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Assessment of the seasonal trends of air pollution: A case study of Gurugram city, Haryana, India

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ABSTRACT

Introduction: The air pollution is a significant environmental issue that profoundly impacts urban areas and their surrounding regions. The processes involved in air pollution are complex, as primary pollutants are released into the atmosphere and then transported by the action of wind. Primary pollutants may undergo chemical reactions, change phases, and eventually be eliminated from the atmosphere through dry and wet deposition.

Materials and methods: The Air Quality Index (AQI) has been used to analyse the variations in the AQI over a span of three years (2019-2021) for Gurugram city. The study aimed to quantify the changes in the AQI values on seasonal basis (winter, summer, and monsoon).

Results: The results show that there has been a slight improvement in the air quality in certain areas, but it still remains critical. Therefore, it highlights the need for continued and concerted efforts to address the issue of air pollution. The deteriorating air quality poses severe threats, including the potential alteration into the natural state of atmospheric composition, besides health-related issues.

Conclusion: It is closely linked to adverse health effects, such as respiratory problems, increased instances of asthma, cancer, and even leads to mortality in extreme cases. The measurements from four monitoring sites namely Seva Sadan, Sector-51, Gawal Pahari, and Manesar, were analysed and a comparison of seasonal trends among these sites were also attempted.

Introduction

Urban sprawl triggers major changes in social, economic, and environmental aspects, leading to higher energy and water use, increased pollution, and damage to land and forests, impacting human health. Environmental harm is acknowledged, but focus often neglects exploration of soil, land degradation, and resource depletion with consumption, pollution, and human health [1]. Clean air is vital for human well-being. However, widespread air pollution remains a major global environmental issue, posing a serious threat to health when it exceeds acceptable limits [2, 3]. In India, air pollution, the third leading cause of death, reduces life expectancy by 2.6 years. Effective pollution management and raising awareness among individuals are crucial for maintaining a healthy standard [4]. Global urban

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areas face a common challenge of air pollution. Comprehensive monitoring tracks pollutants like Suspended Particulate Matter (SPM), Carbon monoxide (CO), Nitrogen dioxide (NO_2), and Sulfur dioxide (SO_2) globally to enhance understanding. To tackle the data overload, creating region-specific air quality indices can simplify communication for scientists, officials, and the public [5].

Air pollution affects around 300 million people globally, constituting 30% of the urban population. In Delhi, 30% of residents suffer respiratory issues due to air pollution, with disease prevalence 12 times higher than the national average [6]. Urban air pollution, mainly fine particulate matters, plagues South Asian cities, causing 2,050,000 deaths and numerous respiratory diseases annually. Its impact surpasses malaria, causing five times more fatalities and illnesses in the region [7].

Rising industrial and developmental activities contribute to severe air pollution, causing about 25% of all deaths in developing countries, as per the World Health Organization (WHO) [8]. Identifying and addressing heavily polluted areas is crucial. Government organizations use the Air Quality Index (AQI) to analyze and predict air pollution levels [9]. Major Indian cities like Delhi, Mumbai, and Kolkata face worsening air quality, largely due to surge in the number of vehicles during last 15 years. To address this, the Air Quality Index (AQI) has been introduced to gauge air quality in Delhi [10]. Air quality considers five criteria pollutants (CO_2, SO_2, NO_2, O_3, and PM_{10}) and follows European standards, providing a comprehensive understanding of air quality [11]. Gurugram's urban sprawl causes worsening air quality, making it the second most polluted city in Haryana. Vehicle emissions raise nitrogen oxides (NO_2) and carbon monoxide (CO_2), while industrial dispersion lowers SO_2 levels [12].

