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A Systematic Review on Long Term Variation of Carbonaceous Aerosols in $Pm_{2.5}$ at Different Sites of "Delhi" Capital City of India

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ABSTRACT: Being a criteria pollutant Fine Particulate Matter ($PM_{2.5}$) exposure not only affects human health but also deteriorates environmental health, air quality and artifacts. Traffic, biomass burning and industrial activities are important contributors to ambient fine particulate matter in major cities of the world. Therefore, to reduce fine particulate matter pollution and the considerable disease burden it causes solutions to bring down ambient fine particulate matter are needed. Carbonaceous aerosols are found to be a significant contributor to fine particulate matter. These aerosols are subdivided into organic carbon and elemental carbon. Elemental carbon is released from primary sources whereas organic carbon can be released either from primary or secondary sources. This paper presents a comprehensive critical review of the assessment of fine particulate matter and its carbonaceous content in the past decade on different sites in New Delhi, the capital of India. Considerable health effects of particulate pollution have also been discussed in the paper. Critically reviewed data showed a non – significant increase in the trend of particulate matter concentration. It was also shown through the data of each study that the emission standards of WHO exceeded by 15 times whereas for NAAQS they exceeded by 5 times respectively.

KEYWORDS: Carbonaceous aerosols, Elemental Carbon, Health Effects, Organic Carbon, $PM_{2.5}$, Particulate Matter.

1. INTRODUCTION

Air pollution is a global concern, it degrades air quality, reduces visibility [1], it also affects the yield of crops, and causes various cardiopulmonary diseases [2,3,4]. According to a report published in 2017 jointly by the Indian Council of Medical Research, Public Health Foundation of India and Ministry of Health and Family Welfare, air pollution causes 26% of premature death in India, where $PM_{2.5}$ is solely responsible for around 12.4 lakh deaths [5]. Particulate matter with a size less than 2.5 µm, is known as $PM_{2.5}$. It is also known as Respirable Suspended Particulate Matter. Out of six criteria pollutants given by NAAQS (Carbon monoxide, lead, nitrogen dioxide, particulate matter, ground-level ozone and sulphur dioxide), particulate matter is a crucial indicator for air pollution. It also affects more people as compared to other pollutants [6,7,8]. $PM_{2.5}$ can penetrate deep into the lungs and can also cause severe breathing and cardiovascular diseases [9]. $PM_{2.5}$is composed of many chemical species. It not only consists of organic compounds, such as elemental carbon (EC) and organic carbon (OC) but also consists of trace elements and ions [10]. The primary sources of air particulate pollution are combustion processes, the transformation of gaseous species and forest fires [11,12, 13]. Carbon species comprise a major portion of $PM_{2.5}$and contribute about 20-60 % to the total mass of particulate matter [14]. They can account for up to 40% of the mass of $PM_{2.5}$ in the urban atmosphere [15] and in the rural atmosphere it can account for up to 70% [16]. Carbonaceous aerosols have also been found associated with various health problems that cause serious respiratory and cardiovascular diseases [17,18,19]. The high loading of carbon species in $PM_{2.5}$ has also been identified as a vital factor for climate change, haze formation, and atmospheric chemical reaction [20,21,22]. Carbonaceous aerosols are usually classified into elemental carbon and organic carbon. Elemental carbon particles have the potential to absorb solar radiation, which results in positive radiative forcing in the atmosphere [23], whereas, organic carbon scatters the sun's radiation causing negative radiative forcing [24].

Elemental carbon is released into the atmosphere from incomplete combustion of biomass, fossil fuel and other materials composed of carbon, such as a primary pollutant. Organic carbon is released into the atmosphere either as a primary pollutant from combustion and/or biogenic sources (primary organic carbon) or as a secondary pollutant, from gas to particle conversion of volatile organic compounds (secondary organic carbon) [25,26]. A major fraction of organic aerosols is water-soluble and it alters the hygroscopic properties of aerosol and their cloud condensation nuclei activity [27]. Elemental carbon contains several functional groups such as alcoholic, phenolic, carboxylic and carbonylic [28]. Elemental carbon is also an important contributor to global warming after CO_2 [29,30]. Organic carbon contains a large variety of organic compounds such as aliphatic, aromatic compounds and acids [31].

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1.1 Effect of Particulate Matter

$PM_{2.5}$ exposure creates a significant risk of respiratory, cardiovascular and neurological diseases. $PM_{2.5}$ exposure increases the risk of stroke, dementia, Alzheimer's disease, Autism spectrum disorder, and Parkinson's disease [32]. Particles having a diameter < 2.5 µm are also known to trigger allergic responses and damage to the airways [33,34]. Studies have also stated that $PM_{2.5}$ enters the bloodstream and then crosses into the blood-brain barrier, which gives it access to the central nervous system. $PM_{2.5}$ consists of heavy metal, organic carbon and polycyclic aromatic hydrocarbon, which are known to cause inflammation, apoptosis and DNA damage by producing reactive oxygen species, causing various complications in the human brain [35,36,37,38,39,34]. $PM_{2.5}$ can also decrease the response capability of the immunity system. Continuous exposure to increased levels of $PM_{2.5}$ was also found to be linked with diabetes and pre-natal disorder, which can lead to preterm births and numerous post-birth health issues which can ultimately result in an untimely death [40].Particulate matter also influences environmental health by contributing to smog/haze formation, material corrosion and damage, ecosystem damage and visibility impairment [41,42].

