and CP regions, underscores the significance of estimation of IE's contribution to ambient $PM_{2.5}$ in different locations of CPP region. Apportionment of the crustal source category (CO) to ambient $PM_{2.5}$ has been observed to be highest in IGP plateau region compared to CPP and CP. Similarly, secondary aerosols (SA) have shown a major contribution to ambient $PM_{2.5}$ in CP region compared to IGP and CPP regions. A big picture of 15 year's secondary aerosols (SA) results of ambient $PM_{2.5}$ of three major plateau regions of India describes that road-traffic is the major contributor to ambient $PM_{2.5}$ in IGP and CPP, whereas secondary aerosols have shown a major contribution to ambient $PM_{2.5}$ of CP region.

Most of the secondary aerosols (SA) studies, conducted in India during the period of year 2001-2015 are reported to use simple factor analysis (PCAs), Source markers/diagnostic ratios and chemical mass balance approaches *viz*. UNMIX and PMF. Few studies have also described the EV-CMB to address the source apportionment results. The findings of all reported source apportionment studies, conducted in India during last 15 years, have been summarized in Table-5.

A major source apportionment study of ambient $PM_{2.5}$ and PM_{10}, sampled during the period of 2007-2010, has been carried out in kerb-, residential- and industrial-sites of six Indian cities, namely Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune [63]. To apportion the natural and anthropogenic sources, 36 chemical species associated to 20 ambient $PM_{2.5}$ and PM_{10} samples for each of three seasons (post-rainy, winter and summer) have been used and three different approaches, namely, source markers, varimax rotation of PCA and EV-CMB8.2 have been used. On analyzing the findings of this SA study using defined source categories in this review, road-traffic, crustal origin and biomass burning have been found to be dominant in relative source contribution estimates of ambient PM_{10}, whereas secondary aerosols, road-traffic and cooking fuel burning have shown major access to ambient $PM_{2.5}$, across the selected cities and defined sites. Karar and Gupta [64] has reported the source apportionment results of ambient PM_{10} measurements in Kolkata during November 2003-November 2004 by executing EV-CMB 8.0 and using source profiles from USEPA speciate 3.2. The findings revealed that the most dominant source throughout the study period at residential site was coal combustion, while vehicular emissions contributed prominently in Industrial site of Kolkata city. Another study, conducted in Mumbai city, addresses the dominance of industrial source contribution to ambient PM_{10} of background site [65]. Similar type of SA study was reported for ambient PM_{10} and $PM_{2.5}$ samples collected from Hyderabad during June 2004-May 2005. Hourly samples of both particulate fractions were collected in the study and SA results describe that re-suspended dust is

TABLE-5
SUMMARY OF AMBIENT PARTICULATE MONITORING, ANALYSIS AND SOURCE APPORTIONMENT RESULTS FOR DIFFERENT LOCATIONS OF INDIA

