

## Comparative study of air quality index of two metropolitan cities (Lucknow and Kanpur) in Year-2023

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### Abstract

In 2023, it was declared that the Bangladesh at the first place and then Pakistan, after which the most polluted country is India at the third place. Polluted air is becoming a very considerate issue all over the world. This study is all about comparing the air quality of two metro cities, Lucknow and Kanpur during (November 2022- October,2023) by monitoring and assessment of few selective basic AQI air pollutants namely Particulate Matter (PM<sub>10</sub>), Sulphur dioxide (SO<sub>2</sub>), Nitrogen dioxide (NO<sub>2</sub>) concentrations and also AQI of Lucknow and Kanpur at 5 representative locations categorized as residential, commercial and industrial areas. Residential area in Lucknow (Mahanagar and Aliganj) and in Kanpur (Kidwai Nagar and Shastri Nagar), Commercial areas in Lucknow (Hazarat Ganj and Ansal T.C.) and in Kanpur (Zareeb Chauki and Ramadevi), Industrial area Talkatora in Lucknow and Panki in Kanpur have been taken under consideration. The result found that 24 hours concentration of PM<sub>10</sub> were in the range of 76.40 to 261.19 µg/m<sup>3</sup> in Lucknow and 74.68 to 400.67 µg/m<sup>3</sup> in Kanpur with an average of 174.34 and 160.36 µg/m<sup>3</sup>, respectively. The average value of PM<sub>10</sub> was above as per the guideline of WHO and permissible limit prescribed by NAAQ in both the cities. Similarly, 24 hours average concentration of SO<sub>2</sub> was below the prescribed level of NAAQ in Lucknow and Kanpur which was in the range of 5.33 to 12.70 µg/m<sup>3</sup> in Lucknow and 2.00 to 9.53 µg/m<sup>3</sup> in Kanpur with an average of 8.71 and 7.19 µg/m<sup>3</sup>, respectively. The 24 hours average concentration of Nitrogen dioxide (NO<sub>2</sub>) was below prescribed level of NAAQ in Lucknow and Kanpur. In Lucknow it was in the range of 13.83 to 48.01 µg/m<sup>3</sup> and in Kanpur 21.45 to 64.02 µg/m<sup>3</sup> with an average of 29.45 and 50.14 µg/m<sup>3</sup>, respectively. The 24 hours AQI was reported in the range of 76 to 211 in Lucknow and 75 to 363 in Kanpur with an average of 150.84 and 142.76 respectively which is greater moderate to severe by NAAQ and WHO guideline throughout the year. Ultimately, this entire study is related to human health because polluted air gives rise to various hazardous diseases such as asthma cancer, premature death cardiovascular diseases, respiratory tract diseases etc.

**Keywords:** PM<sub>10</sub>; SO<sub>2</sub>; NO<sub>2</sub>; Ambient Air Quality (AQI); Lucknow and Kanpur city.

### 1. Introduction

Air pollution means contamination of the air by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Increase in technological, industrial, and agricultural advancement, coupled with increases in population growth, has triggered the deterioration of environmental quality throughout the world. Rapidly growing cities, more traffic on roads, growing energy consumption and waste production, and lack of strict implementation of environmental regulation are increasing the discharge of pollutants into air, water, and soil. Urban ambient air pollution is the result of emissions from a multiplicity of sources, mainly stationary, industrial, and domestic fossil fuel combustion, and petrol and diesel vehicle emissions. (Brulfert et al., 2005; Parra et al., 2006). According to the WHO report, particulate matter (PM) affects more people than any other air pollutant. Even low concentrations of PM have been related to adverse health effects (Agarwal, 2012).

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WHO report (2006) data revealed that there are more than 80% of urban population are exposed to air quality levels above the NAAQ standards and WHO guideline limits (WHO, 2006). However, in recent studies it has been observed that there are about 90% of world population living in the unhealthy air quality limits (WHO, 2016). It to be seems, past few decades due to human activities such as industrialization, fossil fuels burning, rapid increase in automobiles number and intensively use of agrochemicals have accelerated the levels of harmful gases like **SO<sub>2</sub>**, **NO<sub>2</sub>**, CO, O<sub>3</sub> and particulate matter (PM) in environment to worrying levels (Wu et al. 2020; Gurjar et al. 2016).

