University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Levels of Particulate Matter, Black Carbon, and Toxic gases (O_3, NO_2) in Taj City Agra and their Health implications on Human Being

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Article Info

Article type:
Research Article

Article history:
Received: 24 Dec 2022
Revised: 14 Mar 2023
Accepted: 11 May 2023

Keywords:
Particulate Matter
Black Carbon
O3
MPPD
Health risk Assessment

ABSTRACT

Real-time monitoring of Black Carbon and Particulate Matter was done by Aerosol Black Carbon Detector (ABCD) and GRIMM portable aerosol Spectrometer in Agra at five different locations (R1, R2 traffic and R3, R4, R5 residential road sites). Major portion of PM mass was contributed by PM10 followed by PM2.5 and PM1.0. Major portion of PM in number mode is contributed by PM10=PM0.25 followed by PM5.0 =PM0.5, PM1.0, and PM2.5. All the PMs mass and number concentration was highly associated with the R1 site due to the vehicular and other anthropogenic activities and was least at R5 except for PM10. The highest concentration of BC was found at R2 site followed by R1 while During the sampling events NO2 and O3 was found highest at R2 site followed by R1. The source of BC, PMs, NO_2, O_3 at R1& R2 may be vehicular activities, population activities, crowded area, and industrial activities. BC contribution in PM1.0 was highest followed by PM2.5. The children category in the traffic site has high PM deposition mass visualization as compared to the residential road site so they are highly affected by lung diseases instead of the residential road site children category. From health risk assessment results, it was found that no population was at non-carcinogenic risk from chronic exposure to PM10 while children may be at possible risk from acute exposure. However, cancerous risk assessment showed that both children and adult were at risk from exposure of PM2.5 and may develop cancerous diseases.

Cite this article: Rajouriya, K.., Dubey, S., Pratap Singh, Sh., Tripathi, T., John, R., and Taneja, A. (2023). Levels of Particulate Matter, Black Carbon, and Toxic gases (O3, NO2) in Taj City Agra and their Health implications on Human Being. *Pollution*, 9 (3), 1208-1224.
https://doi.org/10.22059/poll.2023.352851.1731

DOI: https://doi.org/10.22059/poll.2023.352851.1731

INTRODUCTION

According to the Global Burden of Disease report 2019, air pollution is considered as a fifth leading risk factor for mortality worldwide and it is more dangerous as compared to other risk factors like malnutrition, physical inactivity and alcohol use (HEI 2019). Increasing urbanisation, industrialization, and motorization in developing countries like India are the major factors that contribute to air pollution. Toxic emissions (Particulate Matter, Black carbon, NOx, Trace Metals, PAHs) from industries, vehicles, and anthropogenic activities represent the main source of air pollutants (Pant and Harrison 2013; Rajouriya et al. 2020). Despite of improvements inefficiency of vehicular combustion and availability of alternative fuels, the use of conventional fuels is expected to increase by 1.4% per year until 2040 and will continue to be the main propulsion system in road transportation (U.S. IEA 2016). According to World Health Organization (WHO 2016), 90% of the world's population live in

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areas with ambient PM2.5 concentrations higher than the guidelines suggested by the WHO, responsible for about 3.0 million premature deaths annually.

In 2017, air pollution was the fifth highest mortality risk factor globally and was associated with about 4.9 million deaths and 147 million years of healthy life lost (HEI 2019). Air pollution accounts for 41% of global deaths from chronic obstructive pulmonary disease (COPD), 20% of deaths from type 2 diabetes, 19% of deaths from lung cancer, 16% of deaths from ischemic heart disease, and 11% of deaths from stroke (HEI 2019). Among various pollutants, particulate matter plays a significant role in polluting air and can be defined as solid or liquid droplets that are suspended in the environment; it is also called particle pollution (Tiwari et al. 2020).These particles are present in the air in different shapes and sizes and get deposited into the lung's respiratory tract on the basis of their shapes and sizes. Such as coarse particles (PM10-2.5) deposit into the upper respiratory tract on the other hand fine particles (PM2.5) collect deeper into the lungs region and causes serious threat to the population (Rajouriya et al. 2020).Traffic emission and some other anthropogenic activities are the main source of Particle Number (PN) concentration (sub-micrometer fraction) and are responsible for toxic effects on human beings (Kumar et al. 2014). Ultrafine Particles travel deeper in the respiratory organ where they react with epithelial cells causing damage (Terzano et al. 2010).

Some other pollutants (Black Carbon, NO_2) also give equal significant contribution in the Air pollution.Black Carbon comprises a substantial fraction of fine PM in traffic environments and it is mainly emitted from vehicular emission (Krecl et al. 2018).It has toxic effect on the environment and also contributes to global warming (Bond et al. 2013), it effects human being health, and may even shorten life expectancy (Janssen et al. 2012).NO_2 (comprised mainly by NO and NO_2 in urban areas) are precursors for a number of harmful secondary air pollutants such as O_3 and $PM_{2.5}$, and play a role in acid deposition and eutrophication (Krecl et al. 2018). The objectives of the present study are 1) To identify the PM, Black Carbon and toxic gases concentration in Taj City, Agra, 2) To examine impact of vehicular emission on BC and PM, 3) To know about the impact of vehicular pollution on residential areas, 4) To explore the relation between BC, PM and Meteorological parameter 5) To assess health risk by Particulate Matter of different sizes.

MATERIALS AND METHODS

Site Description

Agra (27.1767°N, 78.0081°E), the Taj city located in the central part of northern India attracted nearly seven million visitors in 2018-19 (LokSabha 2019). It is situated on the banks of the river Yamuna in Uttar Pradesh. It is about 204 km of south of Delhi and surrounded by the Thar Desert of Rajasthan on its southeast, west and northwest peripheries. Agra has semiarid weather and a subtropical climate. The population of Agra was about 1.84 million in 2017 with a population density of 1084 person km^{-2} and female: male ratio of 0.87:1.0. The summer period is hot and dry with the temperature ranging from 32-48 ºC with predominant wind direction being south– southeast and northeast. In winter the temperature ranges from 2-15 ºC and wind direction changes to west–northwest and north–northwest (IMD 2009). Four main National Highways (NH-2, NH-3, NH-11, and NH-93) pass through the city. Major sources of PM (Particulate Matter) and BC (Black Carbon) pollution in Agra are Vehicles(17%), Industries (9%), Household effluent (Nagar et al. 2021).

Sampling Procedure

Sampling was carried out in Agra at five different locations which included two traffic site (R1& R2) and three residential road sites (R3,R4, and R5).Both of the traffic sites were too crowded and situated at the centre of Agra. Sampling sites were depicted in Figure 1. Black Carbon and Particulate Matter real-time monitoring was done in the month of October by Aerosol Black Carbon Detector (ABCD) and GRIMM aerosol Spectrometer sampler.

