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Assessment of present air quality in Lucknow city and its impact on human health

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ABSTRACT

Introduction: In the current study of specific air pollutants, including levels of NO_2, SO_2, and Particulate Matter (PM_{10}), as well as the Air Quality Index (AQI), has been done on the current state of air quality in Lucknow.

Materials and methods: To assess the ambient air quality in Lucknow, this secondary data was recorded from three key sources: Uttar Pradesh Pollution Control Board (UPPCB), Central Pollution Control Board (CPCB), and Centre for Science and Environment (CSE), from five monitoring stations across various areas of the city, including residential areas like Aliganj and Mahanagar, commercial sectors like Hazratganj and Ansal TC, and the industrial sector of Talkatora.

Results: The results showed that, within a range of 111.24 to 240.89 µg/m^3, the average 24-h PM_{10} concentration was evaluated as 178.09 µg/m^3. The average concentrations of SO_2 and NO_2 over 24 h ranged between 6.96 and 11.50 and 25.28 and 44.41 µg/m^3 respectively. Seasonal fluctuations in PM_{10}, SO_2, and NO_2 were observed, with maximum values recorded in winter at 218.20, 10.32, and 41.43 µg/m^3, and minimum values recorded in monsoon season at 123.47, 7.19, and 28.31 µg/m^3, respectively. Maximum values were recorded in winter at 177 µg/m^3, while lowest values were recorded in monsoon at 111 µg/m^3.

Conclusion: The study focused on monthly and seasonal variations in PM_{10}, SO_2, and NO_2 levels at five representative locations in Lucknow. Key findings revealed that while the annual PM_{10} concentration exceeded National Ambient Air Quality (NAAQ) standards. The SO_2 and NO_2 concentrations remained below recommended levels throughout the year, with lower concentrations observed during the monsoon season compared to summer and winter.

Introduction

Lucknow, a city with a rich history and cultural heritage, is facing a significant environmental challenge due to deteriorating air quality. The city's rapid urbanization, industrialization, and growing population have led to an increase in air pollution, primarily caused by vehicle emissions, industrial activities, and construction operations

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[1]. The levels of Particulate Matter (PM), nitrogen oxides, sulfur dioxide, and other pollutants have exceeded the safe limits, posing serious health risks to the citizens, including respiratory and cardiovascular diseases [2]. According to the World Health Organization (WHO), more than 80% of urban residents are exposed to air quality levels above WHO and National Air Quality (NAAQ) norms. The WHO also reports that 90% of people worldwide live in areas with poor air quality. The effects of air pollution on human health are severe, with exposure to Particulate Matter (PM) linked to respiratory problems, lung tissue damage, and even cancer [3].

The transportation sector is a significant contributor to air pollution in Lucknow, with a large number of deteriorating diesel and petrol vehicles, as well as ineffective traffic control policies. Industrial activities, including medium-sized and small-scale companies, and construction operations, such as the building of highways and flyovers, also contribute to air pollution [4, 5]. The city's air quality is expected to deteriorate further due to the rapid growth in population, industry, transportation, and development activities [6]. Therefore, there is a need for extensive public awareness campaigns, implementation of effective traffic control policies, and enforcement of pollution control measures to mitigate the impact of air pollution on human health and the environment [7].

Initial information on the sources of emissions, their locations, and their strengths is lacking in Lucknow and similar places. Considering the lack of major industries, the number of vehicles in the city is growing quickly; in Lucknow, for instance, around 100,000 new cars are introduced each year. In 2011, the number of registered automobiles in Lucknow reached 1.2 million, according to the Road Transport Office (CSIR-IITR 2012).

The majority of automobile pollution in Lucknow comes from fossil fuel-powered vehicles, such as those that run on petrol or diesel. These emissions are composed of a complex mixture of pollutants, some of which are particulate matter, nitrogen oxides, sulphur dioxide, carbon monoxide, volatile organic compounds, and greenhouse gases, which include carbon dioxide. Several studies show that vehicle emissions dramatically increase ambient air pollution levels in Lucknow, aggravating health problems like respiratory and cardiovascular disorders as well as early death in some populations. Due to urbanisation and industrialization, there has been a substantial rise in vehicle traffic in recent decades, which has raised worries about vehicle emissions globally. The Indian state of Uttar Pradesh's capital, Lucknow, has become used to overcoming this challenge. Due to a growth in cars on the roads of the town and a continuously growing population, Lucknow's air quality is fast deteriorating, threatening the health of its citizens [8].

One of the primary causes of air pollution in Lucknow is the transportation sector [9]. A large number of deteriorating diesel and petrol vehicles, as well as ineffective traffic control policies, are used in the city, which contribute significantly to air pollution [10]. In addition, there are several significant, Air pollution is also caused by medium-sized and small-scale companies located at Talkatora regions in four officially designated industrial sites in and around Lucknow city: which also contribute to air pollution [11]. Furthermore, there are also over 255 functional brick kilns located throughout the city. Nonetheless, lower PM_{10} concentrations in industrial zones indicate that pollution control authorities are paying greater attention to these areas have made comparable observations and recommendations [12].

The Indian government's Smart City Yojana has brought about extensive construction operations in Lucknow, which has increased the city's air pollution. Therefore, it is essential to adopt sustainable and environmentally friendly practices in urban planning and development to reduce the impact of air pollution on human health and the environment [13] .

According to a number of studies, automobiles

that burn fossil fuels create common air pollutants including $PM_{2.5}$, PM_{10}, O_2, NOx, etc., which build up in the ambient air and negatively impact living things in many ways. According to recent studies, the RSPM in Lucknow's metropolitan areas is higher above the WHO and NAAQ (P100) guidelines. excessive PM concentration have numerous serious negative health repercussions on people. The chemical makeup of PM, its size, shape, frequency, and length of exposure all affect how it affects human health. The ambient air standard in India is restricted to two specific PM sizes, such as $PM_{2.5}$ and PM_{10}. Human sickness and mortality are caused by the high concentrations of these PMs in the air.

The purpose of the current study is to monitor the current state of Lucknow's air quality and its detrimental effects on human health. In the current year (2022–2023), secondary data were gathered for this purpose from five representative monitoring sites situated in various Lucknow city localities.

Materials and methods

Study area

The largest ancient city in Uttar Pradesh, Lucknow is located in northern India between latitudes 26°85′ N and longitude 80°95′ E. People refer to it as the "City of Nawabs" informally. Similar to other large cities, Lucknow is reported to have unhealthy and poor air quality. Lucknow is ranked 11th among the top 15 most polluted cities in the world by the World Air Quality Survey (IQ Air, 2019). In January 2019, the city was ranked 9th out of the top 10 most polluted cities in the world by another survey [6].