Research date/City	Sampler	Filter type	Concentration ($\mu g\ m^{-3}$) PM_{10} $PM_{2.5}$	Chemical analysis	Species	Source apportionment method	Source contribution (%)	Ref.
Mumbai	Gent stacked filter unit sampler	Nucleopore polycarbonate filter	$PM_{2.5}$: 44.03, PM10: 107.85	NAA, EDXRF	Si, S, Ca, Ti, Pd, Zn, Fe, Co, Na, K, Sb, Cr, Sc.	FA-MLR	PM_{10}: - sea salt (35%), crustal (25%), industrial (14%), vehicular (10%), fugitive emissions (7%). $PM_{2.5}$: - soil (3%), two-stroke emission with fugitive dust (18%), Industrial emission (23%), motor vehicles (29%), sea salt (9%).	[35]
Nov. 2003 - Nov. 2004 / Kolkata	Respirable dust sampler, High volume Sampler	Quartz microfiber filter	-	ICP-AES, GC-FID, CA, IC	Cr, Zn, Pb, Cd, Ni, Mn, Fe,	CMB	I: - soil dust (36%), coal combustion (17%), solid waste (17%), road dust (16%) and tyre wear (7%). R: - coal combustion (37%), soil dust (19%), road dust (17%) and diesel combustion (15%)	[69]
June 2004 - May 2005 / Hyderabad	TEOM particulate matter analyzer	Teflon-coated borosilicate glass fiber	$PM_{2.5}$: 49.80, PM_{10}: 135.10	ICP-MS	As, Fe, Mn, Cu, Zn, Pb, Cd, Ni, Co, Cr, B, Se	CMB	PM_{10}: - resuspended dust (40%), vehicular pollution (22%), combustion (12%), industrial (9%), refuse burning (7%). $PM_{2.5}$: Vehicular pollution (31%), resuspended dust (26%), combustion (9%), industrial (7%), refuse burning (6%).	[33]
January 2008 - May 2009 / Agra	-	-	-	GRIMM aerosol spectrometer	Fe, Zn, Cu, Cd, Cr, Mn, Ni, Pb	PCA	Rd/Id = automobile (37.06%), chalk dust and soil (36.07%), metal processing (15.17%) Rd/Od = vehicular emission and soil dust (47.56%), vehicular wear and tear (33.79%), garbage burning and other activities (17.98%). R/Id=metal enriched soil, vehicular emission, chalk dust and windblown dust (39.28%), paint, pigments and varnishes (20.92%), incineration activities (25.28%). R/Od = vehicular sources (38.09%), vehicular wear and tear (25.8%), incineration (25.07%).	[47]
Jun 2011- May 2012 / Pune	MiniVol-TAS sampler	PTFE, Quartz microfiber filter papers.	$PM_{2.5}$: 72.3, PM_{10}: 113.8	ICP-AES	Cu, Zn, Mn, Fe, Ba, Ca, Co, Cr, K, Na, Ni, Pb, Sr, Cd, Al, Mg	PCA	Waste incineration (52.5%), traffic emission, gelogenic origin (14.4%) Re-suspended road dust, which includes soil dust mixed traffic-related particles (30.7%), crustal origin emission (13.6%)biomass burning and solid waste incineration, crustal (15.4%),	[50]
December 2008 - November 2009 / Delhi	High–volume samplers (Respirable Dust Sampler)	Whatman GF/A (8" × 10") glass fiber filters	PM_{10}: 178.2	AAS	Fe, Zn, Cu, Cd, Cr, Mn, Ni, Pb	PCA-MLR	crustal (49–65%), vehicular (27–31%) and industrial (4–21%).	[44]
October 2007- march 2009 / Agra	Medium-volume APM 550	PTFE filter paper	$PM_{2.5}$: 72, PM_{10}: 113.8	AAS	Pb, Cd, Ni, Fe, Cr, Mn, Cu	PCA	Ru/Id = cow dung, wood burning and smoking (29%), waste burning (28%), resuspended soil dust (17%). Ru/Od = industrial, refinery emission and resuspended soil (31%), construction and diesel exhaust (27%), anthropogenic activities (18%)	[46]
September 2009 - February 2010 / Nagpur	Partisol Model 2300, 4-channel speciation sampler	PTFE, Quartz microfiber filter papers, Nylone	Geomean $PM_{2.5}$: 80.43	ICP-OES, IC, TOCA	Al, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Si, Zn	CMB	R = vehicular emissions (57%), secondary inorganic aerosol (16%), biomass burning (15%), re-suspended dust (6%). C = vehicular emissions (62%), secondary inorganic aerosol (12%), biomass burning (11%), re-suspended dust (10%). I = vehicular emissions (65%), secondary inorganic aerosol (16%), biomass burning (9%), re-suspended dust (7%).	[51]
July 2008 - May 2009 / Kanpur	Single stage round nozzle, grease impaction substrate based impactor type PM1 sampler	PTFE	Average PM1: 102.46	ICP-OES, IC	As, Fe, Cu, Zn, Pb, Cd, Ni, Cr, Se, V, Ca, Mg	UNMIX	Secondary sources (39%), vehicular emissions (24%), road dust (14%), un-apportioned (12%), coal combustion (11%)	[86]
8 December 2006 - 6 January 2007 / Ahmedabad	mass-flow controlled high volume samplers	Quartz filter, Teflon filter	$PM_{2.5}$: 56, PM_{10}: 171	AAS, ICPMS, IC	Cd, Pb, Fe, Al, Cl, Mg, Ba, Sr, Cu, Mo, Zn, Ni, Co, Mn	PMF	Mineral dust (34%), biomass burning (33%). Industrial or/and incineration emissions (11%), mineral aerosol or soil dust (10%), coal-based power stations/industrial/vehicular emissions (31%), biomass burning (33%)	[34]
March 2007 - February 2008 / Agra	respirable dust sampler	Whatman quartz microfiber filter	PM_{10}: 155.47	ICP-AES, IC	F, Na, Mg, Al, Si, S, Ca, Sc, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Rb, Cd, Ba, Pb	PCA	Windblown dust, re-suspended dust, dust from paved and unpaved roads, and undisturbed soil, agricultural, and construction activities (55.47%), emission associated different process of vehicular movement (16.90%), industrial process (9.04%), biomass burning (7.34%), secondary inorganic origin (4.55%)	[42]