Lucknow metropolitan city is one of the most polluted cities of India. Lucknow city, the capital of Uttar Pradesh the most polluted state of India is located 26° 51' N and 80° 56'E This is second largest city of North India and one of the most famous tourist attractions of the country the population of the city is 28,15,601 according to 2011 census with an area of 310.1 km square. Lucknow is the capital of the most populated state of Uttar Pradesh, it is the second largest city in northern and central India. It is placed among the fastest growing cities and now it is a metropolitan city in India and is rapidly emerging as a manufacturing, commercial and retailing hub. Lucknow has insufficient transport infrastructure. Due to increasing urban population, use of personalized vehicles, mainly two wheelers and intermediate public transport is growing at a rapid rate. Total vehicle population is more than 13 lacs with a growth of 8.68% during 2011–2012 (IITR Report, 2012).

The city of Kanpur has a population of about 3 million and is situated in north-central part of India (longitude 88°22'E and latitude 26°26'N) in Gangetic Plane. Kanpur is the largest industrial metropolis in the State of Uttar Pradesh, India. The atmosphere over the city is considerably polluted. The population level or on the upswing again after few year of control the air quality data of CPCB reviews that the level of particulate pollution in the Kanpur were four to five times. Above the standard the level can be higher during winters level of **NO<sub>2</sub>** though below standards are rising in the city which is clear sign of growing impact of vehicles about 60% of the geographical area of the city has pollution problem with highly polluted City core.

Awareness about air quality index is necessary to the population of especially metro cities camping and awareness programs to know the consequences and health effect of breathing poor air.

The study's purpose to compare the quality status of Air of Lucknow and Kanpur city for year 2023. This study depends upon the concentration of various pollutants (PM<sub>10</sub>, **NO<sub>2</sub>**, **SO<sub>2</sub>**) that come under AQI. The Study shows that both the cities are troubling from declining trend of air quality. To compare the AQI of both cities the secondary data our collector from 5 representative monitoring site of different localities of Lucknow and Kanpur city in the year 2023. T this paper has tried to find out the cause of variation and concentration of pollutants in these two cities.

### **1.1. Source of air pollution in Lucknow and Kanpur**

Emission of air pollutants is caused by different anthropogenic processes which can be categorized into the source groups motor traffic, industry, power plants, trade, and domestic fuel. In industrialized countries like Germany, emissions of "classic" air pollutants are decreasing. This trend is pronounced for carbon monoxide (CO), Sulphur dioxide (**SO<sub>2</sub>**) and total suspended particulate (TSP) and is weakly evident for nitrogen oxides (NO<sub>x</sub>) and non-methane volatile organic compounds (NMVOC). (H. Mayer 1999).

There are four main types of air pollution sources including natural, area, stationary, and mobile sources producing PM<sub>2.5</sub>, PM<sub>10</sub>, reactive gases including volatile organic compounds (VOCs). Primary pollutants (the indicated gases and solid particles) may undergo further toxification in the environment.

### **1.2. Study location and data collection.**

For the comparison of ambient air quality (AQI) in Lucknow and Kanpur city, secondary data has been obtained from the Uttar Pradesh Pollution Control Board (UPPCB), the Central Pollution Control Board (CPCB), and the Centre for Science and Environment (CSE). The assessment of the monthly average concentration of ambient air pollution in Lucknow and Kanpur have been conducted with the recorded data (from Annual Report UPPCB, 2022–2023) against 5 monitoring stations of each city are 2 residential (Mahanagar and Aliganj) in Lucknow and (Kidvai Nagar and Shastri Nagar) in Kanpur, 2 commercial (Hazratganj and Ansal T. C.) in Lucknow and ( Zareeb Chauki and Rama Devi) in Kanpur and 1 industrial (Talkatora) in Lucknow and (Panki) in Kanpur area for each month and comparing the average value with the given NAAQ Standards. Seasonal variations in AQI and its three representative components such as PM<sub>10</sub>, **SO<sub>2</sub>** and **NO<sub>2</sub>** were also recorded.

## 2. Data Analysis and Results

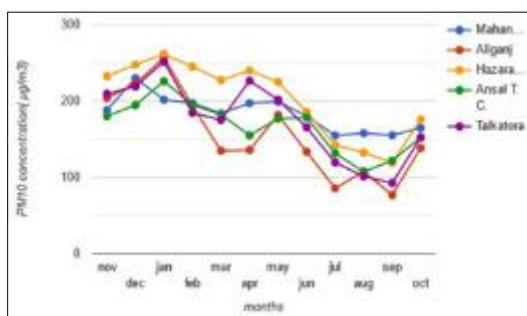
### 2.1. Respirable Suspended Particulate Matter (RSPM or PM<sub>10</sub>)

