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Exposure to Ambient Particulate Matter in a Class 1 Urban Agglomeration City of Mid Brahmaputra Valley

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Abstract: Particulate matter (PM) exposure is linked to the increased health risks including respiratory disorder, cardiovascular ailment, and shortening the life expectancy of human beings. The present study investigated personal exposure to inhalable, thoracic, and alveolic particles in and around five locations of Tezpur city of mid Brahmaputra Valley. A portable aerosol spectrophotometer (GRIMM, model 9.109) was used to retrieve the diurnal variation of PM concentration during the morning, noon, and evening for five working days at various land use of the city. The observations showed that the PM concentrations varied depending upon the different characteristics of the location. The maximum concentration of PM in inhalable, thoracic, and alveolic fractions were 494.87±300 μgm^{-3}, 292.24 ±118 μgm^{-3} and 143.71± 52 μgm^{-3}, respectively. The concentrations of particulates increased from morning to noon and reached maximum level in the evening at all locations except in the residential areas, wherein the concentration level was recorded the highest during morning, decreased during noon and again increased during evening. A high exposure level was recorded at commercial and high-traffic areas as compared to the residential areas. The exposure level was minimum in the remotely located rural area.

Keywords: Particulate matter; Ambient air quality; Exposure; Mid Brahmaputra Valley

1. Introduction

Air quality has a significant role in human health, and particulate matter (PM) in the air is considered as one of the most important criteria air pollutants for its adverse impacts on human health, including reducing life expectancy [1]. The fine particulates due to its small size can enter deep into the lungs, resulting in pulmonary inflation and even destruction of lung tissues [2]. Furthermore, ultrafine particles can enter the blood vessels initiating oxidative stress and inflammation [3].

Fine particulates have been found to be associated with lung cancer, and chronic diseases like diabetes and cardiovascular disease [4]. The toxicity of atmospheric particles depends on size, source of emission, and chemical composition [5]. The degree of human exposure to air pollutants depends on time, location, activity, and their proximity to the pollutant source [6]. Social factors such as socioeconomic status, residential location, and housing structures also have binding on air pollution exposure [7].

The particles of the size range 0.1 to 1 μm can remain in the atmosphere for weeks [8] and, therefore, PM of this size range undergoes trans-boundary transport and even the remotest regions are affected by particulate pollution. The ambient air contains PM ranging from ultrafine to coarse sizes arising from natural as well as anthropogenic sources like road dust resuspension, dust storm, long-range transport, vehicular emission, firewood, coal combustion, residential emissions and industrial activities etc. [9]. Residential, industrial, transportation, and energy sector are the major contributors to atmospheric $PM_{2.5}$ in India [10]. Air quality of large cities is a concern and is a matter of interest for the researchers and policy makers. However, the small cities often remain unnoticed. This study was taken up to assess the respirable PM load and exposure of a small city, Tezpur of mid Brahmaputa Valley. Tezpur is one of the major developing cities of mid-Brahmaputra valley of North East India. This city has typical landuse that most small cities represent. Therefore, the present study was carried out to understand the ambient level exposure of PM among the population of varied landuse of Tezpur.

Table 1. Details of sampling locations

Location	Abbreviations	Type	Description
Mission Chariali	MC	Urban	MC is a major junction point of two National Highways - NH15 and NH715 - in Tezpur. It consists of activities such as commercial, residential and heavy traffic movement of all type of vehicles due to connection with other major roads.
Chowk Bazar	CB	Urban	CB is the main commercial point of Tezpur. This is a commercial area characterised by shops, malls, hotels, restaurants, etc. Traffic load is high with medium size commercial and personal vehicles along with the pedestrians.
Majgaon	MG	Urban	MG is a residential area with medium commercial activity. Traffic load is also medium consisting of medium and small personal vehicles.
Tezpur University	TU	Suburban	TU is an educational residential site located near rural boundaries. Traffic load is less, mainly active during day time.
Silghat	SG	Exurban	SG is a remotely located rural site.

