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MEASUREMENT OF PARTICULATE MATTER (PM_{10} AND $PM_{2.5}$) CONCENTRATION: A CASE OF AHMEDABAD CITY

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ABSTRACT

The air pollution in Indian cities is increasing at an alarming rate. Amongst the world's 10, most air polluted cities, 6 are from India [1].The air consists of various pollutants like SO_2, NO_2, PM_{10}, $PM_{2.5}$, Ozone, CO etc. But $PM_{2.5}$ is the most dangerous, adversely affecting human health. Air pollution is the 5th highest cause of deaths in India [2]. The study intends to find the particulate matter (PM) concentration levels (PM_{10} and $PM_{2.5}$), in Ahmedabad city. 32 areas including commercial, residential, industrial, sensitive etc., across the city, were selected to measure PM_{10} and $PM_{2.5}$ concentration, in the month of December 2013.The study found that, almost 44% of these areas had PM_{10} levels exceeding the permissible limits and 30% of them exceeded the permissible levels for $PM_{2.5,}$ most of them located in the central part of the city. Moreover, certain areas had highly critical PM levels.

KEYWORDS: Particulate Matter, PM_{10}, $PM_{2.5}$, Ahmedabad, Concentration Levels, Air Pollution

INTRODUCTION

Ahmedabad has a hot semi-arid climate with marginally less rain, than required for a tropical climate. There are three main seasons: summer, monsoon and winter. The climate is extremely dry. The highest temperature recorded is 48.5 °C. The southwest monsoon, bring rains to the city from mid-June to mid-September. Geographically, it is located in Gujarat, a state in western India and is spread across an area of 464 km^2. The city has a population of over 5.5 million. The city is divided into 6 zones, namely Central, North, East, West, South and New West (AMC) constituting of 58 wards.

Ahmedabad city has one of the highest air pollution levels in the world. The air pollutants includeSulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Particulate Matters; PM_{10} and $PM_{2.5}$, Ozone (O_3), Lead (Pb), Carbon Monoxide (CO), Ammonia, Benzene, Arsenic, Nickel etc. Particulate matter is a term used for a mixture of solid particles and liquid droplets found in the air. There are two types of particulate matter: i.e, Settable particulate matter (>100microns): These coarse particulate matters are emitted from sources like dust, storm etc., and ii. Suspended particulate matter (10- 100 microns). The suspended particulate matter is further classified as, Respirable suspended particulate matter (RSPM), having to size more than 10 microns and Fine particles having a size less than 10 microns.

As per December 2015 report of Greenpeace, the annual mean $PM_{2.5}$ level in Ahmedabad was 100 µg/m^3 , which is 10 times the annual mean as per WHO guidelines. This high level has many adverse effects on humans. Moreover, in a winter season, due to the temperature inversion, the atmosphere captures the particulate matter and so the concentrations are highest in winters. So, there is a need to measure the PM_{10} and $PM_{2.5}$ concentration in the month of December. The objectives of the research study are:

- To determine the status, point and area concentrations of PM_{10} and $PM_{2.5}$.
- To ascertain whether the prescribed PM_{10} and $PM_{2.5}$ concentration standards are violated.
- To analyze the data using a suitable software and prepare isopleths for the whole city.
- To obtain the knowledge and understanding necessary for developing preventive and corrective measures.

METHODOLOGY

The PM_{10} and $PM_{2.5}$ concentrations were measured across 32 different locations in the Ahmedabad city within 16 days in December 2013, by dividing the research students into two groups. The PM_{10} and $PM_{2.5}$ concentrations were measured at 2 different locations per day for a period of 8 hours per day.