The 24 hours mean concentration of Table-1. Monthly average concentration of PM<sub>10</sub> (µg/m<sup>3</sup>) in different localities of Lucknow city (2022-2023) was observed in Mahanagar, Aliganj, Hazaratganj, Ansal T.C., Talkatora were 183.73,144.46,202.55,166.41 and 174.55 µg/m<sup>3</sup>, respectively. It was recorded maximum 202.55 µg/m<sup>3</sup> in Hazaratganj (commercial area) and minimum 144.46 µg/m<sup>3</sup> in Aliganj (residential area). (Table-1, Fig.1)

**Table 1** Monthly average concentration of PM<sub>10</sub> (µg/m<sup>3</sup>) in different localities of Lucknow city (2022-2023)

| Location    | Type | Month  |        |        |        |        |        |        |        |        |        |        |        | Avg    |
|-------------|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|             |      | nov    | dec    | jan    | feb    | mar    | Apr    | may    | Jun    | jul    | aug    | sep    | oct    |        |
| Mahanagar   | (R)  | 187.54 | 229.57 | 201.27 | 196.83 | 183.43 | 196.76 | 198.56 | 179.94 | 154.40 | 157.39 | 154.76 | 164.28 | 183.73 |
| Aliganj     | (R)  | 203.56 | 222.30 | 256.25 | 193.32 | 134.39 | 135.37 | 181.26 | 133.36 | 85.39  | 107.27 | 76.40  | 138.10 | 144.46 |
| Hazaratganj | (C)  | 232.09 | 247.21 | 261.19 | 244.64 | 226.98 | 239.67 | 224.48 | 185.23 | 142.83 | 132.25 | 118.77 | 175.38 | 202.55 |
| Ansal T.C.  | (C)  | 179.84 | 194.15 | 225.61 | 194.55 | 181.92 | 154.54 | 176.46 | 178.02 | 131.08 | 107.12 | 121.41 | 152.23 | 166.41 |
| Talkatora   | (I)  | 209.15 | 218.46 | 251.28 | 184.25 | 174.84 | 226.17 | 201.27 | 165.28 | 119.23 | 100.87 | 92.09  | 151.74 | 174.55 |
| Average     |      | 202.44 | 222.34 | 239.12 | 202.71 | 180.31 | 190.50 | 196.40 | 168.36 | 126.58 | 120.98 | 112.68 | 156.34 |        |

All the values of PM<sub>10</sub> were recorded above the prescribed NAAQ standard of 100 µg/m<sup>3</sup>, except residential area (Aliganj) in month of July and September, it was recorded 85.39 and 76.40). Also industrial area (Talkatora) was recorded under NAAQ Standard in the month of September, It was recorded 92.09.(table-1)



**Figure 1** Monthly variation of PM<sub>10</sub> concentration in different localities of Lucknow city.

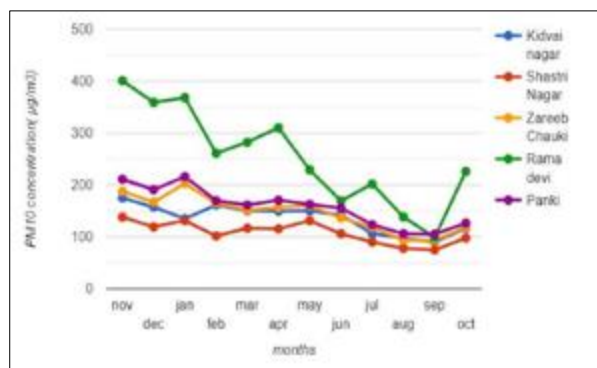
**Table 2** Monthly average concentration of PM<sub>10</sub> (µg/m<sup>3</sup>) in different localities of Kanpur city (2022-2023)