2. Materials and Methods

2.1. Sampling Site

Sampling was carried out at five different locations of mid Brahmaputra Valley during August 2012 to January 2013 (Figure 1). Detailed description of the sampling locations is provided in Table 1. The headquarters of Sonitpur district is located at Tezpur. Tezpur is classified as a Class I Urban Agglomeration city. According to the 2011 Census of India, a Class I urban agglomeration is a collection of towns or cities with a population of 100,000 or more. This place is also a hotspot of cultural heritage due to which there is always an influx of people for official, tourist, and commercial work. This leads to an increase in traffic and vehicular emission. Moreover, the major national highways NH 15 and NH 715 pass through Tezpur. These road junctions have created a heavy load of vehicles from small to heavy vehicles, which lead to high emission of the re-suspended particle from the paved and unpaved roads besides contribution from fossil fuel burning. More so, there are industries like biscuit factories, tea industries, and brick kilns which run on coal and wood fuel, which contribute to a heavy loading of PM. In the rural part of Tezpur, people mainly engage in agriculture. Biomass is the main fuel of this region. People engaged in the different sectors are prone to different levels of PM exposure in the outdoor environment.

2.2. Sampling of Particulate Matter

The PM monitoring was done by a portable aerosol spectrophotometer (GRIMM; Model: 1.109). Air sample was sucked through an inlet at a rate of 1.2 L/min, and airborne particles were detected by light scattering inside a measuring cell. The instrument is capable of recording particle number and mass concentration in 31 size bins from 0.25 to 34 µm. The equipment gives concentrations of respirable particulates taking into account the occupational health. Depending on size of the particles and following the standard of EN 481:1993, the equipment measures the concentration of respirable particulates and categorize as (1) inhalable fraction with size range between 10 to 34 µm (2) thoracic fraction with size range between 4 to 10 µm and (3) alveolic fraction with size less than 4 µm. Detailed working principle of the instrument is provided in the company manual [11].

The GRIMM sampler was kept 1.5 meters above the ground, and sampling was done for 5 days at a location following the IS 5182 standard [12]. The diel variation in the PM concentration was represented by doing hourly sampling during the morning (mor) from 7:00 am to 8:00 am ± 15 minutes, noon from 12:00 noon to 01:00 pm ± 10 minutes and evening (eve) from 5:00 pm to 6:00 pm ± 15 minutes for five working days for each location. Data were recorded in the instrument at 1 minute time interval and downloaded to a personal computer in MS excel format after each day sampling. Statistical parameters were calculated for inhalable, thoracic, and alveolic fractions of particle for all the locations to appreciate the data quality.

3. Results and Discussion

3.1. Diel Variation of PM

Figure 2 shows the diel variation of the five days average concentration of inhalable, thoracic, and alveolic particles during the morning, noon, and evening hours in all the locations. The average concentrations of inhalable, thoracic, and alveolic particles for all locations were variable in nature with time (hourly) except for the SG. The concentrations showed a distinct pattern during morning and noon at SG. Compared to MG and TU, the variation in the inhalable fraction was greater at MC and CB. The highest peak values were observed at MC during 1st half of morning and at CB during evening. In thoracic fraction, more peak variation was observed during the evening hours. The alveolic concentrations at CB, MC, MG, and TU varied greatly during morning hours, with MG displaying the highest values. In contrast to CB and MC, the concentration variation at MG and TU decreased around noon. All of the locations had varying characteristics in the evening.

