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Studies on the variation in concentrations of respirable suspended particulate matter (PM_{10}), NO_2 and SO_2 in and around Nagpur

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सार — इस अध्ययन का उद्देश्य 2011-2018 के दौरान नागपुर (भारत) के आस पास की वायु में श्वसनीय सस्पेंडेड पार्टिकुलेट मैटर (PM_{10}), सल्फर डाइऑक्साइड (SO_2) और नाइट्रोजन डाइऑक्साइड (NO_2) की सांद्रता में दीर्घकालिक भिन्नता का आकलन करना है। उपरोक्त अवधि के दौरान तीन स्थानों अर्थात् आवासीय (स्टेशन-I), औद्योगिक (स्टेशन-II) और वाणिज्यिक स्थान (स्टेशन-III) के प्रदूषण डेटाका विश्लेषण किया गया है। आवासीय, औद्योगिक और व्यावसायिक स्थानों पर PM_{10} की उच्चतम दैनिक औसत सांद्रता क्रमशः 154 μg/m^3, 199 μg/m^3 और 153 μg/m^3 पाई गई, जबकि इन स्थानों पर उपरोक्त अवधि के दौरान वार्षिक औसत सांद्रता 101.87 μg/m^3, 115.37μg/m^3 और 98.75 μg/m^3 पाई गई। SO_2 की उच्चतम दैनिक औसत सांद्रता 18 μg/m^3, 22 μg/m^3, और 19 μg/m^3 पाई गई और संबंधित स्थानों पर वार्षिक औसत सांद्रता 13.25 μg/m^3, 13.5 μg/m^3, 13 μg/m^3 थी। संबंधित स्थानों पर NO_2 की उच्चतम दैनिक औसत सांद्रता 77 μg/m^3, 60 μg/m^3, 60 μg/m^3 और वार्षिक औसत सांद्रता 44.125 μg/m^3, 41.825 μg/m^3 तथा 40.25 μg/m^3 पाई गई। PM_{10} के अत्यधिक प्रभावी कारक आवासीय और वाणिज्यिक स्थानों पर 'मध्यम से उच्च' और औद्योगिक स्थान पर 'उच्च से मध्यम' में बदलते रहते हैं। 2011-2018 के लिए इस क्षेत्र में ग्रहीय सीमा परत की ऊंचाई (PBLH) और संवातन गुणांक (VC) का भी आकलन किया गया। अध्ययन अवधि के दौरान अधिकतम पीबीएलएच और वीसी ग्रीष्म ऋतु में देखे गए और न्यूनतम मॉनसूनोत्तर ऋतु में देखे गए। वार्षिक और ऋतुनिष्ठ वायु गुणवत्ता सूचकांक विश्लेषण से पता चला है कि प्रदूषण का स्तर संतोषजनक से मध्यम स्तर की सीमा में था। PM_{10}, SO_2 और NO_2 के ऋतुनिष्ठ विश्लेषण के एक अध्ययन से पता चला है कि गर्मियों की तुलना में सर्दियों में उच्च सांद्रता पाई गई और मॉनसून ऋतु में सबसे कम सांद्रता पाई गई। अन्य प्रदूषकों के साथ PM_{10} की अन्योन्याश्रितता की जांच के लिए एक समाश्रयण विश्लेषण किया गया । सभी ऋतुओं में PM_{10} और SO_2 के बीच एक सकारात्मक संबंध पाया गया। सभी स्टेशनों पर गर्मियों में PM_{10} और NO_2 के बीच और स्टेशन-I और स्टेशन-III में सर्दियों में एक नकारात्मक संबंध पाया गया। इसी तरह, PM_{10} और मौसम संबंधी प्राचलों जैसे पवन की गति और तापमान के बीच सहसंबंध नकारात्मक पाया गया जबकि यह सापेक्ष आर्द्रता के लिए सकारात्मक था।

ABSTRACT. The objective of this study is to assess the long-term variation in concentrations of Respirable suspended particulate matter (PM_{10}), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in the ambient air of Nagpur (India) during 2011-2018. The pollution data during the above period at three locations, *viz*., residential (Station-I), industrial (Station-II), and commercial location (Station-III) has been analyzed. The highest daily average concentration of PM_{10} at residential, industrial, and commercial locations was found 154 μg/m^3, 199 μg/m^3, and 153 μg/m^3, whereas, the average annual concentration at these locations was found 101.87 μg/m^3, 115.37 μg/m^3 and 98.75 μg/m^3, respectively during the above period. The highest daily average concentration of SO_2 was found at 18 μg/m^3, 22 μg/m^3 and 19 μg/m^3 and the average annual concentration was 13.25 μg/m^3, 13.5 μg/m^3, 13 μg/m^3 at respective locations. And the highest daily average concentration of NO_2 was found 77 μg/m^3, 60 μg/m^3, 60 μg/m^3 and the annual average concentration was 44.125 μg/m^3, 41.825 μg/m^3 and 40.25 μg/m^3 at the respective locations. The exceedance factors for PM_{10} varied from 'moderate to high' at the residential and commercial locations and from 'high to moderate' at the industrial location. Planetary boundary layer height (PBLH) and ventilation coefficient (VC) were also estimated over the region for 2011-2018. The maximum PBLH and VC observed during the study period was in the summer season, and the minimum was in the post-monsoon season. Annual and Seasonal Air quality index analysis shows that the level of pollution was in the range of SATIFACTORY to MODERATE. A study of seasonal analysis of PM_{10}, SO_2 and NO_2 showed that the higher concentrations were found in winter relative to summer with the least concentration occurring during the monsoon season. A regression analysis was performed to check PM10's interdependence with other contaminants. A positive association was found between PM_{10} and SO_2 for all seasons. A negative association was found between PM_{10} and NO_2 in summer for all the stations and winter at Station-I and Station-III. Similarly, the correlation between PM_{10} and meteorological parameters such as wind speed and temperature was found to be negative whereas it was positive for relative humidity.

Key words – Respirable suspended particulate matter (RSPM/PM_{10}), Exceedance factor, Regression analysis, Sulphur Dioxide (SO_2), Nitrogen dioxide (NO_2), Meteorological parameters, planetary boundary layer height (PBLH) and ventilation coefficient (VC).

1. Introduction

India is a developing country where, various development activities like construction, industrialization; micro, small and medium enterprises, etc. are taking place in various sectors to make it economically stable and strong. These anthropogenic activities emit various air pollutants in the environment. The Environment performance index (EPI) 2018 ranked 180 countries based on 24 performance indicators across 10 categories covering environmental health and ecosystem vitality. India gained 177th EPI rank amongst 5 of the bottom-ranked countries (Wendling *et al.*, 2018). As per a report issued by the World Bank in 2016, India suffered a loss of 7.69% GDP due to the degradation of the environment. According to the literature, it is observed that developing countries affect more than developed countries due to particulate matters (Bhaskar and Mehta 2010). As the development increases, the particulate matter affects more to the urban population (Grange *et al*., 2013; Han and Naeher, 2006). Emission from vehicles is the main cause of polluting the environment as it contains various pollutants such as PM_{10}, $PM_{2.5}$, oxides of nitrogen (NO_x), oxides of sulphur (SO_x), carbon dioxide (CO_2), carbon monoxide (CO), and hydrocarbons (HCs). The vehicle demand increases with the increasing population (Bathmanabhan and Madanayak, 2010; Guttikunda *et al*., 2014) and as the vehicle demand goes on increasing, emission in the environment is also increasing (Ghosh, 2015). If there are no regulations, the particulate matter and other pollutants could affect the air quality of cities (Biswas *et al*., 2008).

The particulate matter causes various respiratory diseases, which may lead to the death of the infected person. In major cities in Korea, around 40% death of premature children due to particulate matter inhalation, has been reported in one of the studies (Kim *et al*., 2018). A report for global mortality with the long-term exposure of particulate matter shows that India is more concerned with China. It is also reported that health benefits due to the decrease in the concentration of particulate matter are greater as compared to previous studies (Burnett *et al*., 2018). A study shows that almost 1700 deaths occurred due to air pollution in Himachal Pradesh (Balakrishnan *et al*., 2019). Particulate matter causes heart disease and leads to mortality of human beings (Peters 2005). The risk of heart disease and mortality rate depends upon particulate matter and it has 6.21% risk across Spain (López *et al*., 2005; Maté *et al*., 2010). The decreasing size of particulate matter increases the risk of heart and cardiovascular disease (Guttikunda and Goel 2013; Kim *et al*., 2015). Also, these small particles irritate human skin and cause adverse skin disease that could go beyond the limit and cause mortality (Ngoc *et al*., 2017).

The meteorological parameters like temperature, humidity, solar radiation, etc., affect the concentration of particulate matter (Chan 2002). Stable environment and wind speed is the main concern for the increasing particulate matter concentration in the ambient air (Crawford 1969). The meteorological parameters can be correlated for their effect on the concentration of particulate matter (Kumar and Goyal, 2011a; b; Ragosta *et al*., 2008). Use geographic information system has also been used for the interpolation of these parameters with particulate matter concentration. Spatio-temporal analysis by (Gupta *et al*., 2008) showed that household activities, construction works, etc. are the major sources of particulate matter and gaseous pollutants. An inverse relation has been reported between gaseous and particulate pollutants with wind speed (Gupta *et al*., 2008).

In urban areas, most vehicles operate on diesel engines includes cars, buses, light motor vehicles, etc. emits more particulate matter (Bathmanabhan and Madanayak 2010). It is reported that, in most of the cities all over the world, most of the sources of particulate matter are traffic volume, speed of the vehicle, population of the city, etc. (Ganguly *et al*., 2015; Karner *et al*., 2010). Particulate matter is the composition of various other pollutants which could be generated by human activities and various natural sources (Menzel and Ryther 1964). In various studies, it is seen that particulate matter mostly affects humans, plants and animals (Zhang *et al*., 2017, Saini *et al*., 2022 a, b).

All the metropolitan cities in India are experiencing declining air quality year by year mostly because of various vehicular activities, industrialization, and huge construction activities. There are other sources of these pollutants, for example, marine in Mumbai (Chelani *et al*., 2008; Kothai *et al*., 2008; Kumar *et al*., 2001), biomass burning in Delhi (Shridhar *et al*., 2010), coal combustion

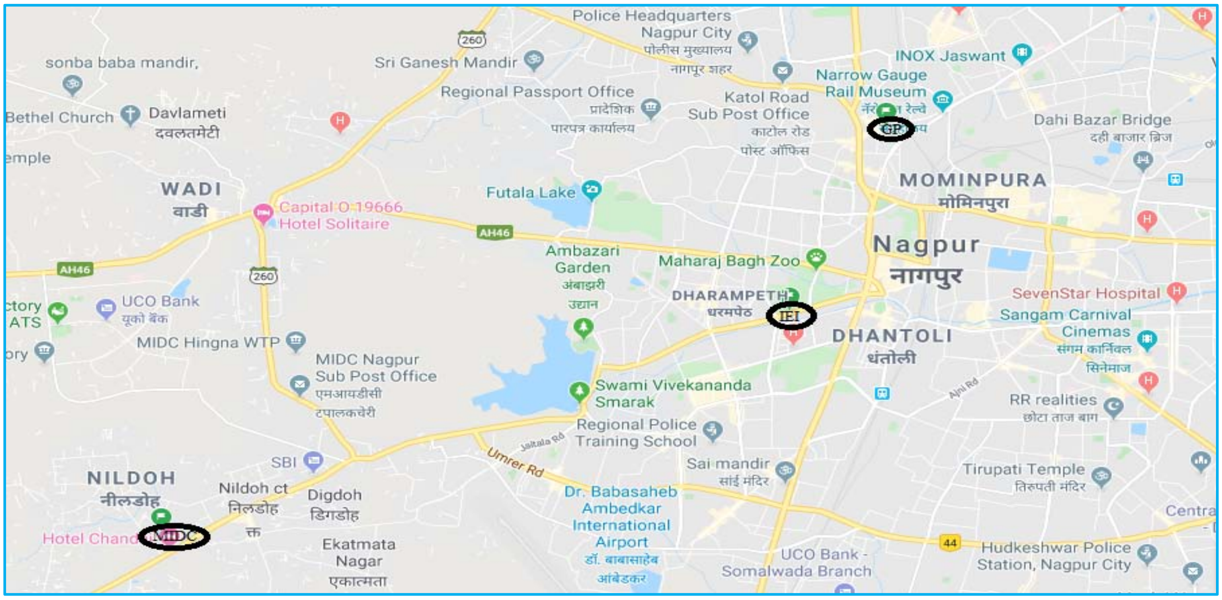


Fig. 1. Location of monitoring stations in Nagpur

in Kolkata (Chowdhury *et al*., 2007) and Jorhat (Khare and Baruah 2010) generate PM_{10} and $PM_{2.5}$. PM_{10} generation due to solid waste burning has been reported in Mumbai (Karar and Gupta, 2007) and Agra (Kulshrestha *et al*., 2009). PM_{10} particles in Delhi (Balachandran *et al*., 2000) and Mumbai (Kothai *et al*., 2008) are reported due to vehicles. Industries emit PM_{10} in the atmosphere in Tirupati (Chandra *et al*., 2006), Kanpur (Chakraborty and Gupta 2009) and Mithapur city (Basha *et al*., 2010). It is also generated due to the crushing dust or road dust, and also burning refuse oil (Shridhar *et al*., 2010), PM_{10} and $PM_{2.5}$ generated due to various industries also seen in Chennai city (Bathmanabhan and Madanayak 2010), due to various type of dust emits PM_{10} particles in Jaipur city of Rajasthan (Soni *et al*., 2018). So, in the present study, the pattern of concentrations of respiratory suspended particulate matter (PM_{10}), SO_2 and NO_2 in Nagpur at various locations over the period of about 8 years has been analyzed.