Major pollutants like PM_{10}, $PM_{2.5}$, CO_2, NO_2, and SO_2 mainly come from industrial and vehicular sources, with vehicles being the primary emitters of CO_2 and NO_2 [13]. Industries are major emitters of PM_{10}, $PM_{2.5}$, and SO_2, while household activities, though contributing less, significantly impact human health. [14]. Delhi's traffic congestion, along with industrial growth in India and other developing nations, raises nitrogen oxide emissions and worsens urban air pollution. The simultaneous increase in both industrialization and number of vehicles in Delhi intensifies the issue [15, 16]. Primary pollutants directly enter the atmosphere, while secondary pollutants result from chemical reactions with primary pollutants or their precursors. City air pollution depends on emission sources, atmospheric processes, and receptor locations. [17]. Metro Indian cities like Delhi, Mumbai, and Kolkata face rising air pollution due to urbanization, industrial activities, and increased vehicular traffic, notably since the 1990s coinciding with the Liberalization, Privatization, and Globalization (LPG) era [18].

This research paper explores factors behind rising air pollution in Gurugram due to urban sprawl. Economic and population growth turned the city into a trade hub, while inadequate land use regulation contracted its periphery. Motor vehicles, the main pollutant source, lead to consistently high SPM levels, reaching 16.7 times the limit in 2021. Additionally, NO_2, sulfur oxides, ozone, lead, and manganese significantly contribute to Gurugram's air pollution.

Objectives

- To assess the ambient air quality of the Gurugram city.
- To analyse the spatial and temporal variations concerning the phenomenon of air pollution in the study area.

Materials and methods

Study area

The Gurugram city is located in the National Capital region, south-east Haryana, India, which has experienced considerable changes in air quality. The phenomenon of air pollution occurred as a result of significant changes in the urban landscape. Gurugram city is one of the most progressive cities of Haryana, having its location in the south-east portion of the state. Gurugram Metropolitan Development Authority (GMDA) has been established through Haryana Ordinance No.2 of 2017. With this Ordinance, the Governor of Haryana established the area with the boundary as specified in the Ist and 2nd Schedule, and containing the area falling within the limits of controlled areas in Gurugram district. It lies between 28°15’0” N, 28°32’30” N latitude and 76°46’20” E, 77°10’20” E longitude, covering 675 sq. km. of area. Gurugram is known as a cyber city as various Cyber Parks, Industrial Development Learning Institutes and Management Centres are located here. The city has the vantage of proximity (approximately 32 km. far) to the nation’s capital, Delhi and is one of the important satellite cities of the National Capital Region (NCR).

Data processing

The AQI was computed using the Maximum Operator Function method, a technique endorsed both by United States Environmental Protection Agency (USEPA) and Central Pollution Control Board (CPCB) for AQI estimation. In contrast to CPCB's approach, this method excludes a factor of 100 as a multiple in the exceed factor of the formula. In accordance with this method,

$$AQI = \text{Pollutants Concentration} * 100 / \text{Pollutant Standard Concentration} \quad (1)$$

Table 1 contains the national standards for air quality regarding certain pollutants. We collected daily air quality data from four stations established by the Central Pollution Control Board (CPCB). The Air Quality Index (AQI) for the specified period (2019 to 2021) was calculated using 24-h or 8-h daily data, employing the Maximum Operator Function Method. To explore seasonal variations in AQI, we divided the 12 months as follows: November to February months as winter season, March to June months as summer season, and July to October months as monsoon season. The daily AQI values derived from the concentration levels of various air pollutants at each station, was then used to determine the percentage codes listed in Tables 2, 3, and 4, considering seasonal averages.

Methodology

This paper primarily utilizes secondary data to assess the air pollution in the study area, seen as impact of urban sprawl. The key methodology employed involves calculating Air Quality Index (AQI) values by using Maximum Operator Function concept in case of major pollutants for assessing their effects and spatial variations across the study area. The calculations have been done on the basis of seasons, comprising winter, summer, and monsoon seasons. The Maximum Operator Function concept has been used to calculate AQI values taken from the CPCB Report, 2020. It is known as "linear segmentation concept," in which the sub-index (Ip) for a given pollutant concentration (Cp) is computed as per the following formulae:

$$I p = [\{(IHI - ILO)/(BHI - BLO)\} * (C p - BLO)] + ILO \quad (2)$$

Where,

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

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}, subtract one from I_{LO}, if I_{LO} is greater than 50.

Air quality index

$$AQI = Max\ (I_1, I_2, ..., I_n) \quad (3)$$

Where;

p= 1, 2, ..., n; denotes n pollutants.