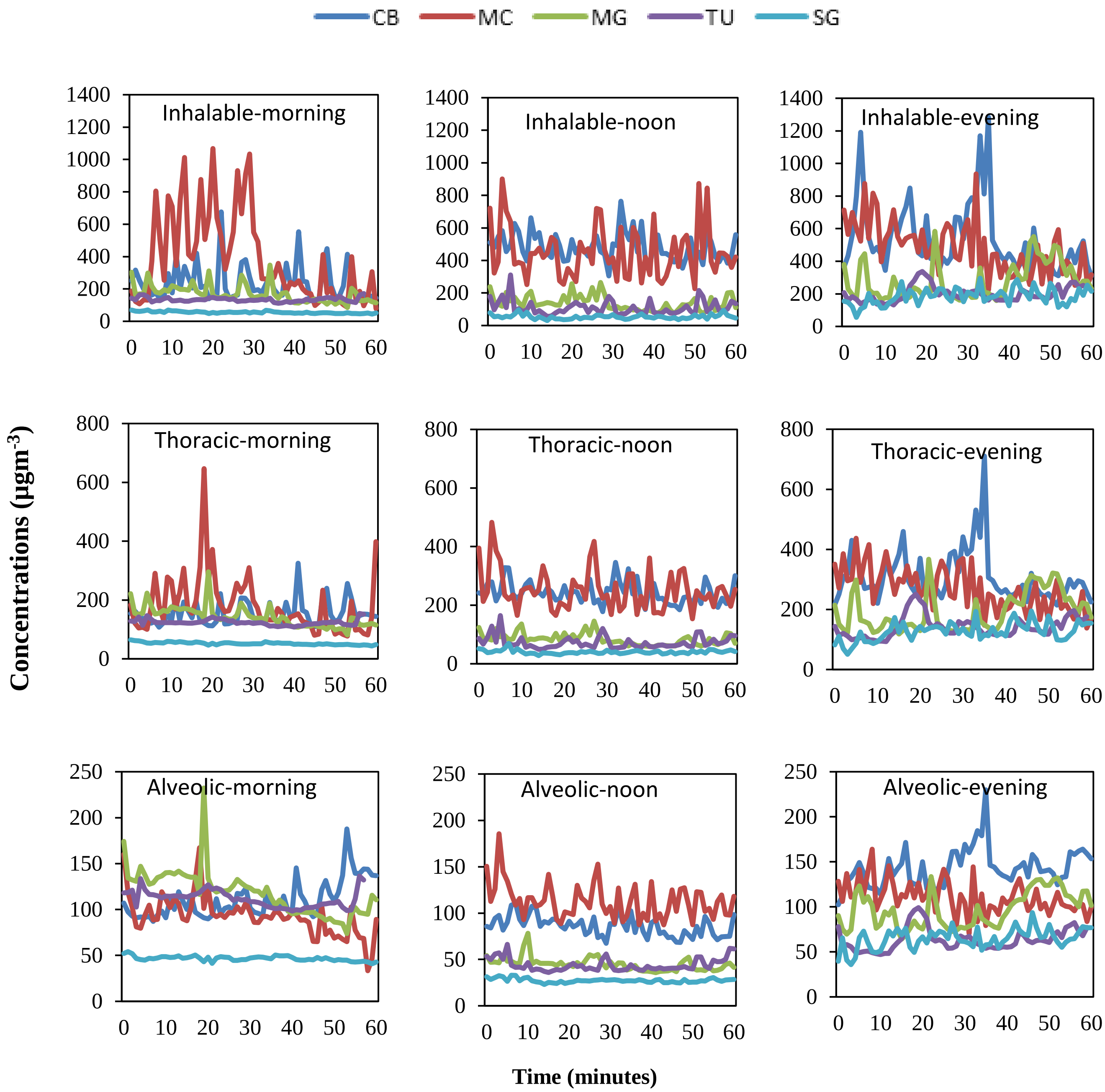

Figure 2. Temporal (diel) variation of different sized particles**.**

At CB the mean exposure level of all fractions of particles was minimum during morning, increased during noon and reached maximum during evening. A similar pattern was observed at MC and SG with the lowest value at SG. SG is a remote location far from busy roads and businesses having a few other anthropogenic activities. At MG and TU, the mean exposure level of all fractions was high during morning, decreased during noon, and again increased during the evening. The concentrations of PM of different fractions showed locational characteristics.

Meteorological condition of a region controls the dispersion of air pollution in the region. The meteorological parameters of the study area are provided in Table 2. The meteorological parameters available for Tezpur airport station was downloaded from wunderground.com. No rainfall was recorded during the sampling period. Wind speed ranged from 0.4 to 3.1 m/s during 54% of the sampling periods. Calm wind conditions prevailed during the study period. This indicated a stable atmospheric condition.