November 2003 - November 2004 / Kolkata	respirable dust sampler (Evirates, APM 460)	quartz microfiber filter paper (GF/A)	PM_{10} geomean 166.07	ICP-AES, GC, Carbon analyzer, IC	Zn, Pb, Cd, Ni, Mn, Fe, Cr	PCA–MLR	R - solid waste dumping contributed 36%, vehicular emissions 26%, coal combustion 13%, cooking 8% and soil dust 4% I - 37% to vehicular emissions, 29% to coal combustion, 18% to electroplating industry, 8% to tyre wear and 1% to secondary aerosol	[70]
Jan 2007 - Jan 2008 / Jorhat	$PM_{2.5}$ sampler (APM-550, Envirotech)	quartz fiber filters	$PM_{2.5}$ mean: 125.75	Ed-XRF, indophenol-blue spectrophotometry	Al, Si, P, S, Na, K, Ca, Ti, V, Cr, Mn, Fe, Te, Co, Ni, Cu, Zn, Cd, Sn, Sb, Pb	PCA	Traffic induced crustal sources (38%); coal combustion (26%), industrial and vehicular emissions (19%), wood burning (9%) and secondary aerosol formation (8%)	[83]
January - December 2010 / Delhi	Particle Sampler (APM 460NL, Make: M/s. Envirotech, India)	Quartz fiber filters	PM_{10}: 213.1	carbon analyzer, IC with Conductivity detector, WD-XRF, NH_3 analyzer	Na, Mg, Al, Si, P, S, Cl, K, Ca, Cr, Ti, Fe, Zn, Mn,	PMF	Soil dust (20.7%), vehicular emissions (17.0%), secondary inorganic aerosol (21.7%), sea salt (4.4%), fossil fuel combustion (17.4%), biomass burning (14.3%), industrial emission (4.5%)	[87]
January 2010 to Dec-11 / Delhi	Respirable Dust Sampler	Quartz fiber filters	PM_{10}: 191.4	carbon analyzer, IC with Conductivity detector, WD-XRF, NH_3 analyzer	Mg, Al, P, S, Si, Cl, K, Ca, Ti, Cr, Mn, Fe, Zn,	PMF	Secondary inorganic aerosol (21.7%), soil dust (20.7%), fossil fuel combustion (17.4%), vehicular emissions (16.8%), biomass burning (13.4%), sea salt (4.6%), industrial emission (5.4%)	[68]
November 2008–April 2009 / Chennai	Envirotech APM 550 Fine Particle Samplers	Teflon filter membrane	Mean $PM_{2.5}$: 65.67, PM_{10}: 87.33	ICP-OES, IC	Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Rb, Se, Sr, Te, Tl, V, Zn	PMF	PM_{10}: Marine aerosol (40.4%), secondary inorganic aerosol (22.9%), vehicular emissions (16%), biomass burning (0.7%), tire and brake wear (4.1%), soil (3.4%), other sources (12.7%). $PM_{2.5}$: Marine aerosol (21.5%), secondary inorganic aerosol (42.1%), vehicular emissions (6%), biomass burning (14%), tire and brake wear (5.4%), soil (4.3%), other sources (6.8%).	[67]
2008 / Delhi	single stage PM_{10} aerosol samplers APM 541 samplers	Teflon Micro fiber filter papers (2 ?m PTFE)	PM_{10}	ED-XRF, IC	Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Sr, Ba, Pb, Cd, Sn, Sb	UNMIX, PMF	Vehicular emissions (60%) followed by crustal elements as a major source	[66]