Air Quality Index (AQI) has been defined as a scale. It is based on the use of color-coding scheme that helps to change diverse category of pollutants into a single numerical value. In this manner, the obtained values show the status of overall air quality, its associated health impacts, susceptibility of certain groups, and the need for preventative measures (CPCB, 2020).

Table 1. AQI and its associated health impacts

AQI	Associated health impacts
Good (0–50)	Minimal impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people
Moderate (101–200)	May cause breathing discomfort to the people with lung disease such as Asthma and discomfort to people with heart disease, children and older adults
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases

Source: Central pollution control board (CPCB), India, 2020

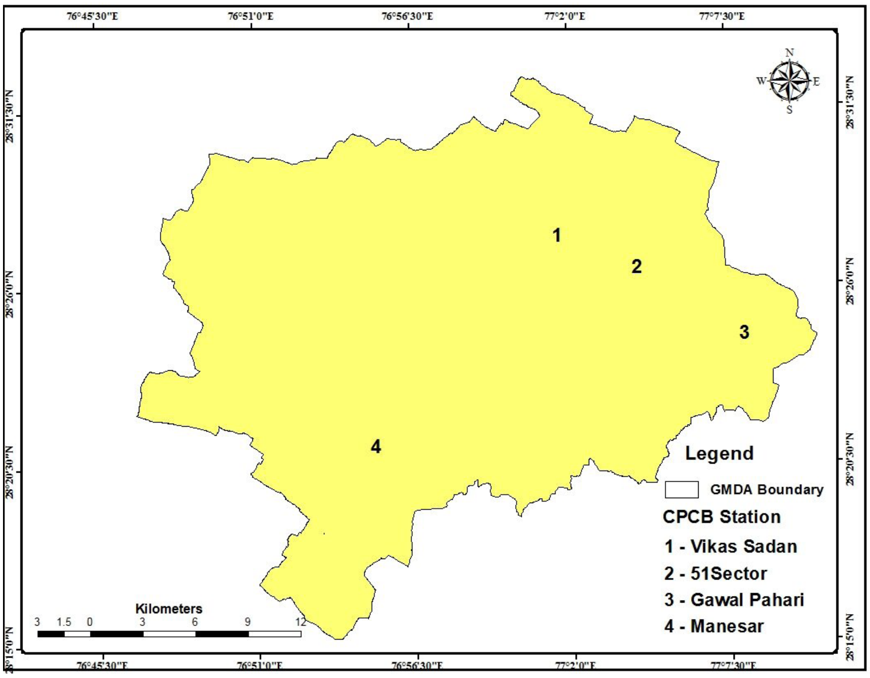

Fig. 1. Location map of CPCB monitoring stations of Gurugram city

Results and discussion

Trends of AQI in Gurugram city, 2019

Table 2 depicts season-wise Air Quality Index (AQI) values for the pollutant $PM_{2.5}$ in Gurugram city throughout the year 2019. Pollutant levels are notably higher in the winter season compared to other seasons, showing significant variations. The concentration level of PM_{10} and $PM_{2.5}$ each is 163 µg/m³, indicating high levels of fine particles in the air. NO_X exhibits concentration level of 186 µg/m³. Similarly, the concentration levels of SO_2 (16 µg/m³), CO (50 µg/m³), O_3 (29 µg/m³), and NO_2 (10 µg/m³) shows fluctuating trend during the winter season, but their values are lower compared to PM_{10}, $PM_{2.5}$, and NO_X pollutants. During the summer season, pollutant levels exhibit decreasing trends compared to the winter season but remain relatively higher. The concentration level of $PM_{2.5}$ was recorded with value of 200µg/m³, which is lower than winter season. Similarly, the concentration level of PM_{10} with an AQI value of 57µg/m³ was lower compared to the winter season. The concentration level of SO_2 increased to 31µg/m³, indicating a higher presence of sulfur dioxide compared to the winter season. Pollutants such as NO_X (38 µg/m³), CO (50 µg/m³), and NO_2 (10 µg/m³) shows varying levels of concentrations but are generally higher compared to the winter season, except for O_3, which is recorded with value of 41 µg/m³.

