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ASSESSING AIR QUALITY DYNAMICS IN UTTAR PRADESH (2016-2022): A COMPREHENSIVE SPATIO TEMPORAL ANALYSIS

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ABSTRACT

This study was created to examine the spatial and temporal fluctuations within the 78 stations that were chosen, encompassing residential, commercial, sensitive, and industrial areas from January 2016 to November 2022 in Uttar Pradesh. For the analysis, the Uttar Pradesh Pollution Control Board (UPPCB) employed monthly pollutant concentrations (PM_{10}, SO_2, and NO_2) measured at several sites scattered throughout the research area from January 2016 to November 2022. According to the descriptive data, the monthly average spatial mean PM_{10} concentrations ranged from 121.97 μg/m³ to 249.14 μg/m³, depending on the site. According to the descriptive statistics, the months of December and August, respectively, saw the highest and lowest spatially variance. It was found from this study that the average pollution levels steadily rise in the following order: residential area, commercial area, and industrial area. The pollutant concentrations have also been mapped using IDW methods.

Keywords: Particulate Matter (PM_{10}), SO_2, NO_2, Inverse Distance Weight, Spatio-Temporal.

I. INTRODUCTION

A combination of man-made and natural factors, including gas and solid particles, contribute to air pollution. Depending on the local climatic conditions, the air quality is constantly changing on a daily and even hourly basis. The main causes of atmospheric pollution include industrial emissions of chemicals, dust, pollen, and mold spores suspended as particles. Gasoline, fuel oil, and natural gas used in power plants, automobiles, and other combustion sources directly release some gaseous air pollutants like sulphur dioxide, nitrogen dioxide, and carbon monoxide into the atmosphere.

In many cities, air pollution is a big concern since it directly and fundamentally affects human health. Air pollution is one of the major environmental issues in urban areas around the world. Air pollution levels have increased globally during the last few decades. While industrial and vehicular activity and traffic in most major cities have reduced air pollution, the effluence levels are still very variable. According to the World Health Organization (WHO), anthropogenic air pollution is a factor in 4–8% of worldwide yearly fatalities [1]. However, the effects of air pollution on public health are assessed in terms of lost production, missed chances for education and other human development, as well as illnesses and deaths (UN, 2001).

In both urban and rural regions around the world, particulate matter (PM) is one of the main contaminants that has an impact on ambient air quality [2]. Particulate matter is frequently classified into the PM_{10} and $PM_{2.5}$ groups based on size. [3] defined fine particles ($PM_{2.5}$) as aerodynamic diameters less than 2.5 m, while [4] classified inhalable particles (PM_{10}) as aerodynamic diameters less than 10 m. According to [5], particulate matter is a broad category of particles that come in a variety of sizes, shapes, compositions, and optical qualities. The increase in particulate matter, such as PM_{10} and $PM_{2.5}$, is linked to the risk to human health as well. Compared to PM_{10}, $PM_{2.5}$ has a larger surface area and acts as a carrier of numerous bacteria, viruses, and heavy metals that can enter the human body. These contaminants are known to cause cardiovascular disease, asthma, bronchitis, neurobehavioral effects, mortality, and other respiratory conditions [6]. Accordingly, seasonal fluctuation has always been a factor in influencing the quantity of air pollutants in the atmosphere [7]. The effects of particulate matter and gaseous pollutants on human health vary with the change of seasons.

The soil, water, and cropping patterns may be seriously harmed by high SO_2 and NO_2 concentrations [8,9]. According to [10], air pollution alters the climate and reduces atmospheric visibility. The indoor-outdoor

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environmental pollutants were measured by [11] in various seasons, and risk assessment was completed using an Integrated Risk Information System. Therefore, study on the features of air pollution is necessary and required to provide logical foundation for creating efficient extenuation strategies.

According to [12], there are significant temporal and regional fluctuations in air quality. It is typically resource-intensive, challenging, or expensive to monitor concentrations over a number of sites in a research region. Monitoring shows the degree of air pollution at a certain location. Thus, a surface grid or contour map is produced using spatial interpolation techniques. Utilizing known concentrations at fewer sites, interpolation techniques estimate concentrations in the studied area. The major goal of this study is to assess the spatiotemporal variance of ambient air pollutants during a seven-year period in Uttar Pradesh among the 78 selected stations.