2. SCOPE AND STRUCTURE OF THE REVIEW

Present review work is aimed at studying the trend of $PM_{2.5}$and the trend of carbonaceous aerosols in $PM_{2.5}$ in New Delhi over the last decade. This review summarizes the data from the papers published between 2011 and 2021 and is structured in the following way: Section 1 gives the general introduction of the selected topic. Section 2 describes the scope of the review. Section 3 gives an overview of the measurement techniques used for $PM_{2.5}$ measurement in Delhi. Section 4 describes the previous findings of $PM_{2.5}$ assessment in the Decade. Section 5 describes the previous findings on Organic Carbon and Elemental Carbon studies. Section 6 describes the conclusion drawn. Abstracts of the articles were read to screen the articles for contextual relevance for our review work. Papers that had substantially relevant content were included in the review. Articles which did not have the primary data were excluded. Full-length articles of the studies were included based on the above-stated criteria. They were further assessed and screened to get the details about the methodologies used, results obtained and discussions.

3. INSTRUMENTS Used for Fine Particulate Matter Measurement

An examination of the articles reviewed here shows that Fine Particulate Sampler APM 550, Beta Attenuation Monitor(BAM1020)Thermo Andersen, Inc. Series FH 62 C14 (C14 BETA),Optical Particle Counter(OPC, Model 1.108, GRIMM Inc.) and Mini- Vol Portable air sampler is used for Fine Particulate Matter assessment. Research papers reviewed here showed that 18 researchers used Fine Particulate Sampler APM 550, 5 researchers used Beta Attenuation Analyzer, 2 researchers used Mini – Vol Sampler and 1 researcher used Optical Particle Counter.

Beta attenuation Monitor uses the industry-proven principle of beta ray attenuation. The measurement principle involves emission, by a small 14C (carbon-14) element, of a constant source of high-energy electrons known as a beta ray through a spot of clean glass 0fibre filter tape. These beta rays are detected and counted by a sensitive scintillation counter to determine a zero reading. The BAM – 1020 automatically advances this spot of tape to the sample nozzle where a vacuum pump then pulls a measured and controlled amount of dust-laden air through the filter tape loading it with ambient dust. This dirty spot is placed back between the beta source and the detector thereby causing an attenuation of the beta ray signals which is further used to determine the mass of the particulate matter on the filter tape and the volumetric concentration of particulate matter in the air. In this instrument, the equipment measuring $PM_{2.5}$utilizes an additional inlet which allows only the particles with a cut-off aerodynamic diameter of 2.5 µm hence this set of equipment measures $PM_{2.5}$ particulate matter only [43].

The fine particulate sampler (APM 550) (Envirotech India Pvt. Ltd.) is based on the impaction principle [44] which separates the particle due to curvilinear motion around the impaction plate. Particles above a certain size possess so much momentum, that they cannot follow the air- stream and fall off to the collection surface. The $PM_{2.5}$ mass concentration was calculated as the difference in post-weight and pre-weight of the filter divided by the volume of air sampled in the given time at the flow rate of 16.7 Lpm [45, 46].

The beta attenuation analyzer (Thermo Andersen, Inc. USA; series FH 62 C14) works with a temporal resolution of 5 min. The 2.5 µm size cut-off was achieved through a sharp cut cyclone inlet with a flow rate of 1 m^3 h^{-1}. The instrument's measuring range is 0-5000 µg m^{-3} for 24 hr average [47,48,49].

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The optical particle counter (OPC, Model 1.108, GRIMM Inc.) is specifically designed for PM_{10}, $PM_{2.5}$, and PM_1 assessment by optical techniques. It is a portable particle analyzer and the optical technique of this instrument enables it to make the precise cut-off diameters for all three PM sizes. This system allows the collection of all three Particulate fractions simultaneously [50].

4. PREVIOUS FINDINGS ON FINE PARTICULATE MATTER ASSESSMENT

In this review paper we have obtained data from different sites in Delhi which are IITM Delhi, G.G.S.I.P University Campus, CSIR-NPL Delhi, Okhla Industrial Area, Indra Gandhi Technical University, Delhi, and IIT Delhi as shown in "table 1". We discussed the data of the common site and an increasing trend of concentration is seen in the discussed data.

Table 1: Summary of $PM_{2.5}$, Elemental Carbon and Organic Carbon in Delhi

Study period	Location	Instrument used for $PM_{2.5}$ assessment	Duration of sampling	Concentration of $PM_{2.5}$ µg/m^3		Average Concentration of EC and OC µg/m^3		Remark	Reference
				Seasonal Average	Average	EC	OC		
22 November 2007 – 26 February 2008 and 2 April – 25 June 2008	G.G.S.I.P University campus	Fine Particulate Sampler (APM 550)	24 hrs		50.6 ± 20.4	-	-	-	63
August 2007 – October 2008	IITM Delhi	Optical Particle Counter (OPC, Model 1.108, GRIMM Inc.)	24 hrs	236 (W), 69 (S), 54 (M) & 389(PM)	-	-	-	-	50
September 2010 – August 2012	IITM Delhi	Beta Attenuation Particulate Monitor Thermo Andersen, Inc. Series FH 62 C14 (C14 BETA)	24 hrs	169.42 (W), 91(S), 56.30 (M), 205(PM)	129.8 ±103.4	-	-	-	49
November 2010 – February 2011	IITM Delhi	Beta Attenuation Particulate Monitor Thermo Andersen, Inc. Series FH 62 C14 (C14 BETA)	24 hrs		209.6 ±145.5	10.4 ± 4.6	54.1 ± 38.7	Highest range 1257.9 is obtained on Diwali due to fire burning	51
December 2010 – November 2011	IITM Delhi	Beta Attenuation Monitor(BAM 1020)	24 hrs	221.1 ± 94.7 (W), 86.4 ± 26.8 (S), 58.5 ±25.2 (M), 199.7 ± 94.2 (PM)	-	-	-	-	43