For the current study, secondary data has been procured from the Uttar Pradesh Pollution Control Board (UPPCB), the Central Pollution Control Board (CPCB), and the Centre for Science and Environment (CSE) for the assessment of Ambient Air Quality (AQI) in Lucknow city. The recorded data (from the UPPCB Annual Report, 2022–2023) against five monitoring stations—two residential (Mahanager and Aliganj), two commercial (Hazratganj and Ansal T. C.), and one industrial (Talkatora) area have been illustrated in Fig. 1 these locations have been employed to assess the monthly average concentration of ambient air pollution in Lucknow. The average value was then compared to the specified NAAQ Standards. Seasonal changes were also noted in the AQI and its three representative components, NO_2, SO_2, and PM_{10}.

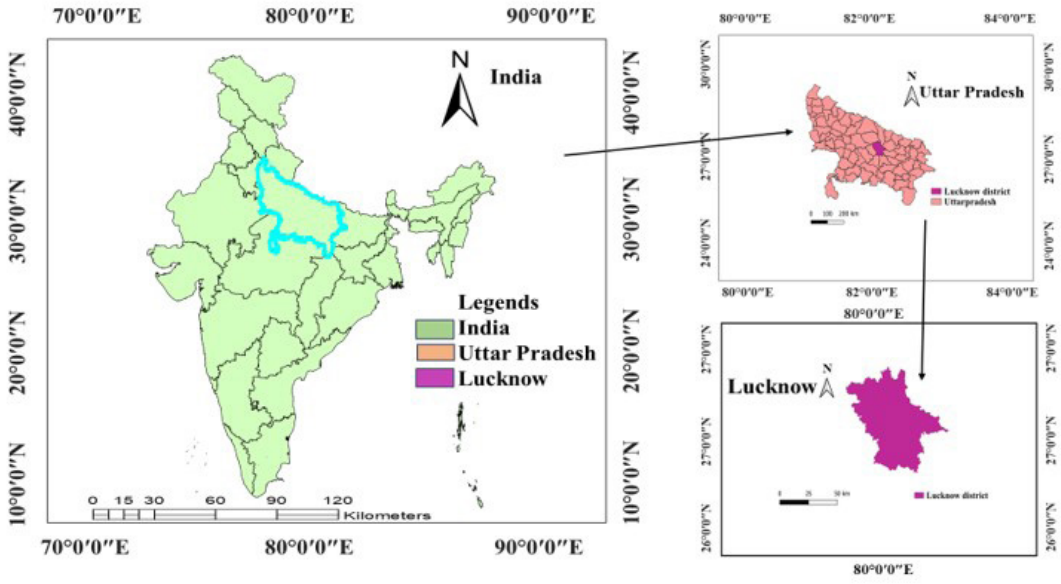

Fig. 1. Luckdown city study area map with all five monitoring locations

Data collection

At all five monitoring sites, the daily average concentrations of SO_2, NO_2, and RSPM (particle size less than 10 mm) have been recorded as part of the SAMP (State Ambient Air Monitoring Programme), which was governed and overseen by the CPCB (Central Pollution Control Board). The samples are gathered through an RDS or respirable dust sampler. Sampling has been conducted twice a week and the samples were collected and subsequently examined for various pollutants utilizing the normal operating methods of the CPCB.

According to the Annual Report UPPCB, 2022–2023, the average monthly concentration of ambient air pollution in Lucknow was evaluated using data collected from five monitoring stations: two residential (Mahanager and Aliganj), two commercial (Hazratganj and Ansal T. C.), and one industrial (Talkatora) area. The average value was compared to the specified NAAQ Standards. Seasonal changes were also noted in the AQI and its three representative components, which are NO_2, PM_{10}, and SO_2.

Data analysis

We use Descriptive statistics in this research article for summarizing and describing the features of a dataset. These statistics provide insights into the central tendency, variability, and distribution of the data. Standard measures of descriptive statistics include:

- Measures of Central Tendency

The arithmetic average of a set of values, calculated by summing all values and dividing by the number of observations.

- Measures of Dispersion

The square root of the variance, providing a measure of the average distance of data points from the mean.

The metrics used to determine data characteristics at different observational sites were annual averages, monthly averages, 24-h averages, exceedance counts, standard deviations and wind rose. Spatio-temporal analysis of air pollutants reveal short term, seasonal and long-term variations. Annual averages indicate the representative long-term effect of the air pollutants. Air quality guidelines based on annual averages of criteria pollutants with averaging time of one year is based on evidence for the lowest pollutant level associated with observable chronic and mostly irreversible adverse effects based on the properties of air pollutants in different meteorological and emission profiles. Similarly, air quality guidelines on short-term 24-h averages of air pollutants with averaging times of 24-h is based on evidence for the lowest pollutant level associated with observable acute adverse effects during temporary exposure. A process to understand the status of air quality in a region is to consider whether the threshold values long-term (annual averages) and short-term (24-h averages) of air pollutants as mandated by CPCB are met and if not to what extent the standards are violated. This will provide an idea about the degree to which the given regions have met their air quality objectives [9].

AQI calculation

Indian AQI range & probable impacts (From CPCB)

0-50: This range defines air quality as good as it shows minimal or no impact on health.

51-100: This is a satisfactory air quality range and it can show effects such as breathing difficulty in sensitive groups.

101-200: The range shows moderate air quality with impacts such as breathing discomfort for children and elderly people, and people already suffering from lung disorders and heart disease.

201-300: AQI falling in this range communicates that the air quality is poor and shows health effects on people when exposed for the long term.

People already suffering from heart diseases can experience discomfort from short exposure.

301-400: This range shows very poor air quality and causes respiratory illness for a longer duration of exposure.

401-500: This is the severe range of AQI causing health impacts to normal and diseased people. It also causes severe health impacts on sensitive groups.