For this purpose the equipment used was:

- **APM 460:** For measuring PM_{10} concentration
- **VFDS 104:** For measuring $PM_{2.5}$ concentration

Selection of Sites

The sites have been selected as far as possible to cover the maximum number of Ahmedabad Municipal Corporation (AMC) wards, considering the land use classification such as residential area, industrial area, commercial area, sensitive area and mixed area. The no. of monitoring stations selected in different zone type is represented in Table 1. Wind pattern of Ahmedabad has also been considered at the time of selection of sites. The buildings for the monitoring have been selected such that the height of the building is between 3 to 10 meters. The buildings have been selected such that there are minimum obstructions nearby. The obstruction criteria can be further understood as Figure 1:

Table 1: Details of Zone Wise Monitoring Station

Zone Type	Number of Monitoring Station
Commercial	2
Industrial	3
Residential + Sensitive	8
Residential + Commercial	13
Residential + Industrial	3
Residential + Commercial + Sensitive	2
Residential + Commercial + Industrial	1

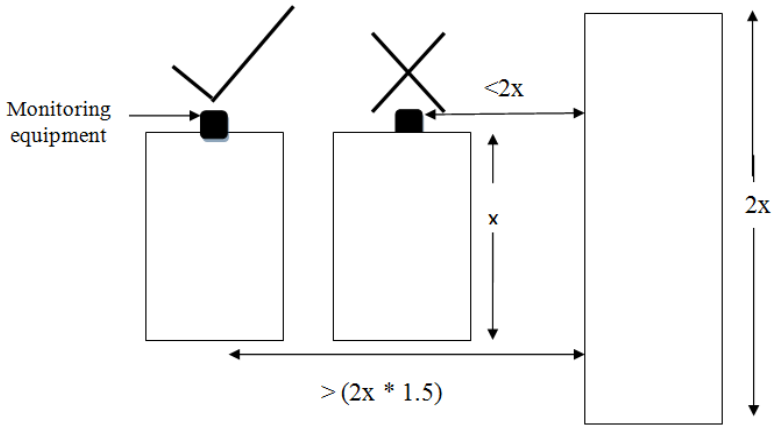

Figure 1: Criteria for Selection of Building to Put Monitoring Instruments

An effort has also been made to name the monitoring stations, based on area classification, namely residential, commercial, industrial, sensitive and mixed use along with the concentration of PM_{10} and $PM_{2.5}$ in µg per cubic meter in respect of observed 8 hours and estimated for 24 hours. The estimations have been done from 8 hours to 24 hours by using following formula: $\frac{C_{long}}{C_{short}} = \left(\frac{t_{short}}{t_{long}}\right)^{p}$

Where,

C_{long} = Concentration for the longer averaging time in µg/m^3

C_{short} = Concentration for the shorter averaging time µg/m^3

t_{long} = Longer averaging time in hours

t_{short} = Shorter averaging time in hours

p = Power law exponent

For different stability conditions, the value of power law exponent is different and is represented as Table - 2.

Table 2: 'p' Values for Different Atmospheric Stability Classes

Atmospheric Stability Class	P Value	Definition
A	0.5	Very unstable
B	0.5	Unstable
C	0.333	Slightly unstable
D	0.2	Neutral
E	0.167	Slightly stable
F	0.167	Stable

Since Ahmedabad predominantly falls under atmosphere stability category A, 0.5 is taken as a value of power law exponent, for estimating the long-term concentration, for 24 hours. The classifications of areas along with the name of monitoring stations have been presented in Table 3, given below:

Table 3: Classifications of Monitoring Stations Based on Land Use

Sr. No.	Commercial	Industrial	Residential + Industrial	Residential + Commercial	Residential+ Sensitive	Residential+ Commercial + Industrial	Residential + Commercial + Sensitive
1	Relief Road city civic canter, Opp. RoopamCinema, relief road	GIDC Area 1	Rakhiyal City Civic Centre, VimalbhaiMunicipal Library Bhavan, rakhial	Maninagar Fire station, Rambaug, Maninagar	CEPT University, Navrangpura	Dudheshwar sub-zonal office, Dudheshwar	Blind people association, Andhjan Mandal, 132ft Ring Road
2	Kalupur Crossroad	GIDC Area 2	Sabarmati sub-zonal office, Sabarmati	Harubhai Mehta Bhavan, Viratnagar road	Girdharnagar ward office, near Civil Hospital, Girdharnagar		Kankaria Zoo, Kankaria
3		GIDC Area 3	Vastral landfill site, Vastral	AMC City Civic Centre, India colony	ChandkhedaNagarpalika Office, Chandkheda Gam		
4				Rajiv Gandhi Bhavan, NarodaRoad	NID, Paldi		
5				Kubernagar sub-zonal office , Kubernagar	Gaushala near Gandhi Ashram		
6				Nava vadajMuster Office, Navavadaj	Sarkhej Ward Office,Sarkhej		
7				AMC NagarpalikaOffice, Memnagar	Kotarpur water treatment plant, Airport Road, Kotarpur		
8				AMC City Civic Centre, K.K.SastriBhavan, Dharnidhar	Sola Civil Hospital, S. G. Highway		
9				Gujarat chamber of Commerce and Industry, Ashram Road			
10				Vadaj AMTS bus terminus, Vadaj			
11				LalDarwaja AMTS Bus Terminus,			
12				AMC Office, Danapith, Astodia			
13				Shahpur Ward Office, Shahpur.			

Measurement of PM_{10}:

To measure PM_{10} concentration, air is drawn through a size-selective inlet and through a 20.3 X 25.4 cm (8 X 10 in) glass fiber filter at a flow rate, which is typically 1132 L/min. The filters are numbered prior to use. The initial weight and the final weight of filter papers are done at "AHMEDABAD TEXTILE INDUSTRY'S RESEARCH ASSOCIATION (ATIRA)" through a gravity scale with a precision of 5 decimal places. The weighing is done as per the standard procedure. Particles of diameter less than 10 microns are collected, by the filter paper. The suction of air can be done by two methods: i.e impaction inlet and cyclonic inlet. Here, the equipment used has impaction inlet. The readings of the flow rate of air are taken through a manometer on an hourly basis and the average flow rate is calculated. The time elapsed can be seen in the time meter. The mass of particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM_{10} in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

Calculation of Volume of Air Sampled

$V=Qt$

Where,

V = *V*olume of air sampled, in m^3;

Q = Average flow rate, in m^3/min; and

t = Total sampling time, in min.

Calculation of PM_{10} in Ambient Air

$PM_{10,}\ \mu g/m^3 = (W_2-W_1)\ X\ 10^6 / V$

Where,

PM_{10} = Mass concentration of particulate matter less than 10 micron diameter.

W_1 = Initial weight of filter paper, in gm

W_2 = Final weight of filter paper, in gm;

V = Volume of air sampled, in m^3.

Measurement of $PM_{2.5}$

An electrically powered air sampler draws ambient air at a constant volumetric flow rate (16.7 lpm) maintained by a mass flow / volumetric flow controller coupled to a microprocessor into specially designed inertial particle size separator (i.e. Cyclones or impostors) where the suspended particulate matter in the $PM_{2.5}$ size ranges is separated for collection on a 47 mm polytetrafluoroethylene (PTFE) filter over a specified sampling period. Each filter paper is weighed before and after sample collection to determine the net gain due to the particulate matter. The mass concentration in the ambient air is computed as the total mass of collecting particles in the $PM_{2.5}$ size ranges divided by the actual volume of air sampled and is expressed in $\mu g/m^3$. The microprocessor reads the initial volume and final volume of air sampler, through this flow rate is calculated

Calculation of Volume of Air Sampled

$V = V_2 - V_1$

Where,

V = Volume of air sampled, in m^3

V_1 = Initial volume, m^3

V_2 = Final volume, m^3

Calculation of $PM_{2.5}$ in Ambient Air

$PM_{2.5,}\ \mu g/m^3 = (W_2-W_1)\ X\ 10^6 / V$

Where,

$PM_{2.5}$ = Mass concentration of particulate matter less than 2.5 micron diameter.

W_1 = Initial weight of filter paper, in gm

W_2 = Final weight of filter paper, in gm

V = Volume of air sampled, in m^3

RESULTS & DISCUSSIONS

These measured and estimated concentrations have been presented in following Table 4 and Table 5 for

commercial, industrial, residential, industrial + residential, commercial + residential, residential + sensitive, residential + commercial + industrial, residential + commercial + sensitive areas for PM_{10} and $PM_{2.5}$ respectively.