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January 2011 – December 2011	IITM Delhi	Beta Attenuation Particulate Monitor Thermo Andersen, Inc. Series FH 62 C14 (C14 BETA)	24 hrs	164.3±40.1(W), 93.7 ± 32.8 (S), 65.9 ± 18.9(M), 196.3±60.1 (PM)	122.3 ± 90.7	-	-	-	52
November 2011-February 2012	IITM Delhi	Medium Volume Sampler (APM 550)	24 hrs.	-	211.67 ± 41.94	10.67 ± 3.56	50.11 ±11.93	-	53
December 2011 – November 2012	IITM Delhi	Fine Particulate Sampler (APM 550	10-12 hrs	229.24±18.11(W),143.46 ±36.66(PreM), 95.96±23.13(M), 222.81±54.56(PM)	153.57±59.57	6.96 ± 3.97	33.51 ± 15.89	-	54
January 2012 – December 2012	IITM Delhi	Medium Volume Sampler (APM 550) (Offline) & Beta Attenuation Analyzer Thermo Andersen, Inc. Series FH 62 C14 (C14 BETA) (Online)	8 hrs (day) & 12 hrs (night)		171.6 ± 51.6 (Offline) , 124.6 ± 87.9 (Online)	5.3 ± 2.3 (day time), 10.3 ±5.7 (night time)	34.1 ± 11.7 (day time), 41.4 ± 17.6 (night time)	Difference between offline and online measurement is due to blockage of filter porous in beta attenuation analyser	61
December 2012 – February 2013	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs	-	186.25 ± 47.46	12.4 ± 4.43	16.46 ± 6.61	-	55
January 2013-May 2014	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs.	196 (W) , 83.6 (S), 58.8 (M)	125.5 ± 77.2	10.3 ± 6.9	17.7 ± 12.2	-	56
January 2013-December 2014	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs	216 ± 93.2 (W), 81.8 ± 24.9 (S), 69.9 ± 56.1 (M)	122 ± 94.1	10.4 ± 8.04	17.9 ± 14.3	-	57

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January 2013 – December 2014	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs	215.7±93.2 (W), 81.5 ± 25.2 (S), 68.6 ± 57.1 (M)	121.9 ± 93.2	10.2 ± 7.54	17.6 ± 14.1	-	58
January 2013 – December 2015	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs	196.8±74.1 (W), 82.9±28.7 (S), 64.4±41.3 (M)	114.7 ± 48.0			-	59
January 2013-December 2016	CSIR-NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs	183 ± 73 (W), 103 ± 35 (S), 69 ± 28 (M), 186 ± 90 (PM)	131 ± 79	7.31 ± 6.17	15.7 ± 12.7	-	60
December 15 2013 – January 15 2014 & June 15 2014 - June 30 2014	Okhla Industrial area	Collected Minivol Sampler	12 hrs	276.9 ± 99.9 (W), 58.2 ± 35 (S)		7.76 ± 7.06 (S) 46.3 ± 18.9 (W)	17.6 ± 8.38 (S) 104.4 ± 40.6 (W)	-	69
November 2015 and October 2016 (During Diwali)	Indra Gandhi Technical University for Women, Delhi	Fine Particulate Sampler (APM 550)	24 hrs		**2015-** 160.76(Pre-Diwali),308.82 (DuringDiwali) ,222.02 (Post Diwali) **2016-** 122.15 (Pre-Diwali),766.15 (DuringDiwali) ,645.18 (Post Diwali)	**2015-** 10.83(Pre-Diwali),5.73 (DuringDiwali) ,9.39 (Post Diwali) **2016-** 8.14 (Pre-Diwali), 8.34 (DuringDiwali) ,14.83 (Post Diwali)	**2015-** 31.83 (Pre-Diwali),48.34 (DuringDiwali) , 38.63 (Post Diwali) **2016-** 36.25 (Pre-Diwali), 64.15 (During Diwali), 106.28 (Post-Diwali)	Adverse meteorological parameters and adverse stubble burning in 2016 caused the concentration to be this much higher.	65
January 2016 – June 2016	Indra Gandhi Technical University for women, Delhi	Fine Particulate Sampler (APM 550)	24 hrs		128.5 ± 51.5	-	-	-	64

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1-15 January 2016 (Phase 1) & 15-30 April 2016 (Phase 2)	CSIR – NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs		**Phase 1** Before – 254 ± 82.5, During- 220.9 ± 77.8, After- 208.5 ± 31.8 **Phase 2** Before 138.0 ± 14.2, During - 163.7 ± 20.7, After - 135.8 ± 23.6	**Phase 1** Before – 12.4 ±2.1, During- 11.6 ±1.1, After – 15.4 ± 1.6 **Phase 2** Before 4.6 ± 1.5, During- 5.3 ± 1.9, After- 3.9 ± 1.4	**Phase 1** Before- 29.3 ± 9.2, During- 27.8 ± 6.1, After-28.8 ±2.6 **Phase 2** Before 10.6 ± 2.9, During- 13.1 ± 6.0, After- 9.6± 1.2	-	66
December 2016 – December 2017	Indra Gandhi Technical University , Delhi	Fine Particulate Sampler (APM 550)	24 hrs	-	134.6 ± 84	-	-	-	70
May 2017- June 2017	Delhi	High Volume Sampler (APM 550)	24 hrs	-	91.5	-	-	-	71
January 2017- December 2017	IIT Delhi	Medium Volume Sampler (APM 550)	8hrs	165 ± 72 (W), 129 ± 78 (M), 108 ± 32 (Pre- M), 323 ± 101 (PM)	181 ± 115	-	-	-	45
January 2018 – December 2018	IIT Delhi IITM Delhi	High Volume Sampler	12 hrs (Jan – mid mar) 24 hrs (mid Mar- Dec)			**At IITD-** 4.2 ± 0.8 (PM), 6.5 ± 2.1 (W), 4.2 ± 0.8 (S) & 2.2 ±0.9 (M) **At IITMD-** 3.7 ± 0.8 (PM), 5.8 ± 1.4 (W), 2.6 ± 0.7 (S) & 1.9 ± 0.8 (M).	**At IITD-** 40.12 ± 15.5 (PM), 31.5 ± 11.7 (W), 10.9 ± 3.9 (S) & 8.4 ±2.6(M). **At IITMD-** 42.2 ± 28.8 (PM), 27.3 ± 9.2 (W), 8.4 ± 2.6 (S) &	-	67

