Asian Journal of Chemistry; *Vol. 34, No. 10 (2022), 2757-2762*

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2022.23885

Comparative Assessment of Seasonal Variation in Size-Segregated Particulate Matters around Urban Drains

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Received: 27 April 2022; *Accepted*: 5 September 2022; *Published online*: 19 September 2022; AJC-20984

The rapidly growing urbanization has resulted in increased environmental pollution and degradation that has equally affected the quality of air and wastewater. Urban drains that carry wastewater from households and industries are also carrying loads of pollutants. The current study was conducted to compare the trend in the concentration of particulate matter (PM) in the air, across the seasons near the urban drains in Delhi, a metropolitan city. The air samples were taken from Najafgarh drain, which is the biggest drain of Delhi city and has a contribution of about 60% of the total wastewater released from Delhi city into river Yamuna. The Indian Standard method IS 5182 Part 24:2019 was used for $PM_{2.5}$ & IS 5182 Part 23:2006 was used for PM_{10} monitoring and analysis. The results of the analysis showed that the variation in particulate matter (PM) is observed with changes in relative humidity and with seasonal changes. The variation in $PM_{2.5}$ levels was seen in a range of 55.30-118.42 μg/m^3 from June 2020 to February 2021 & in PM_{10} levels were seen in the range of 77.54-261.99 μg/m^3 during June 2020 to February 2021 for location L1. The variation in $PM_{2.5}$ levels was seen in a range of 23.84-76.94 μg/m^3 from June 2020 to February 2021 & in PM_{10} levels were seen in the range of 42.06-149.48 μg/m^3 during June 2020 to February 2021 for location L2. Few studies have shown that contaminants can enter into the fresh air from the municipal wastewaters and open drains.

Keywords: Urban drains, PM_{10}, $PM_{2.5}$, Air pollution, Impacts, Air quality index.

INTRODUCTION

Air pollution is a major concern worldwide. Clean air is a necessity and requirement for the existence of humans on this earth, however, the growing industrialization and urbanization have led to several environmental issues, including air pollution [1,2]. As per World Health Organization, 13 of the world's most polluted cities (in terms of $PM_{2.5}$ levels) are in India and Delhi is at the top position among the polluted cities. The air quality in Delhi fluctuates from satisfactory to severe category throughout the year. Based on the receptor modelling approach, The Central Pollution Control Board (CPCB) of India in 2010, has estimated the contributors to particulate matter (PM) as 22-24% for construction activities, 11-25% for garbage burning, 9-21% for vehicle exhaust and 7-13% for diesel generator sets [3]. Biomass and stubble burning in the agricultural fields are also major contributors to smoke, smog and particulate pollution [4]. Particulate matter of sizes 2.5 microns ($PM_{2.5}$) and 10 microns (PM_{10}) have been classified as criteria pollutants under the Clean Air Act 1963 by the US-EPA due to the human health and environmental implications [5]. Indian cities are facing severe particulate matter pollution with range exceeding from both National and International standards [6,7].

The Air Prevention and Control of Pollution Act, 1981 was enacted in India, granting the CPCB the authority to carry out its duties. In 1984, the NAAQM programme was established and on November 11, 1982, the ambient air quality standards were adopted in accordance with Section 16(2) of the Act. Both in 1994 and 2009, these requirements underwent revision. As per Centre Pollution Control Board (CPCB), an ambient concentration of PM_{10} is 60 μg/m^3 annually and 100 μg/m^3 24 h for industrial, residential, rural and other areas as well as ecologically sensitive areas that are notified by Central Government of India. The ambient concentration of $PM_{2.5}$ is 40 μg/m^3

annually and 60 μg/m^3 24 h for industrial, residential, rural and other areas as well as ecologically sensitive areas, which are notified by Central Government of India [8].