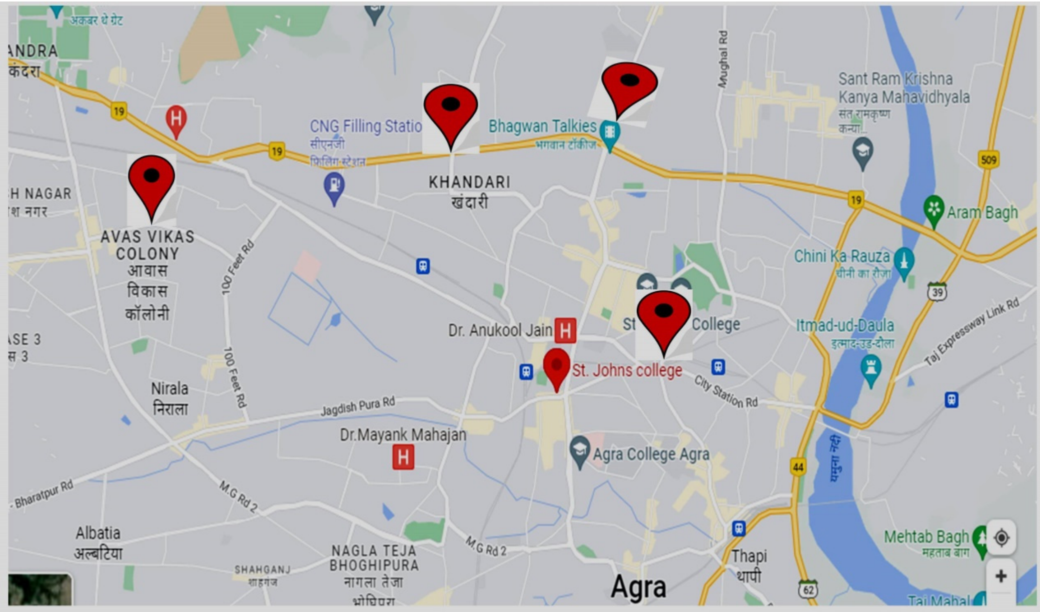

Fig. 1. Five Different Sampling locations at Taj city (Agra)

Instrumentation

Real-time monitoring of PM (diameter range from 0.22 to 32µm) was done by Grimm Portable Aerosol Spectrometer (model 1.109) at five sites (included 2 traffic sites and 3 residential roadside sites). It provides data in countable mode as well as mass mode and can monitor particles in 32 sizes. BC concentrations were estimated by Aerosol Black Carbon Detector (ABCD), Observe Air version 1.0. It consists of photodiodes which measured the transmission intensity of light passing through an aerosol loaded filter (sample) at wavelength 880 nm and compares the same with that of an unexposed blank filter (reference) thereby determining the attenuation (ATN).

Statistical Analysis

Multiple Particle Dosimetry Model (MPPD)

Applied Research Associates, Inc. developed a model namely MPPD to identify the age specific deposition of PM with the various options in it for idealizing human body such as Yeh-Schum, stochastic, age-specific, Weibel and Pacific Northwest National Laboratories models. All these models worked under two categories such as single-path and multiple-path method. In this study, PM deposition in all airways of the lungs is assessed by multiple path methods. Most of MPPD studies are based on human and rat species. The PM properties play a vital role in lung depositions. Accordingly, various options such as density, aspect ratio, PM diameter are essential for calculation. In this model, the diameter can be specified to any of the following: count median diameter, mass median diameter, and mass median aerodynamic diameter. Instead of giving a specific size, the multiple particle sizes, i.e., size-segregated PM concentration can also be given here (Kumar et al., 2019).

Human Health Risk Assessment (WHO1999; USEPA 1988)

The Health risk assessment was done according to USEPA (Figure 2). Health effect due to acute and chronic exposure of PM10 (non-carcinogenic) was calculated by given equation. Exposure factors were taken from literature (Greene et al. 2006; USEPA 2014; USEPA 1997). The carcinogenic risk posed by $PM_{2.5}$ is determined by ELCR factor was calculated using formulae (Figure 2).

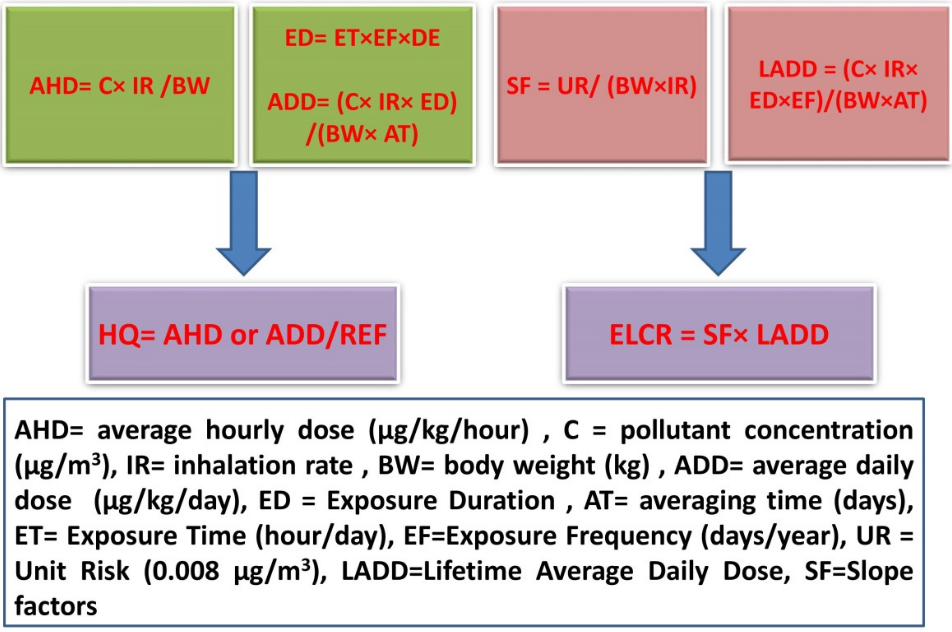

Fig. 2. Health risk assessment model prescribed by USEPA

RESULT AND DISCUSSION

Mass Concentration of Size Segregated Particulate Matter

The real time monitoring of size segregated Particulate Matter (PM) was done at 5 different sites in Agra region including two road-side traffic and three roadside residential locations. The sampling sites are given code as R1, R2, R3, R4, and R5 in which R1 and R2 was Roadside traffic and R3-R5 was residential roadside. GRIMM Aerosol Spectrometer measured different sizes particles ranging from 0.25-32.0mm although we considered only $PM_{10.0}$, $PM_{2.5}$, and $PM_{1.0}$ in mass mode. On analysing site-wise comparison of PM10, PM2.5 and PM1.0 mass, the concentration trend was found as R1>R4>R5>R3>R2, R1>R2>R4>R3>R5, and R1>R2>R3>R4>R5respectively (Figure 3). The Mass concentration of size segregated PM during the study period was recorded as PM_{10} (249.50mg/m^{-3}), $PM_{2.5}$ (68.51mg/m^{-3}), and $PM_{1.0}$ (43.03mg/m^{-3}). Nagar et al. (2021) found PMs Concentration as PM2.5 65; PM10 234 and TSP 465µg/m^{3} at Agra in 2018. On the other hand ,Kulshestra et al.(2009) found PMs levelas PM2.5 (64mg/m^{-3}) and PM10(185mg/m^{-3}) in Agra that is comparable to present study.Major portion of PM is contributed by PM10 (69.10%) followed by PM2.5 (18.97%) and PM1.0 (11.91%). All the PMs Mass concentration was highly associated with the R1 road side-traffic site and lowest found in residential site R5 except PM_{10} due to the earth's crust, and anthropogenic activities such as combustion processes and constructions**.** The average PM_{10} concentration was 5.54 and 2.49 times higher than the limits prescribed by WHO (45mg/m^{-3}) and NAAQS (100mg/m^{-3}) government agencies. On the other hand, $PM_{2.5}$ concentration was 4.56 and 1.14 times higher from WHO (15mg/m^{-3}) and NAAQS (60mg/m^{-3}) limits.