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							6.3 ± 2.6 (M).		
January, February, April&October 2018	**Construction-** IITD **Paved Road Dust** – IITD, CRRI Delhi, Okhla Delhi **Roadside biomass burning-** IITD **Solid Waste Burning-** Bhaswala **Crop Residue Burning –** Panipat	Mini- Vol Portable air sampler	**CON** - 8hrs. **PRD-** 30mins **RBB-** 30mins **SWB** - 30 mins **CPB-** 30mins			**CON-** 17.9 ± 9.3 **PRD-**0.9 ± 0.2 **RBB-** 5.7 ± 3.7 **SWB-** 2.0 ± 1.8 **CPB-** 3.5 ±0.9	**CON-** 12.7 ± 6.4 **PRD-**15.1 ± 4.3 **RBB-** 58.7 ± 7.0 **SWB-** 53.8 ± 5.8 **CPB-** 53.7 ±4.7	-	68
January 2012-December 2021	CSIR – NPL Delhi	Fine Particulate Sampler (APM 550)	24 hrs		133±92 (2012) 136±91(2013) 113±96 (2014) 123±65 (2015) 138±58 (2016) 143±70 (2017) 124±70 (2018) 129±96 (2019) 117±68 (2020) 109±53 (2021)	10.1±6.4 (2012) 11.4±7.5 (2013) 9.5±8.4 (2014) 6.0±3.3 (2015) 4.9±3.8 (2016) 6.5±3.8 (2017) 6.8±4.4 (2018) 7.0±5.1 (2019) 6.2±4.6 (2020) 5.9±3.6 (2021)	18.7±10.6 (2012) 19.3±13.9 (2013) 16.6±14.5 (2014) 13.8±9.1 (2015) 14.5±13.2 (2016) 17.0±11.7 (2017) 13.4±9.5 (2018) 15.8±14.2 (2019) 14.2±11.0 (2020) 14.0±8.9 (2021)		62

PM- Post Monsoon, Pre- M – Pre Monsoon, W- Winter, M- Monsoon, S- Summer

4.1.Seasonal Variation

Various researchers assessed seasonal variation at IITM Delhi as shown in table 1 and their studies showed higher concentrations during post-monsoon and winter, which is due to persistent thermal inversion and foggy conditions at ground level causing accumulation of pollutants near ground level. The lowest concentration is observed during monsoon, which is due to the wash-out effect [51,43,52,49,53,54]. Concentration each year in every season is found to be increasing from the previous and every given concentration is higher than the average concentration prescribed by WHO and NAAQS.

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Some researchers recorded seasonal concentrations of fine particulate matter at CSIR-NPL Delhi and their results showed high concentrations during winter and lower concentrations during the monsoon, higher concentration during the winter season is characterized by intense atmospheric stability and higher pollution levels, due to increased biomass burning activities. However, lower pollution in monsoon is due to frequent rainfall associated with wet deposition of pollutants [55,56,57,58,59,60].

4.2. Average Concentration Assessment and Source Apportionment Studies

At IITM Delhi average concentration was observed by various researchers and the concentration found to be 209.6 ± 145.5 µg/m^3[51], 122.3 ± 90.7 µg/m^3[52], 129.8 ± 103.4 µg/m^3[49], 211.67 ± 41.94 µg/m^3[53], 153.57 ± 41.94 µg/m^3[54] and 171.6 ± 51.6 µg/m^3[61] respectively. As shown in "fig. 1" concentration is found 10-20 times and 2-5 times greater than the annual average standard given by WHO and NAAQS respectively. An increasing trend can also be seen, which is due to the increasing number of vehicles, increased industrial activities etc in the city. A study by 51,53 shows a high peak, which is due to the short study in the winter season. At this time of the year concentration level of pollution is high due to the combined effect of the burning of biofuels and solid waste for heating purposes, calm weather conditions, lower mixing depth and the presence of an inversion layer near the ground surface traps the pollution near the ground.

Concentration of $PM_{2.5}$ observed by various researchers at CSIR – NPL Delhi is 133 ± 92 µg/m^3, 186 ± 47.49 µg/m^3 [62], 136± 91 µg/m^3 [62], 125.5 ± 77.2 µg/m^3[56], 122 ± 94.1 µg/m^3[57], 121 ± 93.2 µg/m^3[58], 113 ± 96 µg/m^3[62], 114.7 ± 48.0 µg/m^3[59], 131 ± 79 µg/m^3 [60], 123 ± 65 µg/m^3 [62], 138 ± 58 µg/m^3 [62], 143±70 µg/m^3 [62], 124±70 µg/m^3 [62], 129±96 µg/m^3 [62], 117±68 µg/m^3 [62], and 109±53 µg/m^3 [62], respectively. Concentration is found to be increasing 11- 18 times and 4- 2 times higher than WHO and NAAQS respectively, as shown in "fig. 2", a peak shown in the study by 55 because its study period is short and is conducted in the winter month when pollution level remains high due to burning of fossil fuels for heating purposes and calm weather condition. The figure shows a non-significant decreasing trend in the concentration of pollutants on the selected site.

Studies conducted by 63 at G.G.S.I.P. University, 64 at Indra Gandhi technical University, Delhi and by 45 at IIT Delhi showed concentrations of 50.6 ± 20.4 µg/m^3, 128.5 ± 51.5 µg/m^3 and 181 ± 115 µg/m^3 respectively, the concentration at all the sites are 5 – 18 times and 4 times higher than WHO and NAAQS, respectively.

Various studies reviewed in this paper also conducted source apportionment studies by applying statistical models. They found almost similar sources which are soil dust, secondary aerosols, construction activities, industrial emission, vehicular emission, agricultural burning and solid waste incineration and biomass burning.