Under the direction of The Ministry of Environment, Forest and Climate Change of India, the Central Pollution Control Boards and the State Pollution Control Boards have developed the National Air Quality Index (NAQI), which informs the people about the air quality using the colour-coded scale. The dark green shows that AQI is in between 0-50 and the air quality is good; light green shows AQI in range of 51-100 and air quality is satisfactory; yellow shows AQI is in range of 101-200 and air quality is satisfactory; dark yellow/mustard colour shows that AQI ranges from 201 to 300 and the air quality is poor; red shows the AQI between 301-400 and the quality of air is very poor; maroon/dark red colour shows the AQI between 401-500 and the quality of air is severe. In 2021, after 16 years, World Health Organization has changed the standard of outdoor air pollution. The ambient concentration of PM_{10} was 50 μg/m^3 24 h and 20 μg/m^3 annually and for $PM_{2.5}$ was 25 μg/m^3 24 h and 10 μg/m^3 annually in 2005. These standards were revised in 2021 where the ambient concentration of PM_{10} is 45 μg/m^3 24 h and 15 μg/m^3 annually [9].

According to the Drainage Master Plan of NCT of Delhi, 201 drains are criss-crossing the land of Delhi. Urbanization, modernization and an increase in the population of Delhi have given rise to the increase in the number of drains. In some places, these drains have been covered to build the road. There are residential colonies of lower and lower-middle-income groups that have been built near those drains [10]. At other locations, these drains have extensive green catchment areas. Both these location types may have characteristic differences in air quality. Many of these drains are unlined and uncovered posing air pollution as well as groundwater pollution [11].

Particulate matter (PM) air pollution is largely responsible for the disruption of the physical environment by causing smog, acid rain and low visibility and also causing public health issues such as common respiratory diseases [12,13] and metabolic ailments like obesity and diabetes mellitus [14]. Such chronic and acute exposure to PM is also linked to an increase in death related to cardiovascular diseases, which include ischemic heart disease, thrombotic stroke and heart failure [15]. In this study, the examination of seasonal and annual trend in the concentration of PM near drains was performed, understanding was drawn about the role of meteorological parameters (wind speed, humidity and temperature) on particulate pollutants.

EXPERIMENTAL

Sampling sites: The capital of India and one of the biggest cities in South Asia is Delhi. It is 216 metres above mean sea level and situated between latitudes of 28.2417ºN and 28.5300ºN and longitudes of 76.5024ºE and 77.2037ºE. Delhi is located in the plains of the Ganges. There are mountainous regions in the north and east, the Great Indian Desert (Thar Desert) of Rajasthan state in the west and hot, central plains in the south. The Yamuna River outlines Delhi's eastern border. Its climate is semi-arid, with lengthy summers lasting from early April to early October, the monsoon season in between and harsh winters lasting from October to February, with a peak in January marked by dense fog [16]. The majority of the year, with the exception of the monsoon season (June–September), the wind blows westward toward the Bay of Bengal. Delhi's population density in 2011 was 11,312 persons per square kilometre. It has a total area of 1384 km^2. It is surrounded by industrial clusters in the National Capital Region (NCR region) which is formed by Faridabad, Ghaziabad, Gurugram and Noida cities [17] which are rapidly developing commercially.

The sub-location taken for monitoring of air pollution was located in southwest Delhi near the sister drains of Najafgarh drain, which is one of the major drains of Delhi that carries wastewater and stormwater from the southwest part of Delhi city to the river Yamuna. Two locations were selected: near a drain covered with concrete and a road built over it (L1), the Dwarka-Dabri Nala road and the other location near the CNG filling station in Sector 5 of Dwarka (L2), which is an open-drain with wild and planted vegetation on the catchment (Fig. 1). The location of the covered drain is inhabited by middle and lower-middle-income people. The service road on either side of the covered drain is uncarpeted due to the constant construction activities and poor maintenance. The traffic on the covered drain road is moderate to heavy with traffic jams at peak hours. L2 has apartment complexes on one side and a green belt on the other. The road crossing over the bridge near the CNG station has low to moderate traffic.