Table 2. Meteorological parameters during the sampling period

Parameters	Mean	Max	Min	SD
Temperature (°C)	21.5	36.0	8.0	5.8
Humidity (%)	77.3	92.5	77.3	4.8
Wind Speed (m s^{-1})	0.4	3.1	0.0	0.2
Pressure (mbar)	1012.8	1023.0	998.0	5.8
Dew Point (°C)	18.2	29.0	9.0	6.5

3.2. Exposure Levels at Different Locations

Figure 3 shows the average concentrations of inhalable, thoracic, and alveolic particles during the morning, noon, and evening at different locations. Values are provided in Table 3. The average concentration of PM was the highest at CB and MC due to high traffic and commercial activity. The average concentrations of PM at MG and TU were lower compared to CB and MC, probably due to less traffic being residential areas. Inhalable, thoracic and alveolic particles showed the lowest concentrations at SG being the remote location. High concentrations of the inhalable particles in comparison to thoracic and alveolic particles in all locations were due to heavy accumulation of re-suspended dust particles from different anthropogenic activities including vehicular movement.

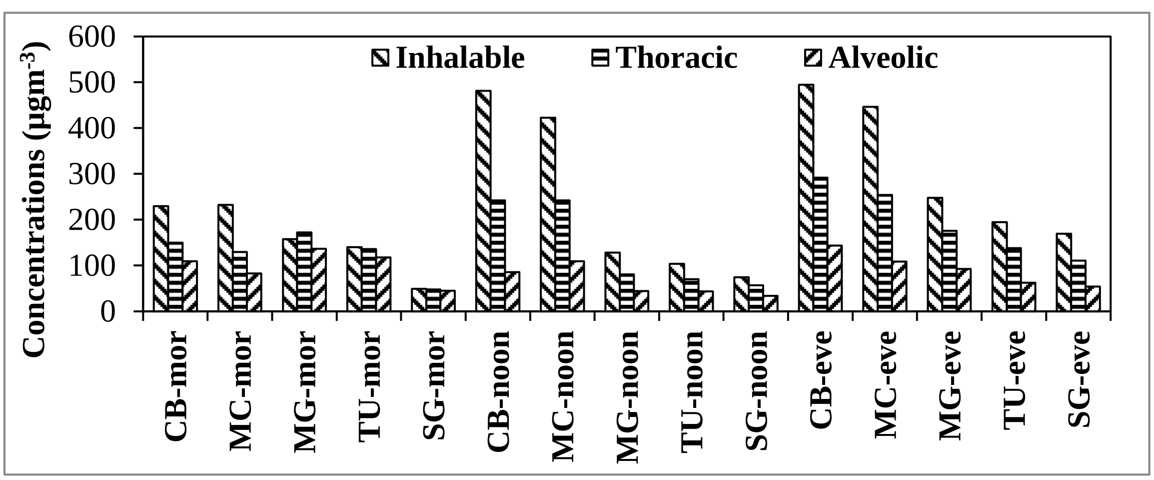

Figure 3. Concentrations of inhalable, thoracic, and alveolic particles during morning (mor), noon and evening (eve) hours at different locations.

The highest concentration of inhalable fraction was observed at MC during evening (446.49 ± 398.52 μgm^{-3}). At CB, the concentration of inhalable fraction was during noon (481.66 ± 274.80 μgm^{-3}) and evening (494.87 ± 300.31 μgm^{-3}). The high concentration along with high standard deviation at MC during evening was due to heavy traffic load in this road junction which introduces an extra amount of re-suspended dust in the inhalable fraction to the atmosphere. As Tezpur's commercial centre, CB saw a spike in business activity in the forenoon and continued until the evening, which resulted in a significant buildup in the inhalation fraction. However, at MG, TU, and SG the concentration of morning time inhalable particles was similar to thoracic and alveolic particles due to less traffic and other emission sources. The thoracic fraction was the highest throughout the day at CB. It was 150.07 ± 85 μgm^{-3} during morning, 242.54 ± 116 μgm^{-3} during noon, and 292.24 ± 118 μgm^{-3} during evening hours followed by MC, MG, TU, and SG.