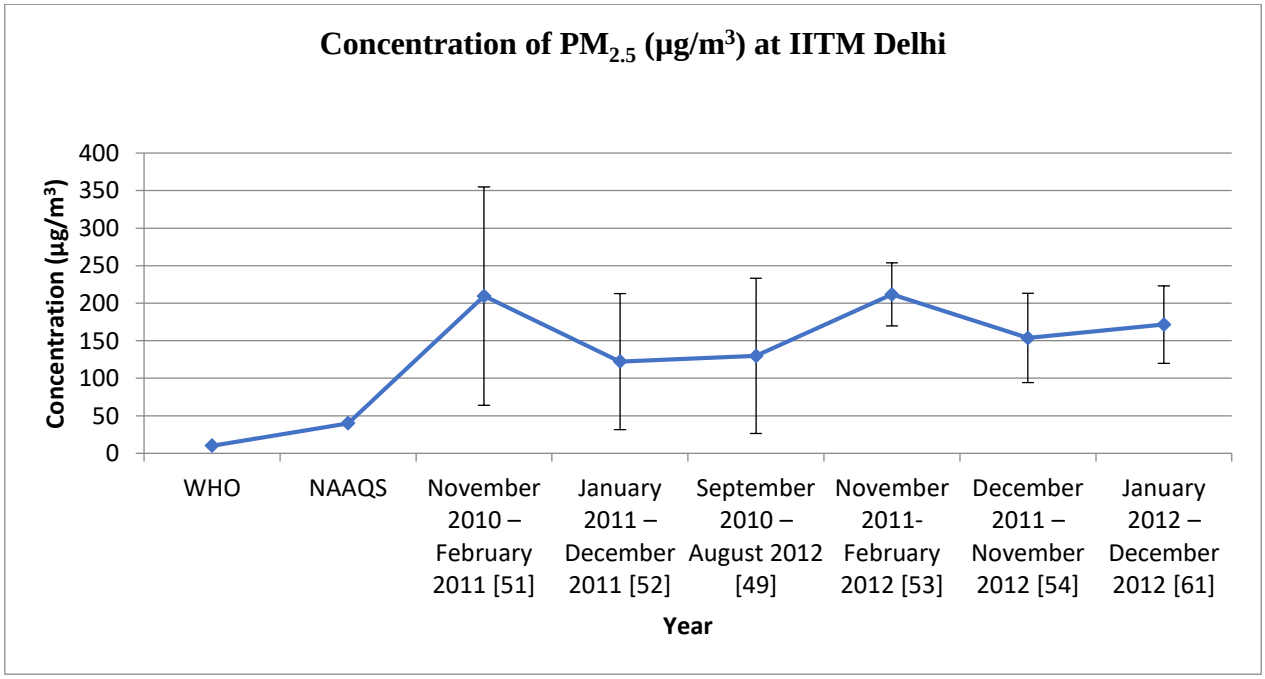

Figure 1: Concentration of $PM_{2.5}$ (µg/m^3) at IITM Delhi

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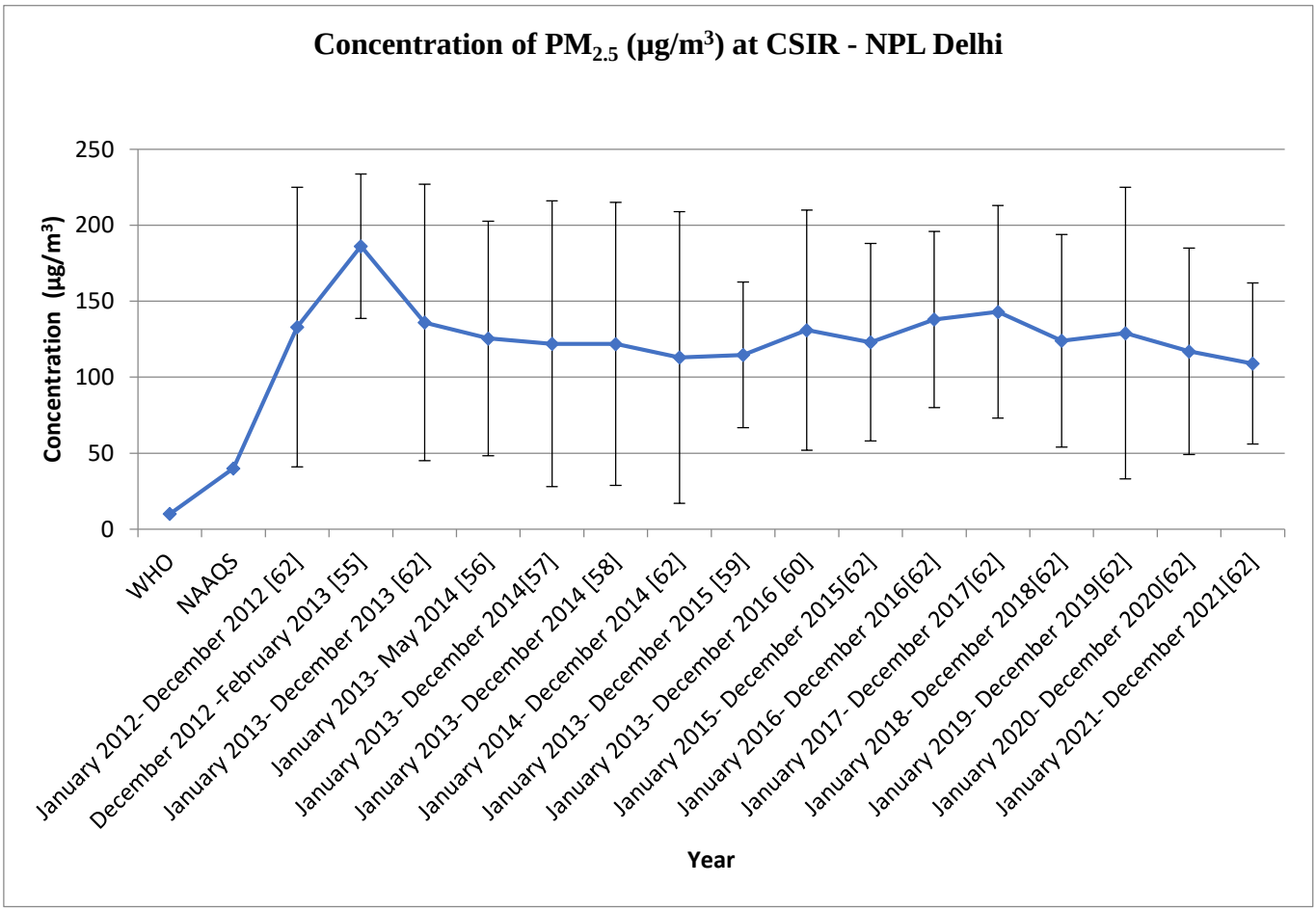