Table 2. AQI values of major pollutants of Gurugram city, 2019

Seasons	Pollutants (in µg/m³), 2019						
	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	O_3	NO_2
Winter	163	302	16	186	50	29	17
Summer	57	200	31	38	50	41	10
Monsoon	133	113	15	31	50	32	6

Source: Calculated from CPCB data, Gurugram city

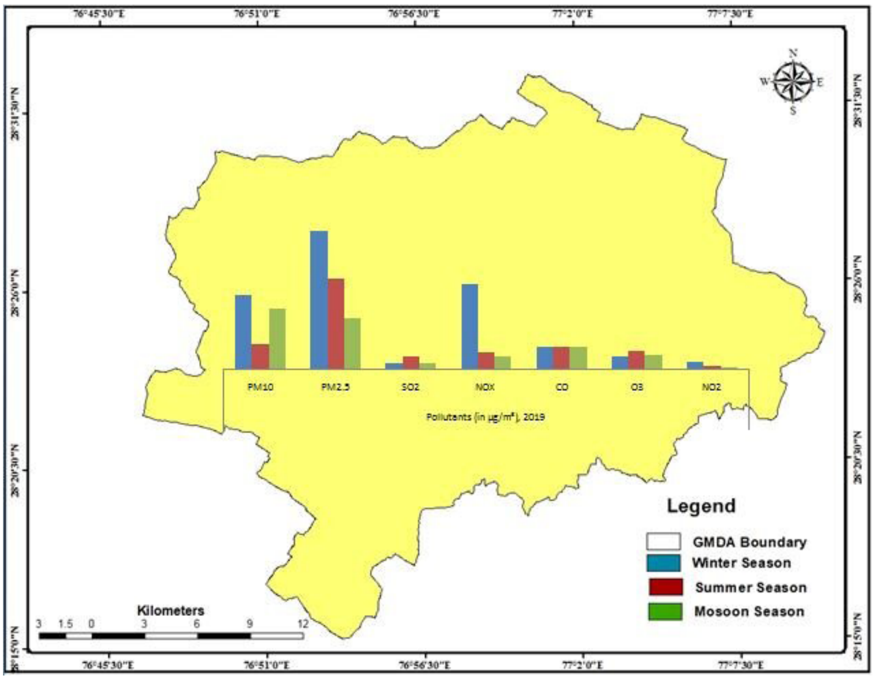

Fig. 2. Seasonal ambient air quality status of Gurugram city, 2019

During the monsoon season, the concentration level of pollutants shows further decreasing trend compared to both winter and summer seasons. $PM_{2.5}$ shows the lowest concentration with an AQI value of 113µg/m³, indicating cleaner air during the monsoon season. Similarly, PM_{10} also shows decreasing value to the tune of 133µg/m³, reflecting relatively cleaner air quality. SO_2 exhibits the lowest concentration of 15µg/m³ during the monsoon season. Additionally, NO_X (31 µg/m³), CO (50 µg/m³), O_3 (32 µg/m³), and NO_2 (6 µg/m³) also have lower concentration levels during the monsoon season compared to winter and summer seasons, respectively.

Trends of AQI in Gurugram city, 2020

Table 3 and the Fig. 3 depict the seasonal air pollution status, AQI values, and concentration levels of major pollutants in Gurugram city during 2020. During the winter season, pollutant levels are higher compared to other seasons, except for NO_2. The remaining pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_X, CO, and O_3 shows varying concentration levels with AQI values of 165µg/m³, 305 µg/m³, 16 µg/m³, 53 µg/m³, 50 µg/m³, and 23 µg/m³, respectively. According to the range of AQI values provided by CPCB (Table 1), the AQI values presented in Table 3 indicates poor condition of air quality in the study area.

During the summer season, pollutant levels exhibits decreasing trend, including PM_{10}, $PM_{2.5}$, SO_2, NO_X, CO, O_3, and NO_2, with AQI values of 107µg/m³, 80µg/m³, 16 µg/m³, 23 µg/m³, 50 µg/m³, 61 µg/m³, and 9 µg/m³, respectively. Table 3 shows higher values of pollutants during the winter season, with some minor variations (lower in case of O_3), thus indicating poorer air quality compared to summer and monsoon seasons.