As Nagpur city is a proposed smart city, it is expected that the quality of ambient air should be within the standards prescribed by Central Pollution Control Board (CPCB 2016), New Delhi, India. Different studies have been conducted by various researchers regarding particulate matter, like various traffic studies (Patni and Student 2017), various disease generation (Patel *et al*., 2001) and the outbreak of the virus in children, and heavy metal pollution (Chaudhari *et al*., 2012). The studies regarding the pollution pattern in Nagpur city have not been reported yet, hence the present work has been planned to study the air pollution pattern in Nagpur city by considering a span of 8 years from 2011 to 2018. During this period there was a lot of development works like; construction activities have taken place in the city. The air pollution data for the above duration has been analyzed to assess and find the quality of air at residential, industrial, and commercial locations. The correlation of particulate matters (PM_{10}) with SO_2 and NO_2 has been studied. The correlation of meteorological parameters with particulate matter has also been studied. The daily, annual and seasonal variation in concentration of these three pollutants at all three locations has been studied. Depending upon the population and the area of the city, the location and number of few additional stations have also been determined and suggested in the present study.

2. Materials and methods

2.1. *Location of Monitoring Stations*

Nagpur is the third-largest city in the state and is known as the sub-capital of Maharashtra which is located at 21.15 latitude and 79.08 longitudes with GPS coordinates 21° 8′ 44.881″ N and 79° 5′ 17.357″ E. It is situated at an elevation of 319 meters above mean sea level. As per the census 2011, Nagpur has a population of 2,228,018. The city falls under the Universal Transverse Mercator (UTM) zone of 44Q with the coordinate of 301470.33,2339479.09 by Koppen climate classification with tropical savannah climate (Aw) with dry condition prevailing for most of the year. The city witnesses very hot weather during summer and spine-chilling winter. Monsoon takes its charge in the month of June.

There are three ambient air monitoring stations located in residential (Station-I), industrial (Station-II), and commercial (Station-III) areas. Station-I in a residential area is located at Institution of Engineers (India), North Ambazari Road, near Ramdaspeth, (Station Code-287, Latitude: 21°08'10.0"N and Longitude: 79° 04' 08.5"E), Station-II in an industrial area is located at the office of Executive Engineer, Maharashtra Industrial Development Corporation (MIDC), Hingna Road, (Station Code-288, Latitude: 21°06'35.5"N and Longitude: 79° 00' 27.2"E) and Station-III in a commercial area is located at Government Polytechnic, Mangalwari Bazar, Sadar, (Station Code 314, Latitude: 21°09'47.6"N and Longitude: 79°04'57.6"E) Nagpur. All three stations are monitored and operated by Visvesvaraya National Institute of Technology (VNIT), Nagpur, India under CPCB's National Air Quality Monitoring Programme (NAMP) sponsored by Maharashtra Pollution Control Board (MPCB), Mumbai, Maharashtra, India. The location of these monitoring stations is shown in Fig. 1.

2.2. *Monitoring programme*

The samples are collected on 24 hourly bases twice a week at uniform intervals at each of the three stations (annual arithmetic mean of a minimum of 104 measurements in a year is taken) as per the guidelines of CPCB. Three parameters, *viz*., sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and respirable suspended particulate matter (RSPM or PM_{10}) are monitored at all three monitoring stations. PM_{10} is collected for24 hours with 8 hourly samplings (3 observations/day), NO_2 is collected for 24 hours with 4 hourly samplings (6 observations/day) and SO_2 is collected for 24 hours with 4 hourly samplings (6 observations/day) twice a week.

The high volume sampler (HVS) consisting of a protective casing, a blower, a voltage stabilizer, a time totalizer, a rotameter and a filter holder capable of supporting 20.3 × 25.4 cm Glass Fibre Filter, the cyclone that uses centrifugal force to remove dust is used for sampling of the pollutants. A particle in a rotating air stream is subjected to a centrifugal force that accelerates it towards a surface where it will influence and lose momentum, thus removed from the air stream. In a typical cyclone pre-collector, the air enters tangentially at its side and swirls around inside. Particles above 10 μm thrown to the cyclone walls and collected at its base ("grit-pot"). The air containing respirable dust leaves through the central exit at the top of the cyclone and collected on the filter paper. The flow rate used for the collection of the sample is 1.1m^3/min. The concentration of particulate matter gravimetrically is determined as follows in equation (1). (IS 5182-4 1999):

$$C_{PM_{10}} = \frac{(W_f - W_i)}{V} \times 10^6 \qquad (1)$$

where,

$C_{PM_{10}}$ – Concentration of RSPM or PM_{10}, μg/m^3

W_i – initial weight of filter, g

W_f – final weight of filter, g

V – Volume of air sampled, m^3

Sulphur dioxide (SO_2) concentration in the air is determined by Improved West and Gaeke method (IS 5182-2 2001) using APM460 respirable sampler with the gaseous sampling instrument attached to it. Sulphur dioxide is absorbed in potassium tetrachloromercurate (TCM) solution. A stable and complex compound, dichlorosulphitomercurateis formed with the chemical reaction of SO_2 present in the air and the solution of tetrachloromercurate. The complex is made to react with pararosaniline and formaldehyde to form intensely colored pararosanilinemethylsulphonic acid. The absorbance of this solution is measured at 560 nm by using a spectrophotometerto determine the concentration of SO_2 in μg/m^3.

Nitrogen dioxide (NO_2) concentration in air is determined by using Modified Jacob and Hochheiser Method (IS 5182-6 2006) using APM460 respirable sampler with the gaseous sampling instrument attached to it. Nitrogen dioxide (NO_2) is absorbed in sodium hydroxide and sodium arsenite solution. The concentration of nitrite ion (NO^{-2}) formed during sampling is determined colorimetrically by the reaction of the nitrite ion with phosphoric acid, sulfanilamide and N-(1-naphthyl)-ethylenediaminedihydrochloride (NEDA) and by measuring the absorbance at 540 nm wavelength by using a spectrophotometer and the concentration of NO_2 is determined in μg/m^3.

2.3. *Analysis*

Numerous statistical methods have been used to find the interrelationship between pollutants and meteorological parameters, including independent weekday and weekend analyses for both annual and seasonal concentrations for the eight-year duration for all three monitoring sites, along with the calculation of exceedance factor, radar plots, and wind rose diagrams. Exceedance factor (EF) is the criterion by which the current air quality is categorized. The exceedance factor (EF) is the ratio of the annual average concentration of the

TABLE 1

Exceedance factor as per CPCB guidelines (CPCB 2016)

S. No.	Exceedance factor range	Pollution level
1	Greater than 1.5	Critical pollution
2	1 to 1.5	High pollution
3	0.5 to 1	Moderate pollution
4	Less than 0.5	Low pollution

pollutant to its standard concentration and mathematically described as follows in equation (2).(CPCB 2016):

$$EF = \frac{C_0}{C_S} \tag{2}$$

where,

EF = Exceedance Factor

C_0 = Observed annual mean concentration of pollutant, µg/m^3

C_S = Standard annual mean concentration of pollutant, µg/m^3

Based on the value of the exceedance factor, the air quality has been divided into four categories as given in Table 1. As per the prescribed equation by the world health organization and national ambient air quality standard, an increase in the percentage of PM_{10} annual mean concentration can be calculated by the following equation (3) (CPCB 2016):

Annual mean pollutant concentration

$$= \frac{C_0 - C_S}{C_S} * 100 \tag{3}$$

2.4. *Planetary boundary layer height (PBLH) and Ventilation Coefficient (VC)*

The boundary layer height (BLH) is one of the important parameters that determine the ability of pollutants to disperse and the structure of turbulence in the boundary layer (Seibert *et al.*, 2000). Time Averaged planetary boundary layer height monthly 0.5 × 0.625 deg. [MERRA-2 Model M2TMNXFLX v5.12.4] mT were downloaded from earth data database. The BLH alone cannot explain about the concentrations of pollutants. Thus, it is important to obtain estimates of the ventilation

TABLE 2

Air Quality Index Categories

AQI	Pollution level	Impact on human health
0-50	GOOD	Minimal Impact
51-100	SATISFACTORY	Minor breathing discomfort to sensitive people
101-200	MODERATE	Breathing discomfort to the people with lung, heart disease, children and older adults
201-300	POOR	Breathing discomfort to people on prolonged exposure
301-400	VERY POOR	Respiratory illness to the people on prolonged exposure
>401	SEVERE	Respiratory effects even on healthy people

coefficient (VC) for the air pollution monitoring and assessment. During the last few decades, there are many studies (Devara & Raj, 1993; Krishnan & Kunhikrishnan, 2004) related to the BLH and VC in order to understand the air quality.

VC (m^2 s^{-1}) was estimated as product of the PBLH and the mean wind speed (WS) in ms^{-1} within PBLH (m) as shown in Equation (4) (Ashrafi *et al.*, 2009):

$$VC = Z_i * U \tag{4}$$

Here Z_i is the PBLH and U is the mean wind speed within the PBLH.

2.5. *Air Quality Index (AQI)*

This index was created to evaluate air quality using a ratio or number. The air quality index is a regular monitoring index that shows the quality of air in the atmosphere of a particular city. It differentiates the effect of pollution level on human health in short period. AQI helps people to know how the local level of pollution effects on their health. AQI has been classified into different pollution levels based on the index number. All different levels of pollution and their health effects on humans are described in Table 2. AQI is calculated by the following equation (5):

$$I_p = \left[\frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})} \times (C_p - B_{LO})\right] + I_{LO} \tag{5}$$

where,

B_{HI} = Breakpoint concentration greater or equal to given concentration.

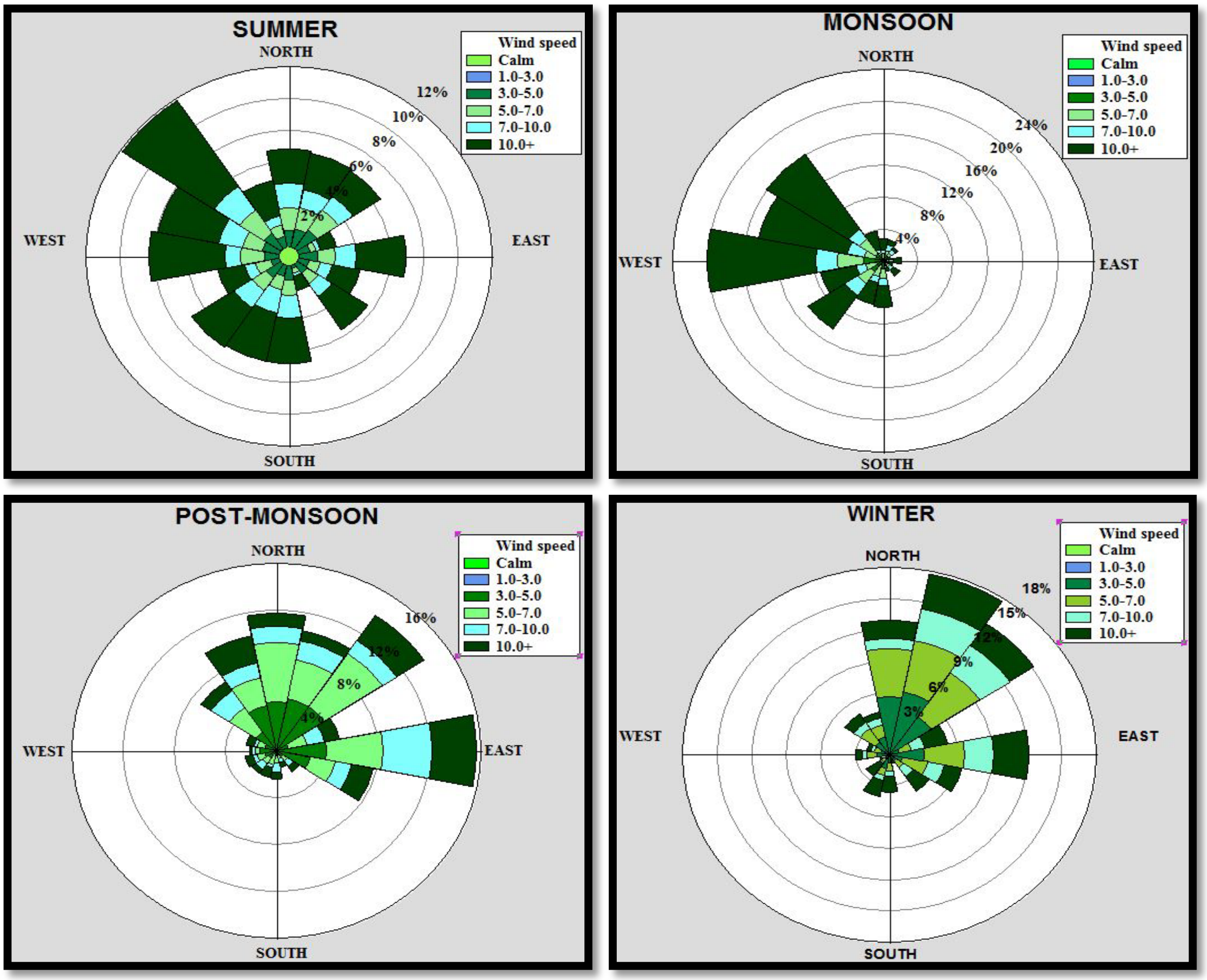


Fig. 2. Wind rose diagram in various seasons over the entire study period

B_{LO} = Breakpoint concentration smaller or equal to given concentration.