For PM_{10}

=IF(B2<=50, (B2-0)*(50-0)/(50-0)+0, IF(B2<=100, (B2-51)*(100-51)/(100-51)+51, IF(B2<=250, (B2-101)*(200-101)/(250-101)+101, IF(B2<=350, (B2-251)*(300-201)/(350-251)+201, IF(B2<=430, (B2-351)*(400-301)/(430-351)+301,(B2-431)*(500-401)/(600-431)+401)))))

For $PM_{2.5}$

=IF(A2<=30, (A2-0)*(50-0)/(30-0)+0, IF(A2<=60,(A2-31)*(100-51)/(60-31)+51, IF(A2<=90,(A2-61)*(200-101)/(90-61)+101, IF(A2<=120,(A2-91)*(300-201)/(120-91)+201, IF(A2<=250,(A2-121)*(400-301)/(250-121)+301, (A2-251)*(500-401)/(500-251)+401)))))

For NO_2

=IF(G2<=40, (G2-0)*(50-0)/(40-0)+0,IF(G2<=80, (G2-41)*(100-51)/(80-41)+51,IF(G2<=380, (G2-81)*(200-101)/(380-81)+101,IF(G2<=800, (G2-381)*(300-201)/(800-381)+201,IF(G2<=1600, (G2-801)*(400-301)/(1600-801)+301,(G2-1601)*(500-401)/(3000-1601)+401)))))

For SO_2

=IF(G2<=40, (G2-0)*(50-0)/(40-0)+0,IF(G2<=80, (G2-41)*(100-51)/(80-41)+51,IF(G2<=380, (G2-81)*(200-101)/(380-81)+101,IF(G2<=800, (G2-381)*(300-201)/(800-381)+201,IF(G2<=1600, (G2-801)*(400-301)/(1600-801)+301,(G2-1601)*(500-401)/(3000-1601)+401)))))

Calculation of standard deviation

$$\sigma = \sqrt{(\Sigma(x - \mu)^2 / N)} \quad (1)$$

Where:

σ = Standard Deviation

μ = Mean of the numbers

N = Total number of data points

Results and discussion

Particulate matters (PM_{10})

Table 1 Mahanagar, Aliganj, Hazratganj, Ansal T.C., and Talkatora recorded 24-h mean PM_{10} concentrations of 165.72, 168.69, 200.27, 189.77, and 176.91 $\mu g/m^3$, respectively. Maximum reported values were 200.27 $\mu g\ m^{-3}$ in the commercial area of Hazratganj, while minimum values were 165.72 $\mu g/m^3$ in the residential area of Mahanagar. Monthly variations in PM_{10} concentrations in Lucknow city's various regions are displayed in Fig. 2.

Residential, commercial, and industrial areas were also shown in Fig. 3 to have seasonal fluctuations in PM_{10} concentrations. In a residential neighbourhood, the average 24-h concentrations of PM_{10} were recorded as 186.14, 111.50, and 208.69 $\mu g/m^3$ throughout the summer months of March through June, July through October, and November through December, respectively. Similarly, during summer, monsoon, and winter, PM_{10} readings in commercial areas were 218.42, 155.46, and 220.01 $\mu g/m^3$, whereas in industrial regions they were 203.78, 103.45, and 225.92 $\mu g/m^3$, respectively. Standard deviation for total mean of PM_{10} is 38.3962.

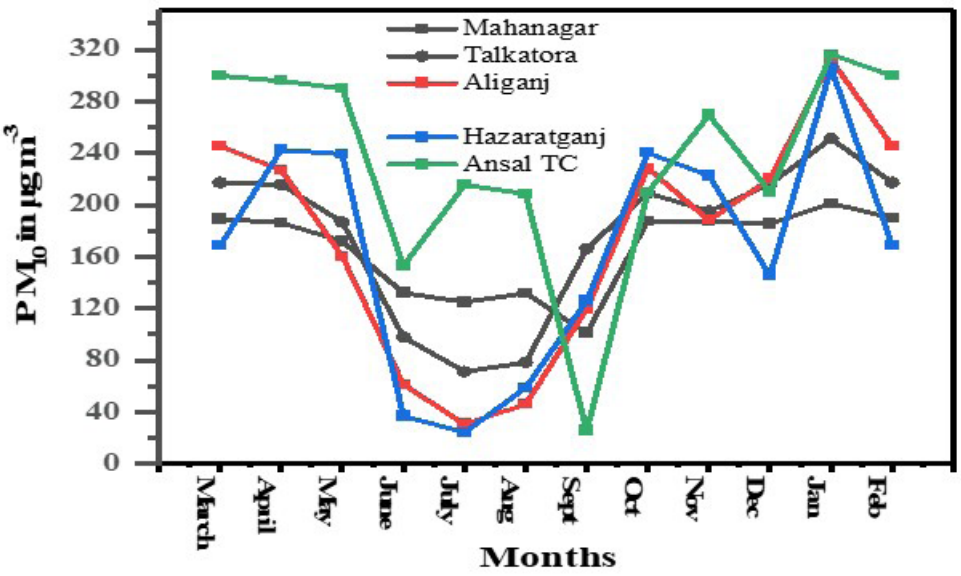

Fig. 2. Monthly variations in PM_{10} concentrations in Lucknow city's regions

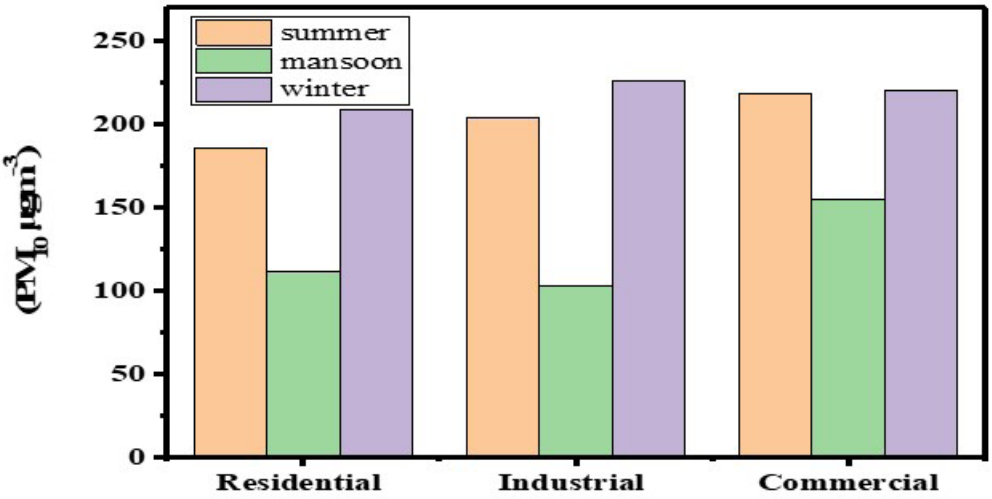

Fig. 3. Seasonal changes in PM_{10} concentrations in Lucknow city's commenrcial, industrial, and residential areas