During the monsoon season, pollutant levels show further increasing values as compared to both winter and summer seasons, with concentration levels of PM_{10} (119 µg/m³) and $PM_{2.5}$ (120 µg/m³), indicating cleaner air. SO_2, NO_X, CO, O_3, and NO_2 also shows lower concentration levels during this season, with NO_2 being the lowest with value of 6 µg/m³.

Table 3. AQI values of major pollutants of Gurugram city, 2020

Seasons	Pollutants (in µg/m³), 2020						
	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	O_3	NO_2
Winter	165	305	16	53	50	23	17
Summer	107	80	16	23	50	61	9
Monsoon	119	120	8	14	50	31	6

Source: Calculated from CPCB data, Gurugram city

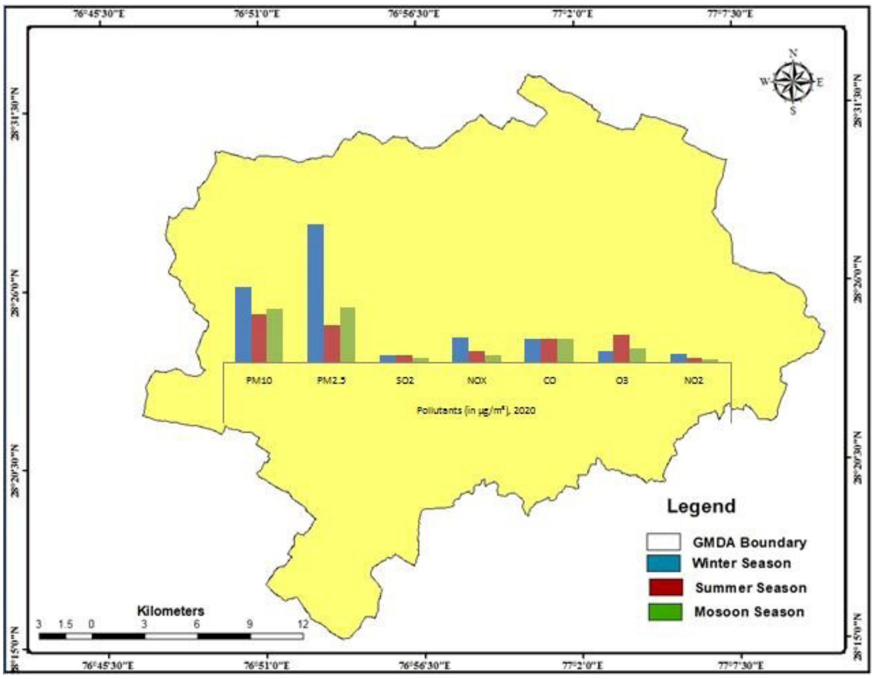

Fig. 3. Ambient air quality status of Gurugram city, 2020

Table 4. AQI values of pollutants of Gurugram city, 2021

Seasons	Pollutants (in µg/m³), 2021						
	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	O_3	NO_2
Winter	196	328	8	35	50	25	8
Summer	149	160	10	18	50	35	8
Monsoon	173	290	9	26	50	30	8

Source: Calculated from CPCB data, Gurugram city

Trends of AQI in Gurugram city, 2021

Table 4 and accompanying Fig. 4 present the seasonal concentration levels of pollutants in Gurugram city. During the winter season, two major air pollutants i.e., PM_{10} and $PM_{2.5}$ recorded very high concentration levels with values of 196 µg/m³ and 328µg/m³. Additionally, other air pollutants like SO_2 NO_X CO at, O_3, and NO_2 recorded varying concentration levels with values of 8 µg/m³, 35 µg/m³, 50 µg/m³ 25 µg/m³ and 8 µg/m, respectively.