From the present study, it was inferred that all the size segregate PM mass concentration was found highest at traffic sites (R1+R2) instead of residential road sites (R3+R4+R5). Mass concentration of fine PM was highest at traffic sites attributed to exhaust emissions, emissions due to wear and tear of vehicle parts such as brake, tyre and clutch and re-suspension of dust (non-exhaust emissions) whereas coarse particles were higher in concentration due to non-exhaust emissions like re-suspension of dust (Thorpe et al., 2007; Kam et al., 2012; Pant and Harrison 2013).

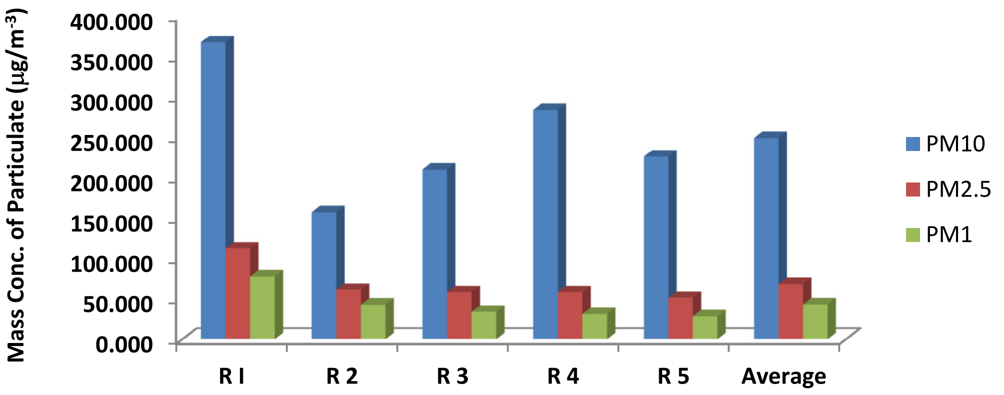

Fig. 3. Size Segregated Particulate Matter mass concentration at different sites of Taj City

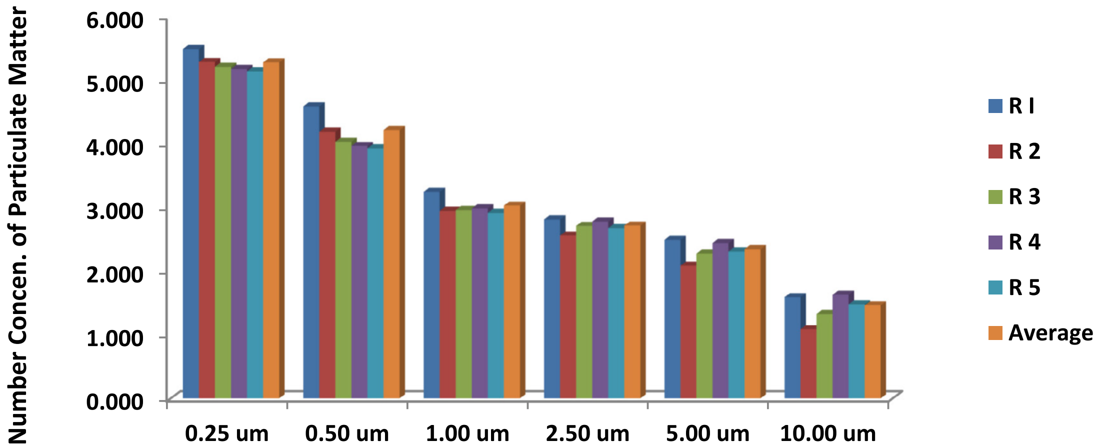

Fig. 4. Particle Size Distribution in Number Mode

Particle size distribution in Number

GRIMM Aerosol Spectrometer measured different sizes Particles ranging from 0.25-32.0mm although for this study we consider only $PM_{10.0}$, $PM_{2.5}$, and $PM_{1.0}$ in number mode. On site-wise comparison, average PM10, PM2.5 and PM1.0 number concentration trend was found as R4>R1>R5>R3>R2, R1>R4>R3>R5>R2 and R1>R4>R3>R2>R5 respectively (Figure 4). The Number concentration (log) of size segregated PM during the study period was recorded as PM_{10}(1.46), $PM_{5.0}$ (2.34) $PM_{2.5}$ (2.71), and $PM_{1.0}$ (3.03), $PM_{0.5}$ (4.21), $PM_{0.25}$ (5.27). Major portion of PM is contributed by PM_{10} (27.70%) followed by $PM_{5.0}$ (22.14), $PM_{2.5}$ (14.26%) and $PM_{1.0}$ (15.91%), $PM_{0.5}$ (22.14), $PM_{0.25}$ (27.70). At all sites, the number concentration of coarse particles was found in lower concentration as compared to fine and ultrafine particles. The concentration of PM in mass as well as number mode given in Table 1.

Black Carbon Concentration

Day-wise variations of BC concentration at 5 sampling sites were depending on the local traffic patterns, predominant wind direction, industrial activities, and population activities. The lowest BC concentrations were monitored at residential sites (R4) and highest at R2 site shown in Figure 5. The overall average of BC concentration in Agra was found 4.54µgm-^{3}. The source of BC at these sites (RI and R2) may be vehicular activities, population activities, crowded area,

Table 1. Descriptive statistics of temperature and concentration of PM_{10}, $PM_{2.5}$, and PM_1 were recorded in the selected locations.

	Statistics	PM_{10}		$PM_{2.5}$		PM_1	
		Count	Mass	Count	Mass	Count	Mass
R1	Min	15.00	197.70	366.00	65.50	962.00	39.80
	Max	117.00	804.50	969.00	172.70	5683.00	131.50
	Averag	38.93	368.11	651.16	112.73	1773.77	78.10
	SD	23.62	119.23	185.27	24.10	895.31	21.00
	Average T (^{0}C)			39.63			
R2	Min	3.00	71.80	189.00	39.30	432.00	23.50
	Max	24.00	252.50	642.00	110.10	2811.00	83.70
	Average	12.23	157.63	364.34	61.38	892.76	42.83
	SD	5.03	54.36	137.36	19.37	447.00	15.20
	AverageT (^{0}C)			38.48			
R3	Min	6.00	107.60	171.00	40.80	514.00	19.50
	Max	58.00	472.40	1288.00	95.70	1557.00	65.60
	Average	21.34	210.61	515.58	58.54	918.10	34. 13
	SD	12.84	80.19	256.30	12.51	259.90	9.75
	AverageT (^{0}C)			37.88			
R4	Min	9.00	103.70	162.00	31.30	427.00	17.20
	Max	410.00	1101.70	1586.00	103.20	2021.00	38.70
	Average	42.70	284.43	604.67	58.58	972.88	31.35
	SD	68.85	218.99	418.48	20.80	474.14	7.15
	AverageT (^{0}C)			40.08			
R5	Min	4.00	102.60	196.00	33.90	514.00	16.40
	Max	93.00	682.60	1684.00	108.70	2043.00	41.80
	Average	30.26	226.71	474.96	51.34	831.64	28.73
	SD	20.54	118.41	275.55	14.31	290.94	8.03
	AverageT (^{0}C)			36.79			