| Location      | Type | Month  |        |        |         |        |        |        |        |        |        |        |        | Avg    |
|---------------|------|--------|--------|--------|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|               |      | nov    | dec    | jan    | Feb     | Mar    | apr    | may    | Jun    | jul    | aug    | Sep    | oct    |        |
| Kidvai Nagar  | (R)  | 174.78 | 157.22 | 134.96 | 161.26  | 150.18 | 149.28 | 150.16 | 141.89 | 106.58 | 97.13  | 89.94  | 116.63 | 135.83 |
| Shastri Nagar | (R)  | 138.04 | 119.20 | 131.19 | 101.75  | 116.74 | 115.42 | 131.23 | 105.86 | 89.95  | 77.86  | 74.68  | 97.65  | 108.29 |
| Zareeb Chauki | (C)  | 187.33 | 166.75 | 202.68 | 164.82  | 151.54 | 156.59 | 159.80 | 136.58 | 118.78 | 93.54  | 92.84  | 118.75 | 145.83 |
| Rama Devi     | (C)  | 400.67 | 358.87 | 368.   | 261.03  | 282.20 | 310    | 228.88 | 169.22 | 201.88 | 138.29 | 98.73  | 225.92 | 253.64 |
| Panki         | (I)  | 210.91 | 190.86 | 216.02 | 169.71  | 161.38 | 170.64 | 162.48 | 155.62 | 123.51 | 105.88 | 105.32 | 126.20 | 158.21 |
| Average       |      | 222.35 | 198.58 | 210.57 | 171.714 | 172.41 | 180.38 | 166.51 | 141.83 | 128.14 | 102.54 | 92.302 | 137.03 |        |

The 24 hours mean concentration of PM<sub>10</sub> was recorded in Kidvai nagar, Shastri nagar, Zareeb chauki, Rama Devi and Panki were 135.83,108.29,145.83,253.64 and 158.21 µg/m<sup>3</sup>, respectively. It was recorded maximum 253.64 µg/m<sup>3</sup> in commercial area (Rama Devi) and minimum 108.29µg/m<sup>3</sup> in Shastri nagar (residential area). (Table-2, Fig-2).

All the values of PM<sub>10</sub> were recorded above the prescribed NAAQ Standard of 100 µg/m<sup>3</sup> except the value of PM<sub>10</sub> were recorded under the NAAQ Standard in the monsoon season in residential area (Shastri nagar). It was 89.95,77.86,74.68 97.65 µg/m<sup>3</sup> in July, August, September, October, respectively.

The value of PM<sub>10</sub> were recorded 97.13 and 89.94 µg/m<sup>3</sup> in month of August, September respectively in Kidvai nagar (residential area). The value of PM<sub>10</sub> in commercial area (Zareeb chauki) were recorded in 93.54 92.84 µg/m<sup>3</sup> in August and September month. Ramadevi (commercial area) were recorded 98.73 µg/m<sup>3</sup> in the month of September. (Table-2).



**Figure 2** Monthly variation of PM<sub>10</sub> concentrations in different localities of Kanpur city.

**Table 3** Monthly variation of PM<sub>10</sub> (µg/m<sup>3</sup>) concentrations in residential, commercial, and industrial areas of Lucknow and Kanpur city

| Location Type | City    | Month  |        |        |        |        |        |        |        |        |        |        |        | Avg    |
|---------------|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|               |         | Nov    | Dec    | Jan    | Feb    | Mar    | Apr    | May    | Jun    | Jul    | Aug    | Sep    | oct    |        |
| Residential   | Lucknow | 195.55 | 225.93 | 228.76 | 195.07 | 158.91 | 166.06 | 189.76 | 156.65 | 119.89 | 132.33 | 115.58 | 151.19 | 164.09 |
|               | Kanpur  | 156.41 | 138.21 | 133.07 | 131.50 | 133.46 | 132.35 | 140.69 | 123.87 | 98.26  | 87.49  | 82.31  | 107.14 | 122.06 |
| Commercial    | Lucknow | 205.96 | 220.68 | 243.4  | 219.58 | 204.45 | 197.10 | 200.47 | 181.62 | 136.95 | 119.68 | 120.09 | 163.80 | 184.48 |
|               | Kanpur  | 294    | 262.81 | 285.34 | 212.92 | 216.87 | 233.29 | 194.34 | 152.90 | 160.33 | 115.91 | 95.78  | 172.34 | 199.73 |
| Industrial    | Lucknow | 209.15 | 218.46 | 251.28 | 184.25 | 174.84 | 226.17 | 201.27 | 165.28 | 119.23 | 127.12 | 92.09  | 151.74 | 174.55 |
|               | Kanpur  | 210.91 | 190.86 | 216.02 | 169.71 | 161.38 | 170.64 | 162.48 | 155.62 | 123.51 | 105.88 | 105.32 | 126.20 | 158.21 |

The residential areas of Lucknow (Mahanagar and Aliganj ) the 24 hours average concentration of PM<sub>10</sub> were in the range of 115.58 to 228.76 µg/m<sup>3</sup> with an average 164.09 µg/m<sup>3</sup> and the residential areas of Kanpur (Kidvai nagar and Shastri nagar) the 24 hour average concentration of PM<sub>10</sub> were in the range of 82.31 to 156.41 µg/m<sup>3</sup> with an average of 122.06 µg/m<sup>3</sup>.