Figure 2: Concentration of $PM_{2.5}$ (µg/m^3) at CSIR - NPL Delhi

4.3. Concentration on Special Events

One of researcher determined the concentration before, during and after Diwali in November 2015 and October 2016 at Indra Gandhi Technical University, Delhi. They observed the following pattern, the pre -Diwali concentration is low as compared to the concentration during the Diwali time and post-Diwali concentration again became low as compared during Diwali time in both years. But there is a significant variation in the concentration, in 2016. During Diwali 2016, concentration was twice as high as compared during Diwali in 2015. The reason behind this variation was higher wind speed and low moisture content during 2015 and adverse meteorological parameters observed for the year 2016 as the westerly winds from adjacent states of Delhi carried smoke released from stubble burning towards Delhi during the Diwali period [65].

To curb the deteriorating air quality of Delhi, the state government announced a plan to restrict the movement of private vehicles. In the plan globally known as "road space rationing", vehicles with odd-numbered registrations will be allowed to ply on odd dates and even-numbered registration will be allowed to ply on even dates of the month between 8 a.m. to 8 p.m., except on Sunday [66]. Impact of an odd-even scheme on the fine particulate pollution concentration is observed by 66 in two phases (Phase 1- 15 Jan 2016 & Phase 2- 15-30 Apr 2016) at CSIR-NPL Delhi. They assessed the concentration 2 weeks prior, during and after 2 weeks of scheme implementation. They found that during Phase 1 the reduction in the concentration of $PM_{2.5}$ accounts was marginally by -13% when compared with data before and after implantation of the odd-even scheme. However, in Phase 2 an opposite observation was made, the concentration was seen increasing marginally by 18% (as shown in table 1), reason behind this is the presence of other sources such as soil dust, secondary aerosol, biomass burning and fossil fuel combustion which also contribute to particulate pollution.

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5. PREVIOUS FINDINGS ON ORGANIC CARBON AND ELEMENTAL CARBON STUDIES

Various researcher observed the concentration of Organic Carbon and Elemental Carbon at IITM Delhi and the results reveal that the average concentration is 54.1 ±38.7µg/m^3&10.4 ±4.6 µg/m^3[51], 50.11 ± 11.93 µg/m^3& 10.67 ± 3.56 µg/m^3[53], and 33.51 ± 15.89 µg/m^3 & 6.96 ± 3.97µg/m^3[54]. In the study of 51,53 concentration of OC & EC was found to be much higher than in 54. This was due to the short study during the winter season as shown in "fig 3".

Some researchers assessed the concentration of OC & EC at CSIR-NPL Delhi and found concentration 16.46 ± 6.61 µg/m^3& 12.4 ± 4.43 µg/m^3[55], 17.7 ± 12.2 µg/m^3 & 10.3 ± 6.9 µg/m^3[56], 17.79 ± 14.3 µg/m^3 & 10.4 ± 8.04 µg/m^3[57], 17.6 ± 14.1 µg/m^3 & 10.2 ± 7.54 µg/m^3[58], 15.7 ± 12.7 µg/m^3 & 7.31 ± 6.17 µg/m^3[60] respectively as shown in "fig 4" , OC & EC contributes to a significant portion of $PM_{2.5}$ as shown in the above given studies. It was also noticed that the concentration of EC and OC is higher in winter as compared to summer and monsoon season which is due to the source strength of $PM_{2.5}$ and prevailing meteorological conditions, sources which are responsible for mainly OC & EC are vehicular traffic and biomass burning.

One of the researcher assessed the concentration at two sites in Delhi one at IIT Delhi and the second at IITM Delhi. IITM Delhi is most polluted site as compared to IIT Delhi in terms of OC with concentration 42.2 ± 28.8 µg/m^3 (Post – Monsoon), 27.3 ± 9.2 µg/m^3 (Winter), 8.4 ± 2.6µg/m^3 (Summer) & 6.3 ± 2.6µg/m^3 (Monsoon) and IIT Delhi 40.12 ± 15.5µg/m^3 (Post – Monsoon), 31.5 ± 11.7µg/m^3 (Winter), 10.9 ± 3.9 µg/m^3 (Summer) & 8.4 ±2.6 µg/m^3 (Monsoon). In terms of EC, IIT Delhi 4.2 ± 0.8 µg/m^3 (Post - Monsoon), 6.5 ± 2.1µg/m^3 (Winter), 4.2 ± 0.8 µg/m^3 (Summer) & 2.2 ±0.9 µg/m^3 (Monsoon)being near to the heavy traffic road is more polluted as compared to IITM Delhi 3.7 ± 0.8 µg/m^3 (Post – Monsoon), 5.8 ± 1.4 µg/m^3 (Winter), 2.6 ± 0.7 µg/m^3 (Summer) & 1.9 ± 0.8 µg/m^3 (Monsoon) [67]. This study showed that the concentration of EC & OC is higher during winter and post-monsoon due to the shallow boundary layer and dominance of biomass burning. A short-term study is also conducted (January, February, April and October 2018) on five sites of the Delhi and measured the concentration of EC and OC, the results are given respectively:- Construction site (17.9 ± 9.3 µg/m^3& 12.7 ± 6.4 µg/m^3), paved road dust site (0.09 ± 0.2 µg/m^3& 15.1 ± 4.3 µg/m^3), roadside biomass burning (5.7 ± 3.7 µg/m^3& 58.7 ± 7.0 µg/m^3), solid waste burning (2.0 ± 1.8 µg/m^3& 53.8 ± 5.8 µg/m^3) and crop residue burning site (3.5 ± 0.9 µg/m^3& 53.7 ± 4.7 µg/m^3) [68]. In this study, the highest percentage of carbonaceous aerosols was found in the combustion source profile site which is due to the burning of carbon-containing material. In paved road emission, EC & OC is due to traffic emission including brake and tyre wear and oil drips.