Table 4: the Measured and Estimated Value of PM_{10}

Sr. No.	Type of Monitoring Station	Station Codes	Address	8 Hour Concentration of PM_{10}, $\mu g/M^3$	Estimated 24 Hours PM_{10} Concentration, $\mu g/M^3$
1	Commercial Area	C1	Relief Road City Civic Centre,Relief Road	439	253
2		C2	Kalupur Crossroad	388	224
3	Industrial Area	I1	GIDC Area 1	198	114
4		I2	GIDC Area 2	258	149
5		I3	GIDC Area 3	59	34
6	Industrial + Residential Area	IR1	VimalbhaiMunicipal Library, Rakhial	81	47
7		IR2	Sabarmati sub-zonal Office, Sabarmati	140	81
8		IR3	Vastral Landfill Site, Vastral	119	69
9	Commercial + Residential Area	CR1	Maninagar Fire Station	152	88
10		CR2	Harubhai Mehta Bhavan, Viratnagar	246	142
11		CR3	India colony, North zone	102	59
12		CR4	Rajiv Gandhi Bhavan, Naroda,	127	73
13		CR5	Kubernagar sub-zonal Office , Kubernagar	271	156
14		CR6	Nava Vadaj muster Office, Navavadaj	184	106
15		CR7	Nagarpalika Office, Manavmandir, Memnagar	130	75
16		CR8	Dharnidhar City Civic Center	131	76
17		CR9	Gujarat Chamber of Commerce& Industry, Ashram road	191	69
18		CR10	Vadaj AMTS Bus Terminus	203	117
19		CR11	LalDarwaja AMTS Bus Terminus	599	346
20		CR12	AMC Office, Danapith, Astodia	213	123
21		CR13	Shahpur Ward Office, Shahpur.	210	121
22	Residential + Sensitive Area	RS1	CEPT University, Navrangpura.	237	137
23		RS2	Girdharnagar ward office, Girdharnagar	76	44
24		RS3	ChandkhedaNagarpalika Office, Chandkheda	122	70
25		RS4	NID, Paldi	104	60
26		RS5	Gaushala near Gandhi Ashram	83	48
27		RS6	Sarkhej Ward Office,Sarkhej	109	63
28		RS7	Sola Civil Hospital, S. G. Highway	133	76
29		RS8	Kotarpur Water Treatment Plant	160	92
30	Residential + Commercial + Industrial Area	RCI1	Dudheshwar sub-zonal Office	182	105
31	Residential + Commercial + Sensitive Area	RCS1	Blind People Association, Andhjan Mandal, Memnagar	130	75
32		RCS2	Kankaria Zoo, Maninagar	292	151