II. METHODOLOGY

SITE DESCRIPTION

A state in northern India referred to as Uttar Pradesh. It makes up about 241 million people, or 16.5% of India's total population, making it both the most populous state in India and the most populous nation subdivision in the world. There are 18 divisions and 75 districts in the state. The Triveni Sangam in Prayagraj (formerly Allahabad), a Hindu pilgrimage site, is where the state's two principal rivers, the Ganges and its tributary Yamuna, meet. Rajasthan shares borders with the state on the west, Haryana, Himachal Pradesh, and Delhi on the northwest, Uttarakhand on the north, Bihar on the east, Madhya Pradesh on the south, and Chhattisgarh and Jharkhand on the south. It is the fourth-largest state according to size of area in India, obscuring 240,928 km^2 (93,023 sq mi), or 7.3% of the country's total land area. With a gross domestic product of 18.63 lakh crore (US$230 billion) and a per-capita GSDP of 68,810, Uttar Pradesh has India's third-largest state economy.

There are four seasons in Uttar Pradesh, which has a humid subtropical climate. The summer season, which lasts from March to May, and the monsoon season, which lasts from June to September, follow the winter in January and February. In some areas of the state, the summers are extremely hot and dry, with temperatures ranging from 0 to 50 °C (32 to 122 °F) and the Loo, or dry, hot winds. Between semiarid and subhumid is the Gangetic plain. In the southwest section of the state, the average annual rainfall is 650 mm (26 inches), whereas in the eastern and south eastern regions, it is 1,000 mm (39 inches).

The study focuses on a selection of 27 districts within UP. These areas were chosen based on the availability of air quality data on the UPPCB portal. The list includes prominent cities such as Agra, Firozabad, Ghaziabad, Gorakhpur, Kanpur, Lucknow, Meerut, Moradabad, Noida, Prayagraj, and Varanasi, along with others like Sonbhadra, Gajraula, Jhansi, Khurja, Ayodhya, Bareilly, Mathura, Rae Bareli, Saharanpur, Unnao, Hapur, Greater Noida, Muzaffarnagar, Aligarh Hathras and Bagpat.

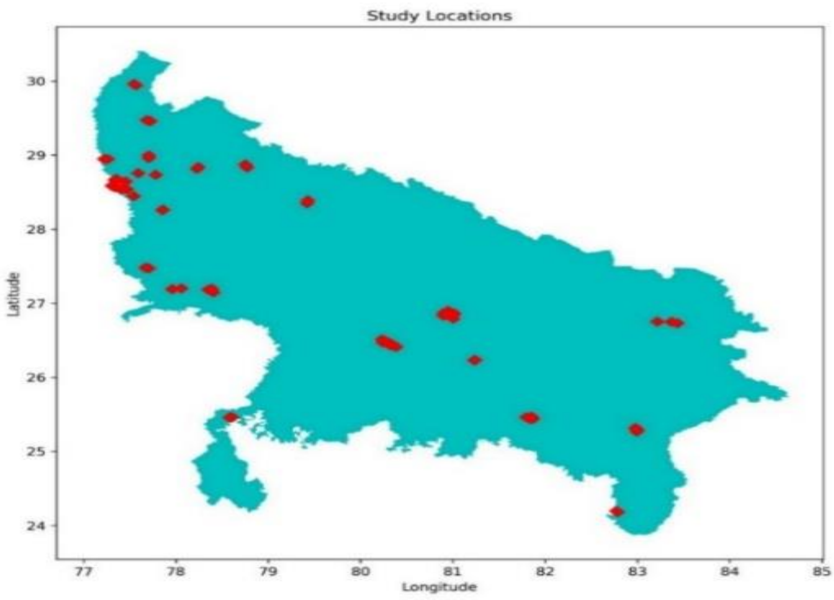

Fig.1. Map of study area, Uttar Pradesh state, India

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DATA COLLECTION AND ANALYSIS

Initially, a GIS was used to create the spatial data for the study region. A GIS environment is used to build the map of the research region in Uttar Pradesh. The UPPCB's air monitoring network was utilized for collecting monthly data of air pollutants (PM_{10}, SO_2, and NO_2) during the time period of January 2016 to November 2022.

This study comprises two distinct types of investigations. In the first type, we examined monthly variations using the combined data gathered from all 78 stations. Conversely, in the second type, we initially categorized and segregated the data from these 78 stations (Table1) based on their area type, such as residential, industrial and commercial. Subsequently, we analyzed individual seasonal, and yearly variations for each distinct area type.