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

C_p = Pollutant concentration

3. Results and discussion

To study the different trend analyses, *viz*., weekly, weekend days, seasonal, annual for PM_{10}, SO_2 and NO_2 at all three stations, the data has been collected from the website of Maharashtra Pollution Control Board (MPCB) Mumbai. The meteorological data, wind speed, temperature, atmospheric pressure, relative humidity were acquired from Indian Meteorological Department (IMD) Pune.

3.1. *Brief description of meteorological parameters*

To analyze the effect of meteorological parameters on air pollution concentration at all three locations, the meteorological data from 1st Jan, 2011 to 31st Dec, 2017 has been used. The wind rose diagram has been prepared for wind speed and direction observed at all three locations for the given duration. The longest value of spike in the wind rose diagram shows the predominant frequency of wind blowing from a particular direction. The value of dominant wind speed falls in the range of 0 to 3.8 km/h from the North-East direction in the winter season. From the wind rose diagram in Fig. 2, it is clear that the wind remains calm for about 87% of the time in a year and 9.2% from the specific direction for the given data. The range of daily 4 hr duration temperature is 8 °C to 53.8 °C. Variability of wind speed is in the range of 0 km/h to 36 km/h during the period of 2011 to 2017. The relative humidity is found in the range of 3% to 100%.

Figs. 3(a-c). Annual average concentration of (a) PM_{10}, (b) SO_2 and (c) NO_2 at all three monitoring site

TABLE 3

Daily and annual variation of (a) $PM_{10,}$ (b) SO_2 and (c) NO_2

Year	2011	2012	2013	2014	2015	2016	2017	2018
(a) Annual average concentration of (RSPM-PM_{10}) at all monitoring stations								
monitoring station I	101.5±34.5	115.13±39.04	106.49±23.65	103.49±29.65	117.21±43.45	90.29±18.07	84.38±18.42	109.47±19.52
monitoring station II	112.0±36.0	143.38±55.15	131.66±36.29	128.08±49.45	120.76±28.86	102.76±19.62	98.22±30.99	118.12±26.92
monitoring station III	96.65±32.5	118.04±28.81	145.36±46.34	107.86±34.01	116.73±42.98	101.93±29.71	97.46±26.50	136.07±38.07
(b) Annual average concentration of SO_2 at all monitoring stations								
monitoring station I	11.72±2.47	13.53±42.7	11.06±1.01	10.54±13.6	10.41±2.04	10.48±2.42	10.31±2.32	14.26±4.7
monitoring station II	11.29±1.30	12.12±2.48	10.98±1.55	10.75±1.51	10.08±1.77	10.24±2.21	11.10±2.93	15.43±6.5
monitoring station III	16.14±6.40	18.5±7.73	16.28±6.02	15.19±6.02	14.55±6.18	14.03±5.97	14.59±8.60	14.60±9.5
(c) Annual average concentration of NO_2 at all monitoring stations								
monitoring station I	44.7±16.49	52.12±24.41	36.57±8.68	30.74±6.38	34.11±9.27	31.91±10.51	31.74±9.09	37.66±8.33
monitoring station II	40.42±9.85	43.80±15.76	38.48±9.35	32.27±8.63	31.82±7.31	33.40±11.47	33.85±10.25	36.96±11.03
monitoring station III	37.28±8.22	65.25±30.06	48.53±20.64	44.54±20.18	45.69±20.87	42.37±20.47	42.89±20.24	54.54±23.5

The correlation between meteorological parameters with the particulate matter has been analyzed. It is found that at the constant volume of water vapour the temperature decreases and the relative humidity increases. Whereas, the relative humidity decreases with increasing temperature at a constant water vapour content.

3.2. *Daily and Annual variation*

The annual average concentrations of PM_{10}, SO_2 and NO_2 are shown in Table 3 and represented graphically in Figs. 3(a-c). It is found that the concentration of PM_{10} at all three locations is greater than the prescribed standard (100 μg/m^3). However, the concentration of SO_2 and NO_2 are lower than the prescribed standards (80 μg/m^3) at all the stations.

The highest value of the daily average concentration of PM_{10} was observed as 161μg/m^3 on 18th November, 2015 at the starting of the winter season at monitoring station-I (IEI), 18μg/m^3 for SO_2 on 15th November, 2012 and 77μg/m^3 for NO_2 on 13th November, 2012. Similarly, the highest daily average concentration of PM_{10} at monitoring Station-II (MIDC)was observed as 199μg/m^3 on 7th November, 2012, 22μg/m^3 for SO_2 on 18th November, 2018 and 60μg/m^3 for NO_2 on 10th November, 2012. At monitoring Station-III (GP), the daily average concentration of PM_{10} was found 153μg/m^3 on 20th July, 2013 in monsoon season, 19μg/m^3 for SO_2 on 24th November, 2018 and 60μg/m^3 for NO_2 on 15th November, 2012 at the starting of the winter season. As per NAAQS, the annual average concentration of PM_{10} is 100μg/m^3 and 80 μg/m^3 for SO_2 and NO_2. By comparing the NAAQS, it is observed that the concentrations of the pollutants are below the standard in the years 2011, 2012, 2017 at monitoring station-I (IEI). Station-I comes under the residential zone, where the pollutants are contributed by household activities like cooking, sweeping, refuse burning, etc. and the vehicles. For the years 2013, 2014, 2015, 2016 and 2018 the value of the annual average concentration of PM_{10} is slightly more while the concentration of SO_2 and NO_2 are below the standards. At monitoring station-II (MIDC), the concentration of PM_{10} is more than the standard. The concentration of PM_{10} is within the limits for the years 2016 and 2017 only. The higher concentration is because of emissions from the industries like Bajaj steel industries, JK industries, Nagpur Refractories Pvt. Ltd., etc., located near the monitoring station. Monitoring station III (GP) has the concentration level more for the years 2016 and 2018. The concentration of particulate matter is within the standard value. It is found that the annual average concentration increased during the years 2011 to 2016. After that, the concentration decreased for the next year it was due to the application of BS-IV vehicles by the government of India, which helped in decreasing the concentration of particulate matter and decreasing the pollution level with the improvement of air quality.

Another interpretation from the observed data is that there is no uniform increment or decrement at the monitoring stations I (IEI), II (MIDC) and III (GP). It can be seen from Fig. 3(a) that the concentrations are more (143.38 μg/m^3) at station II (MIDC). It is because of various types of industries (*i.e.*, steel industry, dairy industry, beverage industries, etc.,) in that area. The other two sites IEI and GP, also show the same trend of concentrations of particulate matter, which is because of commercial and vehicular activities. From the Fig. 3(a), it can be seen that there is a decreasing trend in the concentration of particulate matter, which is because of the awareness about the pollution and various rules and regulations implemented in the industries. In residential area, the predominant sources of particulate matter pollution are mobile sources.

The average annual concentration for SO_2 shown in Fig. 3(b) follows almost the same trend for the entire study period. The concentration of SO_2 is the same for the years 2011 to 2014 (10.75 μg/m^3 to 12.12μg/m^3) after that it decreases (10.08 μg/m^3) and in recent years 2017 and 2018 its value is increasing (14.59 μg/m^3 and 15.53 μg/m^3). For station II (MIDC), it is 15.43 μg/m^3 in 2018 and it is even more for the other two stations (14.26 μg/m^3 at IEI and 14.60 μg /m^3 at GP) as compared to the previous years. The increase in pollution in the industrial area is due to the increased number of vehicles of the workers and the increasing industrial activities. The annual average value suggested by the central pollution control board for residential, industrial, and commercial regions is 80μg /m^3, which is much more as compared to the concentration of SO_2 at all three stations. So SO_2 is below the NAAQS.

The annual average concentration of NO_2 for all the three monitoring sites is detailed in Table 3(c) and Fig. 3(c). The annual average permissible concentration of NO_2 given by the central pollution control board for the residential, industrial, and commercial area is 80 μg/m^3. The study shows that the annual average concentration exceeds in the year of 2012 only (95.31 μg/m^3). Rest of the study period, the concentration of NO_2 is below the standard.

3.3. *Annual Exceedance factor*

The annual exceedance factor has been summarized in Table 4. According to the exceedance factor, it is observed that the pollution level is moderate to high. The maximum value of pollution is found in the year 2013,

TABLE 4

Exceedance factor for all three monitoring stations

	Year	2011	2012	2013	2014	2015	2016	2017	2018
Exceedance factor for RSPM-PM_{10} at all the monitoring stations for the study period									
Exceedance factor	station I	0.96	0.97	1.06	1.05	1.05	1.03	0.93	1.1
pollution level		moderate	moderate	high	high	high	High	moderate	high
Exceedance factor	station II	1.16	1.33	1.22	1.2	1.16	0.96	0.99	1.21
pollution level		High	high	high	high	high	moderate	moderate	high
Exceedance factor	station III	0.88	0.85	0.96	1	1	1.19	0.94	1.08
pollution level		moderate	moderate	moderate	moderate	moderate	High	moderate	high

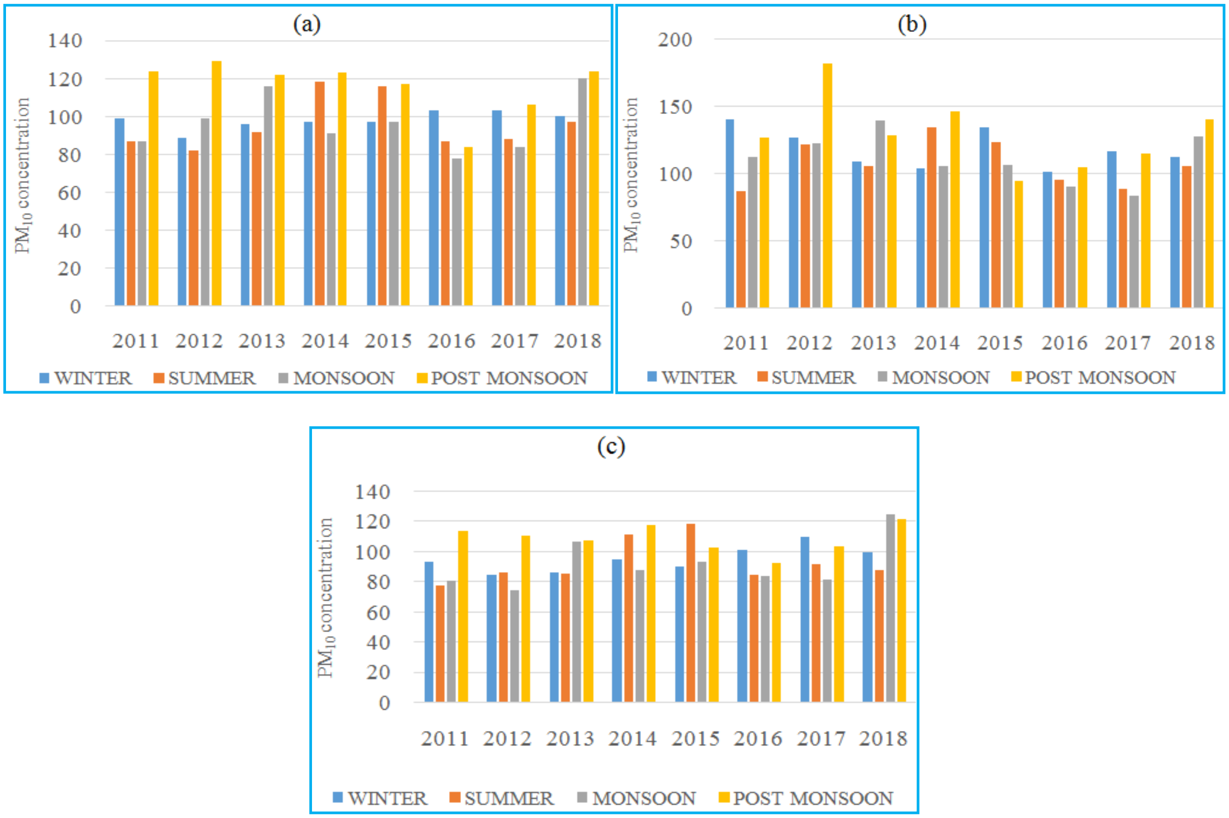
TABLE 5

Average particulate matter PM_{10} concentration (in µg/m^3) in each season for all three monitoring stations