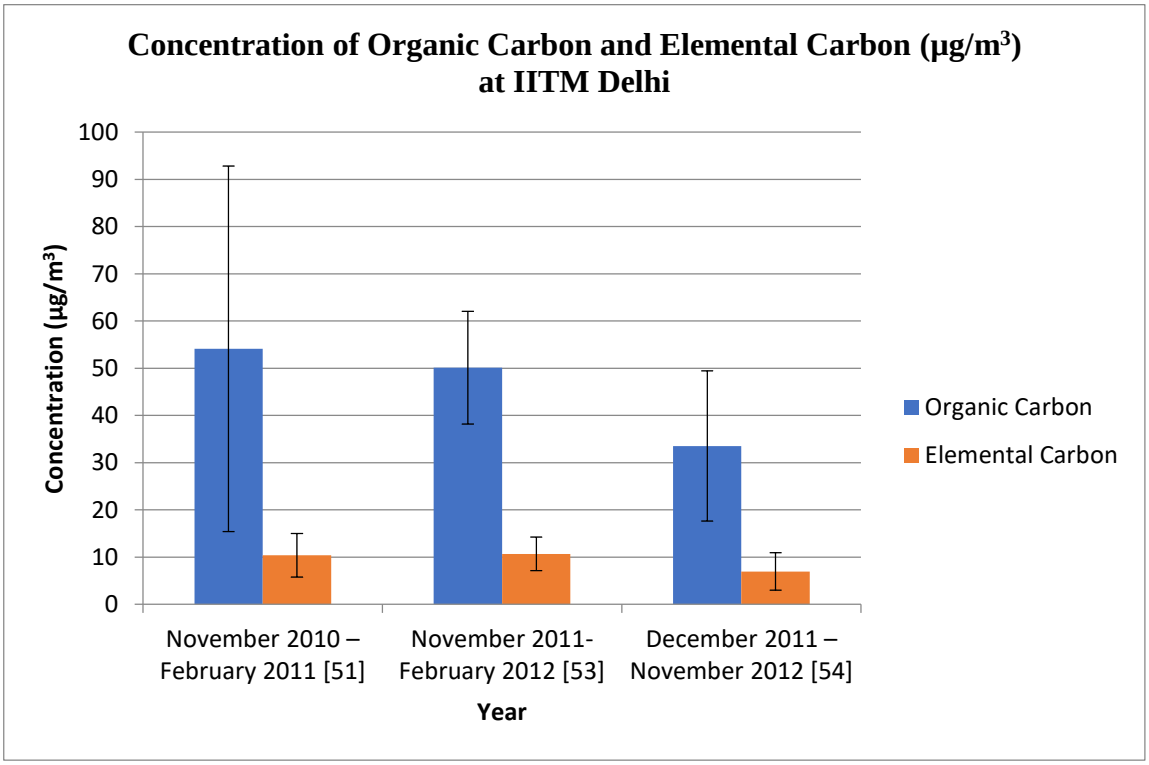

Figure 3: Concentration of Organic Carbon and Elemental Carbon (µg/m^3) at IITM Delhi