It was interesting to note that fine fractions of particles were higher during the morning hours in residential areas. In the alveolic fraction of particle, the person at MG and TU experienced the highest exposure during morning; 116.04 ± 81.87 μgm^{-3} and 113.83 ± 89 μgm^{-3}, respectively. A study on individual exposure to ultrafine particles had reported several significant household sources, including hair dryers, toaster ovens, and gas and electric stoves [13]. Since in the residential areas diverse sources of PM are available, alveolic fraction was recorded maximum at MG. Kulkarni and Patil [14] also reported high personal exposure in outdoor residential micro-environment (308 μgm^{-3}). The highest exposure level of alveolic particles was recorded at MC (109.63±94 μgm^{-3}) during noon and at CB (143.71±52 μgm^{-3}) during the evening. MG is a residential area in an urban location, and TU is a rural residential institute. People of these areas experienced low particulate exposure as compared to CB and MC. Among all the locations a person at SG experienced the lowest exposure. The lowest concentration was recorded in all fractions of particles in this location. Long-range transport of particulates are the major source of particulates at SG, being located remotely. However, in all the locations, the concentration exceeded the WHO recommended daily air quality guideline (AQG) level of PM_{10} (45 μgm^{-3}), which is a great concern for the health-related issues [15]. Although we had considered a low time spent (~ 1hr), but high exposure to thoracic and alveolic particles causes serious health consequences to the receptor [16].

Table 3. Statistical analysis of inhalable, thoracic, and alveolic particles of different locations [SD: standard deviation; COV: coefficient of variation; units of mean, SD and median: μgm^{-3}]

Name of parameters	**CB**			**MC**			**MG**			**TU**			**SG**		
	Morning	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**
Inhalable															
Mean	229.75	481.66	494.87	232.48	422.39	446.49	157.59	128.32	247.56	140.50	103.60	194.94	49.36	74.33	169.83
SD	201.10	274.80	300.31	300.33	352.45	398.52	115.79	104.28	159.90	105.53	77.43	136.86	11.37	37.83	114.90
Median	193.45	420.00	434.30	149.60	354.90	319.30	150.40	98.30	202.35	153.20	96.60	144.30	45.70	64.00	139.60
Skewness	2.46	1.29	1.56	3.34	1.03	1.64	1.35	2.08	1.79	0.73	2.03	1.81	2.06	1.24	1.08
Kurtosis	7.46	2.17	3.53	12.33	0.52	2.39	3.70	6.07	5.30	2.17	6.85	3.90	4.25	1.60	0.57
COV	0.88	0.57	0.61	1.29	0.83	0.89	0.73	0.81	0.65	0.75	0.75	0.70	0.23	0.51	0.68
Thoracic															
Mean	150.07	242.54	292.24	129.92	241.99	253.98	137.49	80.42	175.90	127.37	70.43	137.92	48.02	56.77	111.00
SD	85.06	115.77	117.74	93.28	193.49	213.54	95.31	56.32	105.44	98.40	45.18	97.87	9.26	21.15	60.11
Median	125.55	207.80	259.60	99.05	185.80	200.35	144.10	65.80	147.80	138.60	69.20	114.55	45.60	54.15	92.50
Skewness	0.93	1.05	1.81	1.97	0.98	1.73	0.44	2.08	1.58	0.69	1.49	2.16	2.33	0.83	1.05
Kurtosis	0.68	1.00	5.89	4.29	0.26	2.73	-0.62	8.47	4.36	2.40	5.87	6.39	6.73	1.16	0.53
COV	0.57	0.48	0.40	0.72	0.80	0.84	0.69	0.70	0.60	0.77	0.64	0.71	0.19	0.37	0.54
Alveolic															
Mean	109.44	85.98	143.71	83.19	109.63	108.95	116.04	44.42	92.93	113.83	43.98	62.72	45.37	33.67	54.42
SD	63.42	27.65	51.63	53.78	93.78	83.94	81.87	27.46	49.86	89.16	24.79	36.68	8.14	8.35	23.76
Median	85.75	79.20	137.60	59.50	67.80	75.90	132.95	39.40	84.90	132.80	39.30	59.45	43.30	32.90	46.70
Skewness	0.90	0.99	0.13	0.67	1.19	1.49	0.15	2.18	1.62	0.24	0.05	1.47	3.00	1.46	1.67
Kurtosis	-0.21	2.17	-0.71	-1.03	0.12	1.75	-1.13	10.93	4.24	-0.71	-1.32	4.23	11.18	7.00	2.44
COV	0.58	0.32	0.36	0.65	0.86	0.77	0.71	0.62	0.54	0.78	0.56	0.58	0.18	0.25	0.44