Table 1. The average monthly concentrations of PM_{10} ($\mu g/m^3$) in several locations in Lucknow city (2022-2023)

Locations	Type	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
Mahanagar	R	189.33	186.3	171.9	132	124.9	131.9	100.97	187.54	187.3	185.44	201.27	189.83	165.72
Aliganj	R	214.3	202.7	160.8	98.47	79.2	88.9	135.13	203.56	178.3	198.33	256.25	214.3	168.69
Hazaratganj	C	202.12	233.95	232.56	145.82	140.39	155.14	184	232.9	225.44	192.33	261.19	202.12	200.27
Ansal TC	C	218.45	216.8	214.3	155.6	182.4	179.4	100.97	179.84	205.5	180	225.61	218.45	189.77
Talkatora	I	217.33	215.7	186.9	97.94	71.2	78.3	166.38	209.15	195.2	216.2	251.28	217.33	176.91
Average		165.8	211.09	193	125.87	119.67	123.1	137.49	202.59	198.34	194.46	239.12	200.83	180.27

Sulphur dioxide (SO_2)

Average monthly concentrations of SO_2 (µg/m^3) in several locations in Lucknow city are shown in Table 2. Mahanagar, Aliganj, Hazratganj, Ansal T.C., and Talkatora had mean SO_2 concentrations of 8.26, 8.14, 8.95, 8.52, and 8.74 µgm^{-3} over 24 h. The highest reported value was 8.95 µgm^{-3} in the commercial area of Hazratganj, while the minimum was 8.14 µg/m^3 in the residential area of Aliganj. Variation in SO_2 concentration for different locations throughout the study period is displayed in Fig. 4.

Residential, commercial, and industrial regions also documented seasonal fluctuations in SO_2 concentrations shown in Fig. 5. In a residential neighbourhood, the average 24-h concentrations of SO_2 were recorded as 8.42, 6.67, and 9.48 µg/m^3 throughout the summer months of March through June, July through October, and November through December, respectively. Similarly, throughout summer, monsoon, and winter, SO_2 levels in commercial areas were reported at 8.22, 7.59, and 10.84 µg/m^3, whereas in industrial sectors they were 8.96, 7.31, and 10.64 µg/m^3, respectively. In winter, the highest measured SO_2 concentration in the commercial sector was 10.84 µgm^{-3}, whereas in a residential area, the lowest concentration was 6.67 µg/m^3 during the monsoon. Each SO_2 result was found to be lower than the recommended WHO guidelines 20 µg/m^3 and NAAQ Standard 80 µgm^{-3}. Standard deviation for total mean of SO_2 is 2.4613.

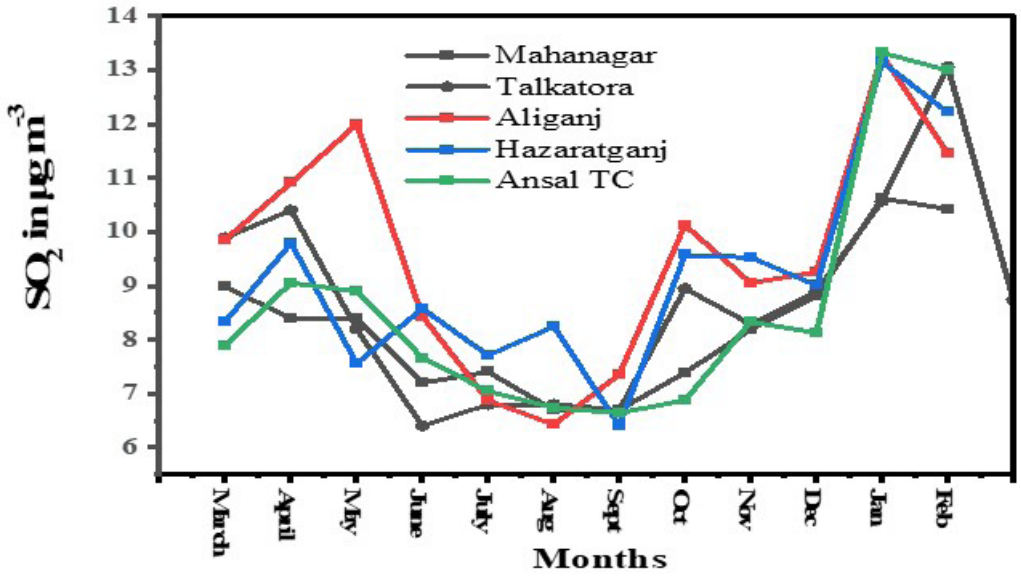

Fig. 4. Monthly variations in SO_2 concentrations in Lucknow city's various regions

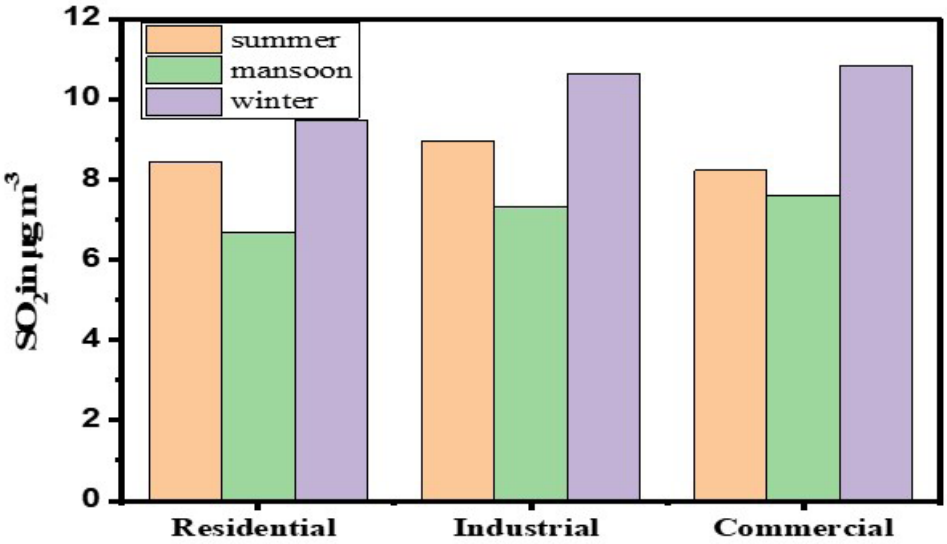

Fig. 5. Seasonal changes in SO_2 concentrations in Lucknow city's commercial, industrial, and residential areas