Monitoring and measuring instruments: Monitoring and analysis of PM pollutants in ambient air were done using the respirable dust sampler (Model G151 manufactured by Greentech Instruments) or high volume sampler for PM_{10} and fine dust sampler for $PM_{2.5}$ (Model DFPM002 manufactured by Dutt Instruments) conforming to the requirements EPA, NAAQS and CPCB, glass fiber filter of 20.3 cm × 25.4 cm (8 inches × 10 inches) size for PM_{10} and Teflon membrane filters of 46.2 mm diameter with a polypropylene support ring having a pore size of 2 μ for $PM_{2.5}$ sampling, Semi-Micro Balance (AUW220D) for weighing the filters, the non-serrated plastic forceps for handling filters, relative humidity-temperature meter, stopwatch, top-loading orifice kit. All equipments were calibrated by laboratories certified by National Accreditation Board for Testing and Calibration Laboratories, Government of India.

Method for the assessment of PM_{10}: The Indian Standard method IS 5182 Part 23:2006 Reaffirmed 2017 was followed for the sampling of PM_{10}. The air was drawn through a size-selective inlet of respirable dust sampler and a 20.3 × 25.4 cm (8 × 10 in) GF filter at a flow rate of around 1132 L/min for 4 h. Conditioning of the filter was done before sampling in an air-tight desiccator at 25-30 ºC for 24 h. The filter was used to catch particles whose aerodynamic diameter was less than the input cut-point. The filter paper was conditioned again for 24 h in the desiccator and the final mass of filter paper was noted down. The mass of the PM_{10} particles was then found by the difference in filter weights before and after sampling. The concentration of PM_{10} was then calculated by using eqn. 1 [18]:

$$C_{PM_{10}}\ (\mu g/m^3) = \frac{W_f - W_i}{V} \times 10^6$$

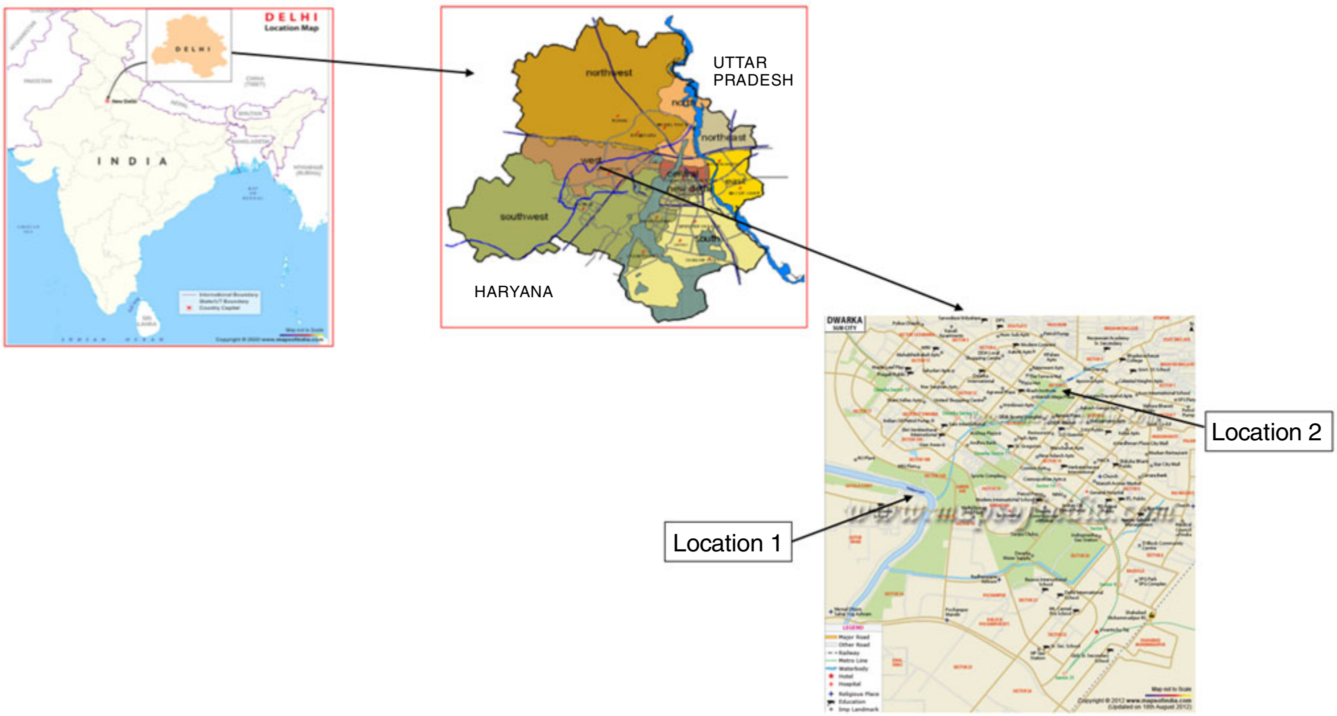

Fig. 1. Map showing the sampling location 1 (Dabri Nala) and location 2 (CNG filling gas station, secto-5, Dwarka, New Delhi

where $C_{PM_{10}}$ = concentration of PM_{10} ($\mu g/m^3$); W_f = initial weight of filter (g); W_i = initial weight of filter (g); 10^6 = conversion of g to µg; V = volume of air sampled (m^3).

Method for the assessment of $PM_{2.5}$: The Indian Standard method IS 5182 Part 24:2019 was followed for $PM_{2.5}$ monitoring and analysis. Throughout the 4 h, ambient air was pulled at a volumetric flow rate of 16.7 L/min into impactors or separators made specifically to separate and collect $PM_{2.5}$ on a 47 mm polytetrafluoroethylene filter [19]. Each filter was preconditioned before sampling and after sampling. The filter was weighed before and after sample collection and the gain in weight due to the particulate matter was determined using eqn. 2:

$$PM_{2.5} = \frac{M_f - M_i \times 10^3}{Q_{avg} \times t \times 10^{-3}}$$

where $PM_{2.5}$ = total mass of fine particulate collected during sampling period (µg); M_f = final mass of the conditioned filter after sample collection (mg); M_i = initial mass of the conditioned filter before sample collection (mg); 10^3 = unit conversion factor for milligrams (mg) to micrograms (µg); V = total sample value (m^3); Q_{avg} = average flow rate over the entire duration of the sampling period (L/min); t = duration of the sampling period (min); 10^{-3} = unit conversion factor for liters (L) into cubic meters (m^3).

PM_{10} and $PM_{2.5}$ data: Data were obtained by the manual sampling of PM_{10} and $PM_{2.5}$ for 10 days continuously at locations L1 and L2 each month from June 2020 to April 2021. The time of manual monitoring was morning 8 am to 12 noon, evening 4:00 pm to 8:00 pm and midnight to 4:00 am. Time was chosen such that the maximum pollution load time is selected. Midnight was chosen so that effect of traffic on pollution could be ascertained. Daily 24 h data and 4 hourly data were also downloaded from the CPCB pollution monitoring station at NSIT, Dwarka (Delhi) and DPCC stations at Malaria Research Center, Sector-8, Dwarka (Delhi) for the same period to enable comparison with the manual monitoring data as the locations of this research are located in the radius of about 5 km distance. The daily average concentration was computed for all the days of each month. Monthly averaging was also done to obtain the variation in the concentration during different seasons of the year. The average pollutant level in the 4 h monitoring of morning, evening and night for each month was also computed. The ratio of the annual mean concentration of a pollutant to its respective standard maximum limit as per NAAQS gives us the exceedance factor (EF) [20] and was calculated using eqn. 3:

$$\text{Annual EF} = \frac{C_O}{C_S}$$

where C_o = observed annual mean value and C_s = prescribed standard.

The ratio of the observed concentration of atmospheric contaminants to their recommended standard limits is known as the air quality index (AQI) [21]. AQI was calculated using the formulas undertaking the mass concentration of PM_{10} and $PM_{2.5}$ into consideration:

$$AQI = \frac{1}{3}\left[\left(\frac{PM_{2.5}}{sPM_{2.5}}\right) + \left(\frac{PM_{10}}{sPM_{10}}\right)\right] \times 100$$

The $sPM_{2.5}$, sSO_2, sNO_2 are the ambient air quality standards maximum limits as per NAAQS and $PM_{2.5}$, SO_2 and NO_2 are the actual observed values of pollutants [22].