In order to comprehend the distribution and behavior of the pollutants (PM_{10}, SO_2, and NO_2) in Uttar Pradesh, a thorough analysis of their concentration was first conducted. In order to accomplish this, the pollutants concentration are being studied depending on the months (January–December), years (2016–2022), and seasons (winter, summer, monsoon, postmonsoon). This guarantees a better comprehension of the geographical and temporal behavior of air contaminants. To map air pollution, geostatisticians frequently use spatial interpolation [13]. Within the spatial range of the known values, this method comprises estimating the point values of unknown locations using the point values of known regions [14]. the performance and geographical variability of this method are constrained by the quantity and uniform distribution of point data. According [14], this method is still often used for the spatial assessment and distribution of air contaminants. IDW is one of the most frequently used interpolation methods available. For multivariate interpolation, the IDW can be utilized. Air pollution studies [13] have proven the effectiveness of IDW. Accordingly, Inverse Distance Weighting (IDW) was used in this investigation.

Table 1. Air quality monitoring sites.

		Area Type				
S. No	**Cities**	**Commercial**	**Residential**	**Industrial**	**Sensitive**	**Total No. of Stations**
1	Lucknow	4	2	1		7
2	Kanpur	2	5	1		8
3	Agra				2	2
4	Sonbhadra		2			2
5	Gazraula	1		1		2
6	Ghaziabad	1	1	2		4
7	Varanasi	1	3	1		5
8	Noida	1	2	1		4
9	Firozabad				3	3
10	Jhansi	1	1			2
11	Khurja		1	1		2
12	Allahabad	4	1			5
13	Merrut	1	1			2
14	Moradabad	1	1			2
15	Bareilly	1	1			2
16	Rae Bareli	1	1	1		3
17	Mathura				2	2
18	Saharnpur	1	1			2

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19	Gorakhpur	1	1	1		3
20	Unnao		2			2
21	Hapur		1	1		2
22	Greater Noida			2		2
23	Muzaffarnagar	2				2
24	Bagpat		1	1		2
25	Ayodhya	1	1			2
26	Aligarh	1	1			2
27	Hathras	2				2
						Total Station=78

III. RESULTS AND DISCUSSION

Monthly variation

We looked into the monthly variations in air pollution concentrations over Uttar Pradesh using data on contaminants. The monthly fluctuations in the concentrations of the three pollutants (PM_{10}, SO_2, and NO_2) are shown in figures 2, 3, and 4. December had the highest monthly mean PM_{10} concentration (249.14±69.20) μg/m^3, and August had the lowest (121.97±35.99) μg/m^3. The monthly mean concentration of SO_2 was also highest (12.69±7.16) μg/m^3 in December and lowest in (8.67±4.16) μg/m^3 in August. NO_2 concentrations ranged from 33.94 to 36.32 μg/m^3, with December having the highest values (36.32±14.61) μg/m^3 and August having the lowest (23.80±9.59) μg/m^3.

Table 2. Monthly distribution of particulate matter and gaseous pollutant concentrations from 2016 to 2022.

	Pollutants		
	PM_{10}	**SO_2**	**NO_2**
MONTHS	**MEAN**	**MEAN**	**MEAN**
Jan	226.37±55.65	12.07±6.34	33.94±11.57
Feb	211.92±46.24	11.88±5.96	33.50±12.50
Mar	202.09±41.71	12.11±5.61	32.53±10.64
Apr	210.13±52.71	11.74±5.60	31.34±10.65
May	183.74±39.98	11.23±5.59	30.11±9.79
Jun	172.59±32.80	10.34±4.80	28.12±10.27
Jul	132.65±34.87	8.87±3.99	25.03±10.05
Aug	121.97±35.99	8.67±4.16	23.80±9.59
Sep	129.13±32.39	9.25±4.42	25.07±9.25
Oct	190.37±44.84	11.41±5.45	30.34±10.38
Nov	248.18±68.24	12.59±6.52	35.84±13.25
Dec	249.14±69.20	12.69±7.16	36.32±14.61

AIR POLLUTANT SPATIOTEMPORAL CHARACTERISTICS BASED ON TYPE OF AREA

Variation of ambient pollutants during the study period

According to data from 78 monitoring stations in Uttar Pradesh, the annual variation of ambient air pollutants (PM_{10}, SO_2, and NO_2) is shown in Fig.5. The findings clearly show that particulate matter annual average concentrations were greater than the CPCB standard's limits in each kind of area, whereas NO_2 and SO_2

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concentrations were within the standard range in every type of area. Every year, all of the commercial, residential, and industrial zones had PM_{10} concentrations that were higher than the CPCB threshold (60 μg/m³). The industrial area has the greatest PM_{10} levels. Between 2016 and 2022, the PM_{10} concentrations in industrial areas ranged from 214 μg/m³ to 209.76 μg/m³. Similar to this, industrial areas likewise had the greatest SO_2 concentrations. In industrial areas, SO_2 concentrations ranged from 14.57 μg/m³ in 2016 to 15.28 μg/m³ in 2022.