Season	Station	2011	2012	2013	2014	2015	2016	2017	2018
Seasonal trends at all monitoring stations									
Winter	I(IEI)	99	89	96	97	97	103	103	100
	II(MIDC)	141	127	109	104	135	102	117	113
	III(GP)	93	84	86	94	90	101	109	99
Summer	I(IEI)	87	82	92	118	116	87	88	97
	II(MIDC)	87	122	106	135	124	96	89	106
	III(GP)	77	86	85	111	118	84	91	87
Monsoon	I(IEI)	87	99	116	91	97	78	84	120
	II(MIDC)	113	123	140	106	107	91	84	128
	III(GP)	80	74	106	87	93	83	81	124
Post Monsoon	I(IEI)	124	129	122	123	117	84	106	124
	II(MIDC)	127	182	129	147	95	105	115	141
	III(GP)	113	110	107	117	102	92	103	121

which is 1.06. Whereas, it is near to the threshold value 1.33 in the year 2012. In the residential area (IEI), the pollution level is not as much as compare to the monitoring station II (MIDC). The pollution level at monitoring station II (MIDC) is high because of the particulate matter pollution generated by various industries. At monitoring station III (GP) the pollution level is from moderate to high. For the years 2016 and 2018, it is high with the values of 1.19 and 1.08 respectively. The categories of the given stations can be changed by making strict rules for vehicles and some regulations applied to the industries.

Further, with the comparison of the given annual concentration of particulate matter with the NAAQS, it is observed that the comparison of percentage increase in the pollution level with the guidelines according to the NAAQS standards is 70% for station I (IEI), 90% for station II (MIDC) and 63% for station III (GP). It is observed that the increase in percentage over the guidelines prescribed by the NAAQS is much higher. It is due to higher stringent regulatory values as NAAQS has flexible values. The value for station II is much higher due to the presence of industries near the station. For station I and station III, the highest values are due to the presence



Figs. 4(a-c). Seasonal variation of PM_{10} at (a) station I (IEI), (b) station II (MIDC) and (c) station III (GP)

of vehicles and various other factors. For the control measures, the rules can be applied for the consumption of fuel, scrap the older vehicles, which generate more pollution due to the addition of particulate matter in the area, and introducing new technologies in the vehicle. The control measures can be applied to those industries, which have more generations of particulate matter, some limits imposed on them, and industries exceeding the limits may be penalized.

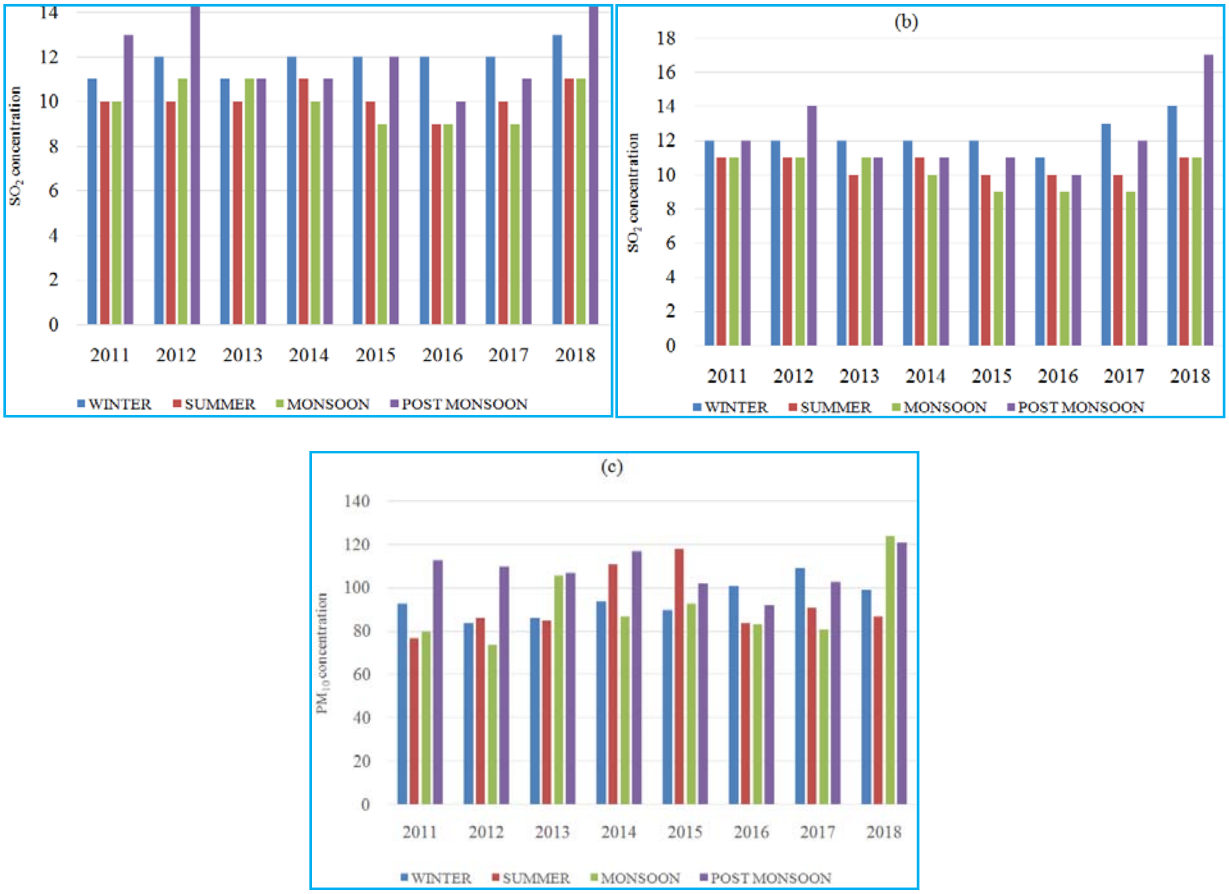
The monitoring was done for 829, 828 and 833 days at all three stations (*i.e.*, I - IEI, II - MIDC and III - GP, respectively) during 2011-2018 and it was found that the concentration of SO_2 and NO_2 not exceeded from there permissible value prescribed by the central pollution control board, whereas the exceeded number of days for the RSPM-PM_{10} was 341, 457 and 297 from the observed days 829, 828 and 833 at all the three stations such that I IEI, II MIDC and III GP respectively.

3.4. *Seasonal variation*

3.4.1. *Particulate matter*

The analysis of the variation of PM_{10} in each season has been carried out and is given in Table 5. The whole year has been divided into four seasons, which are winter from December to February, summer from March to May, monsoon from June to September, and post-monsoon from October and November. Nagpur receives plenty of precipitation in the monsoon season which results in a rise in the humidity. After that, post-monsoon season occurs, and various work which was shut down due to monsoon, back to their normal routine. From Figs. 4(a-c), it can be seen that the maximum value of particulate matter is in the post-monsoon season, then the winter season which has the maximum value of pollution due to low mixing height. The summer season which is severely hot due to the nearest to tropic of cancer. The maximum value of temperature was observed on 27th May, 2013, which is 46.4 °C. The average maximum value of temperature in 2012 and 2018 was 32.8 °C. It is observed that the maximum value of pollution due to particulate matter PM_{10} is in the post-monsoon season.

For all three sites, the seasonal variation of pollution has been studied from 2011 to 2018. During the winter season because of lower temperatures, the mixing height reduces due to inversion conditions due to the longer nights; the concentration of the pollutants is increased at ground level. Expanded calm conditions throughout the winter season further add to the enmeshment of particulate

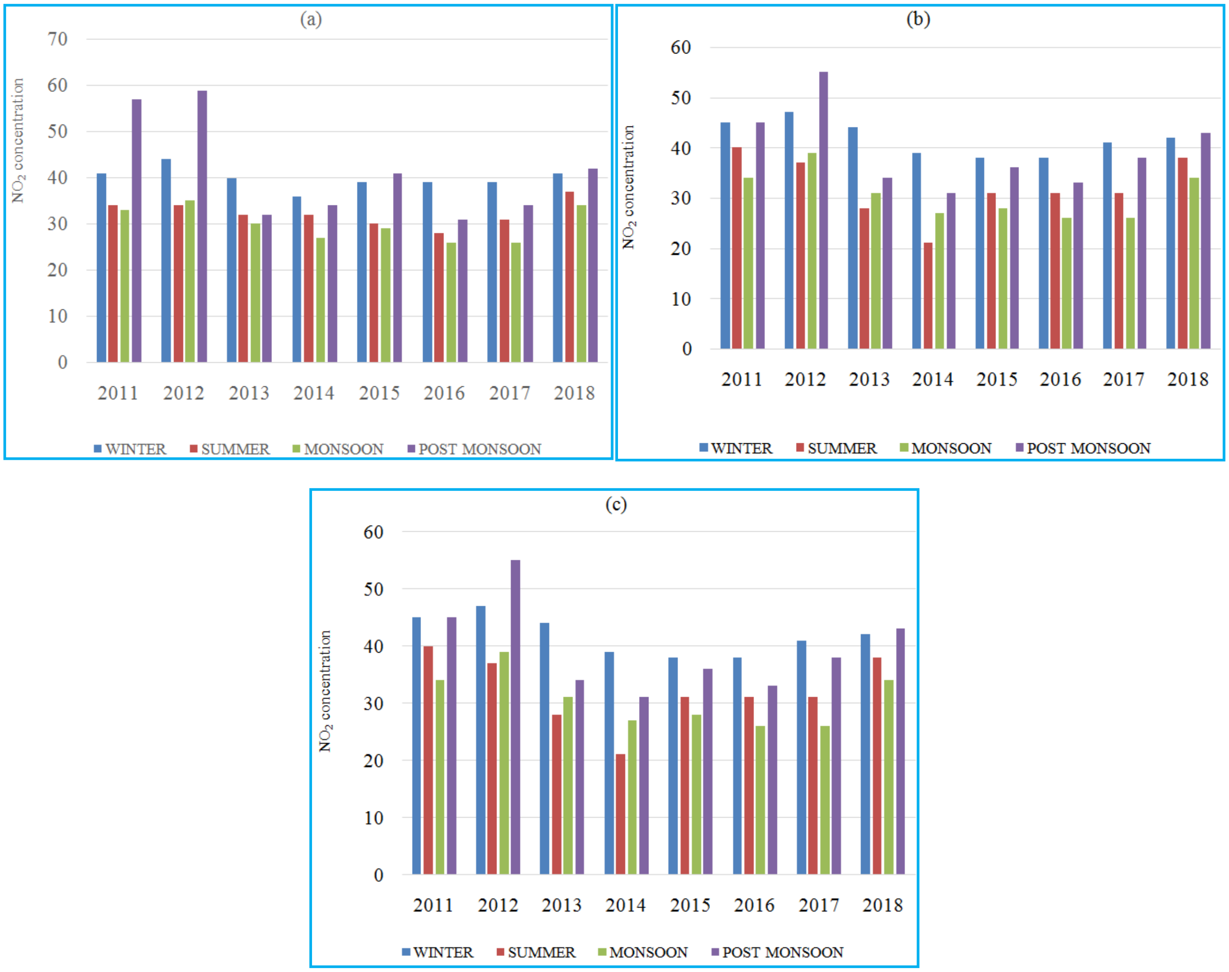


Figs. 5(a-c). Seasonal variation of SO_2 at (a) station I (IEI), (b) station II (MIDC) and station III (GP)

TABLE 6

Average SO_2 concentration (in µg/m^3) in each season for all three monitoring sites

Season	Station	2011	2012	2013	2014	2015	2016	2017	2018
Seasonal trends of SO_2 at all monitoring stations									
Winter	I(IEI)	11	12	11	12	12	12	12	13
	II(MIDC)	12	12	12	12	12	11	13	14
	III(GP)	11	11	11	12	12	11	12	13
Summer	I(IEI)	10	10	10	11	10	9	10	11
	II(MIDC)	11	11	10	11	10	10	10	11
	III(GP)	11	11	10	10	11	9	9	11
Monsoon	I(IEI)	10	11	11	10	9	9	9	11
	II(MIDC)	11	11	11	10	9	9	9	11
	III(GP)	10	11	11	9	9	9	8	10
Post Monsoon	I(IEI)	13	15	11	11	12	10	11	15
	II(MIDC)	12	14	11	11	11	10	12	17
	III(GP)	13	14	11	11	11	10	11	16