Meteorological data: The local weather data *i.e.*, ambient temperature, relative humidity, solar radiation and wind speed were obtained from mentioned sites and Indian Meteorological

Department (IMD). This information was used to understand the effect of weather conditions on PM_{10} and $PM_{2.5}$ in the four seasons namely monsoon (June–September), post-monsoon (October–November), winter (December–February) and summer (March-May) as defined by the Indian Meteorological Department (IMD).

Quality control/quality assurance of data used in the study: All the equipment used for manual monitoring was calibrated by NABL accredited calibration laboratories to maintain traceability to SI units and ensure the integrity of primary data. Intermediate checks were carried out on equipment in a planned schedule by standards like calibrated rotameters and standard weight which were further calibrated by NABL accredited laboratories.

Secondary data was taken from the articles published in journals and reports issued by the Central Pollution Control Board and World Health Organization (WHO) and the US EPA (Environment Protection Agency). The CPCB (Central Pollution Control Board) follows its quality control and quality assurance program to ensure timely calibration and maintenance of instruments and equipment used for ambient air quality monitoring and evaluation of monitoring stations.

RESULTS AND DISCUSSION

Monitoring and analysis of the $PM_{2.5}$ and PM_{10} was also done continuously 10 days each month (1st to 10th) from June 2020 to April 2021 at two locations namely a covered drain and an open drain in the southwest region of Delhi.

Analysis of $PM_{2.5}$: The 10 days the monthly average concentration of $PM_{2.5}$ from June 2020 to April 2021 was found in the range of 55.30 µg/m³ to 132.31 µg/m³ at the site L1. $PM_{2.5}$ levels at site L2 were in the range of 27.98 µg/m³ to 104.92 µg/m³ (Table-1). Locations L1 and L2 were situated at a distance of 100 m from the drains. The monthly average concentration of $PM_{2.5}$ of the sites L1 and L2 is shown in Fig. 2, respectively. The highest levels of $PM_{2.5}$ found were 212.81 µg/m³ on 7th April 2021 and 178.2 µg/m³ on 6th April 2021 in the period of 4 pm to 8 pm monitoring. The least level of $PM_{2.5}$ was 34.1 µg/m³ on 5th Oct 2020 at midnight sampling and 10.79 µg/m³ on 9th Oct 2020 at 8 am to 12 pm sampling.

The results of the annual location wise average concentration of $PM_{2.5}$ at sites L1 and L2 along with standard deviation, standard error, maximum and minimum concentration are given in Table-2. Location L2 has a lower PM load compared to location L2. Annual variation in $PM_{2.5}$ in the study showed a similar trend with the relaxation of lockdown due to declining Covid incidences from June 2020, the concentration of PM gradually increased and reached the maximum in November 2020 and December 2020 and then fell lower and again increases as the summer approached in April 2021.

The lowest level of $PM_{2.5}$ was observed in October 2020 due to increased humidity and wind speed. The PM levelswere

TABLE-1
CONCENTRATION OF PM_{10}, $PM_{2.5}$ AND METEOROLOGICAL CONDITIONS AT TWO STUDY LOCATIONS FROM JUNE 2020 TO APRIL 2021

Month	Location 1		Location 2		Meteorological conditions		
	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	RH %	AT*C	WS (m/s)
Jun-20	60.61	96.21	45.49	66.93	50.76	31.67	0.87
Jul-20	73.17	107.86	51.63	78.48	48.02	35.41	1.17
Aug-20	66.58	90.61	42.4	59.04	53.38	34.2	1.18
Sep-20	57.38	77.54	27.98	42.06	60.01	31.89	1.23
Oct-20	55.3	117.31	23.84	72.80	65.12	30.56	1.06
Nov-20	110.84	261.99	60.93	109.06	62.58	31.67	0.91
Dec-20	94.56	240.51	37.98	74.27	67.37	30.92	1.09
Jan-21	102.03	218.43	45.84	74.08	68.42	29.38	1.09
Feb-21	118.42	251.16	76.94	149.48	70.21	16.38	0.66
Mar-21	100.92	247.42	73.12	168.55	46.27	23.76	0.94
Apr-21	132.31	249.67	104.92	172.87	18.86	28.48	1.04
Exceedance factor	2.2	2.96	1.34	1.61	–	–	–