Table 5: The Measured and Estimated Value of $PM_{2.5}$

Sr. No.	Type of Monitoring Station	Station Codes	Address	8 Hour Concentration of $PM_{2.5}$, $\mu g/M^3$	Estimated 24 Hours $PM_{2.5}$ Concentration, $\mu g/M^3$
1	Commercial Area	C1	Relief Road City Civic Centre, Relief Road	127	73
2		C2	Kalupur Crossroad	102	59
3	Industrial Area	I1	GIDC Area 1	108	62
4		I2	GIDC Area 2	137	79
5		I3	GIDC Area 3	51	29
6	Industrial + Residential Area	IR1	VimalbhaiMunicipal Library, Rakhial	61	35
7		IR2	Sabarmati sub-zonal office, Sabarmati	82	47
8		IR3	Vastral Landfill Site, Vastral	95	55
9	Commercial + Residential Area	CR1	Maninagar Fire Station	74	43
10		CR2	Harubhai Mehta Bhavan, Viratnagar	76	44
11		CR3	India colony, north zone	59	34
12		CR4	Rajiv Gandhi Bhavan, Naroda	94	54
13		CR5	Kubernagar sub-zonal Office, Kubernagar	66	38
14		CR6	Nava vadaj muster office, Navavadaj	96	55
15		CR7	Nagarpalika Office, Memnagar	115	66
16		CR8	Dharnidhar City Civic Center	111	64
17		CR9	Gujarat Chamber of Commerce& Industry, Ashram road	92	53
18		CR10	Vadaj AMTS Bus Terminus	73	42
19		CR11	Laldarwaja AMTS Bus Terminus	98	57
20		CR12	AMC Office, Danapith, Astodia	104	60
21		CR13	Shahpur Ward Office, Shahpur	100	58
22	Residential + Sensitive Area	RS1	CEPT University, Navrangpura.	113	65
23		RS2	GirdharnagarWard Office, Girdharnagar	56	32
24		RS3	ChandkhedaNagarpalika Office, Chandkheda	86	50
25		RS4	NID, Paldi	84	49
26		RS5	Gaushala near Gandhi Ashram	78	45
27		RS6	Sarkhej Ward Office,Sarkhej	66	38
28		RS7	Sola Civil Hospital, S. G. Highway	38	22
29		RS8	Kotarpur Water Treatment Plant	75	43
30	Residential + Commercial + Industrial Area	RCI1	DudheshwarSub-zonal Office	54	31
31	Residential + Commercial + Sensitive Area	RCS1	Blind People Association, Memnagar	112	65
32		RCS2	Kankaria Zoo, Maninagar	227	131

DISCUSSIONS

For Commercial area, Table 4tends to indicate that the PM_{10} concentration is to the tune of 439 $\mu g/m^3$ (8 hours) and 253$\mu g/m^3$ (24 hours) at Relief Road City Civic Centre, followed by 388 $\mu g/m^3$ (8 hours) and 224 $\mu g/m^3$ (24 hours) at Kalupur crossroad which are much above the prescribed value of National Ambient Air Quality Standards (NAAQS) of

100µg/m^3 (24 hours). The data represented in Table 5 indicate that $PM_{2.5}$ concentration is to the tune of 127 µg/m^3 (8 hours) and 73 µg/m^3 (24 hours) at Relief Road City Civic Centreexceeding the prescribed norms of 60 µg/ m^3 (24 hours), followed by 102 µg/m^3 (8 hours) and 59µg/m^3 (24 hours) at Kalupur crossroad. It may be noted that the values of PM_{10} and $PM_{2.5}$are higher than the prescribed standard. This may be attributed to the high density of vehicles, less carrying capacity of roads leading to traffic congestion and other commercial activities.

For Industrial area, the PM_{10} concentration is maximumtothe tuneof258 µg/m^3 (8 hours) and 149 µg/m^3 (24 hours) atGIDC Area 2 followedby 198µg/m^3 (8 hours) and 114 µg/m^3 (24 hours) at GIDC Area 1 and 59µg/m^3(8 hours) and 34 µg/m^3 (24 hours) at GIDC Area 3.The data represented in Table 5 indicate that $PM_{2.5}$ concentration is to the tune of 137 µg/m^3 (8 hours) and 79 µg/m^3 (24 hours) at GIDC Area 2 followed by 108 µg/m^3 (8 hours) and 62 µg/m^3 (24 hours) at GIDC Area 1 and 51 µg/m^3 (8 hours) and 29 µg/m^3 (24 hours) at GIDC Area 3. The data represented that at GIDC Area 1 and GIDC Area 2, PM_{10} and $PM_{2.5}$ concentration exceeding the prescribed norms of 100 µg/m^3 (24 hours) and 60 µg/m^3 (24 hours) respectively. The higher concentrations may be on account of the release of air pollutants from industrial chimneys having low height and other transport vehicles along with fugitive emissions from different industries.