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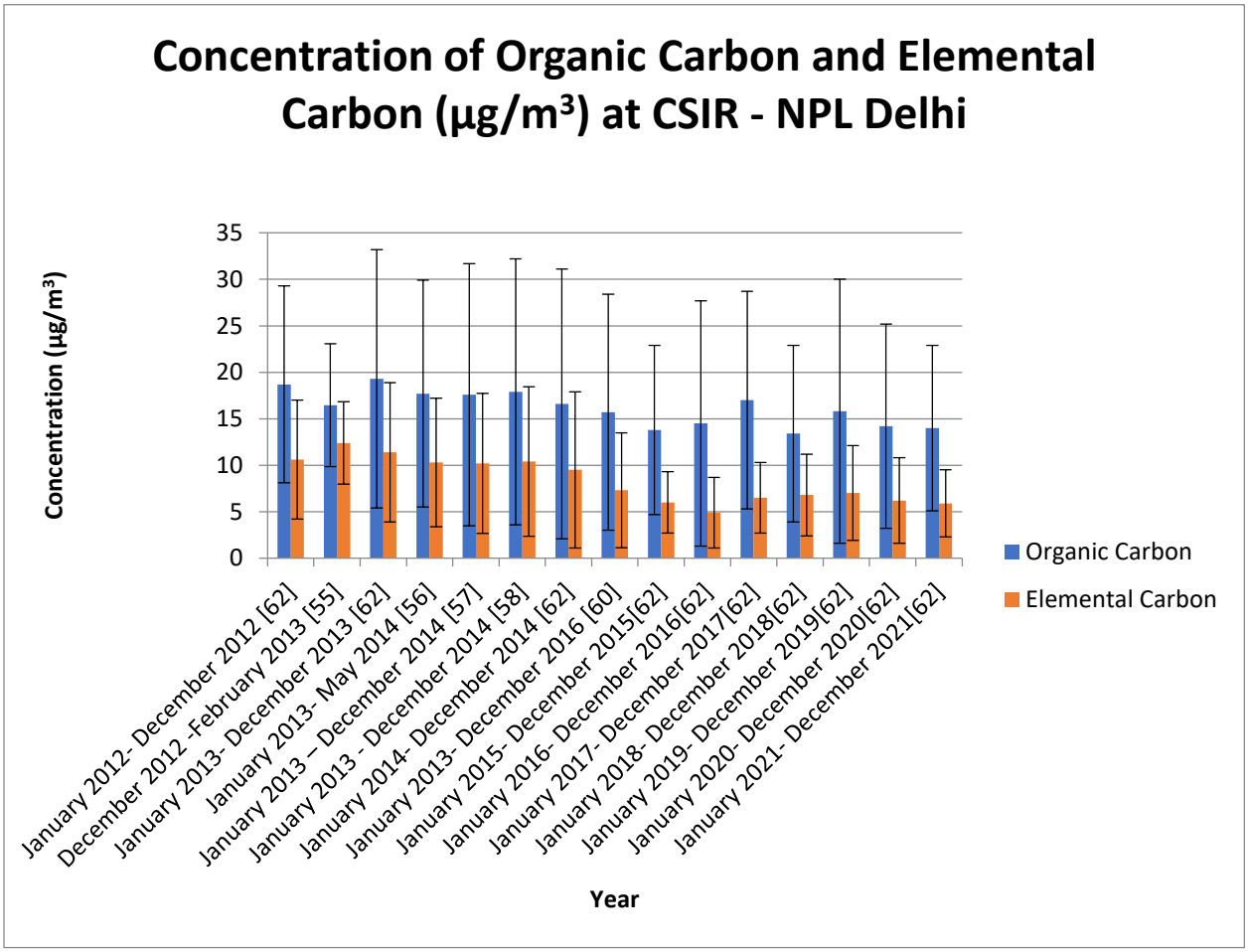

Figure 4: Concentration of Organic Carbon and Elemental Carbon (µg/m^3) at CSIR - NPL Delhi

5.1. Concentration on Special Events

Concentration was measured at festival Diwali times in the city during November 2015 and October 2016 and the result observed during both periods showed greater variation. They observed the results as – pre–Diwali, during – Diwali and post – Diwali. The concentration of EC and OC during 2015 is 10.83 (Pre-Diwali), 5.73 (During – Diwali), 9.39 (Post – Diwali) & 31.83 (Pre –Diwali), 48.34 (During – Diwali), 38.63 (Post – Diwali) and during 2016 8.14 (Pre-Diwali), 8.34 (During – Diwali), 14.83 (Post – Diwali) & 36.25 (Pre –Diwali), 64.15 (During – Diwali), 106.28 (Post – Diwali) [65]. In both years concentration varies significantly which is due to low wind speed along with high humidity during the Diwali period in 2016 and this led to an increase in the concentration of pollutants in the lower atmosphere. In addition, smoke released from stubble burning which was carried by westerly winds from adjacent states during Diwali, the period was also responsible for high levels of OC during the post – Diwali. EC was lower during both years which is because EC is used as a tracer for vehicular emission. The day of Diwali, being a national holiday has a lower traffic density which accounts for lower levels of EC.

Concentration was also measured during the odd-even strategy applied to the city they measured the concentration before, during and after the odd-even strategy in two phases and the results showed that the concentration of EC and OC Phase 1, Before odd even – 12.4 ±2.1, During odd-even - 11.6 ±1.1, After odd even – 15.4 ± 1.6 & Before odd een - 29.3 ± 9.2, During odd-even - 27.8 ± 6.1, After odd even - 28.8 ± 2.6 in Phase 2 Before odd even - 4.6 ± 1.5, During odd-even – 5.3 ± 1.9, After odd even - 3.9 ± 1.4 &Before 10.6 ± 2.9, During- 13.1 ± 6.0, After- 9.6± 1.2 [66].

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6. CONCLUSION

In every study, the concentration of $PM_{2.5}$ is found to be exceeding the annual standard concentration prescribed by WHO and NAQQS by 10-20 and 2 – 5 times. A non-significant decreasing trend in concentration can be observed. A varied seasonal trend in the concentration can also be seen. Concentration is found to be higher in post-monsoon and winter whereas lower in monsoon and summer. The reason behind high concentration in post-monsoon and winter is a persistent thermal inversion, foggy conditions, firecrackers burning during Diwali, increased agricultural burning, bio-fuels and solid waste burning for heating purposes, while low concentration during monsoon is a wash-out effect and during summer higher wind speed and a deeper mixing layer can lead to the better dispersion of pollutant which in turn leads to lower concentration.

Elemental carbon and Organic carbon contribute to a significant portion of $PM_{2.5}$. Studies reviewed here show an increase in the concentration of carbonaceous aerosols. Dominant sources of carbonaceous aerosols are vehicular traffic and biomass burning. More critical studies on carbonaceous aerosols are required to reduce their concentration in the environment. Till now there is no threshold value available for Organic carbon and Elemental carbon, therefore more studies on these species will give a proper picture for understanding their behaviour in the atmosphere and how they are affecting the health of the atmosphere and human beings. Elemental carbon is also a major contributor to global warming after CO_2.Therefore studies focusing on source reduction of EC are also needed.

Source apportionment studies in the research papers that were discussed reveal common sources of particulate pollution in the city such as soil dust, secondary aerosols, vehicular emission, industrial emission and biomass burning. A high concentration of $PM_{2.5}$ also leads to respiratory and cardiovascular diseases. That is the reason why governments around the world should set up strategies for controlling $PM_{2.5}$ emissions and also develop guidelines for limiting $PM_{2.5}$ exposure.

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