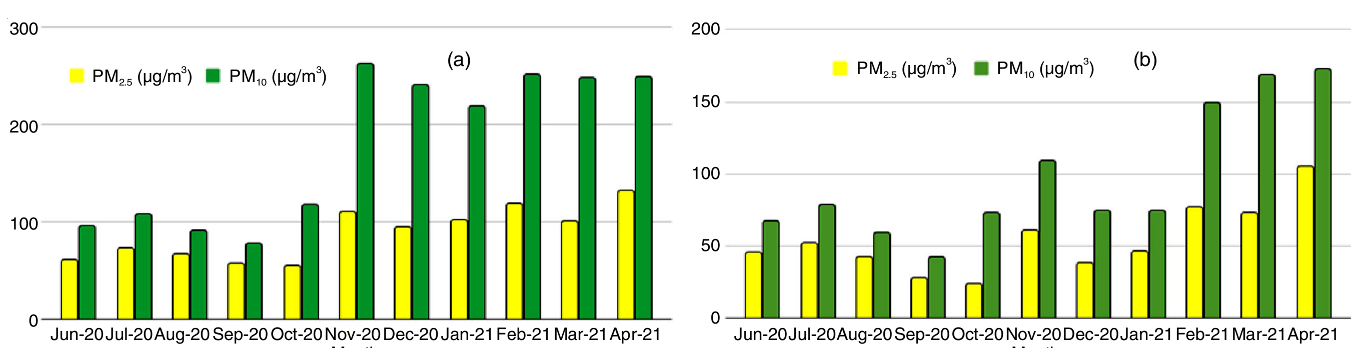

Fig. 2 PM_{10} and $PM_{2.5}$ concentration in µg/m³ at (a) Dabri Nala Road (Location 1) and (b) CNG filling station in Sector 5 of Dwarka (Location 2)

TABLE-2
MONTHLY AIR QUALITY INDEX AT DIFFERENT LOCATIONS

Month	Location L1 AQI	Location L2 AQI
Jun-20	103.78	74.85
Jul-20	120.50	86.60
Aug-20	105.67	68.10
Sep-20	90.74	46.36
Oct-20	111.17	60.11
Nov-20	237.88	111.25
Dec-20	212.28	72.59
Jan-21	206.35	79.15
Feb-21	238.20	147.04
Mar-21	221.45	154.30
Apr-21	248.70	183.37

elevated in April 2021 due to the lower humidity during the observation and complete lifting up of the lockdown. The $PM_{2.5}$ concentration at both sampling locations was under the permissible limit of CPCB India's National Ambient Air Quality Standards for only 17.5% times at L1 and 83.5% times at L1 in the year. The maximum limit of $PM_{2.5}$ as per NAAQS is 60 $\mu g/m^3$ for 24 h.

Analysis of PM_{10}: The 10 days the monthly average concentration of PM_{10} from June 2020 to April 2021 was found in the range of 77.54 $\mu g/m^3$ to 261.99 $\mu g/m^3$ at the site L1. At site L2, the maximum PM_{10} was found 172.87 $\mu g/m^3$ and the minimum was 42.06 $\mu g/m^3$ (Table-3). The highest concentration of PM_{10} was found at sampling point L1 due to heavy traffic and the presence of shops and renovation activities taking place in the nearby residential colonies and roads. The monthly average concentration of PM_{10} of the site L1 and L2 are shown in Fig. 2. The highest concentration of PM_{10} in the observational period was found on 1st April 2021 between 4 pm to 8 pm at sites L1 and L2 where the PM_{10} was 345.74 and 287 $\mu g/m^3$. The most probable reason for this can be the complete lifting of the lockdown and resumption of all kinds of activities at both locations. A similar trend was obtained for the lowest level of PM_{10} as well. It was found at 51.81 and 22.87 $\mu g/m^3$ in the midnight to 4 am monitoring of 9th Sept 2020. The results of the annual location-wise average concentration of PM_{10} and $PM_{2.5}$ are shown in Fig. 3.