In commercial areas of Lucknow ( Hazarat Ganj and Ansal T.C.) the average concentration of PM<sub>10</sub> were in the range of 199.68 to 243.4 µg/m<sup>3</sup> with an average of 184.48 µg/m<sup>3</sup> and In commercial areas of Kanpur ( Zareeb chauki and Rama Devi) the average concentration of PM<sub>10</sub> were in the range of 95.78 to 294 µg/m<sup>3</sup> with an average of 199.73 µg/m<sup>3</sup>.

The Industrial areas of Lucknow (Talkatora ) the 24 hours average concentration of PM<sub>10</sub> were in the range of 92.09 to 251.28 µg/m<sup>3</sup> with an average 174.55 µg/m<sup>3</sup> and the Industrial areas of Kanpur (Panki) the 24 hour average concentration of PM<sub>10</sub> were in the range of 105.32 to 216.02 µg/m<sup>3</sup> with an average of 158.21 µg/m<sup>3</sup>.(Table-3).

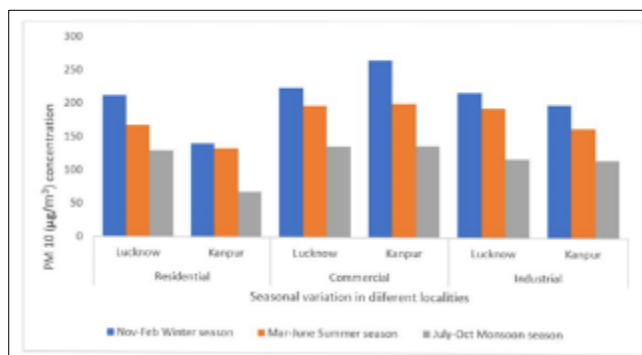
**Table 4** Seasonal variation of PM<sub>10</sub> (µg/m<sup>3</sup>) concentration in residential, commercial, and industrial area

| Location Type | City    | Winter (Nov-Feb) | Summer (Mar-Jun) | Monsoon (Jul-Oct) |
|---------------|---------|------------------|------------------|-------------------|
| Residential   | Lucknow | 211.32           | 167.84           | 129.74            |
|               | Kanpur  | 139.79           | 132.59           | 67.44             |
| Commercial    | Lucknow | 222.40           | 195.91           | 135.13            |
|               | Kanpur  | 263.64           | 199.35           | 136.09            |
| Industrial    | Lucknow | 215.78           | 191.89           | 117.54            |
|               | Kanpur  | 196.87           | 162.53           | 115.22            |

The seasonal variation of PM<sub>10</sub> concentration were also recorded in residential areas, commercial areas, and industrial areas. In residential areas of Lucknow 24-hour average concentration of PM<sub>10</sub> were observed 211.32,167.84 and 129.74 µg/m<sup>3</sup> in Winter (Nov-Feb), Summer (Mar-Jun) and Monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Lucknow average PM<sub>10</sub> concentration were recorded 222.40,195.91 and 135.13 µg/m<sup>3</sup> in Winter, Summer, and Monsoon season respectively and in Industrial areas of Lucknow the average PM<sub>10</sub> concentration were recorded 215.78,191.89 and117.54 µg/m<sup>3</sup> in Winter, Summer, and Monsoon, respectively.

The maximum concentration of PM<sub>10</sub> was recorded 222.40 µg/m<sup>3</sup> in Winter in Commercial area and was minimum 117.54 µg/m<sup>3</sup> in monsoon season in Industrial area of Lucknow. (Table-4, Fig-2).



**Figure 3** Seasonal variation of PM<sub>10</sub> concentration in residential Commercial and Industrial areas of Lucknow and Kanpur city.

The seasonal variation of PM<sub>10</sub> concentration were also recorded in residential areas, commercial areas, and industrial area. In residential areas of Kanpur 24-hour average concentration of PM<sub>10</sub> were observed 139.79,132.59 and 67.44 µg/m<sup>3</sup> in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively. Similarly in commercial areas of Kanpur average PM<sub>10</sub> concentration were recorded 263.64,199.35 and 136.09 µg/m<sup>3</sup> in winter, summer, and monsoon season respectively and in Industrial areas of Kanpur the average PM<sub>10</sub> concentration were recorded 196.87, 162.53 and 115.22 µg/m<sup>3</sup> in winter, summer, and monsoon, respectively. The maximum concentration of PM<sub>10</sub> was recorded 263.64 µg/m<sup>3</sup> in winter in commercial area and was minimum 67.44 µg/m<sup>3</sup> in monsoon season in industrial area. (Table-4, Fig-3).