Seasonal variation of ambient pollutants

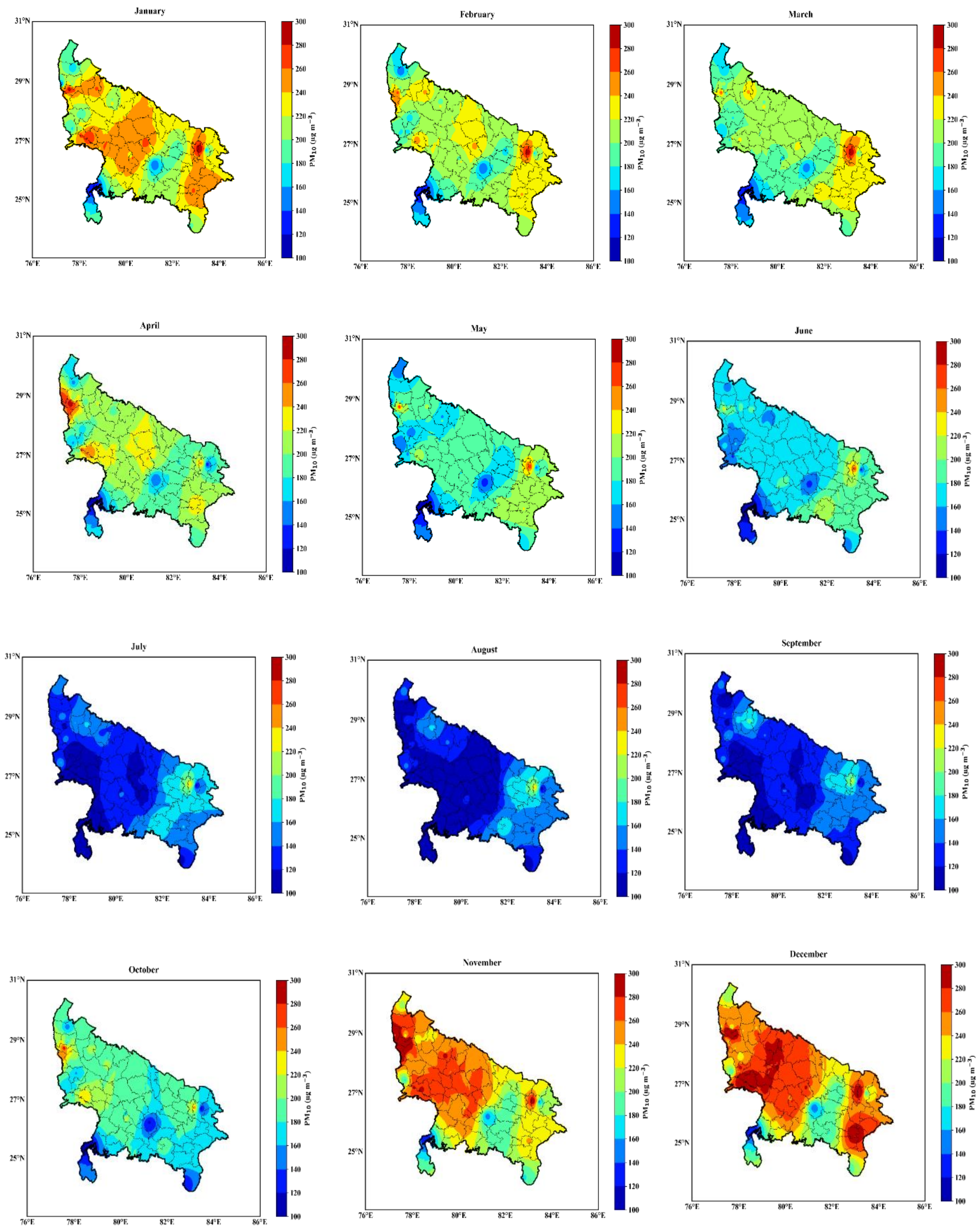

Fig.2 Monthly Spatial variation plot of PM $_{10}$ using inverse distance weighted (IDW) technique