For Industrial and Residential area, from Table 4, the measured data indicate thatthe PM_{10} concentration is maximum to the tune of140µg/m^3 (8 hours) and 81 µg/m^3 (24 hours) at Sabarmati sub-zonal Office followed by 119 µg/m^3 (8 hours) and 69 µg/m^3 (24 hours) at Vastral landfill site and 81 µg/m^3 (8 hours) and 47 µg/m^3 (24 hours) at VimalbhaiMunicipal Library, Rakhial. The data represented in Table 5, indicate that the $PM_{2.5}$ concentration is maximum to the tune of 95 µg/m^3 (8 hours) and 55 µg/m^3 (24 hours) at Vastral landfill site followed by 82 µg/m^3 (8 hours) and 69 µg/m^3 (24 hours) atSabarmati sub-zonal Office and 81 µg/m^3 (8 hours) and 47 µg/m^3 (24 hours) at VimalbhaiMunicipal Library, Rakhial. It may be noted that at all the above locations, the concentration of PM_{10} and $PM_{2.5}$are within the24 hours average standards.

For Commercial and Residential area,the measured data represented in Table 4 shows thatthe PM_{10}concentration is maximumtothetuneof 599 µg/m^3 (8 hours) and 346 µg/m^3 (24 hours) at Laldarwaja followed by271 µg/m^3 (8 hours) and 156µg/m^3 (24 hours) at Kubernagar sub-zonal Office,246 µg/m^{3}and 142 µg/m^3 (24 hours) atViratnagar,213 µg/m^3(8 hours) and 123 µg/m^3 (24 hours) atAstodia,210 µg/m^3 (8 hours) and 121 µg/m^3 (24 hours) at Shahpur, 203µg/m^3(8hours) and 117 µg/m^3 (24 hours) at Vadaj AMTS Bus Terminus,191 µg/m^3(8 hours) and 69 µg/m^3 (24 hours) atGujarat Chamber of Commerce and Industry, Ashram Road,184 µg/m^3(8 hours) and 106 µg/m^3 (24 hours) at Nava VadajMuster Office, 152 µg/m^3(8 hours) and 88 µg/m^3 (24 hours) at Maninagar Fire Station,131 µg/m^3(8 hours) and 76 µg/m^3 (24 hours) at Dharnidhar City Civic Center,130 µg/m^3 (8 hours) and 75 µg/m^3 (24 hours) at NagarpalikaOffice, ManavMandir, 127 µg/m^3(8 hours) and 73 µg/m^3 (24 hours) at Rajiv GandhiBhavan,Naroda,102µg/m^3(8 hours) and 59 µg/m^3 (24 hours)at India colony, North Zone.It also indicates that at 7 locations out of 13 locations, the levels are found exceeding the prescribed standards of100 µg/m^3 (24 hours average).The measured data represented in Table 5 shows that the $PM_{2.5}$concentration is maximum to the tune of 115 µg/m^3 (8 hours) and 66 µg/m^3 (24 hours) atNagarpalika office, ManavMandir, Memnagar, followedby 111 µg/m^3 (8 hours) and 64 µg/m^3 (24 hours) at Dharnidhar Civic Center, 104 µg/m^3 and 60 µg/m^3 (24 hours) at Astodia, 100 µg/m^3 (8 hours) and 58 µg/m^3 (24 hours)Shahpur,98 µg/m^3 (8 hours) and 57 µg/m^3 (24 hours) at Laldarwaja, 96 µg/m^3 (8 hours) and 55 µg/m^3 (24 hours) at Nava VadajMuster Office, 94 µg/m^3 (8 hours) and 54 µg/m^3 (24 hours) at Rajiv Gandhi Bhavan, Naroda, Memco, 92 µg/m^3 (8 hours) and 53 µg/m^3 (24 hours) at Gujarat Chamber of Commerce and Industry, Ashram Road, 76 µg/m^3 (8 hours) and 44 µg/m^3 (24 hours) at

Viratnagar, 74 µg/m^3 (8 hours) and 43 µg/m^3 (24 hours) at Maninagar Fire Station,73µg/m^3 (8 hours) and 42 µg/m^3 (24 hours) at Vadaj AMTS Bus Terminus, 66 µg/m^3 (8 hours) and 38 µg/m^3 (24 hours) at Kubernagar sub-zonal Office, 59 µg/m^3 (8 hours) and 34µg/m^3 (24 hours) at India Colony.It also indicates that for PM_{10}at 7 locations out of 13 locations, the levels are found exceeding the prescribed standards of 100 µg/m^3 (24 hours average) and for $PM_{2.5}$ at 2 locations out of 13 locations, the levels are found exceeding the prescribed standards of 60 µg/m^3 (24 hours average).The reasons for higher levels are predominantly on account of high density of automobiles and vehicular congestions.