Note: I = industrial site, R = residential site, C = Commercial site, Rd = Road side, Id = Indoor, Od = Outdoor, Ru = Rural, NAA = Neutron Activation Analysis, EDXRF = Energy Dispersive X-Ray Fluorescence, CA = Carbon Analyzer, IC = Ion Chromatography

dominating in relative source contribution estimates of both aerosol fractions [33]. In another SA study, conducted on 24-hourly ambient $PM_{2.5}$ samples, collected during September 2009-February 2010 at three locations in Nagpur city, namely residential, commercial and industrial, two receptor models (Enrichment Factor and EV-CMB 8.2) have been used to differentiate crustal and non-crustal source and to quantify the major source contribution estimates, respectively. This study has shown use of source profiles of Indian origin to execute the EV-CMB 8.2 and found that vehicular sources are dominated in relative source contribution estimates of ambient $PM_{2.5}$ [51].

Apart from the use of EV-CMB to apportion the sources of aerosols, some other studies have shown the use of PMF to extract the source-factors from chemical receptor profiles of ambient aerosols. In a study, reported for an urban location of Ahmedabad, Western India, PMF was executed and showed five- and six-source factors for $PM_{2.5}$ and PM_{10} [34]. The PMF results suggest anthropogenic sources contributed about 80% and 40-50 % of $PM_{2.5}$ and PM_{10} mass, respectively; attributed to the fact that PMF is only capable to predict the general type of sources, contributing ambient aerosols. The findings of the study exhibit large temporal variations during winter due to influence of air masses from different source have also reported the application of UNMIX6.0 and PMF techniques to predict the source contributions to ambient PM_{10} samples of Delhi during the year 2008 [66]. The findings of source-factors have explained the specific chloride source in the region with relative contribution of 86 %. Another study, conducted in Chennai during 2008-2009, address the source apportionment of ambient $PM_{2.5}$ and PM_{10} samples, collected from a busy roadside location. Marine aerosols and secondary aerosols have been found to be the major contributor to ambient PM_{10} and $PM_{2.5}$, respectively [67]. An important observation, associated to the model execution protocol, described in the reported SA studies using PMF, is that authors did not presented the standard approach to select the number of factors to run the PMF model [67,68]. Similarly, most of the EV-CMB based study have not shown model sensitivity testing using MPIN matrix to address the source-species relationship [33,51,69].

On assessing the other reported SA approaches, Principle Component Analysis-Multi Linear Regression (PCA-MLR) analysis predicted municipal solid waste management (36 %), vehicular emissions (26-29 %) and coal combustion (13-29 %) contributors to ambient PM_{10} samples, collected in Kolkata during November 2003- November 2004 [70]. Similarly, Habil [47] reported the principle component analysis (PCA) approach to address the sources of 24 h ambient PM_{10} measurements during 2008-09 in Agra city. Khillare and Sarkar [44] have also identified crustal, vehicular and industrial emission as major contributing sources for ambient $PM_{2.5}$ in Delhi with contributing 49-65 %, 27-31 % and 4-21 %, respectively using PCA-MLR during the year 2008-2009.

Conclusions

In this review, the status of the annual trends of concentration and chemical characteristics along with source apportionment (SA) results associated to ambient particulate matter ($PM_{2.5}$ and PM_{10}) were described for three different geographical plain of India. The published studies during the period of 2001-15 are confined to address the mass concentration and associated chemical characteristics in different urban locations of India. As far as source apportionment studies of the ambient aerosol are concern, some research publications have shown the execution of air quality receptor models *viz*. PMF5.0, EV-CMB 8.2 and UNMIX 6.0; simple factor analysis and reported diagnostic ratios/source marker species were used to address the sources of ambient aerosols. Average particulate matter concentrations have exceeded the Indian NAAQS standards with increasing degree of spatiotemporal variation in all selected plateau region during the reviewed period of year 2001-2015. Increasing urban-industrialization, higher consumption of coal and other minerals, increasing road traffic density and increasing open burning events of larger heaps of unprocessed municipal solid wastes could be the major factors behind the increasing trend of ambient aerosol fractions.