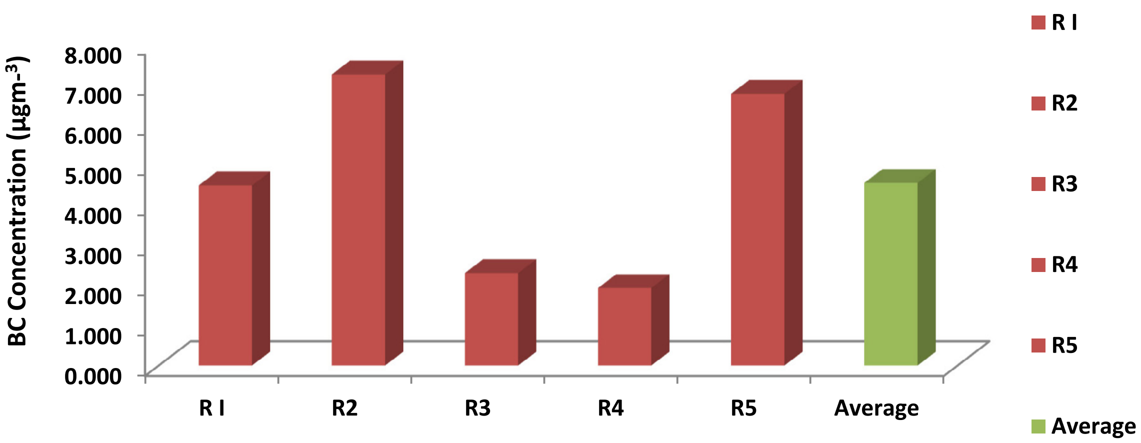

Fig. 5. Black Carbon Concentrations at Different Sites of Agra

and industrial activities. According to CPCB report in 2019 the 24 h average BC concentration must be 4.5~5 μg m^{-3}. Ambade et al.(2021) found average concentration of BC as 9.40± 2.73 μg m^{-3}, 1.85 ±0.36 μg m^{-3}, 2.24 ±0.55 μg m^{-3}, 2.69± 0.71 μg m^{-3}, 4.11 ±1.02 μg m^{-3} and 5.64 ±1.68 μg m^{-3} during normal days, lockdown 1.0, lockdown 2.0, lockdown 3.0, lockdown 4.0, and unlock down 1.0, respectively in India. On global comparison of BC, it was found that BC level of the present study was higher from Babu and Moorthy 2002 (4.2μg m^{-3}) and Safai et al. (2007) (4.1μg m^{-3}) in Bangalore and Pune in India (Urban) respectively except other given studies in Table 2.

NO_2 and O_3 Concentration at different sites

Day-wise NO_2 and O_3concentration at five different sites varied depending on surrounding land use, local traffic patterns, and prevailing wind direction, as depicted in Figure 6. During the sampling events NO_2 and $O_3$was found highest at R2 site (Khandari Crossing) followed by R1. Overall average of O3 and NO_2 was 0.010ppm and 0.004ppm respectively. Min et al.(2016) observed O_3 and NO_2 concentration level as 28.43 and 43.37 ppb in Nanjing, China.

Table 2. Comparison of BC mass concentration measured at different locations over India, and the world

Study	Place	Duration	Concentration of BC (μgm^{-3})
Present Study 2021	Agra, India	October, 2021	4.54
Kumar and Soni 2020	Delhi, India (Urban)	2016 to 2018	13.57
Kumar and Soni 2020	Kolkata, India (Urban)	2016 t0 2018	12.08
Rajesh and Ramachandran 2018	Ahmedabad, India (Urban)	January 2014 to December 2015	10.30
Tiwari et al. 2013	Delhi, India (Urban)	January to December 2011	6.64
Verma et al. 2013	Kolkata, India (Urban Mega-City)	December 2009-2010	35
Cao et al. 2009	Xian, China (Urban)	September 2003 to August 2005	14.7
Safai et al. 2007	Agra, India (Urban)	December 2004	20.6
Hussain et al. 2007	Lahore, Pakistan (Urban)	November 2005 to January 2006	21.7
Nair 2007	Kharagpur, India (Semi-Urban)	December 2004	16.5
Safai et al. 2007	Pune, India (Urban)	January to December 2005	4.1
Ganguli et al. 2006	Delhi, India (Urban Mega-City)	December 2004	29
Babu and Moorthy 2002	Trivandrum, India (Urban Costal)	August 2000 to October 2001	5
Babu and Moorthy 2002	Bangalore, India (Urban)	November 2001	4.2
Castanho and Artaxo 2001	Sao Paulo, Brazil (Urban)	July to September 1997	7.6
Ruellan and Cachier 2001	Paris, France (Urban)	August to October 1997	14

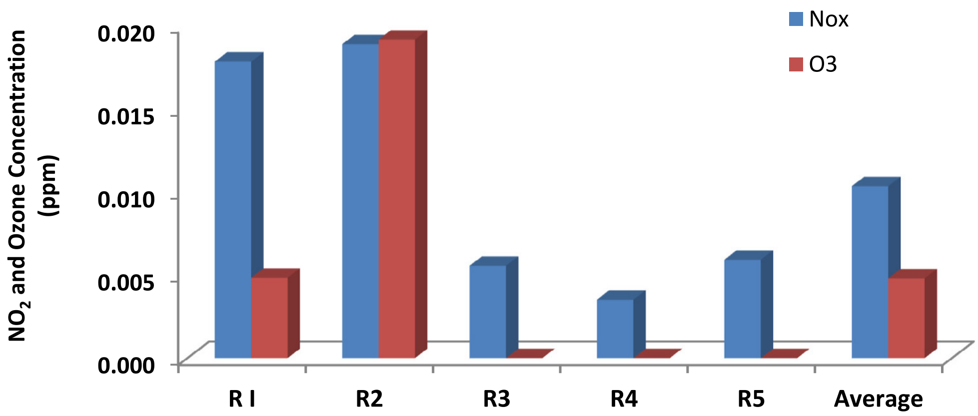

Fig. 6. Monitored Concentrations of NO_2 and Ozone in Taj City

Over all Comparison of monitored pollutant

Relationship between BC and PMs

The average of BC/PMs (PM10, PM2.5, and PM1) ratios was observed as 0.68%, 3.29%,6.16%. Ratio for individual PM10, PM2.5, and PM1 samples ranging from 0.68-4.60%,3.29-13.19%, and 5.76-23.56%. Site comparison of BC/PMs ratio trend was found as R1-5.74%(PM1)>3.98% (PM2.5)>1.22%(PM10); R2-16.93%(PM1)>11.81%(PM2.5)>4.60% (PM10); R3-6.75%(PM1)>3.93% (PM2.5)>1.09%(PM10); R4-6.16%(PM1)>3.29%(PM2.5)> 0.68%(PM10); R5-23.56%(PM1)>13.19% (PM2.5)>2.99% (PM10).Relation between BC and PMs was depicted in Table 3. From the trends it was inferred that BC contribution in PM1.0 was highest followed by PM2.5. Madhavi Latha and Badarinath (2005) reported BC as 7% of TSP at Hyderabad ,India, and Safai et al. (2007) reported BC as 2.3% of TSP for Pune, India. Venkatachari et al. (2006) reported higher BC fractions, 13% and 11% of PM2.5 mass at two sites in New York City.