The highest and lowest concentration was found at L1 and L2 for both PM_{10} and $PM_{2.5}$, respectively. Annual variation in PM_{10} and $PM_{2.5}$ in the study showed a similar trend with the relaxation of lockdown by the government due to declining Covid-19 incidences from June 2020, concentration of PM gradually increased and reached the maximum in November 2020 and December 2020 and then fell lower and again increases as the summer approached in April 2021. The lower particulate pollution was observed from June 2020 to October 2020 with the lowest in September 2020 during the whole period of observation. Fig. 4 shows the variation in levels of particulate matter (PM_{10} and $PM_{2.5}$) at both locations.

The results have shown that the level of $PM_{2.5}$ was more at L1 (Dabri Nala) than the L2 (CNG filling station, Sector-5, Dwarka). In April 2021, the levels of $PM_{2.5}$ were recorded as 132.31 $\mu g/m^3$ which was the highest of all months at Dabri Nala (L1) and 104.92 $\mu g/m^3$ as the highest at the CNG filling station, Sector-5, Dwarka (L2). The results have shown that the level of PM_{10} was more at L1 (Dabri Nala) than the L2 (CNG filling station, Sector-5, Dwarka). In November 2020, the levels of PM_{10} were recorded as 261.99 $\mu g/m^3$ as the highest at Dabri Nala (L1) and 172.87 $\mu g/m^3$ as the highest at CNG filling station, Sector-5, Dwarka (L2).

Exposure to particulate matter is hazardous to health. It is an endocrine disruptor that affects the human respiratory system, nervous system and cardiovascular system. The effects of particulate matter depend upon the concentration and size being exposed. The results from the study show that the annual EF for $PM_{2.5}$ at L1 was 2.2; at L2 was 1.34, whereas the annual EF for PM_{10} at L1 was 2.96 and at L2 was 1.61. Monthly variation in AQI of both locations is seen from June 2020 to April 2020. The recorded AQI at L1 for June 2020, July 2020,

TABLE-3
LOCATION WISE ANNUAL PM_{10} AND $PM_{2.5}$ CONCENTRATION FOR THE PERIOD JUNE 2020 TO APRIL 2021

Location	$PM_{2.5}$					PM_{10}				
	Average	Std. Dev.	Std. errors	Max. level	Min. level	Average	Std. Dev.	Std. errors	Max. level	Min. level
L1	88.37	26.93	8.12	132.31	55.30	178.06	78.05	23.53	261.98	77.54
L2	53.73	23.78	7.17	104.92	23.84	97.06	45.94	13.85	172.87	42.06

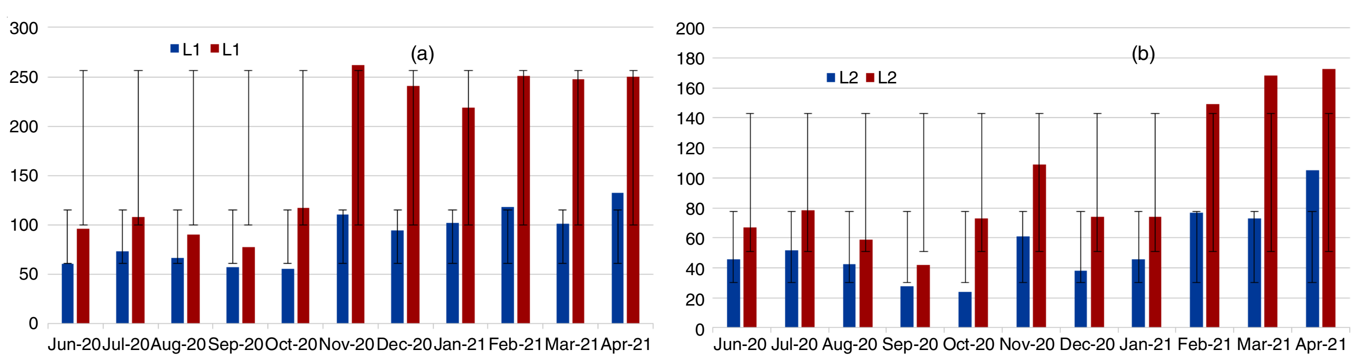

Fig. 3. Concentration of PM_{10} and $PM_{2.5}$ with standard deviation at (a) Location 1 (Dabri Nala) and (b) Location 2 CNG filling gas station, Sector 5, Dwarka)