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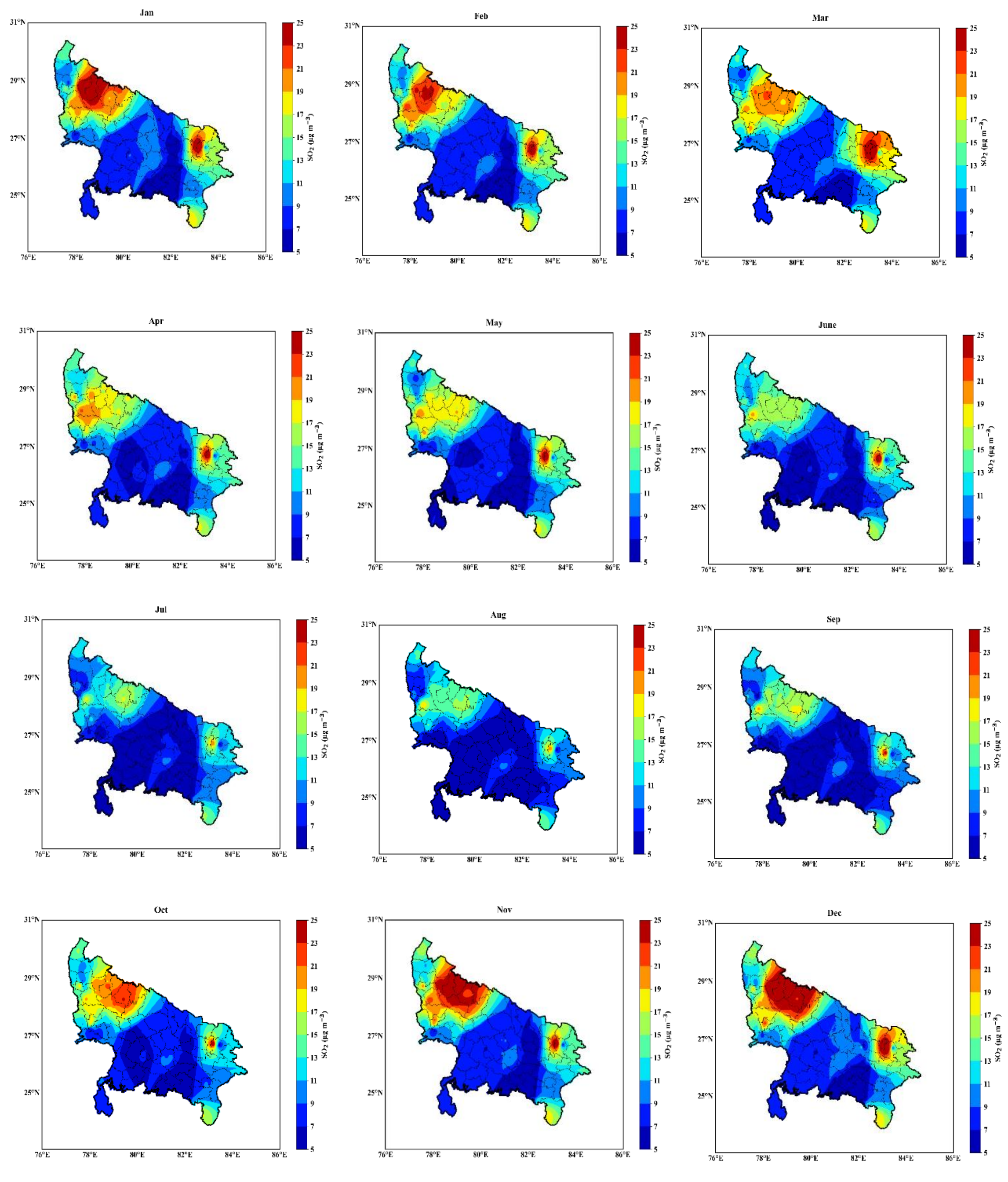

Fig.3 Monthly Spatial variation plot of SO_2 using inverse distance weighted (IDW) technique

Fig. 6 show the seasonal variation of PM_{10}, SO_2, and NO_2 at 78 fixed monitoring sites in Uttar Pradesh. The findings revealed that each location type's seasonal average particulate matter (PM_{10}) concentration exceeded the cpcb standard's set limits. The average PM_{10} concentration in commercial areas varied significantly across time, with winter having the greatest value (231.90± 53.47 $\mu g/m^3$) and monsoon having the lowest value (134.45± 32.74 $\mu g/m^3$). All of the monitoring locations saw low wind flow throughout the winter, which led to a minute distribution of pollutants and increased PM_{10} concentrations [15]. High wind flow and dust particle washing from the atmosphere by rainfall were blamed for the lowest PM_{10} concentration during the monsoon season. In the winter, an industrial region had the highest PM_{10} concentration. The concentration of PM_{10} in the industrial area was distributed as follows: post monsoon (253.77± 55.49 $\mu g/m^3$), winter (252.50 ±52.20 $\mu g/m^3$), summer (214.75 ±41.62 $\mu g/m^3$), and monsoon (141.66 ±37.45 $\mu g/m^3$).