Figure 4 shows the percentage contribution of inhalable, thoracic, and alveolic fraction of particles in all sampling locations. The total contribution of thoracic plus alveolic particles ranged from 66.21% to 40.54%. The inhalable particles ranged in between 59.45% to 33.78%. The inhalable particles can be removed easily by the body's natural defence mechanism. However, the fine fraction especially alveolic particles can enter deep into the respiratory system and causes adverse health problems such as black lung, asthma, bronchitis, cardiovascular diseases, and neurodegenerative disorders like Parkinson's disease and Alzheimer's disease [17-22].

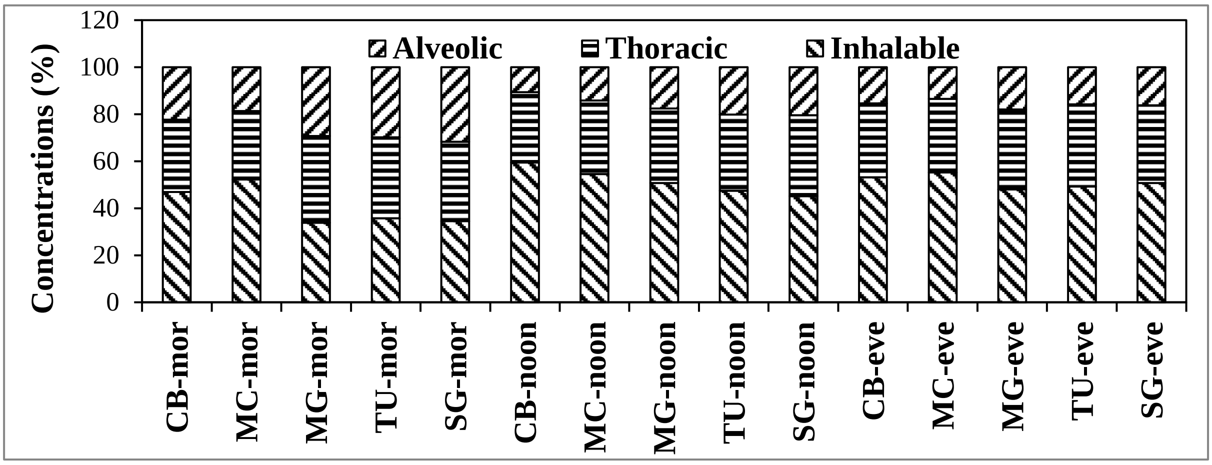

Figure 4. Percentage composition of inhalable, thoracic, and alveolic particles during morning (mor), noon and evening (eve) hours at different locations

3.3. Data Appreciation by Statistical Analysis

Regression analyses were carried out between different fractions of particles. Linear regression was performed between thoracic (Th.) vs. inhalable (Inh.), alveolic (Alv.) vs. inhalable (Inh.), and alveolic (Alv.) vs. thoracic (Th.) (Table 4). The correlation between thoracic vs. inhalable was significant in all locations at all time; the coefficient of determination (r^2) ranged from 0.52 to 0.94. The correlation between alveolic vs. thoracic was also significant in all locations at all time with a r^2 value of 0.51 to 0.96, except at CB (r^2=0.05) during the evening. This could be due to the high build-up of coarse particles that always occurs around CB in the evening, which is the primary hub of Tezpur's commercial activity. The correlations between alveolic vs. inhalable showed maximum significant values at TU (r^2=0.85) and MG (r^2=0.69) during the morning hours due to the moderate traffic load in the residential area.

Statistical parameters namely, mean, median, skewness, kurtosis (k), standard deviation (SD), and coefficient of variation (COV) for all locations are given in Table 3. Earlier researchers also used these parameters to check data quality [8, 23]. With the variation between mean and median, high values of SD were observed almost for all times for every location in all fractions of particles. This indicated that the curves were not normal, and values were distributed far from each other. Curve with platykurtic and leptokurtic distribution was observed. The distribution with $K<3$ is platykurtic, and with $K>3$ the curve are leptokurtic in nature. As per the skewness is concerned all values showed positively skewed distribution i.e. all data were shifted toward the left side of the distribution. COV is the most important statistical parameter to justify variation in the data set. In our study COV values were below 1 in all categories of particulates in all the locations showing low variance. However, COV value was 1.29 for MC during the morning in inhalable fraction. MC is the main road junction and people from different areas pass through MC during the morning hours.