For Residential and sensitive area, the measured data represented in Table 4, reveal the factthat the PM_{10} concentration is maximum to the tune of 237 µg/m^3(8 hours) and 137 µg/m^3 (24 hours) at CEPT University followed by 160 µg/m^3 (8 hours) and 92 µg/m^3 (24 hours) at Kotarpur Water Treatment Plant,133 µg/m^3(8 hours) and 76 µg/m^3 (24 hours) at Sola Civil hospital,122 µg/m^3(8 hours) and 70 µg/m^3 (24 hours) at Chandkheda Gam, 109 µg/m^3(8hours) and 63 µg/m^3 (24 hours) at SarkhejRoza,104 µg/m^3(8 hours) and 60 µg/m^3 (24 hours) atNID,Paldi,83 µg/m^3(8 hours) and 48 µg/m^3 (24 hours) atGandhi Ashram and76µg/m^3(8 hours) and 44 µg/m^3 (24 hours) at GirdharnagarWard Office.For$PM_{2.5}$, the data represented in Table 5 reveal the fact that, the $PM_{2.5}$ concentration is maximum to the tune of 113 µg/m^3 (8 hours) and 65 µg/ m^3 (24 hours) at CEPT university followed by 86 µg/m^3 (8 hours) and 50 µg/m^3 (24 hours) at Chandkheda Gam, 84µg/m^3 (8 hours) and 49 µg/m^3 (24 hours) at NID, Paldi, 78 µg/m^3 (8 hours) and 45 µg/m^3 (24 hours) at Gandhi Ashram, 75 µg/m^3 (8 hours) and 43 µg/m^3 (24 hours) at Kotarpur Water Treatment Plant, 66 µg/m^3 (8 hours) and 38 µg/m^3 (24 hours) at Sarkhej Roza, 56 µg/m^3 (8 hours) and 32 µg/m^3 (24 hours) at Girdharnagar ward office and 38 µg/m^3 (8 hours) and 22 µg/m^3 (24 hours) at Sola Civil Hospital. For both PM_{10} and $PM_{2.5}$, the exceeding level beyond the norms has been found in CEPT University partly due to the fact that monitoring is done at the breathing zone level(1.5m) and partly on account of the construction activities being carried out in and around the CEPT campus.

For combination of commercial, residential and industrial area, the measured data shows that the PM_{10} concentration is to the tune of 182 µg/m^3 (8 hours) and 105 µg/m^3 (24 hours) which is higher than the permissible value of 100 µg/m^3 (24 hours) and the $PM_{2.5}$ concentration is to the tune of 54 µg/m^3 (8 hours) and 37 µg/m^3 (24 hours) at Dudheshwar sub-zonal Office. This may owe partly due to the burning of cowdung, wood and other non-conventional fuels and partly on account of the clusters of small-scale industries.

For combination of residential, commercial and sensitive zone, the measured data indicate that the PM_{10} concentration is maximum to the tune of 292 µg/m^3 (8 hours) and 150 µg/m^3 (24 hours) at Kankaria Zoo followed by 130 µg/m^3 (8 hours) and 75 µg/m^3 (24 hours) at the Blind People Association, Andhjan Mandal, respectively. The PM_{10} concentration observed at Kankaria Zoo has been found beyond permissible norms partly due to vehicular air pollution along with heavy traffic density and partly on account of the coal storage warehouse, the locomotive warehouse locatedwithin100-200m distance. For $PM_{2.5}$, the data represented in Table 5 indicate that, the $PM_{2.5}$ concentration is maximum to the tune of 227 µg/m^3 (8 hours) and 131 µg/m^3 (24 hours) at KankariaZoo followed by 112 µg/m^3 (8 hours) and 65 µg/m^3 (24 hours) at the Blind People Association, Andhjan Mandal. At both places, $PM_{2.5}$ concentration exceeding the permissible norms.