Table 2. Average monthly concentrations of SO_2 (µg/m^3) in several locations Lucknow city (2022-2023)

Location	Type	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
Mahanagar	R	8.98	8.4	8.4	7.2	7.4	6.7	6.7	7.39	8.19	8.81	10.62	10.42	8.26
Aliganj	R	8.32	9	9.7	7.4	6.39	6.1	6.7	8.49	7.8	7.93	10.53	9.35	8.14
Hazaratganj	C	8.17	9.54	7.44	8.4	7.58	8.08	6.36	9.33	9.29	8.8	12.7	11.82	8.95
Ansal TC	C	8.05	8.8	8.7	7.9	7.5	7.3	7.24	7.39	8.33	8.2	11.56	11.35	8.52
Talkatora	I	9.89	10.4	8.2	6.4	6.8	6.8	6.7	8.95	8.29	8.9	10.57	13.06	8.74
Average		8.68	11.02	8.49	7.46	7.13	6.99	6.6	8.31	8.38	8.52	11.2	11.2	5.52

Oxides of nitrogen (NOx)

Table 3 shows the monthly average concentration of NO_2 (µg/m^3) in several locations. Mahanagar, Aliganj, Hazratganj, Ansal T.C., and Talkatora had 24-h mean concentrations of NO_2 of 34.53, 34.43, 34.53, 32.84, and 35.39 µg/m^3, respectively. A maximum of 35.39 µg/m^3 was reported in Talkatora, an industrial region, while a minimum of 32.84 µg/m^3 was recorded in Hazratganj. (Business area). Fig. 6 shows monthly variation in average concentration in Lucknow city.

Residential, commercial, and industrial areas were also shown in Fig. 7 to exhibit seasonal fluctuations in NO_2 concentrations. In a residential neighbourhood, the average 24-h concentrations of NO_2 were recorded as follows: 32.50, 26.28, and 41.25 µg/m^3 for the summer months of March through June, July through October, and November through December, respectively. Comparably, NO_2 readings in commercial areas were 43.09, 26.59, and 41.47 µg/m^3, whereas in industrial areas they were 33.26, 32.06, and 41.57 µg/m^3, respectively, during the summer,

monsoon, and winter. In winter, the highest observed NO_2 concentration in an industrial area was 41.57 µg/m^3, whereas in a residential area, the lowest concentration was 26.28 µg/m^3 during the monsoon. Every NO_2 result was found to be lower than the recommended NAAQ Standard of 80 µg/m^3. Standard deviation for total mean of NO_2 is 7.044.

Table 3. Average monthly concentrations of NO_2 (µg/m^3) in several locations Lucknow city (2022-2023)

Location	Type	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
Mahanagar	R	36.9	35.7	31.1	31	24.1	25.6	29.5	29.54	41.12	44.43	45.97	39.49	34.53
Aliganj	R	36.96	30	26.7	31.7	23.36	22.6	23.3	32.69	38.55	43.42	41.67	40.76	34.43
Hazaratganj	C	37.35	31.9	30.2	29	23.38	23.17	27.8	37.76	42.84	41.62	48.01	41.46	34.53
Ansal TC	C	43.57	28.9	32.4	31.4	21.48	24.7	24.91	29.54	35.71	40.66	43.18	37.64	32.84
Talkatora	I	34.36	33.9	33.7	32.9	30.15	28	30.6	39.52	40.88	38.39	43.81	40.76	35.39
Average		44.75	32.08	30.8	31.2	24.49	24.73	27.22	33.81	39.82	41.7	44.52	40.02	34.34

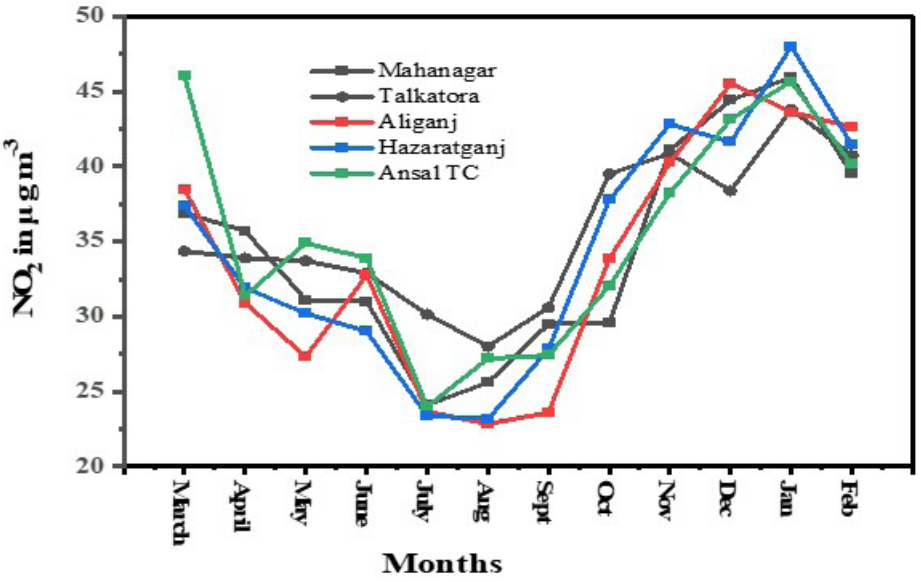

Fig. 6. Monthly variations in NO_2 concentrations in Lucknow city's various regions

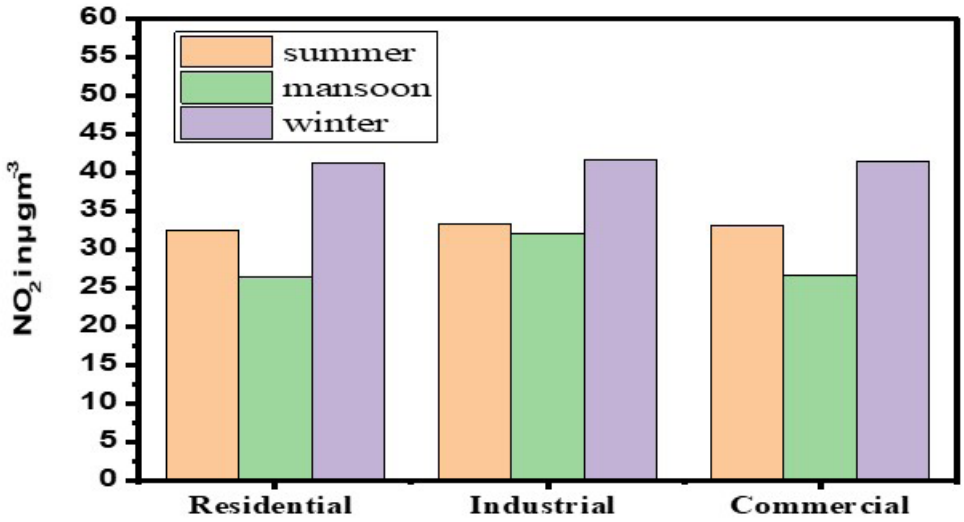

Fig. 7. Seasonal changes in NO_2 concentrations in Lucknow city's commercial, industrial, and residential areas