Impact factors of BC variation

Meteorological Factors

The day to day variation of BC/PM10, BC/PM2.5 and BC/PM1.0 ratio, Wind Speed, and PM10, PM2.5, and PM1.0 was measured and depicted in Figure 7 (a, b, and c). In an aerial view, the BC/PM10varied from 1.164% to 3.62% with an average of 1.96% over theobservation period. The BC/PM2.5varied from 4.24% to 12.54% with an average of 7.21% over theobservation period. The BC/PM1.0varied from 5.99% to 20.69% with an average of 11.54% over theobservation period. The maximum BC/PM10(3.62%) appeared on 6 October of the sampling on the other hand BC/PM2.5 (12.54%), BC/PM1.0 (20.69%) was found highest

Table 3. Relation between Black Carbon and Size Segregated PM

Site	Black Carbon (BC)	PM10	PM2.5	PM1
R I		1.22%	3.98%	5.74%
R2		4.60%	11.81%	16.93%
R3		1.09%	3.93%	6.75%
R4	BC	0.68%	3.29%	6.16%
R5		2.99%	13.19%	23.56%
Average		1.82%	6.64%	10.57%

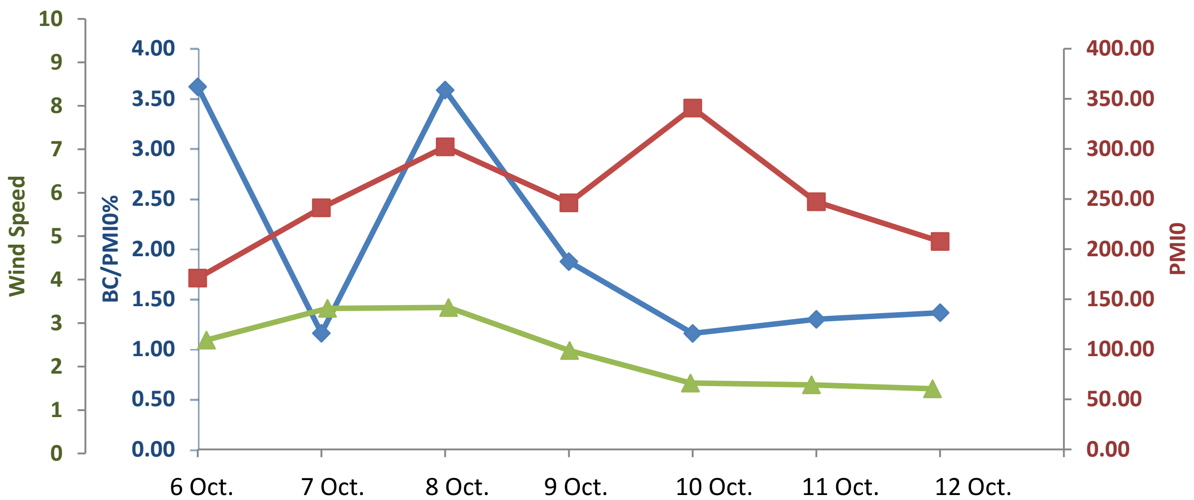

Fig. 7 (a). Series of daily BC/PM_{10} ratio, wind speed and PM_{10} in the month of October and the transverse solid line is the average of BC/PM_{10}

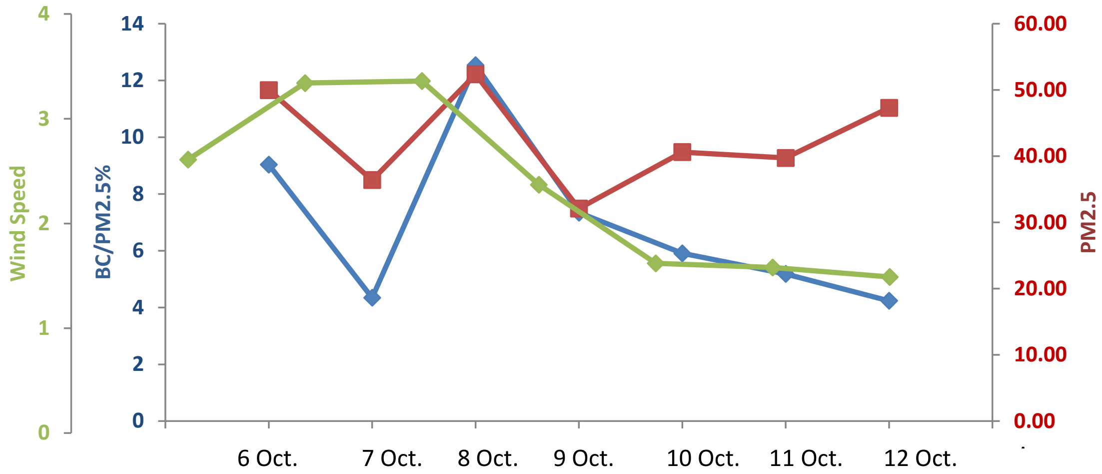

Fig. 7 (b). Series of daily $BC/PM_{2.5}$ ratio, wind speed and $PM_{2.5}$ in the month of October and the transverse solid line is the average of $BC/PM_{2.5}$

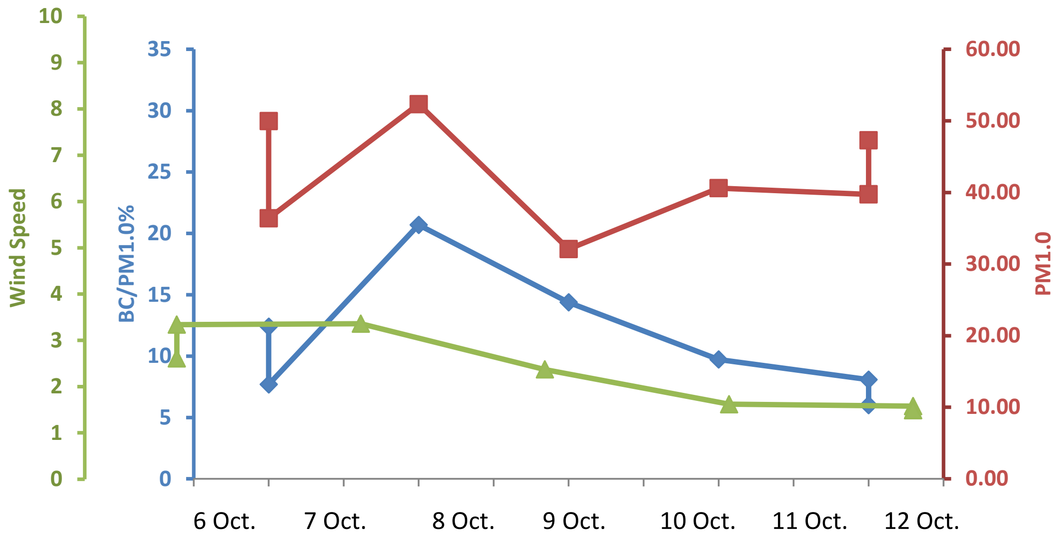

Fig. 7 (c). Series of daily $BC/PM_{1.0}$ ratio, wind speed and $PM_{1.0}$ in the month of October and the transverse solid line is the average of $BC/PM_{1.0}$

on 8 October. On size-wise comparison of PMs, the average BC/PM1.0 (11.54%) was found to be highest followed by BC/PM2.5 (7.21%). The BC abundance of $PM_{2.5}$ is known to be affected by a combination of various pollution sources and meteorological factors .The BC/PM2.5 reflects the BC contribution to PM2.5, and it can be used to track their interaction depending on ambient conditions as a function of time. From the results of Zha et al. (2014) it was found that BC concentration was highly associated with PM1.0 followed by $PM_{2.5}$. In an aerial view, the BC/PM2.5 varied from 1.4% to 32.4% with an average of 5.3% over the observation period.