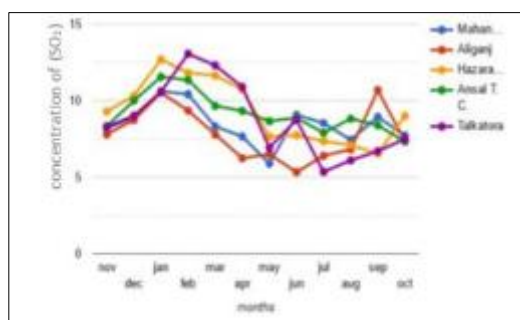
## 2.2. Sulphur dioxide (SO<sub>2</sub>)

The 24 hours mean concentration of SO<sub>2</sub> was observed in Mahanagar, Aliganj, Hazaratganj, Ansal T.C and Talkatora were 8.47, 7.79, 9.32, 9.18 and 8.79 µg/m<sup>3</sup>, respectively. It was recorded maximum 9.32 µg/m<sup>3</sup> in Hazarat Ganj (commercial area) and minimum 7.79 µg/m<sup>3</sup> in Aliganj (residential area). (Table-5, Fig.4).

**Table 5** Monthly average concentration of SO<sub>2</sub> (µg/m<sup>3</sup>) in different localities of Lucknow city (2022-2023)

| Location    | Type | Month |       |       |       |       |       |      |      |       |      |       | Avg  |      |
|-------------|------|-------|-------|-------|-------|-------|-------|------|------|-------|------|-------|------|------|
|             |      | nov   | dec   | jan   | feb   | mar   | Apr   | may  | Jun  | jul   | aug  | sep   |      | oct  |
| Mahanagar   | (R)  | 8.19  | 8.91  | 10.62 | 10.42 | 8.32  | 7.66  | 5.89 | 9.07 | 8.53  | 7.44 | 8.94  | 7.73 | 8.47 |
| Aliganj     | (R)  | 7.80  | 8.74  | 10.53 | 9.35  | 7.80  | 6.24  | 6.50 | 5.33 | 6.40  | 6.82 | 10.69 | 7.34 | 7.79 |
| Hazaratganj | (C)  | 9.29  | 10.32 | 12.70 | 11.82 | 11.64 | 10.73 | 7.65 | 7.75 | 7.35  | 7.10 | 6.55  | 9.00 | 9.32 |
| Ansal T.C.  | (C)  | 8.33  | 10.00 | 11.56 | 11.35 | 9.66  | 9.33  | 8.66 | 8.88 | 7.90  | 8.82 | 8.39  | 7.33 | 9.18 |
| Talkatora   | (I)  | 8.29  | 9.02  | 10.57 | 13.06 | 12.31 | 10.90 | 6.93 | 8.75 | 5.35  | 6.10 | 6.70  | 7.50 | 8.79 |
| Average     |      | 8.38  | 9.39  | 11.19 | 11.2  | 9.95  | 8.97  | 7.13 | 7.95 | 7.106 | 7.25 | 8.25  | 7.78 |      |

It was recorded maximum 12.70 µg/m<sup>3</sup> in January in Hazaratganj (commercial area) and minimum 5.33 µg/m<sup>3</sup> in June in Aliganj (residential area). (Table-5, Figure-4).



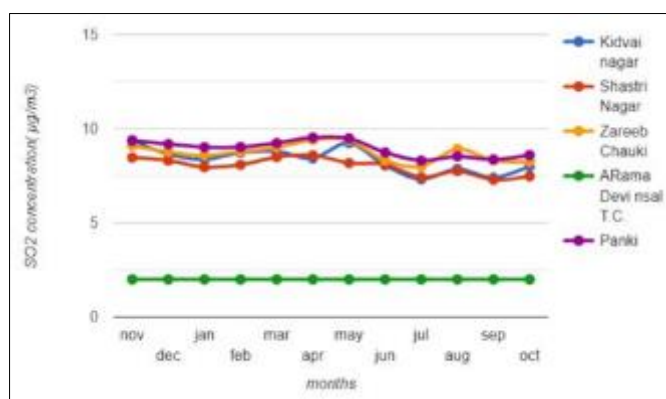
**Figure 4** Monthly variation of SO<sub>2</sub> concentration in different localities in Lucknow.