Figs. 6(a-c). Seasonal variation of NO_2 at (a) station I (IEI), (b) station II (MIDC) and (c) station III (GP)

TABLE 7

Average NO_2 concentration (in μg/m^3) in each season for all three monitoring sites

Season	Station	2011	2012	2013	2014	2015	2016	2017	2018
Seasonal trends of NO_2 at all monitoring stations									
Winter	I(IEI)	41	44	40	36	39	39	39	41
	II(MIDC)	45	47	44	39	38	38	41	42
	III(GP)	41	41	39	37	38	36	37	40
Summer	I(IEI)	34	34	32	32	30	28	31	37
	II(MIDC)	40	37	28	21	31	31	31	38
	III(GP)	37	38	42	30	36	28	29	36
Monsoon	I(IEI)	33	35	30	27	29	26	26	34
	II(MIDC)	34	39	31	27	28	26	26	34
	III(GP)	32	37	30	26	30	28	24	33
Post Monsoon	I(IEI)	57	59	32	34	41	31	34	42
	II(MIDC)	45	55	34	31	36	33	38	43
	III(GP)	45	56	31	36	38	31	35	42

matter fixations. The condition is worse due burning of the biomass which adds the PM_{10} to the surrounding air. The higher concentration of the particulate matter is in the winter season near about 140µg/m^3 as compared to other seasons. In the present study, the post-monsoon season is also considered and it is seen that the concentration is above 100 µg/m^3 at all monitoring stations in the post-monsoon season, which is because during the rainy season, particulate matter washed out from the air and after the end of the monsoon period as the air gets humid, it traps more pollutants and thus PM_{10} concentration increases. Besides when the scarcity of water comes and the air becomes a little bit dry then pollutants concentration increases near the ground level. Because of this reason, also, the concentration of PM_{10} will be low in the monsoon season and the relative humidity will be higher for this season, which forced to stop the pollution and generate concentration on the lower side. There could be some other factors for the pollution, which are deposition of pollen grains from various plants and replenishment of dust due to wind movement. A similar pattern of pollution is seen in other studies as well (Khillare and Sarkar 2012; Saravanakumar *et al*., 2016; Tolis *et al*., 2014; Yadav *et al*., 2014).

3.4.2. *Sulphur dioxide (SO_2)*

Variation of SO_2 in different seasons for the entire study period is tabulated in Table 6. From Figs. 5(a-c), it is observed that the maximum concentration occurred post-monsoon (above 10 µg/m^3) for all three sites in the entire study period. Also, the comparison of all three sites shows that the maximum value of SO_2 concentration is for an industrial site (monitoring station II MIDC) ranges from 10 µg/m^3 to 17 µg/m^3. For the entire study period, the maximum value occur 17 µg/m^3 in the year 2018. It is because of a rapid increase in the vehicles and various industrial operations after the monsoon season to acquire the maximum product.

3.4.3. *Nitrogen dioxide (NO_2)*

The variation of the average concentration of NO_2 for the entire period for all the seasons is tabulated in Table 7. In a comparison of three sites in Figs. 6(a-c), the maximum value occurs 55µg/m^3 for monitoring station II (MIDC) in the year 2012, which is the same for monitoring site III (GP) (56 µg/m^3). Monitoring station I (IEI) shows the lower average value of NO_2 concentration. Also, in comparison for the all-season, maximum value occurs in the post-monsoon season ranges from 31 µg/m^3 to 59 µg/m^3 as similar to the particulate matter and SO_2. The maximum value for monitoring station II (MIDC) is 59 µg/m^3. Except this, the concentration for all seasons below the standard, this could not affect the environment.

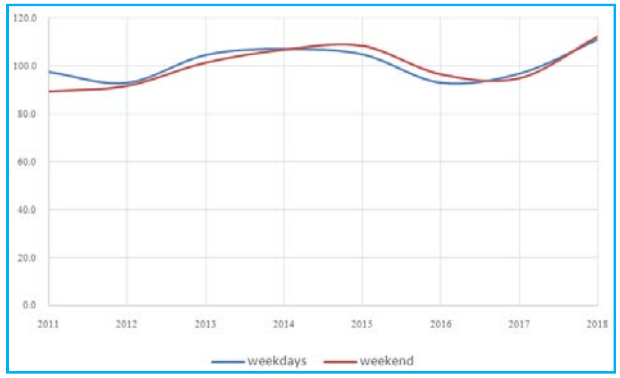


Fig. 7. Annual average seasonal analysis of PM_{10} at monitoring station I (IEI)

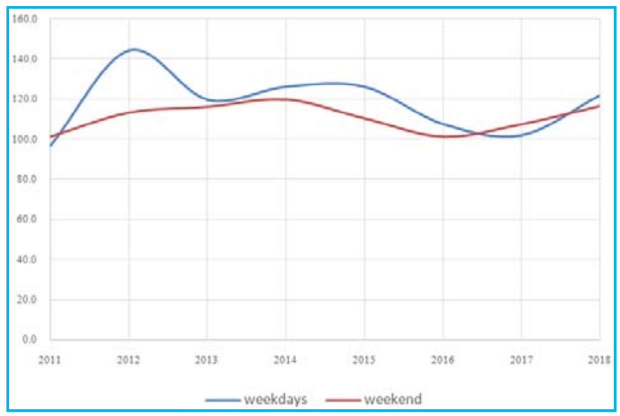


Fig. 8. Annual average seasonal analysis of PM_{10} at monitoring station II (MIDC)

3.4.4. *Weekdays and weekend trend of particulate matter*

Observed concentration of particulate matter over the years from 2011 to 2018 has been analyzed to find the weekdays and weekend trends at all three monitoring stations. From the study, it is found that the concentration of particulate matter for weekdays is more as compared to the weekend for the entire study period. From the research conducted at Lahore city in Pakistan, it is studied that the increase in the weekend pollutants is more than the weekdays (Khanum *et al*., 2017). Similar other studies were done to find the weekend and weekdays trends and it was observed the pollution due to particulate matter is more on weekdays as compared to the weekends in the city Delhi in India (Gour *et al*., 2013). In another study is has been observed that the concentration of particulate matter for size PM_{10}, $PM_{2.5}$ and CO is more for the weekdays as compared to the weekends (Yadav *et al*., 2014).

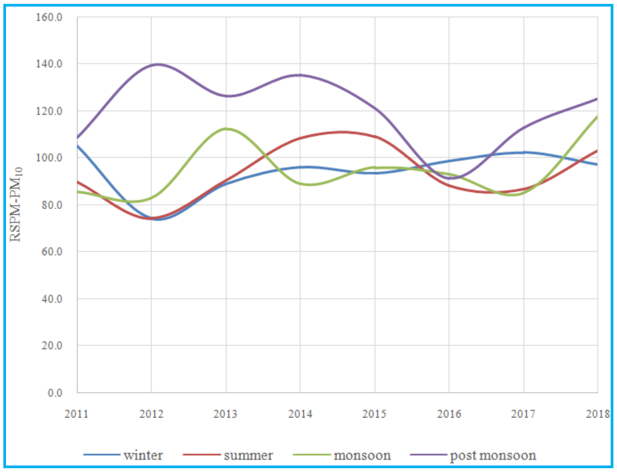


Fig. 9. Annual average seasonal weekdays analysis at monitoring station I (IEI)

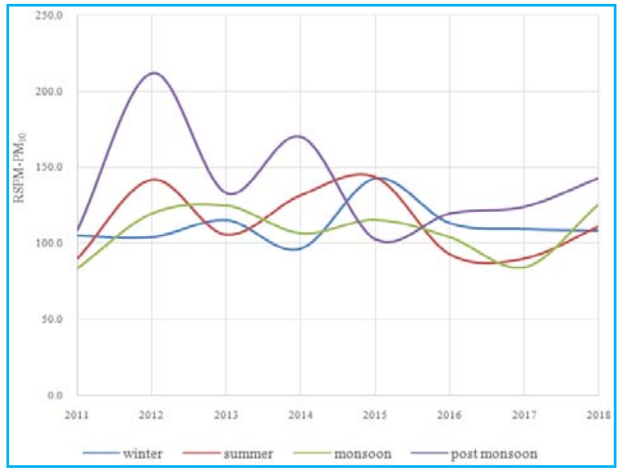


Fig. 11. Annual average seasonal weekdays analysis at monitoring station II (MIDC)

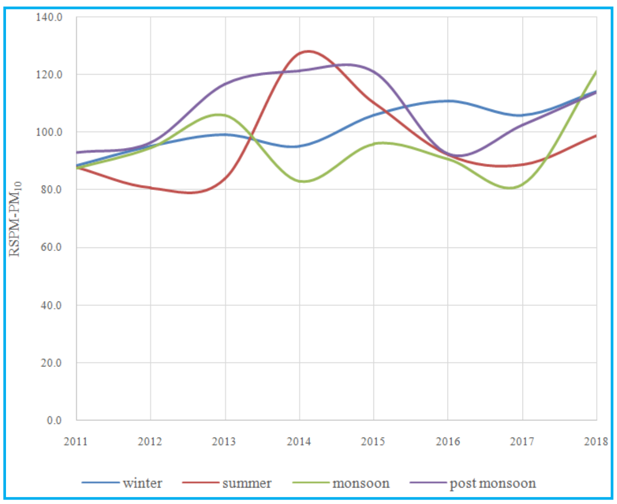


Fig. 10. Annual average seasonal weekend analysis at monitoring station I (IEI)

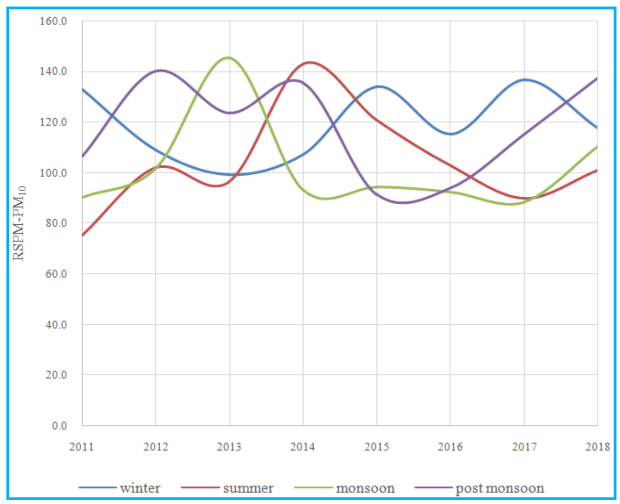
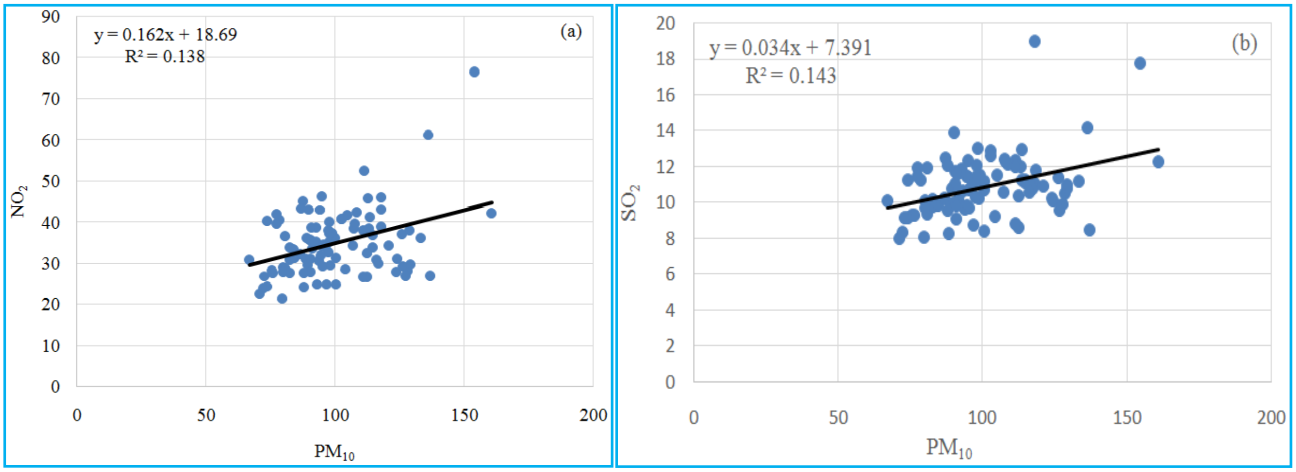