Total Deposition fraction of PM

The PM deposition fraction that is deposited into the entire lungs airways is considered the total deposition fraction. Assessment of the total deposition of size-segregated PM fraction in the entire human airways is the essential step for further regional (Head, Pulmonary, Tracheobronchial) deposition investigations in the lungs (Kumar et al., 2019). The total

Table 4. Total and Regional Deposition fraction (in %) of size segregated PM in Human lungs of different age categories in traffic site and residential road site

	PM1.0 regional Deposition (Traffic Site)				PM2.5 regional Deposition (Traffic Site)				PM10 regional Deposition (Traffic Site)			
	Head	**TB**	**Pulmonary**	**% total**	**Head**	**TB**	**Pulmonary**	**% total**	**Head**	**TB**	**Pulmonary**	**% total**
3 month	38.719	10.911	50.370	20.468	47.184	48.057	4.747	16.236	85.101	14.953	0.004	16.501
23 month	49.829	11.406	38.791	18.003	58.375	28.182	13.443	15.409	89.294	10.706	0.004	16.492
3 year	48.996	9.886	41.118	18.618	58.130	23.245	18.624	15.792	89.309	10.691	0.005	16.620
9 year	45.996	9.848	44.156	20.563	56.708	30.276	13.028	16.846	91.031	8.969	0.002	16.696
18 year	16.139	19.435	64.426	11.053	89.480	4.266	6.253	17.846	99.575	0.425	0.002	16.845
21 year	15.752	18.601	65.689	11.294	88.920	5.294	5.785	17.871	99.575	0.425	0.001	16.845
	PM1.0 regional Deposition (Residential Road Site)				**PM2.5 regional Deposition (Residential Road Site)**				**PM10 regional Deposition (Residential Road Site)**			
	Head	**TB**	**Pulmonary**	**% total**	**Head**	**TB**	**Pulmonary**	**% total**	**Head**	**TB**	**Pulmonary**	**% total**
3 month	37.594	11.050	51.356	20.490	45.309	45.203	9.488	16.249	85.959	14.041	0.003	16.590
23 month	48.633	11.586	39.781	17.932	56.953	24.908	18.126	15.219	90.148	9.852	0.003	16.475
3 year	47.810	10.045	42.145	18.543	56.416	20.821	22.763	15.640	90.001	9.999	0.002	16.693
9 year	44.847	9.964	45.166	20.476	53.812	25.865	20.323	16.893	91.797	8.203	0.001	16.659
18 year	15.613	19.422	64.964	11.153	85.367	4.557	10.087	17.972	99.645	0.369	0.001	16.792
21 year	15.227	18.584	66.230	11.405	84.538	5.225	10.237	18.027	99.631	0.369	0.000	16.792

deposition fraction of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ under the nasal breathing scenario is quantified and presented in Table 4. Among the three sizes, $PM_{2.5}$ (17.871-15.409% and 18.027-15.219%) has the highest total deposition followed by PM_{10} (16.84-16.49% and 16.79-16.47%) and $PM_{1.0}$ (20.56-11.053 % and 20.49-11.15%) in the human respiratory tract via nasal in different age groups of R1+R2 site area as well as R3+R4+R5. While Kumar et al., 2019 found highest total deposition of PM_{10} in human airways instead of other size segregated particles. The highest deposition fraction for PM_{10} and $PM_{2.5}$ are recorded in the age group of 18 and 21 years age group respiratory tract whereas their lowest deposition fraction is observed in 3 months and 23-month age group in both sites of Agra. The highest and lowest total deposition fractions of $PM_{1.0}$ were recorded in 9 years and 18 years respectively in both sampling sites. On site-wise comparison, size-segregated PM deposition was found highest in the respiratory tract of the Traffic sampling site residents as compared to residential road site. From the observed results it was inferred that population of Traffic sampling site were at highest health risk as compared to the residential road site, especially in the case of the children age group.

Regional Deposition Fraction

PM deposition in each part (head, TB, and pulmonary) of the lungs is known as a regional deposition. It is useful to know about the region-wise deposition of size segregated PM in the lungs. The total and regional deposition fractions of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} in various age category are depicted in Table 4. In the MPPD model, 28 airway generations are available. The first generation starts in the bronchi, and the last generation corresponds to the alveoli sacs. Also, the average concentration of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ in mg/m^3 during the study period is utilized for calculating the deposition in all age groups (3 month -21 years). From the results, it was observed that PM_{10} and $PM_{2.5}$ were highest deposited in the head region [(99.57-85.101%, 89.48-47.18%) Traffic site and (99.645-85.959%, 85.367-45.309%) Residential road site] followed by Tracheobronchial (TB) region in both sampling sites. Similar dominant deposition of PM_{10} in the head region is observed in previous study results (Behera et al., 2015; Kumar et al., 2019). $PM_{1.0}$ has the highest total deposited mass per area in children followed by infants and adults in both sites. From the calculated results, it was revealed that children with 3 month and 9 years age group have the highest deposition and highly affected by lung diseases in both sampling sites.

Although the deposited mass is low in infants, the high deposition per unit area is due to the large surface area to volume ratio when compared to adults. On the other hand PM_{10} was highly deposited in head region followed by TB region. A recent study (Islam et al., 2017) reported that a large portion of inhaled PM is deposited in the upper respiratory tract while the PM with smaller diameter has reached the alveolar sac region. This study also showed that coarse particles deposition is significantly higher in the head region when the breathing flow rate is high and the finer particles deposition in deeper airways during a low breathing rate. The variation in deposition percentage in our study is also mainly due to the airway geometry, PM size, and its deposition mechanisms. The coarse fraction due to its large size cannot follow the airway path and mostly gets deposited by inertial impaction in the head region and its bifurcations. Particle deposition in alveolar and TB regions is enhanced by Sedimentation and diffusion mechanisms (Kumar et al., 2019).

Age Specific Lobar Deposition of Size Segregated PM

Age-specific, PM Mass deposited per unit surface area of each lobar bronchus in the lungs is known as a lobar deposition (Kumar et al., 2019). Size-segregated lobar deposition fraction in infants, children, and adult categories are presented in Table 5. From the results it was inferred that PM1.0 has largely deposited in Left Lower (LL) lobe (38.095-32.385% and 38.102-32.385%) followed by Right Lower (RL) lobe in Traffic as well as in Residential road site and same trend was found in the case of PM2.5. PM10 [55.20-29.22% (Traffic Site) and 56.22-

Table 5. Age specific Lobar Deposition fraction of Size segregated PM in traffic site and residential road site

	PM1.0 Lobar Deposition (Traffic Site)					**PM2.5 Lobar Deposition (Traffic Site)**					**PM10 Lobar Deposition (Traffic Site)**				
	LU	**LL**	**RU**	**RM**	**RL**	**LU**	**LL**	**RU**	**RM**	**RL**	**LU**	**LL**	**RU**	**RM**	RL
3 month	10.387	35.378	8.969	7.972	37.294	9.540	35.954	8.653	5.633	40.221	2.715	33.937	8.145	0.000	55.204
23 month	20.367	33.603	12.912	5.132	27.985	19.826	33.676	12.885	5.633	27.980	16.981	30.728	14.286	6.739	31.267
3 year	13.841	32.482	9.653	7.967	36.057	13.367	31.778	10.750	7.409	36.696	7.299	38.524	10.543	0.649	42.985
9 year	15.667	32.385	12.429	5.689	33.829	15.412	32.151	12.541	5.417	34.480	13.514	37.323	12.870	2.188	34.106
18 year	17.582	32.471	7.814	6.547	35.586	17.436	31.795	9.333	6.769	34.667	16.337	32.673	9.901	6.436	34.653
21 year	14.388	38.095	12.801	7.885	26.831	14.369	38.058	12.718	7.961	26.893	12.329	36.073	14.155	8.219	29.224
	PM1.0 Lobar Deposition (Residential Road Site)					**PM2.5 Lobar Deposition (Residential Road Site)**					**PM10 Lobar Deposition (Residential Road Site))**				
	LU	**LL**	**RU**	**RM**	**RL**	**LU**	**LL**	**RU**	**RM**	**RL**	**LU**	**LL**	**RU**	**RM**	**RL**
3 month	10.386	35.386	8.939	7.975	37.315	9.434	35.790	8.449	6.008	40.319	2.395	33.316	8.069	0.000	56.221
23 month	20.376	33.595	12.905	5.120	28.004	19.925	33.676	12.909	5.582	27.908	16.776	30.921	13.487	6.908	31.908
3 year	13.834	32.460	9.634	8.004	36.067	13.453	31.680	10.663	7.595	36.609	6.740	38.995	10.110	0.347	43.809
9 year	15.705	32.385	12.436	5.688	33.786	15.424	32.013	12.526	5.487	34.550	13.339	37.662	12.554	1.922	34.523
18 year	17.581	32.445	7.842	6.561	35.572	17.453	31.835	9.213	6.816	34.682	16.250	33.125	10.000	6.250	34.375
21 year	14.406	38.102	12.767	7.899	26.826	14.417	38.163	12.721	7.915	26.784	12.000	36.000	14.286	8.000	29.714