Table 4. Regression analyses between inhalable, thoracic, and alveolic particles [Th.: Thoracic; Inh.: inhalable; Alv.: alveolic]

Site	Parameters	Best Fit Equation			R^2		
		Morning	Noon	Evening	Morning	Noon	Evening
CB	**Th.** vs **Inh.**	y = 1.905x - 56.124	y = 2.1839x - 48.021	y = 2.3146x - 181.54	0.65	0.85	0.83
	Alv. vs **Inh.**	y = 0.897x + 131.59	y = 7.6697x - 177.76	y = -0.3865x + 550.41	0.08	0.60	0.01
	Alv. vs **Th.**	y = 0.9967x + 40.989	y = 3.7905x - 83.361	y = 0.5122x + 218.63	0.55	0.82	0.05
MC	**Th.** vs **Inh.**	y = 2.9082x - 145.34	y = 1.6909x + 13.209	y = 1.8055x - 12.067	0.82	0.86	0.94
	Alv. vs **Inh.**	y = 2.5457x + 20.72	y = 2.7536x + 120.5	y = 3.4917x + 66.062	0.21	0.54	0.54
	Alv. vs **Th.**	y = 1.2383x + 26.914	y = 1.8416x + 40.088	y = 2.1626x + 18.356	0.51	0.80	0.72
MG	**Th.** vs **Inh.**	y = 1.1598x - 1.8758	y = 1.7249x - 10.396	y = 1.4162x - 1.5565	0.91	0.87	0.87
	Alv. vs **Inh.**	y = 1.1755x + 21.176	y = 3.0474x - 7.0585	y = 2.0728x + 54.929	0.70	0.64	0.42
	Alv. vs **Th.**	y = 1.1105x + 8.6247	y = 1.9366x - 5.6128	y = 1.7417x + 14.039	0.91	0.89	0.67
TU	**Th.** vs **Inh.**	y = 1.0228x + 10.233	y = 1.5775x - 7.5105	y = 1.3498x + 8.7849	0.91	0.85	0.93
	Alv. vs **Inh.**	y = 1.0889x + 16.551	y = 2.1114x + 10.728	y = 2.7591x + 21.895	0.85	0.46	0.55
	Alv. vs **Th.**	y = 1.0831x + 4.0737	y = 1.5681x + 1.4595	y = 2.3017x - 6.4409	0.96	0.74	0.75
SG	**Th.** vs **Inh.**	y = 1.1037x - 3.6356	y = 1.4989x - 10.763	y = 1.5952x - 7.2372	0.52	0.70	0.70
	Alv. vs **Inh.**	y = 1.0466x + 1.885	y = 2.3089x - 3.4048	y = 2.6601x + 25.061	0.56	0.26	0.b30
	Alv. vs **Th.**	y = 1.0612x - 0.123	y = 1.9462x - 8.7504	y = 2.0952x - 3.023	0.87	0.59	0.69

4. Conclusions

Exposure to inhalable, thoracic, and alveolic particulates in all five locations was high. The maximum concentrations of particulates in inhalable, thoracic, and alveolic fractions were 494.87±300 μgm^{-3}, 292.24 ±118 μgm^{-3} and 143.71± 52 μgm^{-3}, respectively. Personal exposure varied within different locations of Tezpur. A person at MC and CB, being the commercial hub of Tezpur, experienced maximum exposure compared to other locations. While a person in residential areas, namely MG and TU, experienced medium exposure. SG, a remote rural area, had the lowest recorded exposure level. However, in all sampling sites, the concentration crossed the 24-h WHO recommendation level of PM_{10}. Particulate concentrations were generally indicative of the landuse and ongoing activities in the study sites.

Multidisciplinary Domains

This research covers the domains (a) Climate change, livelihood, natural calamities and (b) Communication for health, culture, social issues, and development.

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Conflicts of Interest

The authors declare no conflict of interest.

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