In Fig. 6, the seasonal variation of gaseous pollutants like SO_2 and NO_2 was depicted. With the maximum value in winter (11.22 ±4.84 $\mu g/m^3$) and the lowest one in monsoon (8.44 ±3.66 g $\mu g/m^3$), the average seasonal

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concentration of SO_2 in residential areas showed significant temporal fluctuation. The highest SO_2 concentration was found in industrial locations, which were studied among residential, commercial, and industrial sites. This may be the result of emissions from the burning of fossil fuels and industrial boilers, which may have contributed to the rise in SO_2.The average NO_2 concentration in industrial areas varied from post-monsoon (35.36±10.69 µg/m^3) through winter (34.75±11.67 µg/m^3), summer (31.33±9.88 µg/m^3), and monsoon (24.03±10.18 µg/m^3). This might be brought on by the heavy use of vehicles, use of fossil fuels, and little winter precipitation.

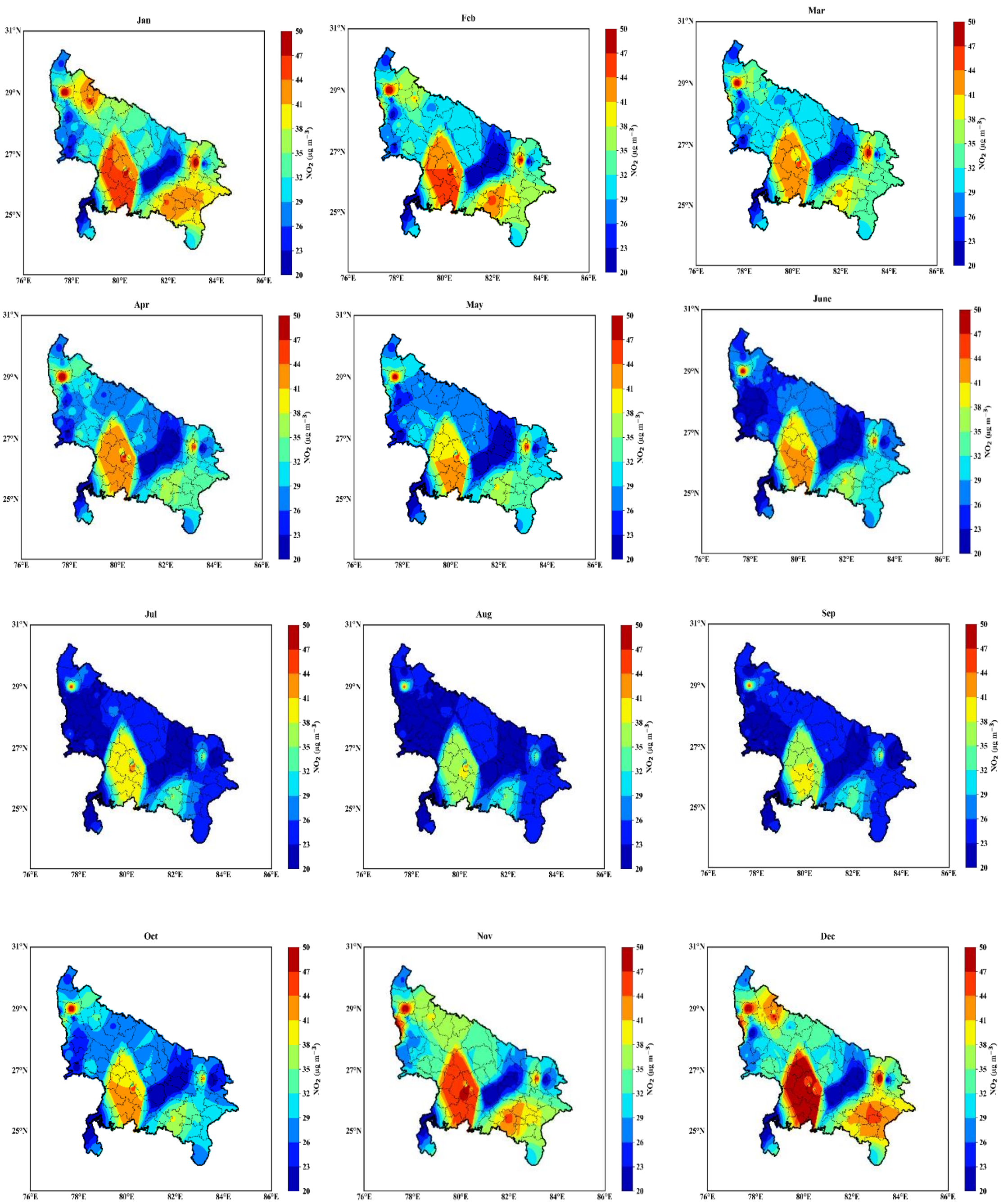

Fig.4 Monthly Spatial variation plot of NO_2 using inverse distance weighted (IDW) technique