During the summer season, the concentration levels of PM_{10}, $PM_{2.5}$, SO_2, NO_X, CO, O_3, and NO_2 were recorded with varying values of 149µg/m³, 160 µg/m³, 10 µg/m³, 18 µg/m³, 50 µg/m³, 35 µg/m³, and 8 µg/m³, respectively. During the monsoon season, the air quality level exhibited seasonal variations throughout the year 2021. Notably, this season shows slightly lower concentration levels of PM_{10}, $PM_{2.5}$, SO_2, NO_X, CO, O_3, and NO_2, with AQI values of 173µg/m³, 290µg/m³, 9µg/m³, 26 µg/m³, 50 µg/m³, 30 µg/m³, and 8 µg/m³, respectively.

AQI status in Gurugram city

The classification of AQI pollutant levels into categories follows the National Ambient Air Quality Standards (NAAQS) of India and may differ from other countries. This classification system helps to understand the health effects associated with different levels of air pollution. These values are then compared with defined breakpoint AQI values provided by the Central Pollution Control Board (CPCB) in India. The AQI scale ranges from 0 to 500 µg/m³ and shows associated health impacts with respect to various types of air pollutants. Using this scale, the health effects of recorded concentration levels of major pollutants can be assessed.

Table 5. Overall AQI status in Gurugram city from 2019-2021

Years/Seasons	2019	2020	2021
Winter	302	305	328
Summer	200	107	160
Monsoon	133	120	290

Source: Calculated from CPCB Data, Gurugram City

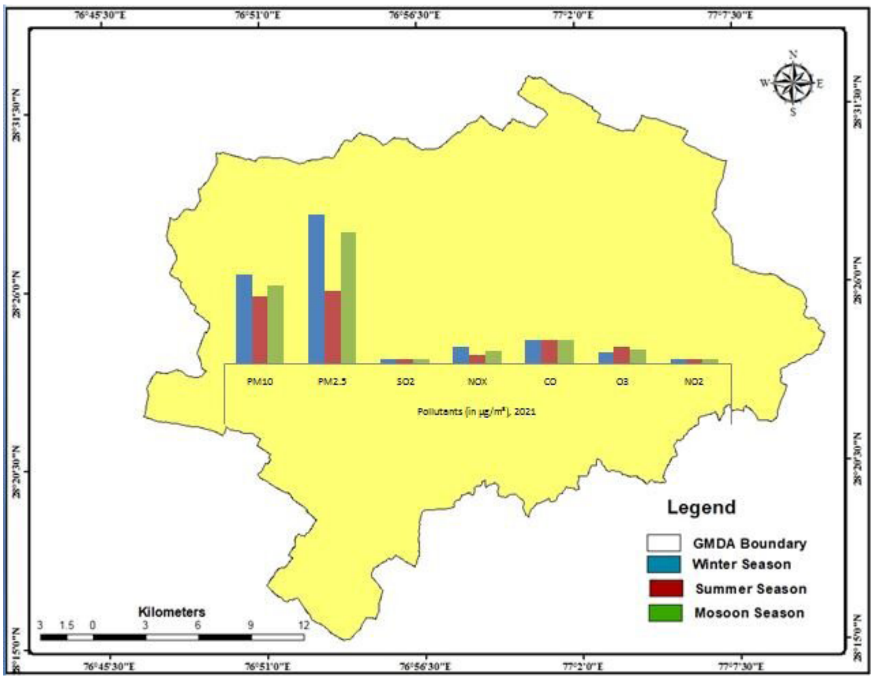

Fig. 4. Ambient air quality status of Gurugram city, 2021

Fig. 5 illustrates the maximum values of the pollutant Air Quality Index in Gurugram city during 2019, 2020, and 2021 years. The Air Quality Index values depicts fluctuating trend during different seasons over the three chosen years of study. The numbers reflect the air quality levels, with higher values indicating poorer air quality. This suggests that there are variations in air quality across seasons and years, providing insights into the air quality status during these time periods.