29.71% (Residential Road Site)] was highest in RL followed by LL. Kumar et al., 2019 and Islam et al., 2017 found similar results as present study that highest deposition of PM in lower lobes instead of upper Lobes. Manigrasso et al., 2017 found highest (1.9 times) PM deposition in left lobe (17.17 $\times 10^9$ particles) from right lobe (32.76 $\times 10^9$ particles). On site-wise comparison of size segregate PM lobar deposition, it was found that Traffic site has highest deposition as compared to residential road site. From the results, it was inferred that, traffic site peoples was higher at risk and face several health problems related to the lungs. This variation in PM deposition is attributed to lobar volume. Lower lobes with larger volume experiences high PM deposition whereas middle lobe with smaller volume receives lower deposition (Kumar et al., 2019). This fine fraction deposition in lobar regions leads to decreased lung function, increased development of chronic obstructive pulmonary disease and respiratory morbidity (Zhao et al., 2017; Guo et al., 2018).

Deposited Mass visualization

From the results calculated by the Age-Specific 5 Lobe model, it was revealed that the maximum deposition of PM_{10} and $PM_{2.5}$ mass concentration was in 9 years [0.8187, 0.6198mg (Traffic Site) and 0.7334, 0.3219mg (Residential Road Site)] and 3 years [0.5709, 0.1081mg (Traffic Site) and 0.5069, 0.0566mg (Residential road site)] age group while $PM_{1.0}$ was highly visualize in adults age group (21, 18 years). From the results, it was concluded that mass

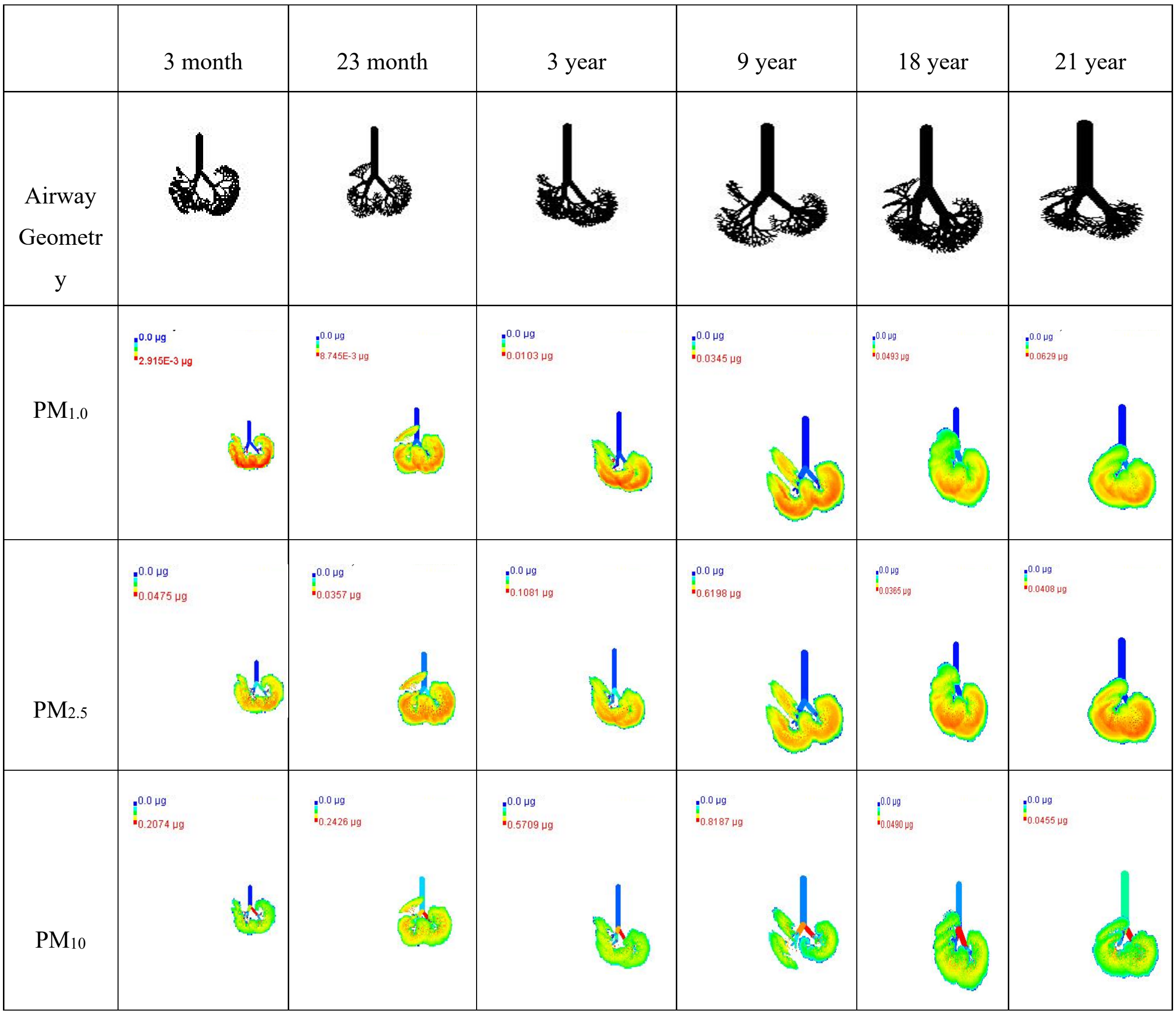

Fig. 8a. Deposited Mass visualization in lung in µg (R1+R2)