**Table 6** Monthly average concentration of SO<sub>2</sub> (µg/m<sup>3</sup>) in different localities of Kanpur city (2022-2023)

| Location      | Type | Month |      |      |       |      |      |      |      |      |      |      |      | Avg  |
|---------------|------|-------|------|------|-------|------|------|------|------|------|------|------|------|------|
|               |      | nov   | dec  | jan  | Feb   | Mar  | Apr  | may  | Jun  | Jul  | aug  | sep  | oct  |      |
| Kidvai Nagar  | (R)  | 9.40  | 8.64 | 8.37 | 8.73  | 8.80 | 8.43 | 9.24 | 8.05 | 7.32 | 7.86 | 7.40 | 8.01 | 8.35 |
| Shastri Nagar | (R)  | 8.47  | 8.31 | 7.96 | 8.09  | 8.49 | 8.59 | 8.18 | 8.10 | 7.43 | 7.75 | 7.29 | 7.48 | 8.01 |
| Zareeb Chauki | (C)  | 9.10  | 8.77 | 8.58 | 8.79  | 9.00 | 9.41 | 9.39 | 8.31 | 8.00 | 7.92 | 8.32 | 8.24 | 8.65 |
| Rama Devi     | (C)  | 2.00  | 2.00 | 2.00 | 2.00  | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Panki         | (I)  | 9.37  | 9.18 | 9.02 | 9.03  | 9.24 | 9.53 | 9.49 | 8.74 | 8.31 | 8.53 | 8.37 | 8.60 | 8.95 |
| Average       |      | 7.66  | 7.38 | 7.18 | 7.328 | 7.50 | 7.59 | 7.66 | 7.04 | 6.61 | 6.81 | 6.67 | 6.88 |      |

The 24 hours mean concentration of SO<sub>2</sub> was observed in Kidvai nagar, Shastri nagar, zareeb chauki, Rama Devi and Panki were 8.83, 8.01, 8.65 2.00 and 8.95 µg/m<sup>3</sup>, respectively. It was recorded maximum 8.95 µg/m<sup>3</sup> in Panki (Industrial area) and minimum 2.00 µg/m<sup>3</sup> in Rama devi (commercial area). (Table-6, Fig.5).

It was recorded maximum 9.40 µg/m<sup>3</sup> in November in Kidvai nagar (residential area) and minimum 2.00 µg/m<sup>3</sup> (constant entire year) in Panki (industrial area), (Table-6, figure-5).



**Figure 5** Monthly variation of SO<sub>2</sub> in different localities of Kanpur.

**Table 7** Monthly variation of SO<sub>2</sub> (µg/m<sup>3</sup>) in residential commercial and industrial area

| Location Type | City    | Month |       |       |       |       |       |      |      |      |      |      |      | Avg  |
|---------------|---------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|
|               |         | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May  | Jun  | Jul  | Aug  | Sep  | oct  |      |
| Residential   | Lucknow | 7.99  | 8.82  | 10.57 | 9.88  | 8.06  | 6.95  | 6.19 | 7.2  | 7.46 | 7.13 | 9.81 | 7.53 | 8.13 |
|               | Kanpur  | 8.93  | 8.47  | 8.16  | 8.41  | 8.64  | 8.51  | 8.71 | 8.07 | 7.37 | 7.80 | 7.34 | 7.74 | 8.18 |
| Commercial    | Lucknow | 8.81  | 10.16 | 11.63 | 11.58 | 10.65 | 10.03 | 8.15 | 8.31 | 7.62 | 7.96 | 7.47 | 8.16 | 9.25 |
|               | Kanpur  | 5.55  | 5.38  | 5.29  | 5.39  | 5.5   | 5.70  | 5.69 | 5.15 | 5.5  | 4.96 | 5.16 | 5.12 | 5.32 |
| Industrial    | Lucknow | 8.29  | 9.02  | 10.57 | 13.06 | 12.31 | 10.90 | 6.93 | 8.75 | 5.35 | 6.10 | 6.70 | 7.50 | 8.79 |
|               | Kanpur  | 9.37  | 9.18  | 9.02  | 9.03  | 9.24  | 9.53  | 9.49 | 8.74 | 8.31 | 8.53 | 8.37 | 8.60 | 8.95 |

The residential areas of Lucknow (Mahanagar and Aliganj ) the 24 hours average concentration of SO<sub>2</sub> were in the range of 6.19 to 10.57 µg/m<sup>3</sup> with an average 8.13 µg/m<sup>3</sup> and the residential areas of Kanpur (Kidvai nagar and Shastri nagar) the 24 hour average concentration of SO<sub>2</sub> were in the range of 7.34 to 8.93 µg/m<sup>3</sup> with an average of 8.18 µg/m<sup>3</sup>.