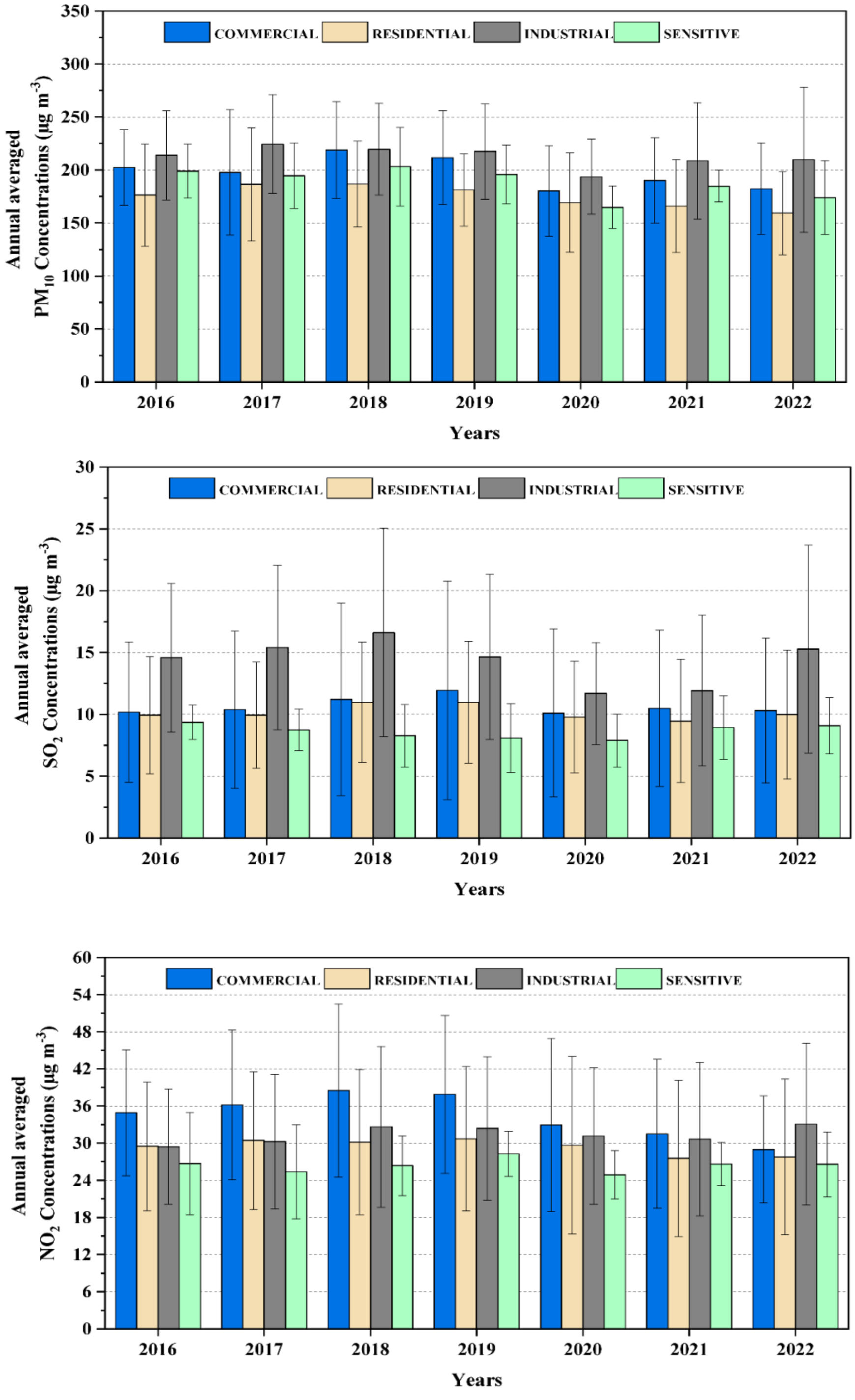

Fig.5 Annual mean concentrations of the pollutants at each site. The vertical error bars denote one standard deviation values.