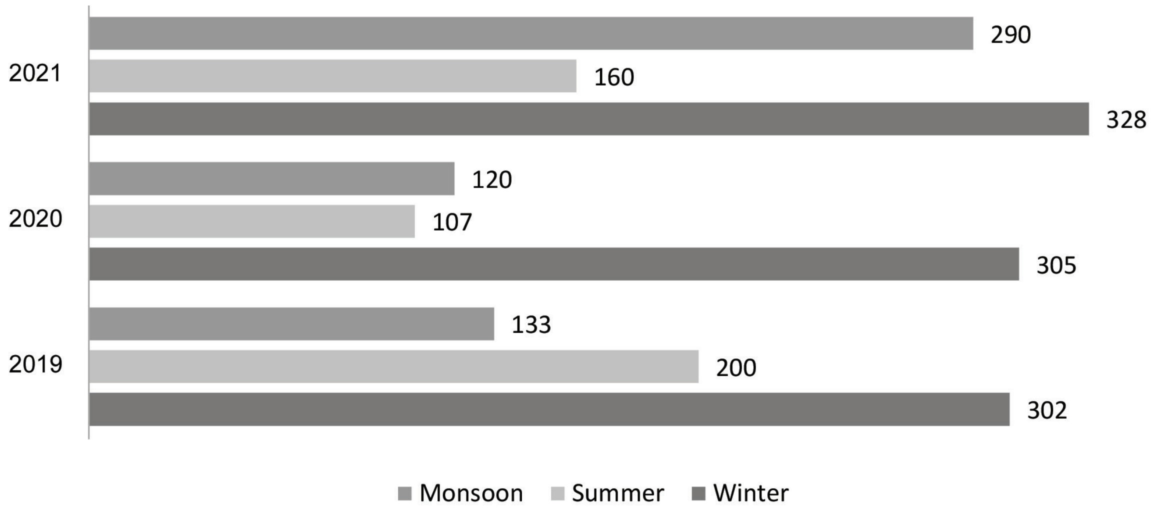

Fig. 5. Air quality level of Gurugram city 2019, 2020 and 2021

Table 6. AQI status in Gurugram city from 2019-2021 (in µg/m³)

Years/Season	2019	2020	2021
Winter	VP	VP	VP
Summer	M	M	M
Monsoon	M	M	P

Source: Calculated from CPCB Data, Gurugram City.

Tables 5 and 6 shows the overall Air Quality Index (AQI) values along with air quality status recorded in Gurugram city during three seasons: winter, summer, and monsoon. During the winter seasons of 2019, 2020, and 2021 years, the AQI values of major pollutants were classified as VP (very poor). During the summer seasons of 2019, 2020 and 2021, consistent AQI values of major pollutants have been classified as M (moderate). During the monsoon seasons of 2019, 2020, and 2021 years, the AQI values of major pollutants are consistently classified as M (moderate), M (moderate), and P (poor).

Conclusion

This study indicates that seven major pollutants, primarily emitted from mobile sources like vehicles, have led to increased Air Quality Index (AQI) values in all CPCB stations, especially during the winter season. All pollutants in Gurugram city exceed the permissible limits defined by the World Health Organization (WHO). Two severe categories of pollutants, namely PM_{10} and $PM_{2.5}$, shows crossing the threshold standards set by the Central Pollution Control Board (CPCB). SO_2 levels have declined in Gurugram city. However, NO_2 levels have increased across the city due to the growing number of vehicles passing through neighbouring districts and states.

The concentration of Suspended Particulate Matters (SPM), such as PM_{10} and $PM_{2.5}$, varies depending on the location. Residential areas like Sector 51 and Gawal Pahari shows a significant upward trend in the values of these pollutants. Manesar, an industrial area, shows a decreasing trend. Construction activities contribute to the rising levels of SPM across various spatial locations in the entire city. The gap in air pollution levels between residential and industrial areas is notable. Population growth and rising pollution levels in the future could worsen the issue of air quality. Despite initiatives like converting public transport to CNG, the increase in petrol-driven vehicles, especially two-wheelers and cars, may counteract these efforts. The air quality of Gurugram faces risks year-round, with high PM_{10} and $PM_{2.5}$ levels in all seasons. Winter season often witnesses worsening of air quality, likely due to stable winds and slow velocity blowing from the west to southeast.

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Competing interests

The authors declare no competing interests related to the material discussed in this paper.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors."

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