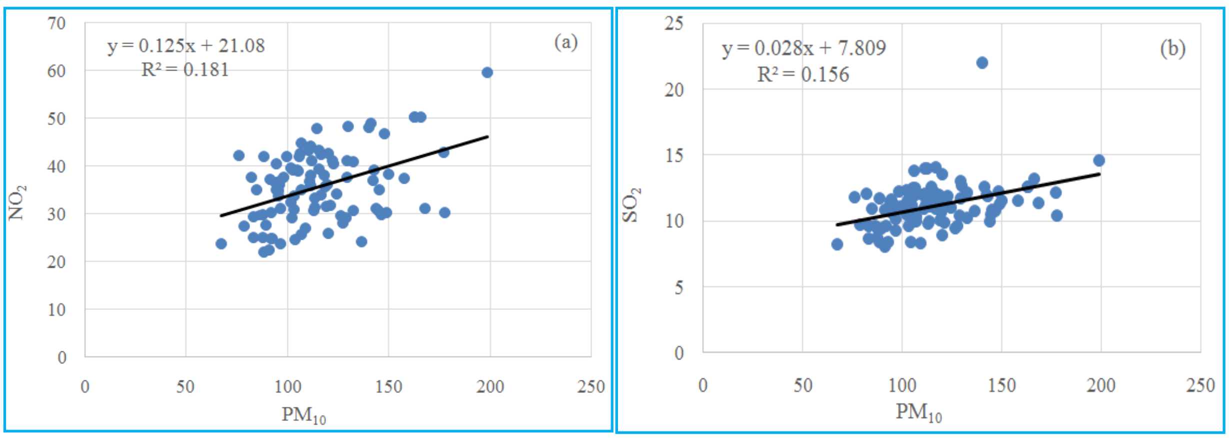
Fig. 12. Annual average seasonal weekend analysis at monitoring station II (MIDC)

From Fig. 7, at the monitoring station I (IEI), the analysis shows that the pollution is more for weekdays over the entire period for 2011, 2012, 2013, 2014, 2017 and 2018 but for the year 2015 and 2016 the trends found reverse and are more for the weekends as compared to the weekdays. It could be because as Nagpur proposed to be one of the smart cities, various constructions and industrialization took place in this period. Similarly, for monitoring station II (MIDC) in Fig. 8, it is an industrial area, and the trends following the same pattern, as of the first site that is week days pollution is more than the weekend pollution due to particulate matter. It is more for the entire period 2011-2016 and 2018, as compared to the weekend and it exceeds the weekdays in the year 2017 only due to the industrialization of various industries.

The study also depicts the seasonal variation of the pollutants for both the monitoring station I (IEI) and monitoring station II MIDC during weekdays and weekends. For station I (IEI) in Fig. 9, it is observed that the particulate matter concentration is more for the post-monsoon season for the most entire period and is more for winter 2016. In Fig. 10, the seasonal trend of weekend analysis shows a maximum concentration of particulate matter in the summer season of the year 2014. A similar observation has been observed for station II (MIDC), an industrial site, from Fig. 11 analysis for weekdays shows that the concentration is more for the post-monsoon season and only for the year 2015 it is more for the summer season in the weekdays, likewise, the trends shown in Fig. 12, gives the annual average seasonal



Figs. 13(a&b). Scatter plot of (a) PM_{10} *vs.* NO_2 and (b) PM_{10} *vs.* SO_2 at monitoring station I (IEI)



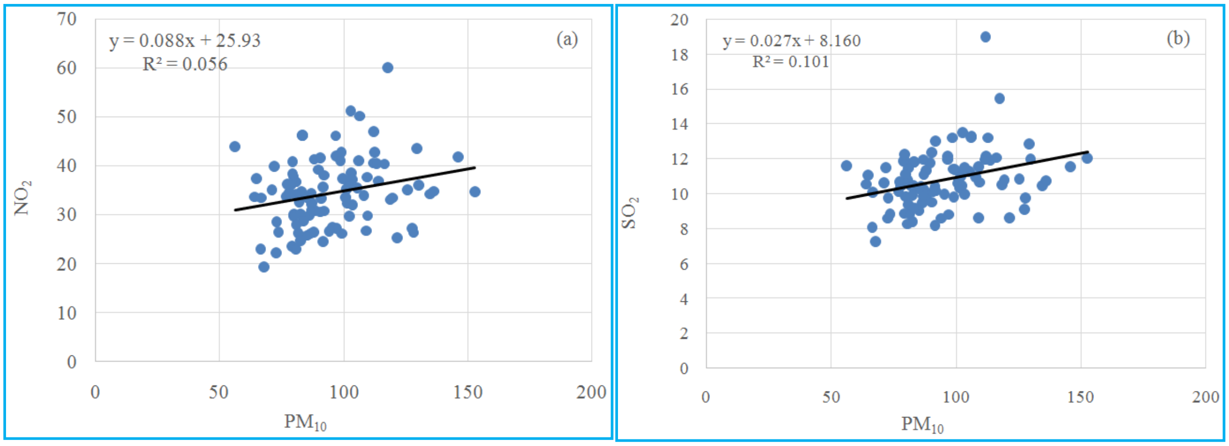
Figs. 14(a&b). Scatter plot of (a) PM_{10} *vs.* NO_2 and (b) PM_{10} *vs.* SO_2 at monitoring station II (MIDC)

weekend analysis at monitoring station II (MIDC), it is seen from the trends that for the year 2011, 2015, 2016, 2017 the peak is recorded in the winter season. While in the years 2012, 2014 and 2015 the peak of particulate matter concentration is observed in the post-monsoon, monsoon, and summer seasons respectively.

To sum up, the PM_{10} fixation was resolved to be almost restricted during the end of the week and weekdays over the examination period. Nagpur being a smart city of the state has state organizations to set up here because of which an enormous number of government workplaces and industries situated in Nagpur. These variables have added to the increment in the number of vehicles utilizing in the city during the weekdays. In any case, such workplaces and instructive segments closed at end of the week the reduction in lasting vehicular populace emerging from residents than the concentration of pollutants recorded less. A similar observation has been reported by (Gour *et al*., 2013) for the National Capital Territory region of Delhi and Shimla (Ganguly and Thapa, 2016).

3.5. *Influence of PM_{10} by SO_2 and NO_2*

Mathematical analysis is done for the concerned monitoring stations for this study. The method used for this purpose is regression analysis, which shows the correlation between the PM_{10} and the two other pollutants NO_2 and SO_2 for all the monitoring stations. The correlation between PM_{10} with the NO_2 and SO_2 is shown in Figs. 13(a&b), 14(a&b) and 15(a&b) for the respective stations. The correlation coefficient is shown in Table 8. From the data, it is found that there is a weak correlation between PM_{10} with SO_2 and NO_2. As the correlation of PM_{10} with the NO_2 is more for station II (MIDC) as compared to the other two stations which could be because of the presence of various industries like steel industry, dairy industry, beverage industry, etc., in the area. Similarly, the correlation of PM_{10} with the SO_2 is also shown the same pattern and it shows a higher correlation for station II (MIDC) from 0.27 to 0.85 and lowers for station III (GP) from 0.31 to 0.76, which is because of the less anthropogenic activities that occurred



Figs. 15(a&b). Scatter plot of (a) PM_{10} *vs*. NO_2 and (b) PM_{10} *vs*. SO_2 at monitoring station III (GP)

TABLE 8

Correlation Coefficients of SO_2 and NO_2 with PM_{10}

Correlation Coefficient r	SO_2			NO_2		
	I(IEI)	II(MIDC)	III(GP)	I(IEI)	II(MIDC)	III(GP)
Winter	0.15	0.04	0.34	-0.53	0.40	-0.43
Summer	0.52	0.27	0.02	-0.14	-0.27	-0.11
Monsoon	0.79	0.85	0.31	0.58	0.68	0.20
Post Monsoon	0.67	0.53	0.76	0.58	0.66	0.53

in that area. It shows a weaker correlation of particulate matter with SO_2 as compared to NO_2 for station I (IEI) and station III (GP). This could be because of more vehicles used in that region. Moreover, the correlation for SO_2 with comparison to NO_2 for PM_{10} is less for station II (MIDC) because of emission by various industries.

As shown in Table 8, the correlation of SO_2 and NO_2 described for the seasonal analysis and initiate that, the SO_2 for station I (IEI) and station II (MIDC) is highest in the season of monsoon. For station III (GP) it has a maximum correlation in the season of post-monsoon. Likewise, the correlation of NO_2 with PM_{10} is highest for the season of monsoon at all three stations for the entire study period. The overall influence of pollution due to these pollutants can be seen on monitoring station I and station II, because at station I, is due to the anthropogenic activities, and for station II it is because of the industrial activities.

3.6. *Effect of temperature, humidity, and wind speed on the concentration of PM_{10}, SO_2 and NO_2*

The correlation coefficient 'r' calculated for the various meteorological parameters with the particulate matter PM_{10}, SO_2 and NO_2 as shown in Table 9.

3.6.1. *Correlation on the concentration of PM_{10}*

Correlation factor (r) values demonstrate a negative correlation coefficient with humidity for the winter season at all three stations. This negative correlation may be due to the saturation of particulate matter in the atmosphere. A very good positive correlation between humidity and particulate matter for other seasons is primarily because of the low deposition of the pollutants in the regions. Wind speed is the major factor for the movement of various pollutants and it generates various effects on the concentration of particulate matter in the city on flat planes. The determining factor is dispersing coefficient. It shows in the study that if the wind speed is less, the concentration of the pollutants will be high. And the pollution level would increase near the surface of the earth. There is a negative correlation between the wind speed and the particulate matter because of the less movement of wind over the city which deposited more pollutants all over the city. The correlation of particulate matter with temperature is negative for Station II (MIDC). It is because of the rise in the atmospheric temperature due to various heat emissions from different industries hence increase the pollution level. Station II (MIDC) is an industrials site that shows a stronger correlation with

TABLE 9

Correlation Coefficient (r) of various meteorological parameters with PM_{10}, SO_2 and NO_2

PM_{10}	Temp			Humidity			Wind Speed		
(r)	I(IEI)	II(MIDC)	III(GP)	I(IEI)	II(MIDC)	III(GP)	I(IEI)	II(MIDC)	III(GP)
Winter	0.55	-0.15	0.79	-0.19	-0.76	-0.29	-0.22	0.80	-0.15
Summer	-0.87	-0.55	-0.74	0.70	0.53	0.60	-0.50	-0.48	-0.41
Monsoon	-0.63	-0.66	-0.47	0.54	0.57	0.47	-0.07	0.17	-0.20
Post Monsoon	0.25	-0.52	0.07	0.17	0.45	0.24	0.50	0.34	0.60
Overall	-0.67	-0.65	-0.18	0.39	0.19	0.38	-0.07	0.39	-0.46
SO_2 (r)									
Winter	0.61	-0.26	0.05	-0.11	-0.08	-0.09	-0.30	-0.19	-0.54
Summer	-0.65	-0.28	-0.51	0.07	0.03	0.05	-0.48	0.21	-0.06
Monsoon	-0.49	-0.54	-0.67	0.31	0.36	0.58	0.42	0.48	0.19
Post Monsoon	0.07	-0.07	-0.01	-0.21	-0.07	-0.21	0.00	-0.15	0.12
Overall	-0.38	-0.30	-0.47	-0.12	-0.35	-0.17	0.40	0.47	0.52
NO_2 (r)									
Winter	-0.05	-0.44	-0.50	-0.24	-0.01	-0.27	0.74	0.51	0.71
Summer	-0.12	0.35	-0.12	-0.49	-0.49	-0.30	-0.04	0.66	-0.47
Monsoon	-0.52	-0.49	-0.48	0.45	0.39	0.48	0.13	0.17	0.01
Post Monsoon	0.16	-0.08	0.00	-0.46	-0.30	-0.23	0.03	-0.18	-0.06
Overall	-0.17	-0.06	-0.36	-0.48	-0.52	-0.24	0.62	0.51	0.49

particulate matter as compared to the other two sites for the entire study period.

3.6.2. *Correlation on the concentration of SO_2*

Correlation coefficient (r) values as tabulated in Table 9demonstrate that the overall correlation for the entire study period is negative for temperature and humidity but it is positive for the wind speed for the entire study period for all three monitoring stations. As the speed of wind is less it increases the deposition of gases near the ground hence collection of gases is more on this criterion in the post monsoon season at all the three monitoring station. And it shows a good correlation for humidity in the monsoon season for all the monitoring station, it could be because the humidity is more for the monsoon season at all monitoring stations. The same pattern is studied for the wind speed. But for the temperature in the monsoon season, the correlation is negative for SO_2.

3.6.3. *Correlation on the concentration of NO_2*

As the pattern, is seen in the correlation of SO_2, same as followed for the $NO_{2.}$ Overall correlation is shown negative for the temperature and humidity and overall positive correlation is shown for the wind speed for NO_2. The positive correlation shows in the season of monsoon for humidity else it is negative for all the seasons all over the entire study period. The wind speed correlation of NO_2 is positive most of the time for all the seasons and a good correlation shows for the monitoring site (MIDC) which is an industrial site.

Hence, the meteorological parameters affect the surface pollution as the temperature and wind speed decreases near the surface these pollutants cannot escape the mixing height and accumulate near the surface of earth and increase the level of pollution at all the monitoring station.