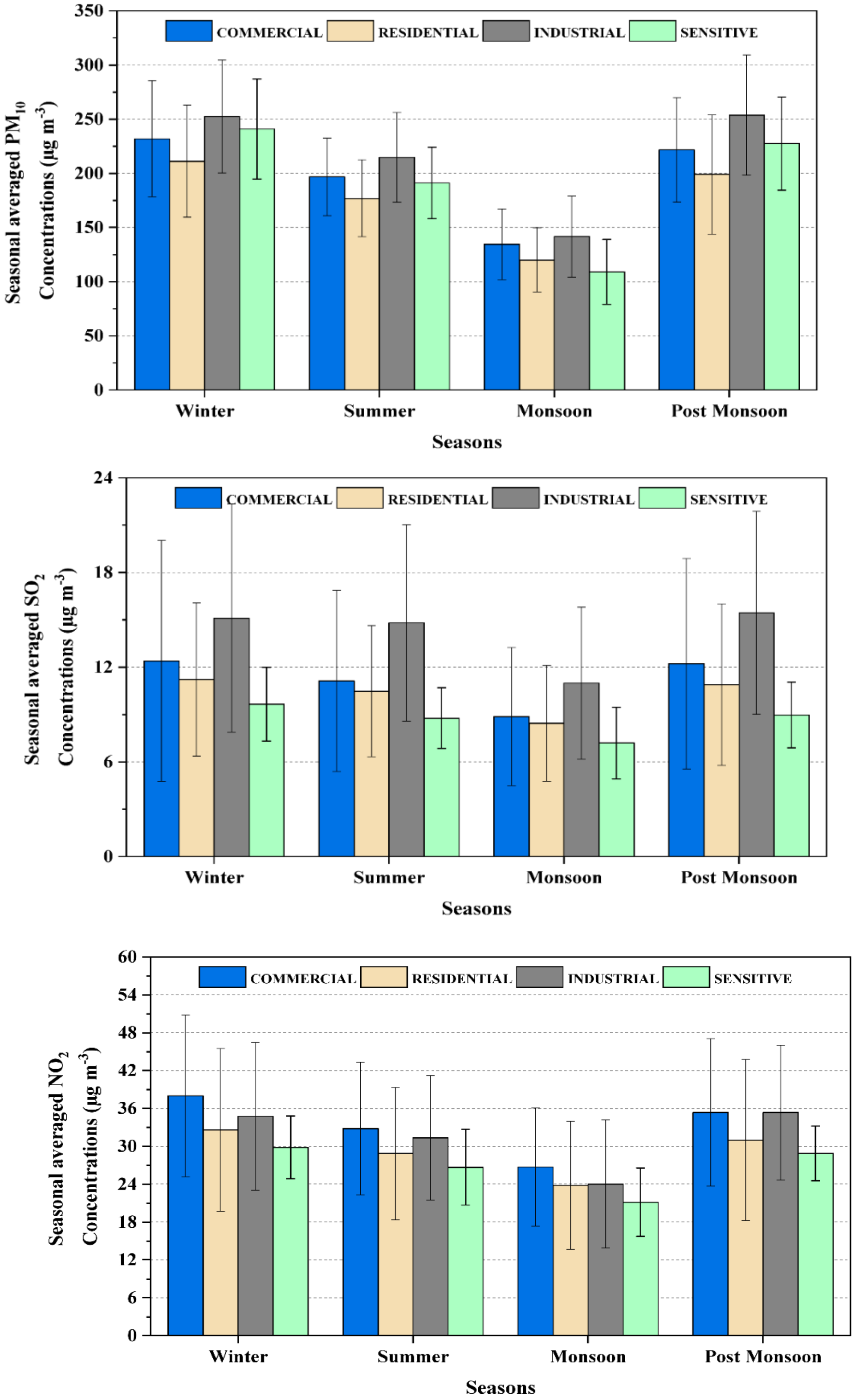

Fig.6 Seasonal mean concentrations of the pollutants at each site. The vertical error bars denote one standard deviation values.

IV. CONCLUSION

From January 2016 to November 2022, the ambient air pollution level in the state of Uttar Pradesh fluctuated. It was found that particle matter (PM) concentrations were higher than those of gaseous pollutants, and that particulate matter was the principal cause of significant air pollution. At all the different location types (commercial, residential, industrial, and sensitive), the annual and seasonal mean PM_{10} concentrations were higher than the CPCB standards limit. Indicating the combined effects of vehicle movement, road dust, industrial sources, emissions from the combustion of fossil fuels, biomass burning, and unfavorable meteorological conditions, the PM_{10}, SO_2, and NO_2 exhibited the highest levels in winter and the lowest level in the monsoon. The amount of air pollutants in the atmosphere is greatly influenced by meteorological conditions. The outcome illustrates that there are considerable seasonal and geographic variations in air pollution. The monsoon had the best air quality out of the four seasons, while the winter had the worst.

The results of this study will be a useful resource for the scientific community, legislators, regulators, and anyone else interested in the effects and mitigation of air pollution over this significant study region because it is a major source of natural dust and is rapidly urbanizing and industrializing.

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