Ambient air quality (AQI)

Table 4 shows the Average monthly concentrations of AQI in several locations in Lucknow city. Mahanagar, Aliganj, Hazratganj, Ansal T.C., and Talkatora recorded 24-h mean AQI levels of 142.68, 162.53, 193, 158.44, and 143.92, respectively. There was a minimum of 142.68 in Mahanagar, a residential area, and a high of 193 in Hazratganj, a commercial sector. Fig. 8 shows Monthly variations in AQI concentrations in Lucknow city's various regions.

Residential, commercial, and industrial areas were also shown in Fig. 9 to exhibit seasonal fluctuations in AQI levels. In residential areas, the average 24-h AQI level was recorded at 155.8, 105.3, and 171.5 during the summer months of March through June, July through October, and November through December, respectively. Similarly, throughout the summer, monsoon, and winter, the AQI in commercial regions was measured as 179,136.9 and 182.5, and in industrial areas, as 169, 92.5, and 176.7, respectively. In commercial areas, the highest recorded AQI readings were 182.5 during the winter, while in industrial areas, the lowest levels were 92.5 during the monsoon. Every AQI result was found to be higher than the recommended NAAQ Standards (0-50).

Figs. 10a, 10b, 10c, and 10d show the area-wise fluctuation in the concentrations of pollutants PM_{10}, SO_2, NO_2, and AQI, respectively. In industrial and residential areas, the highest and minimum concentrations of PM_{10} are 251.28 and 228.76 µg/m^3, respectively. The concentration of SO_2 in residential and industrial areas is 10.57 and 13.06 µg m^{-3}, respectively. In residential and commercial areas, the concentration of NO_2 is 43.82 and 45.59 µg/m^3, respectively. The industrial and residential areas had the highest and lowest concentrations of AQI, respectively, at 201 and 180. Standard deviation for total mean of AQI is 27.3778.

Table 4. Average monthly concentrations of AQI in several locations in Lucknow city (2022-2023)

Location	Type	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
Mahanagar	R	160	158	141	158	121	117	109	101	158	161.23	168	165	142.68
Aliganj	R	176	168	133	152	98	79	87	123	169	168.44	206	162	162.53
Hazaratganj	C	168	189	188	184	130	127	137	156	188	158.11	211	196	192.84
Ansal TC	C	179	178	176	170	137	155	153	101	153	152.33	184	163	158.44
Talkatora	I	178	177	158	163	98	71	78	123	173	154.11	201	156	143.92
Average		172.2	174	159.2	165.4	116.8	109.8	112.8	120.8	168.2	158.84	194	168.4	160.08

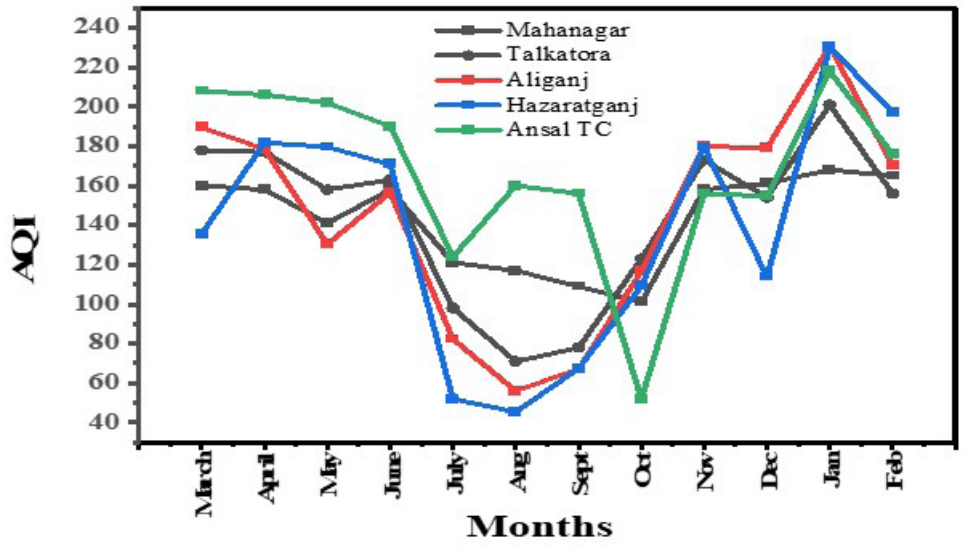

Fig. 8. Monthly variations in AQI concentrations in Lucknow city's various regions

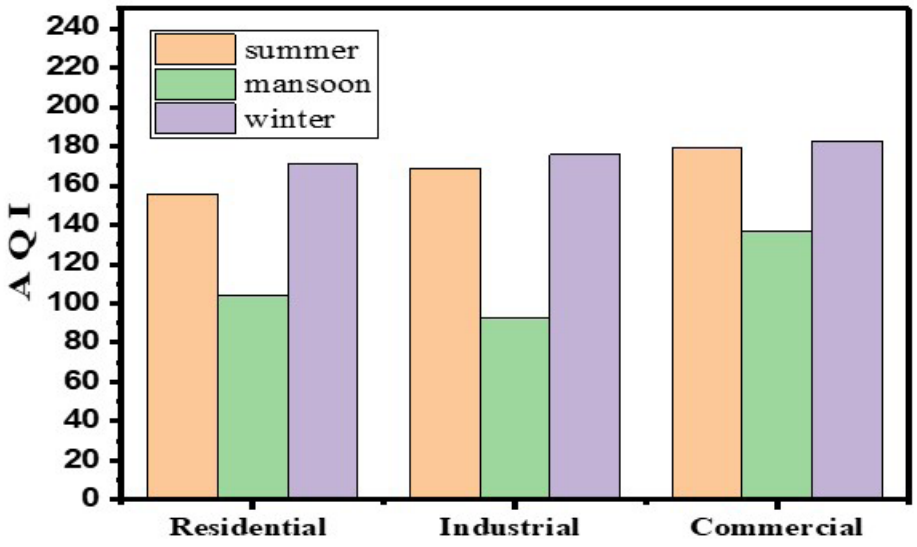

Fig. 9. Seasonal changes in AQI concentrations in Lucknow city's commercial, industrial, and residential areas