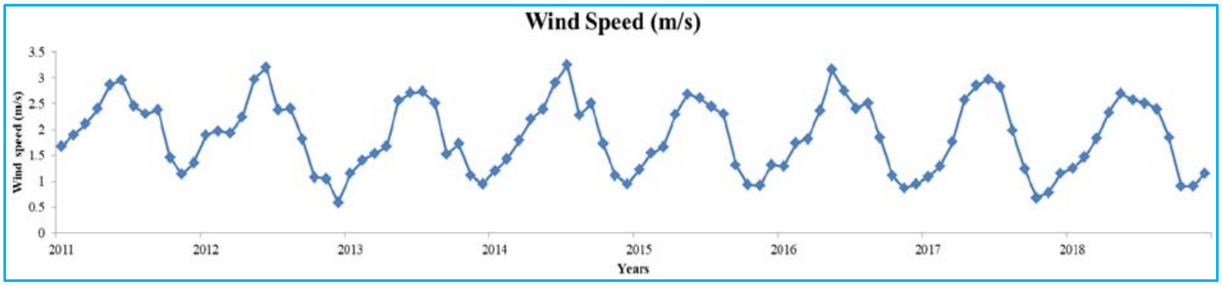


Fig. 16. Monthly variation of Wind speed all over the Nagpur City for study period of 2011-2018

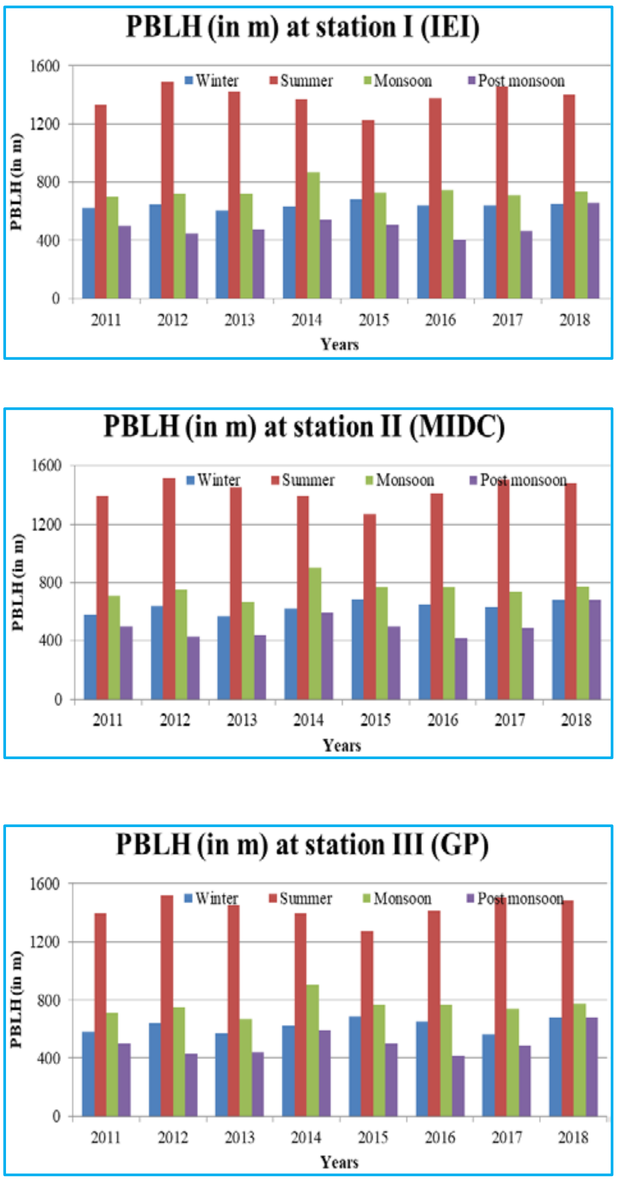


Fig. 17. Planetary Boundary Layer Height (PBLH) in m at all the three stations, *i.e.*, I (IEI), II (MIDC) and III (GP) over the study period of 2011-2018

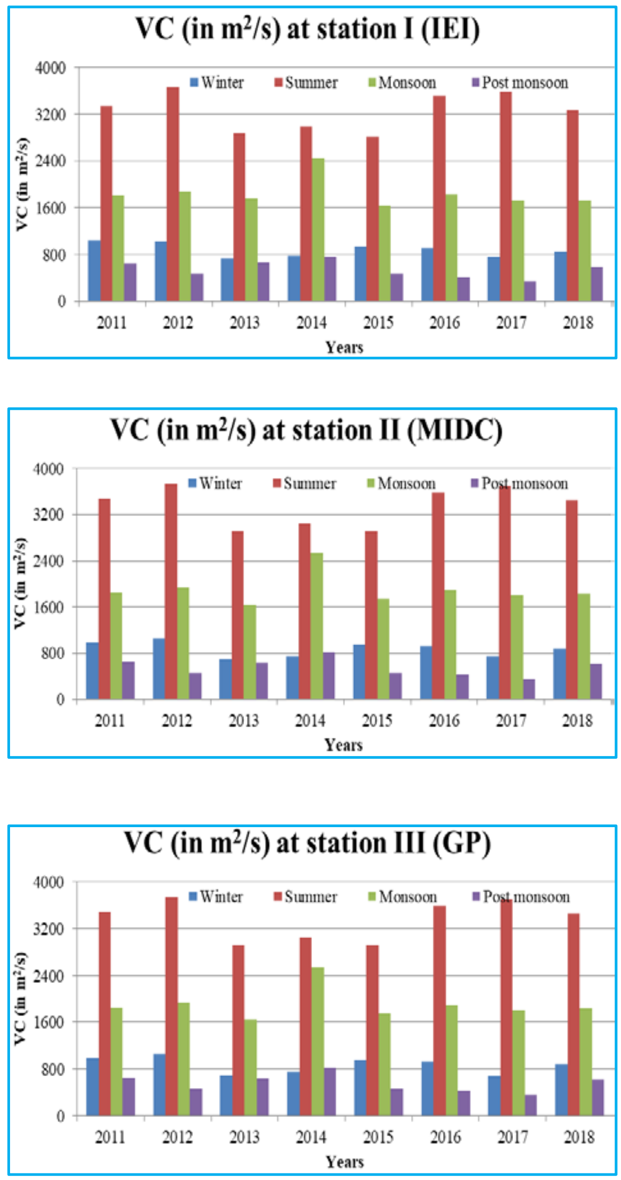


Fig. 18. Ventilation Coefficient (VC) in m^2/s at all the three stations, *i.e.*, I (IEI), II (MIDC) and III (GP) over the study period of 2011-2018

TABLE 10

Annual Air Quality Index

Station	(I) IEI	(II) MIDC	(III) GP
Annual AQIs for the study period			
2011	96	111	88
2012	97	122	85
2013	104	115	96
2014	103	113	100
2015	103	111	100
2016	88	97	89
2017	93	99	94
2018	107	114	105

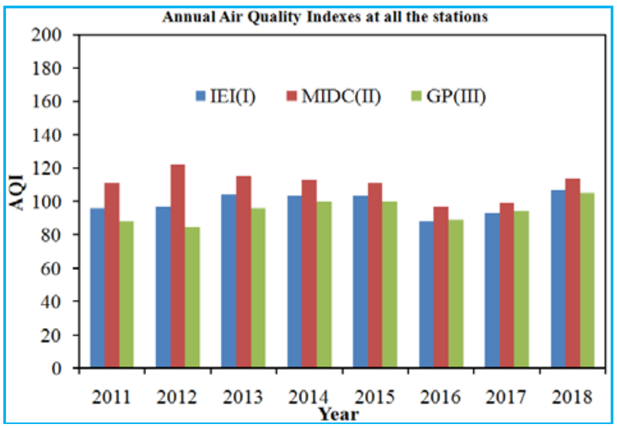


Fig. 19. Annual Air Quality Index

3.7. *Effect of planetary boundary layer height (PBLH) and ventilation coefficient (VC)*

The monthly variations of wind speed are taken from the Indian Meteorological Department during the period from 2011-2018 at study site and plotted in Fig. 16. Wind speed is observed to be high during June (monsoon season) and low in January (winter season). Similarly, the monthly variations of PBLH can be seen from the Fig. 17 with rise in the summer season from region of Hyderabad. It was noticed that higher values in May as a result of high thermal convection processes during summer and lower values are in July (monsoon season). The monthly variations of VC are shown in Fig. 18. The highest value of VC is observed during May (*i.e.*, in summer) due to high PBLH obtained. The lowest value of VC is observed during January (*i.e.*, in winter). The lowest value during winter is associated with low PBLH and WS. It shows that the dispersion of pollutants in the lower atmosphere is due to the convection and mixing. Thus, higher the VC value

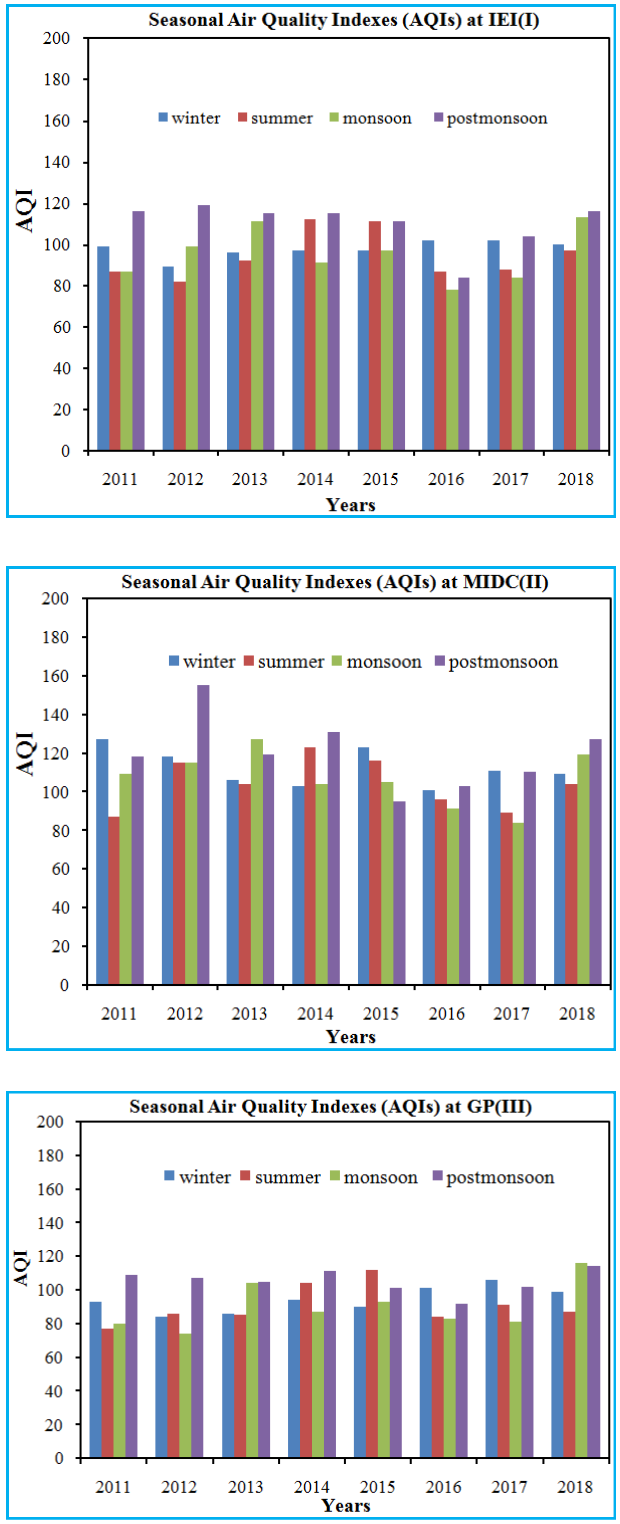


Fig. 20. Seasonal Variation of Air Quality Index

leads to low pollution, and low pollution values lead to more pollution.

TABLE 11

Seasonal Analysis of Air Quality Index

Station	(I) IEI				(II) MIDC				(III) GP			
Season	winter	summer	monsoon	postmonsoon	winter	summer	monsoon	postmonsoon	winter	summer	monsoon	postmonsoon
2011	99	87	87	116	127	87	109	118	93	77	80	109
2012	89	82	99	119	118	115	115	155	84	86	74	107
2013	96	92	111	115	106	104	127	119	86	85	104	105
2014	97	112	91	115	103	123	104	131	94	104	87	111
2015	97	111	97	111	123	116	105	95	90	112	93	101
2016	102	87	78	84	101	96	91	103	101	84	83	92
2017	102	88	84	104	111	89	84	110	106	91	81	102
2018	100	97	113	116	109	104	119	127	99	87	116	114

3.8. *Air Quality Indices (AQIs)*

3.8.1. *Annual Air Quality Indices at all the stations*

Air quality index at all three stations has been determined and shown in Table 10 and it is graphically represented in Fig. 19. From Table 2 and Table 10, it can be seen that the AQI at three monitoring station varies from 51-200. This indicates that the quality of air at three stations was SATISFACTORY to MODERATE. For station (I) IEI residential area in the year 2013, 2014, 2015, 2018 it was MODERATE pollution, rest of the year was in Satisfactory level of pollution. For station (II) MIDC industrial area in most of the years shows MODERATE pollution, except 2016 and 2017 which shows SATISFACTORY level. For station (III) GP commercial area in most of the years shows SATISFACTORY pollution, except 2015, 2016 and 2018, which shows MODERATE level.