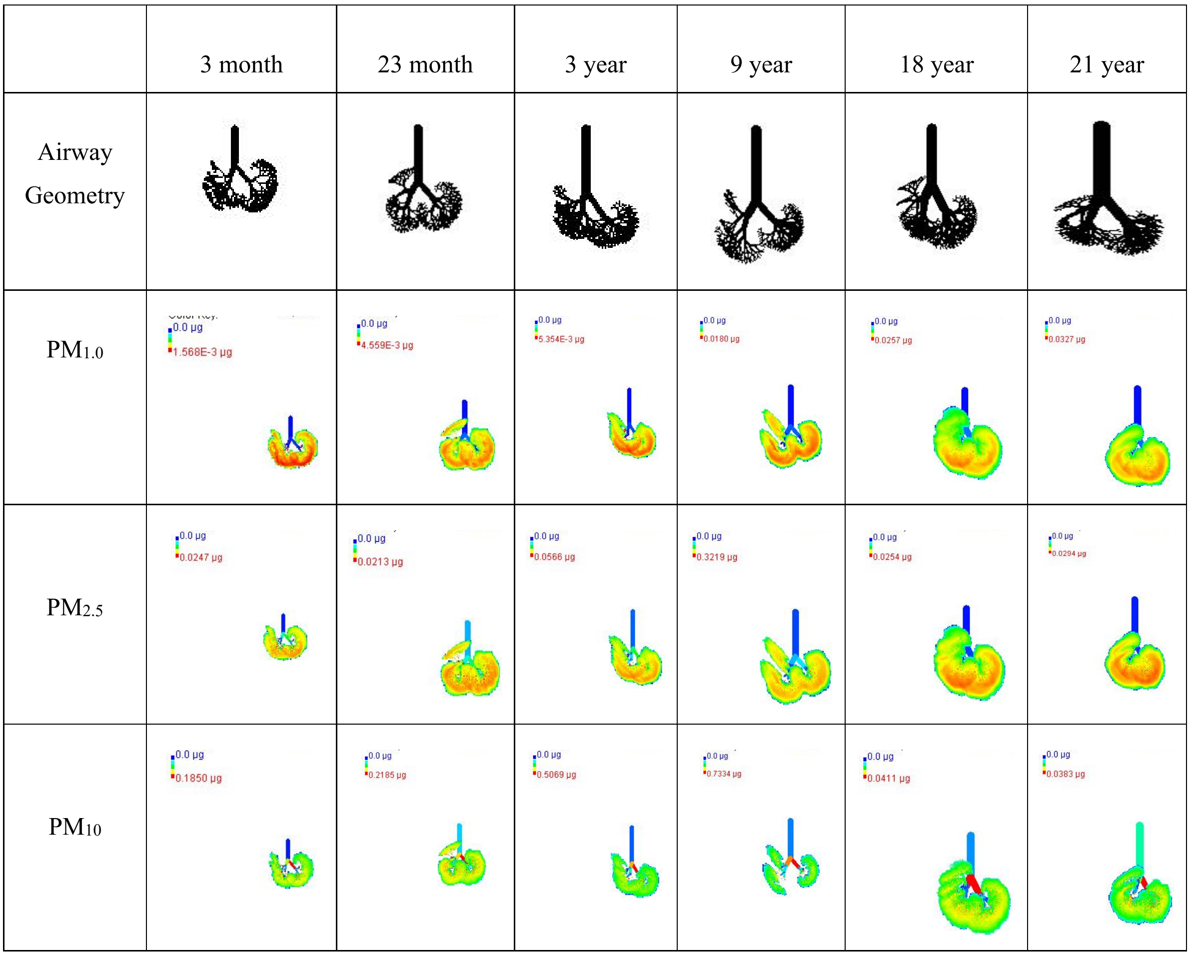

Fig. 8b. Deposited Mass visualization in lung in µg (R3+R4+R5)

Table 6. Carcinogenic and Non-Carcinogenic Health Risk Assessment of PM10 and PM2.5 at Traffic and residential road site

Sites	PM size	Exposure Scenario	Child	Adult
		HQ (Hazard Quotient)		
Traffic	PM10	Acute	5.010	0.939
		Chronic	0.218	0.041
Residential		Acute	4.459	0.836
		Chronic	0.194	0.036
		ELCR (Excess Lifetime Cancer Risk)		
Traffic	PM2.5		2.6×10^{-4}	9.3×10^{-5}
Residential			1.6×10^{-4}	5.9×10^{-5}

visualization of different sizes of PM was high in 3 and 9-year-old children except in the case of PM1.0 depicted in Figure 8a and 8b. From the overall comparison of size segregated PM deposition, it was inferred that PM_{10} was highly visualize in human airways in both sites. On site wise comparison, it was revealed that the children category in the traffic site has high PM deposition mass visualization as compared to the residential road site so they are highly affected by lung diseases instead of the residential road site children category.

Health Risk Assessment

When the value of HQ <1.0, there is no non-carcinogenic for the population and when HQ>1.0, it may cause non-carcinogenic health risk. The results of this study show that a sensitive exposed population (Child) may be at risk of developing health-related problems from acute exposure to PM_{10} in traffic as well as residential road sites. Due to the PM10 acute exposure, various non-carcinogenic diseases may be caused in children at all sites. However, from chronic exposure of PM10; both adults and children were at no non-carcinogenic risk as HQ <1 at all sites. Health risk assessment results are depicted in Table 6.

At traffic sites and residential road site, the values of ELCR for exposed children were 2.6×10^{-4} and 1.6×10^{-4} while for adults the values were 9.3×10^{-5} and 5.9×10^{-5} respectively. All the values exceeded the safer limit (ELCR$\geq10^{-6}$) prescribed by USEPA inferred that the exposed population i.e. both children and adults may develop cancerous diseases from exposure to $PM_{2.5}$.

CONCLUSION

Five locations in Agra, Taj City were selected to conduct campaign for environmental monitoring of PMs, Black Carbon and meteorological parameters by Aerosol Black Carbon Detector (ABCD) and GRIMM portable aerosol Spectrometer in the month of October. Major portion of PM in mass mode is contributed by PM10 (69.104%) followed by PM2.5 (18.977%) and PM1.0 (11.919%). On the other hand, major portion of PM in number mode is contributed by PM_{10} (27.70%) and $PM_{0.25}$ (27.70%) followed by $PM_{5.0}$ (22.14), $PM_{2.5}$ (14.26%) and $PM_{1.0}$ (15.91%), $PM_{0.5}$ (22.14%). All the PMs Mass and Number concentration was highly associated with the R1 traffic site due to the vehicular and other anthropogenic activities and lowest found in residential site R5 except PM_{10}. On the other hand, the highest concentration of BC was found at R2 site followed by R1 (Traffic sites). During the sampling events NO_2 and O_3 was found highest at R2 site (Khandari Crossing) followed by RI. Overall average of O3 and NO_2 was 0.010 and 0.004 respectively. The source of BC, PMs, NO_2, O_3 at these sites (R1& R2) may be vehicular activities, population activities, crowded area, and industrial activities. From the relationship between BC and PMs it was inferred that BC contribution in PM1.0 was highest followed by PM2.5. The children category in the traffic site has high PM deposition mass visualization as compared to the residential road site so they are highly affected by lung diseases instead of the residential road site children category. For the acute (annual) exposure scenario for normal and worst-case exposures, HQ>1.0 for children and inferred that sensitive exposed population may be at risk of developing health-related problems from acute exposure to PM_{10} in both sites. The ELCR values for Children (2.6×10^{-4}, 1.6×10^{-4}) and Adult (9.3×10^{-5}, 5.9×10^{-5}) exceeded limit values (ELCR>10^{-6}) as prescribed by USEPA. These carcinogenic health risk assessment results showed that a population at traffic site may be at carcinogenic risk of developing health-related problems from exposure to $PM_{2.5}$ and causes serious threat to the population.

ACKNOWLEDGEMENT

Authors are highly thankful to the Department of Chemistry, Dr. Bhimrao Ambedkar University, Agra, India for providing necessary facilities to conduct this work.

AUTHOR CONTRIBUTION

Ajay Taneja- Conceptualization, Review, Supervision; Kalpana Rajouriya- Writing Manuscript, Prepared Figures 1-7, and Table 3 and 4, Sampling; Stuti Dubey- Review and Editing, sampling, suggestion for figure; Shailendra Pratap Singh- sampling; Tulika Tripathi-sampling; Rini John -sampling.

FUNDING

This work was supported by Rashtriya Uchchattar Shiksha Abhiyan (RUSA) fund, India.

CODE AVAILABILITY

The Particle in mass and number mode was downloaded using Spectrometer V 2.2.3 while concentration of Black Carbon, NO_2 and O_3 was downloaded by software Observe Air version 1.0.

CONFLICT OF INTEREST

Authors have no conflict of interest.

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