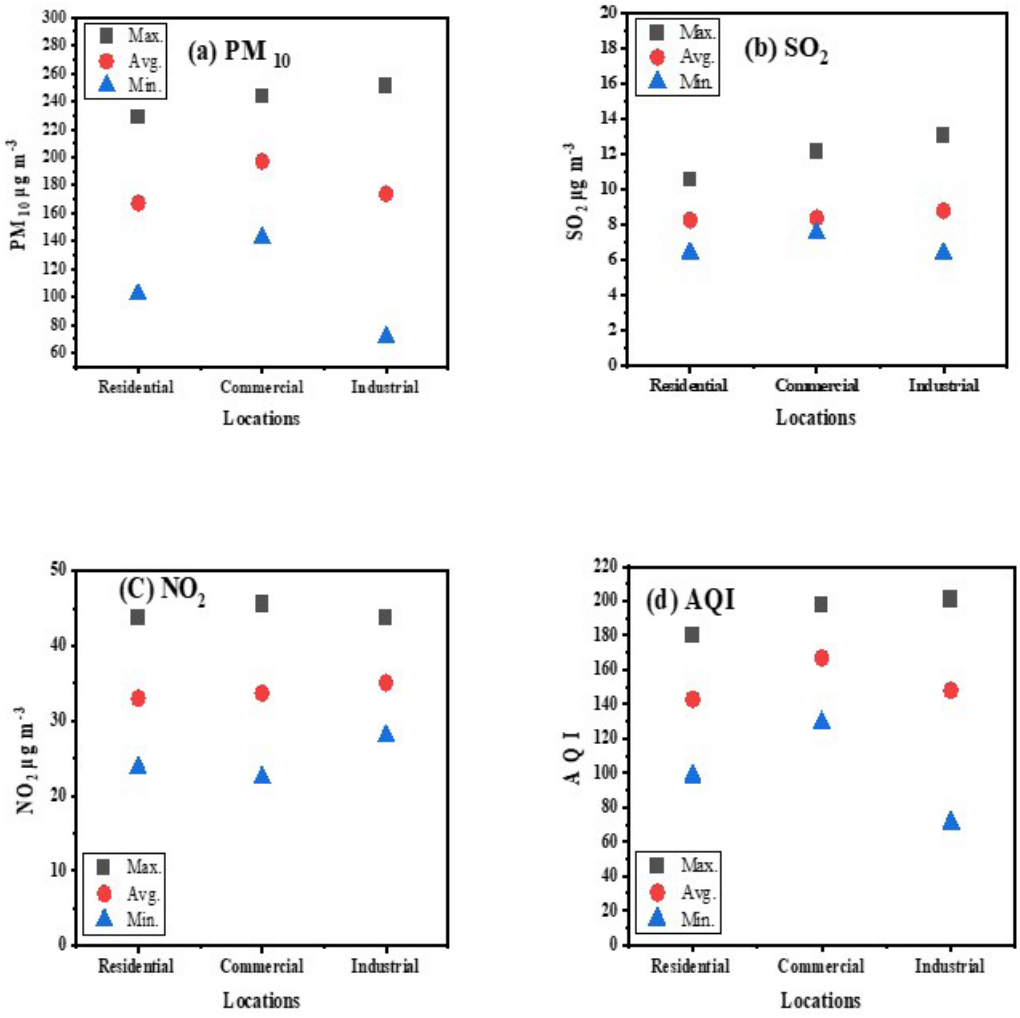

Fig. 10. Area-wise fluctuation in the concentrations of pollutants PM_{10}, SO_2, NO_2, and AQI

According to the current study, Lucknow's PM concentrations were higher throughout the year 2023 than the recommended levels set by the NAAQS and WHO. It can be ascribed to the city of Lucknow's rapid industrialization, urbanization, and development of a number of beneficial projects, such as the building of flyovers, roads, highways, multi-story residences, and shopping centres.

The growing use of fossil fuels by power-heavy industries, transportation, construction, vehicle emissions, and biomass combustion are all responsible for the elevated PM concentrations in megacities. There are notable seasonal fluctuations in PM concentrations in Lucknow city's urban areas as well; wintertime is said to have the highest concentrations, while the monsoon season has the lowest. Wintertime emissions from fossil fuels, burning of agricultural climate conditions, and burning of biomass for heating are all associated with increased concentrations of PM_{10}, according to

the current study. The buildup of PM particles in the air may also be facilitated by unfavourable winter weather conditions, such as high humidity, slow winds, and a lower boundary layer height[14]. PM concentrations were found to be lowest during the monsoon season, which is explained by the rainfall, which causes the majority of PM to wash from the air and land on the ground. Another explanation could be the notable drop in PM concentrations during the monsoon season as a result of construction work being halted at this time. Residential regions had the lowest average annual concentrations of PM_{10}, whereas business sectors had the highest. According to earlier research, industrial districts had the highest concentration, followed by commercial and residential sectors. Increased vehicle activity and inadequate traffic management systems are to blame for the higher PM_{10} in commercial districts [15]. Yet lower PM concentrations in industrial zones indicate that pollution control authorities are paying greater attention to these locations.

According to the current investigation, Lucknow city had higher PM_{10} concentrations from 2022 to 2023 above the recommended levels found in the NAAQS and WHO guidelines. It might be ascribed to the fast urbanisation and industrialization as well as other beneficial activities like building flyovers. Around Lucknow, there are developments in shopping centres, highways, and multi-storey apartments. The PM concentrations in Lucknow's urban areas also exhibit notable seasonal fluctuations, with winter being the largest and monsoon being the lowest. The current study reports a greater concentration of PM_{10} in the winter, which is consistent with large emissions from burning fossil fuels, agricultural leftovers, winter heating with biomass burning, and meteorological factors. Winter's unfavourable weather, which includes high humidity, sluggish winds, and a lower boundary layer height, may further encourage the buildup of PM particles in the atmosphere[16].