3.8.2. ***Seasonal Air Quality Indices***

Air quality index at all three stations has been determined for all the seasons also and shown in Table 11 and it is graphically represented in Fig. 20. This indicates that the quality of air at three stations was SATISFACTORY to MODERATE in all the seasons as the value lies in the range of 51-200 categories. For station (I) IEI residential area post monsoon season value of AQI shows MODERATE pollution, rest of the seasons was in SATISFACTORY level of pollution. For station (II) MIDC industrial area in most of the season shows MODERATE pollution with higher values in the post monsoon. For station (III) GP commercial area in most of the seasons shows SATISFACTORY pollution, except post monsoon season, which shows MODERATE level.

4. Results based on trend analysis

4.1. *Need of monitoring stations*

Nagpur is the 13th largest city of India according to population, known as the cleanest one in Maharashtra state, and is developing and spreading day by day. According to the population and the requirement of several of stations, it seems that the number is not sufficient as far as monitoring and knowing the concentrations of these pollutants. Presently there are three monitoring stations under NAMP, whereas based on the population in the city it requires five more stations in addition to the existing monitoring stations. The combination of three stations may not identify the proper quality of ambient air and coverall the area, which is about 227 km^2. For the large area of the city, these stations are not sufficient, to know the representative quality of ambient air in the city. The population of the city is also growing day by day hence it is required to increase the number of monitoring stations in the city.

Results and reactions of particulate matter analyzed within nearly one km space are discussed in the literature (Maantay 2007). It is observed that there is more traffic flow occurred near the Sitabuldi region and much more near the railway station of Nagpur, the Ganeshpeth bus stand region and more populated area under the region of Mominpura, Sa tranjipura, Nehru Nagar, Ashi Nagar and Lakadganj. Due to more population in a various residential area, more vehicle used for the mode of transportation and as of the bus stand there the congestion could be seen in the traffic for the start-stop generate the more particulate matter. These are the areas, which could be the main hub of the generation of particulate matter and these sites would give us a better understanding of the quality of air in the city. Hence proper monitoring of air

TABLE 2

Minimum number of stations based on the population of the evolving area

Pollutants	Population of evaluation area	Minimum number of AAQ monitoring station
SPM (HI-Vol.)	<100000	4
	100000-1000000	4+0.6 per 100000 population
	1000000-5000000	7.5+0.25 per 100000 population
	>5000000	12+0.16 per 100000 population
SO2 (bubbler)	<100000	3
	100000-1000000	2.5+0.5 per 100000 population
	1000000-10000000	6+0.15 per 100000 population
	>10000000	20
NO2 (bubbler)	<100000	4
	100000-1000000	4+0.6 per 100000 population
	>1000000	10

quality is required in these areas as otherwise, it could lead to a rise in health issues among the people residing in these areas due to high concentration of particulate matter.

Many kinds of literature available show the analysis and effects of particulate matter on the health of people. The deaths increased from about 0.2 to 0.6% by the 10 µg increment the particulate matter. If the present people are exposed to pollution due to particulate matter, there could be health issues to the workers of various industries, which could decrease the production of the industries. There could be various models to generate the data of particulate matter based on existing sites, for the sites that have no monitoring station. Such models could be the Gaussian model, regression model, and receptor-based model. Some modern techniques could use to know the spatially variable pollutants with the help of a geographic information system. IDW, Kriging, etc. are the techniques used for the GIS software which gives the data for the site which has no monitoring station (Yangyang *et al*., 2015).

4.2. *PM_{10} concentration affected by the anthropogenic and natural activities*

Particulate matter concentration is generated either due to anthropogenic activities or naturally. As the population goes on increasing over the years and the use of various vehicles are increased, which consumes either diesel or petrol. Due to the combustion of fuel, the vehicles emit particulate matter and other gases pollutants in the ambient air. Various industries generate smoke, which releases various pollutants into the environment. Natural factors could be the wind propagation and the movement of pollen grains are various cyclones generate the particulate matter. The Central pollution control board gives the guideline for these factors and classifies them based on a scale from 0 to 3, where 0 shows no impact for the particulate matter and 3 show the high impact for the particulate matter generation.

4.3. *Regional PM_{10} and the domestic PM_{10}*

As the height above the mean sea level increases, the effect of regional particulate matter is observed as compared to the local particulate matter concentration. Based on the height of the monitoring sites could be affected by the regional pollutants with the local particulate matter. The altitude of Nagpur is 310 m above the mean sea level and the region is in the flat territory of India. Thus, the effects of regional particulate matter are not more on the local particulate matter because the height is not much more than the regional pollutants come in contact with the local pollutants. Hence, at a particular site, it is observed that the effect of particulate matter pollution gives the somehow appropriate concentration of pollutants in the atmosphere. As the height increases, the effect of local particulate matter goes on decreasing as discussed in the study (Han and Naeher 2006). Thus, PM_{10} concentration is affected by various meteorological parameters such as wind speed, humidity, temperature, etc. and various studies show the effects of pollutants generated from primary sources could be effective by the height.

4.4. *New monitoring station in the Nagpur city and their locations*

After nominated as one of the smart cities, Nagpur has seen growth in various sectors such as industries, the start of the metro rail project, development of various

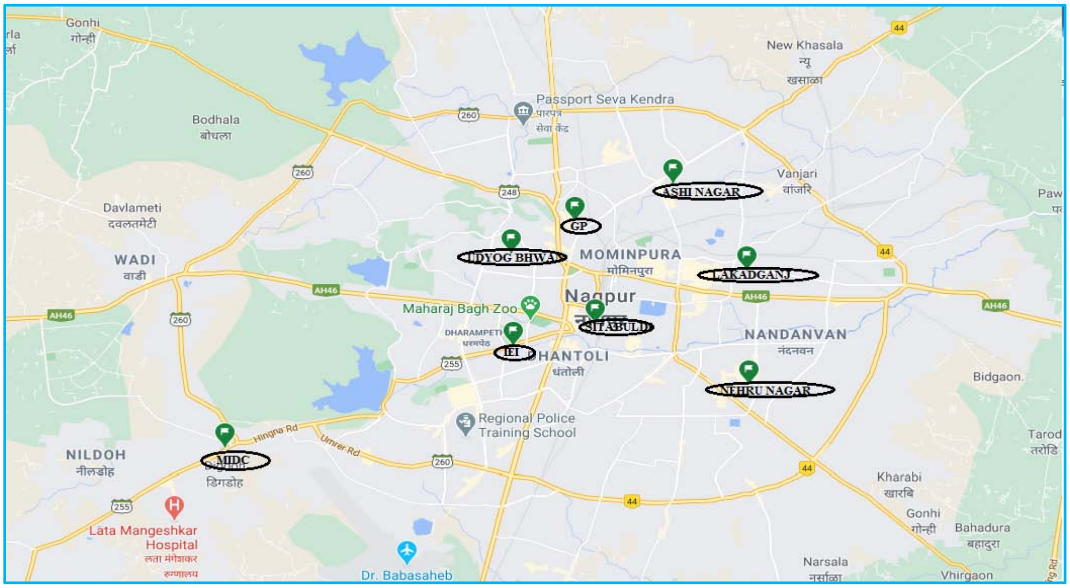


Fig. 21. Design monitoring stations located in the city

tourist spots, etc. Because of these activities, the generation of particulate matter has increased, hence monitoring should be appropriate and correct to know the quality of ambient air in the city. As per the census 2011, Nagpur has a population of 2405665 with a population density of 11000 people per km^2. Around 779259 are the main workers and 2.5 lakh children living in the city here who may affect because of the low quality of air.

According to (IS 5182 - 14 2000) the number of ambient air monitoring stations can be decided, which is given in Table 12. From the guidelines, if the population is less than 1 lakh, only 4 stations are sufficient in the area for air quality monitoring under the National ambient air monitoring program.

If the population varies from 1 lakh to 10 lakhs, monitoring stations should be 4 in addition to 0.6 per 1 lakh population. As the population of Nagpur is 793816 resides in ten zones, it comes under the second part of this guidelines. According to this, there should be eight stations in the city area. As of now in the city, there are three monitoring stations under NAMP, which have been discussed in the present study. In addition to these three stations about five more stations are required for the representative concentration of pollutants in the city. With the addition of these stations, it will be helpful to find out the main sources of the pollutants. The stations should be located in crowded residential areas. The possible monitoring locations can be established in Sitabuldi, Nehru Nagar, Ashi Nagar and Lakadganj, so we need to establish four more stations in the city as per the requirement of CPCB guidelines under NAMP. One monitoring station is already established in the civil lines area, Udyog Bhawan under the SAMP (state ambient air monitoring programme).

The whole city is divided into 10 zones that contain 38 wards distributed in each zone. The main hotspot from this could be ward number 4 which has almost 60949 populations in the Lakadganj zone. Due to this much population, there will be more vehicles and various household activities occurs in the region and affects the population in the zone. This zone almost carries about 90 thousand populations so there should be one monitoring station placed. That will be the hotspot for the generation of particulate matter pollution.

Another zone that comes under, the zone of Nehru Nagar consists of ward no. 26, 27, 28 and 30. The population resides in these four wards has almost 92729 in the Nehru Nagar zone. Due to this much population resides in a small area of the city this could be the hotspot for the particulate matter pollution concerned with the pollution in the atmosphere. So, one monitoring station should be placed here in this zone to know the quality of ambient air of Nagpur city.

The other hotspot for the particulate matter pollution zone Ashinagar in wards 2, 3, 6, 7 contains almost 94 thousand of population. Because of such huge population lives in that region, there should place another monitoring site.

Another hotspot could be the area of Sitabuldi, as there are various markets with the addition of bus stands for transportation to the other part of the state. Because of which highest traffic is experienced at that location due to which the concentration of particulate matter could be more for the ambient air quality in atmosphere.

As Nagpur a developing city in the country there are some lakes like Ambazhari, Sonegaon Lake, Futala Lake isa various tourist attraction. This also includes factors of generated congestion and more vehicular activities will occur in the city so monitoring sites should be sufficient to know the actual quality of air in the city. Such the sites which are available and that should be present in the city are shown in Fig. 21.

5. Conclusions

From the analysis of air pollution data from 2011 to 2018 at all the three monitoring locations, the following conclusions can be drawn:

(*i*) The concentration of PM_{10} is found to be more in the city at all the monitoring stations. This concentration exceeds many times more than the prescribed limit, and hence Nagpur has an alarming situation for the particulate matter pollution. The highest daily average concentration of PM_{10} was found 154 $\mu g/m^3$, 199 $\mu g/m^3$ and 153 $\mu g/m^3$, whereas, the average annual concentration was found 101.87 $\mu g/m^3$, 115.37 $\mu g/m^3$ and 98.75 $\mu g/m^3$ at all three monitoring stations, *i.e.*, IEI, MIDC and GP respectively.

(*ii*) The concentrations of SO_2 are in the range of 11 to 20 $\mu g/m^3$, which is found to be below the prescribed standard of SO_2, *i.e.*, 80 $\mu g/m^3$.

(*iii*) The concentration of NO_2 is found in the range of 35 to 45 $\mu g/m^3$ at all the stations, which is also below the prescribed standard of NO_2, *i.e.*, 80 $\mu g/m^3$.

(*iv*) The wind rose diagram in all four seasons, *i.e.*, summer, monsoon, post-monsoon, and winter shows the movement of airflow above the city and found that most of the time the movement of air is from NE direction towards the city in the post-monsoon season as more value of particulate matter found in that season.

(*v*) The maximum concentration of pollutants is found in the post-monsoon season at all the stations.

(*vi*) The minimum concentration of all the pollutants found in the monsoon.

(*vii*) The weekdays-weekend analysis shows that the concentration of the pollutants is less on the weekends as compared to weekdays due to less movement of vehicles.

(*viii*) The PM_{10} has a positive correlation with SO_2 in all the seasons and the monsoon and post-monsoon season with NO_2.

(*ix*) Correlation of various meteorological parameters temperature, humidity and wind speed with PM_{10}, SO_2 and NO_2 shows negative most of the time in all the seasons over the entire study period.

(*x*) The highest value of VC observed was during summer compared to the other seasons. This could be due to the higher values of PBLH. However, lower values of PBLH and WS result in lower values of VC during winter period. The stronger winds carry the pollutants away from the region which disperses and dilute them. Pollutant particles are generally suspended up to the height of PBLH. Above the boundary layer concentration of the pollutants are very less.

(*xi*) Air quality index analysis concluded that the quality of air was in the SATISFACTORY to MODERATE level of pollution.

(*xii*) Based on the population of the city there is a need for about 4 additional monitoring stations under the National Air Quality Monitoring Programme to get the representative air pollution data.

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