Most of the reviewed studies were conducted with traditional chemical species *i.e*. elemental, ions, organic carbon, elemental carbon characteristics and few studies reported the limited number of organic chemical marker species, belong to VOCs and PAHs, associated with ambient aerosols. Carbonaceous matter (TC) has been observed to be the major component (>50 %) of ambient aerosol fractions in India. The relative occurrence of different chemical components in ambient $PM_{2.5}$ of different Indian locations during the reviewed period is found to be TC > ions > crustal elements > traces metals. The occurrence of the higher relative contribution of ionic component compared to crustal elements attributes to the assumption of increasing contributions from emissions resulting from combustion activities. On comparing the application of different modelling tools to apportion the ambient aerosol fractions, reported during the reviewed period, PCA was executed prominently in about 60 % of reported studies, followed by PMF technique in 25 % of studies. The EV-CMB modelling has been reported in 15 % of reported studies during the reviewed period and almost all of these studies reported to use USPEA's Speciate Source Profiles to execute EV-CMB, due to unavailability of locally derived source profiles.

The previous source apportionment (SA) studies have identified major contribution from emissions resulting from road-traffic with 56 % standard deviation across the different urban locations of India. The order of relative source contributions (RSC) of emissions resulting from other sources has been observed to be: marine/sea salt > crustal > industrial = secondary aerosols > biomass burning. The orders of RSC for different plateau regions of India are found to be: road-traffic > crustal> industrial > secondary aerosols > biomass burning (IGP); road-traffic > industrial = secondary aerosols > crustal = biomass burning (CPP) and secondary aerosols > marine/sea salt > industrial = road-traffic > crustal > biomass burning (CP). The SA studies are important to better understand PM pollution sources and associated dispersion pattern to design more cost-effective control technologies and formulating policies strategies implications. The more advanced, confident and accurate SA study plan required to fulfill PM pollution control strategies for Indian subcontinent in future. The important conclusions drawn from reported studies on ambient aerosol monitoring and analysis are: (a) Average 50 % and 14 % increase in annual average ambient $PM_{2.5}$ and PM_{10} levels, respectively, has been observed during the last fifteen years since from 21st century. $PM_{2.5}$ has shown three-fold higher increment compared to those evaluated for PM_{10} during last 15 years. This might be due to sharp shoot-up in high-temperature combustion processes associated with industrial activities, increasing the density of road traffic activities with increasing urbanization and lacking in availability of scientific policies for environment pollution management in Indian. (b) Significant different have been observed in reported values of annual averages of ambient $PM_{2.5}$ and PM_{10}, reported by journal publications of research institutions and regulatory agency (CPCB) for Indian scenario. The CPCB reported values were found to be significantly lower than those reported in research publications of research institutions. (c) Higher degree of variation in RSC of ambient aerosols has been observed across the different geographical plateau regions of India; attribute to design location-specific control measures.

Future directions

• Limited organic molecular markers, associated with ambient aerosols are reported in published articles. A large number of markers, associated with aerosols, may be included in the chemical analysis of obtained precise results of source apportionment.

• Species source apportionment for ambient aerosols using air quality receptor models should also be carried out to address the associated RSCs.

• Most of the ambient air quality studies (64 %) are reported for IGP, whereas CP (11 %), and CPP (14 %) were studied less extensively. More ambient air quality studies should be carried out in different locations of CPP and CP regions.

• Nearly 70 % of the country's population lives in rural areas [32] and no ambient air quality studies have been reported for rural regions. Comparison of Source apportionment results associated with ambient air quality should be taken into account for rural and urban environments.

• Due to occurrence of larger degree of variation and uncertainties associated with RSCs results of ambient air quality in different locations of India due to use of factor analysis approaches (PCAs and PMF) and use of USEPA based source profiles for execution of EV-CMB, use of larger database of receptor aerosol profiles along with locally derived source profiles is recommended to execute EV-CMB/PMF 5.0 in future.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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