The current study's findings of lower SO_2 and NO_2 concentrations from the recommended standards values (60 µg/m³) of NAAQ and WHO guidelines are consistent with those of [17] Similar observations were previously observed in the city of Lucknow. February and January saw the highest monthly average concentrations of SO_2 and NO_2, respectively, while July saw the lowest concentrations of both. Regarding seasonal fluctuations, the concentrations of SO_2 and NO_2 were found to be lowest in residential areas during the monsoon season and to be highest in industrial areas during the winter. It was discovered that the current results were comparable to those of

According to reports, industrial districts had the highest concentrations of SO_2 and NO during the winter, while residential areas had the lowest concentrations during the monsoon. The excessive burning of fossil fuels like coal and oil in industries, traffic jams, burning of agricultural residues, burning of biomass for home heating to prevent cooling, and uncontrolled use of firecrackers during festivals like Dashhara and Diwali, as well as the celebration of the New Year, may all contribute to the average increase in SO_2 and NO_2 in the winter. Additionally, these wintertime weather patterns contribute to the buildup of contaminants in the environment. Because rainfall removes pollutants from the air, the lowest concentrations of SO_2 and NO_2 were recorded during the monsoon season. [17]

The monsoon season saw the lowest recorded PM_{10} concentrations, which can be related to the rainfall, which causes the majority of the PM to evaporate from the atmosphere and descend to the ground. The other explanation could be a notable drop in PM concentrations during the monsoon season as a result of a construction activity halt during this time [18].

Wintertime concentrations of SO_2 and NO_2 may be higher than in other seasons because of

increased biomass burning and unfavourable weather. Certain individuals have observed a connection between elevated gaseous pollutants and a rise in hospital admissions, as the most vulnerable populations, such as children, the elderly, and Pregnant women are particularly impacted. According to the WHO and NAAQS norms, Lucknow City's AQI increased during the evaluation year 2022–2023. It was said to be very bad in the winter and moderately unhealthy in the monsoon. Wintertime extreme harmful AQI levels may be caused by changing weather patterns, decomposing biomass, a rise in building activity, etc. On the other hand, lower AQI during the monsoon season compared to winter and summer may be caused by fewer construction projects and less vehicle exhaust [19].

Health effects associated with the air pollution

Currently, air pollution is thought to be the biggest hazard to environmental health worldwide. Around 7 million people worldwide pass away as a result of air pollution each year. Poor air quality can lead to or worsen a variety of illnesses, including cancer, asthma, cardiovascular disease, and pulmonary conditions. The International Agency for Research on Cancer states that one of the main causes of cancer in humans is outdoor particulate matter that is linked to metal residues and other carcinogenic chemicals [20].

According to a recent estimate by the World Health Organisation, exposure to air pollution poses a significant risk for major non-communicable diseases. It is the environmental factor that contributes most to the burden of disease. Dust, soot, and liquid droplets are examples of the tiny airborne particles that make up Particulate Matter (PM). The bulk of particulate matter (PM) in metropolitan areas is produced indirectly by gases and vapours and directly by the burning of fossil fuels by power plants, automobiles, non-road equipment, industrial emissions, and construction activities [21].

Nitrogen Oxide (NOx) is a mixture of NO and NO_2, usually released by motor vehicles and other pollutants connected to traffic. Its high concentration near roads and highways can increase the risk of bronchitis, asthma, and heart disease. A high NO_2 concentration results in lung congestion and coughing.symptoms such as dyspnea, headaches, throat, eye, and chest irritation, and chest pain [22].

Similar to this, burning fossil fuels that include sulphur, such as coal, extracting and smelting metal, operating ship engines, heavy machinery, diesel generators, etc., all release sulphur dioxide. Because of its increased concentration in the air, it irritates the eyes, aggravates asthma, makes people more vulnerable to respiratory infections and has an effect on the heart [14]. In addition, during rainfall, SO_2 and NO_2 react with water to generate nitric acid and sulfuric acid, respectively. Acid rain, a term used to describe the presence of these acids in rainwater, is mostly to blame for deforestation [1] .

Lucknow is characterised by high levels of air pollution, especially in the winter when the atmospheric conditions intensify the pollution. The residents have a greater chance of being exposed to hazardous pollutants if they reside near busy roads, industries, or construction sites. Particularly susceptible to the negative effects of Lucknow's air pollution are children, the elderly, and persons with underlying medical conditions. Extended exposure to air pollution may raise the burden of respiratory disorders, cardiovascular problems, and early mortality in metropolitan areas [23].

Stronger industry and vehicle emission regulations, the creation of greener technology, the implementation of transportation projects, and education efforts aimed at reducing pollution sources and preserving public health are just a few of the broad approaches required to combat Lucknow's air pollution [20].

Table 5. Human Health Impacts of pollution in the air

Pollutants	Impacts on the health of humans
Sulphur Dioxide	Negatively impact lung function
Particulate Matter	Respiratory system Irritating lung tissue and causing long-term disorders. Including carcinogenic Trace substance, Immune system.
Hydrocarbons	Potential to cause cancer
Carbon Monoxide	Cardiovascular disease, Fetuses, Anemic, Nervous system malfunction, Perception and assessment, Headaches and Nausea, Personal Comfort and Productivity Retardation.
Nitrogen Oxides	Lung function impairment and pulmonary disorders irritations of the throat, nose, and eyes.

Conclusion

This study aimed to evaluate the present condition of the air quality in Lucknow. This was carried out by gathering secondary data from the Uttar Pradesh Pollution Control Board website and evaluating monthly and seasonal variations in PM_{10}, SO_2, and NO_2 at five representative locations. The findings of the study showed that although the annual concentration of PM_{10} is higher than that recommended by the WHO and NAAQ Standards, it is still lower than in prior years. Its wintertime peak concentration was recorded in January 2023, while its minimum was recorded

in August 2022. Throughout the research year, SO_2 and NO_2 concentrations were found to be below the recommended levels every month. It was discovered that the concentrations of SO_2 and NO_2 were lower during the monsoon season than in summer and winter. The city of Lucknow is a serious cause for concern. Therefore, in collaboration with social welfare organisations and educational institutions, pollution control board authorities must organise a large-scale camping and awareness campaign for the general public living in megacities.

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Competing interests

All contributors declare that no relationships of interest occur.

Author's contributions

Vipin Kumar: Data curation, Investigation, Methodology, Writing – original draft, Writing – review and editing, Validation, Software investigation. Prabhat Kumar Patel: Supervision, Validation, Visualization, Writing – review and editing, conceptualization.

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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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