CONCLUSIONS

- Around 0.5568 Km^2 area of Ahmedabad falls under highly critical and alarming levels i.e PM_{10} concentration > 250 µg/m^3 (24 hours of observation) which include the areas, namely Paldi, Gita Mandir, Jamalpur,

and Behrampura. Around 40 Km^2 area of Ahmedabad falls under critical level, i.e. PM_{10} concentration between 100 $\mu g/m^3$ and 250 $\mu g/m^3$ (24 hours of observation) which include the areas, namely Vatva, Memco, Kubernagar, Kankaria, Maninagar, Dharnidhar, Navrangpura, Ellisbridge, Vastrapur, Gulbaitekra, Nehrunagar, Kalupur, Laldarwaja, Shahpur and Dariyapur. Around 224 Km^2 area of Ahmedabad falls under moderate level, i.e. PM_{10}concentration between 60 $\mu g/m^3$ and 100 $\mu g/m^3$ (24 hours of observation) which include the areas, namelyJivraj, Satellite, Old Vadaj, RTO, Sabarmati, Kotarpur, Vastral, Odhav, Viratnagar, India colony and Danapith. Around 201 Km^2 area of Ahmedabad falls below safe levels i.e, PM_{10} concentration<60 $\mu g/m^3$ (24 hours of observation) which include they are as namely Rakhial, Ashram Road, Girdharnagar, Sarkhej, Bopal, Sola, S. G. Highway, Chandkheda Gam, Army cantonment and Naroda.

- Similarly, around 0.928 Km^2 area of Ahmedabad falls under highly critical and alarming levels i.e $PM_{2.5}$concentration> 100 $\mu g/m^3$ (24 hours of observation) which include the areas, namelyOdhav, Kankaria, Maninagar, DanilimdaandKalupur. Around 7 Km^2 area of Ahmedabad falls under critical level, i.e. $PM_{2.5}$concentration between 70 $\mu g/m^3$ and 100 $\mu g/m^3$ (24 hours of observation) which include the areas, namely, Vatva, Gita Mandir, Khadia, Gomtipur, Jamalpur, Khokhra, Kalupur, LalDarwaja, and Saraspur. Around 235 Km^2 area of Ahmedabad falls under moderate level, i.e. $PM_{2.5}$concentration between 40 $\mu g/m^3$ and 70 $\mu g/m^3$ (24 hours of observation) which include the areas, namelyChandkheda, RTO circle, Viratnagar, Rakhial, Vastral, India Colony, Paldi, Dharnidhar, Nehrunagar, Ellisbridge, Gulbaitekra, Navrangpura, Satellite, Jodhpur, Jivrajand Vastrapur. Around 220 Km^2 area of Ahmedabad falls below safe levels i.e, $PM_{2.5}$ concentration< 40 $\mu g/m^3$ (24 hours of observation) which include the areas, namely Sarkhej, Sola, Gota, Bopal, Ghuma, S. G. Highway, Chandkheda gam, Kotarpur, Army Cantonment, Naroda, Kubernagar, Memco, Girdharnagar, Sabarmati, Old Wadajand Maninagar.
- Considering 24 hours average values concentration, 14 areas of Ahmedabad have been found to exceed the permissible levels of PM_{10} whereas 9 locations are beyond permissible levels in respect of $PM_{2.5}$.
- 8-hour duration of sampling to monitor during daytime from 9 am to 5 pm tends to indicate excessively high levels, which reveal the fact that such a higher exposure of PM_{10} and $PM_{2.5}$ concentrations are witnessed during working hours which may have the significant impact on human health.
- Well defined environmental strategies need to be put in place, particularly in respect of automobile and industrial air pollution control, regulatory and enforcement mechanisms, urban planning and long-term monitoring and evaluation programs.

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