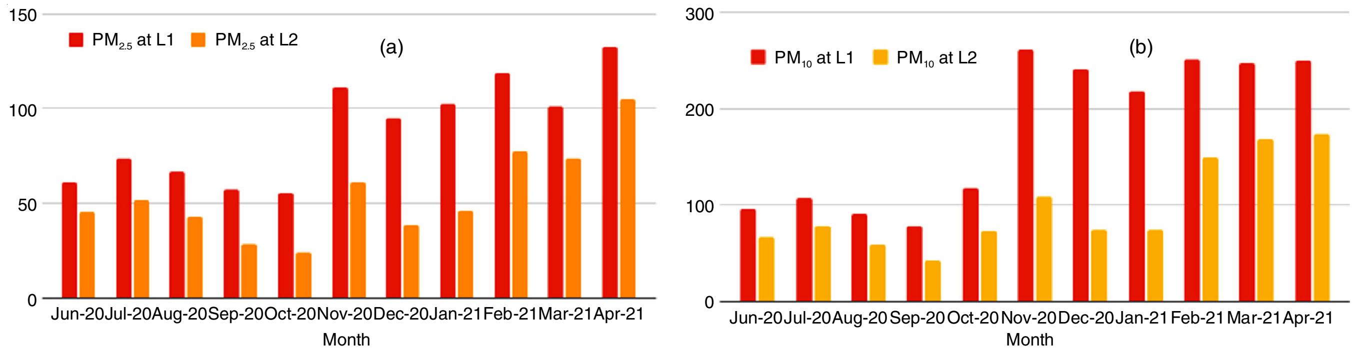

Fig. 4. (a) $PM_{2.5}$ and (b) PM_{10} variation at location 1 and location 2

August 2020, September 2020, October 2020, November 2020, December 2020, January 2021, February 2021, March 2021 and April 2021 were observed as 103.78, 120.5, 105.67, 90.74, 111.17, 237.88, 212.28, 206.35, 238.2, 221.45 and 248.7, respectively. Whereas the AQI of both locations is seen from June 2020 to April 2020. The recorded AQI at L1 for June 2020, July 2020, August 2020, September 2020, October 2020, November 2020, December 2020, January 2021, February 2021, March 2021 and April 2021 were observed as 74.85, 86.6, 68.1, 46.36, 60.11, 111.25, 72.59, 79.15, 147.04, 154.3 and 183.37, respectively. AQI variation was observed during seasonal changes. At L1 (Dabri Nala), the AQI was recorded as 105.3, 174.3, 218.8 and 235.07 for monsoon, post-monsoon, winter and summer seasons respectively. Whereas, at L2 (CNG gas filling station), AQI was recorded as 68.9, 85.5, 99.4 and 168.8 for monsoon, post-monsoon, winter and summer seasons, respectively.

Conclusion

In summary, the study showed that the AQI at both locations (L1: Dabri Nala and L2: CNG gas filling station, sector-5, Dwarka) during the monsoon season was low as the rain settle downs the particulate matter and the associated winds aid the dispersion of pollutant. The concentration of PM_{10} was more at L1 than the L2 sites. In November 2020, the levels of PM_{10} were recorded as 261.99 $\mu g/m^3$ as the highest at L1 and 172.87 $\mu g/m^3$ as the highest at L2. The study also showed AQI variation was observed during seasonal changes. At L1, the AQI was recorded as 105.3, 174.3, 218.8 and 235.07 for monsoon, post-monsoon, winter and summer seasons, respectively. Whereas, at L2, AQI was recorded as 68.9, 85.5, 99.4 and 168.8 for monsoon, post-monsoon, winter and summer seasons, respectively.

CONFLICT OF INTEREST

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

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