In commercial areas of Lucknow ( Hazarat Ganj and Ansal T.C.) the average concentration of SO<sub>2</sub> were in the range of 7.47 to 11.58 µg/m<sup>3</sup> with an average of 9.25 µg/m<sup>3</sup> and In commercial areas of Kanpur ( Zreeb chauki and Rama Devi) the average concentration of SO<sub>2</sub> were in the range of 4.96 to 5.70 µg/m<sup>3</sup> with an average of 5.32 µg/m<sup>3</sup>.

The Industrial areas of Lucknow (Talkatora ) the 24 hours average concentration of SO<sub>2</sub> were in the range of 6.10 to 13.06 µg/m<sup>3</sup> with an average 8.79 µg/m<sup>3</sup> and the Industrial areas of Kanpur (Panki) the 24 hour average concentration of SO<sub>2</sub> were in the range of 8.31 to 9.53 µg/m<sup>3</sup> with an average of 8.95 µg/m<sup>3</sup>.(Table-7).

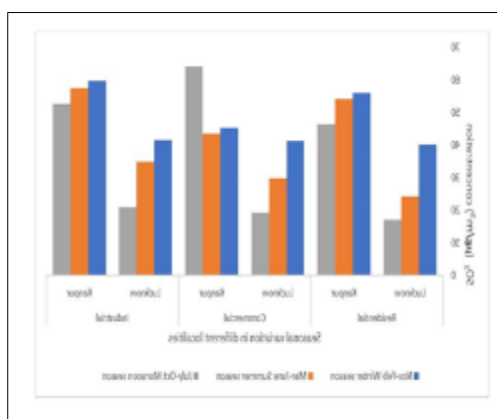
**Table 8** Seasonal variation of SO<sub>2</sub> (µg/m<sup>3</sup>) concentration in residential, commercial, and industrial areas of Lucknow and Kanpur city

| Location Type | City    | Winter (Nov-Feb) | Summer (Mar-Jun) | Monsoon (Jul-Oct) |
|---------------|---------|------------------|------------------|-------------------|
| Residential   | Lucknow | 9.31             | 7.1              | 7.98              |
|               | Kanpur  | 8.49             | 8.48             | 7.56              |
| Commercial    | Lucknow | 10.54            | 9.28             | 7.80              |
|               | Kanpur  | 5.40             | 5.51             | 5.06              |
| Industrial    | Lucknow | 10.23            | 9.72             | 6.41              |
|               | Kanpur  | 9.15             | 9.25             | 8.45              |

The seasonal variation of SO<sub>2</sub> concentration were also recorded in residential area, commercial area, and industrial area. In residential areas of Lucknow 24-hour average concentration of SO<sub>2</sub> were observed 9.31, 7.1 and 7.98 µg/m<sup>3</sup> in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Lucknow average SO<sub>2</sub> concentration were recorded 10.54, 9.28 and 7.80 µg/m<sup>3</sup> in winter, summer, and monsoon season respectively and in Industrial areas of Lucknow the average SO<sub>2</sub> concentration were recorded 10.23, 9.72 and 6.41 µg/m<sup>3</sup> in winter, summer, and monsoon, respectively.

The maximum concentration of SO<sub>2</sub> was recorded 10.54 µg/m<sup>3</sup> in winter in commercial area and was minimum 6.41 µg/m<sup>3</sup> in monsoon season in Industrial area of Lucknow. (Table-8, Fig-6).

**Figure 6** Seasonal variation of SO<sub>2</sub> (µg/m<sup>3</sup>) concentration in residential, commercial, and industrial areas of Lucknow and Kanpur city.

The seasonal variation of SO<sub>2</sub> concentration were also recorded in residential area, commercial area, and industrial area. In residential areas of Kanpur 24-hour average concentration of SO<sub>2</sub> were observed 8.49, 8.48 and 7.56 µg/m<sup>3</sup> in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Kanpur average SO<sub>2</sub> concentration were recorded 5.40, 5.51 and 5.06 µg/m<sup>3</sup> in winter, summer, and monsoon season respectively and in Industrial areas of Kanpur the average SO<sub>2</sub> concentration were recorded 9.15, 9.25 and 8.45 µg/m<sup>3</sup> in winter, summer, and monsoon, respectively.

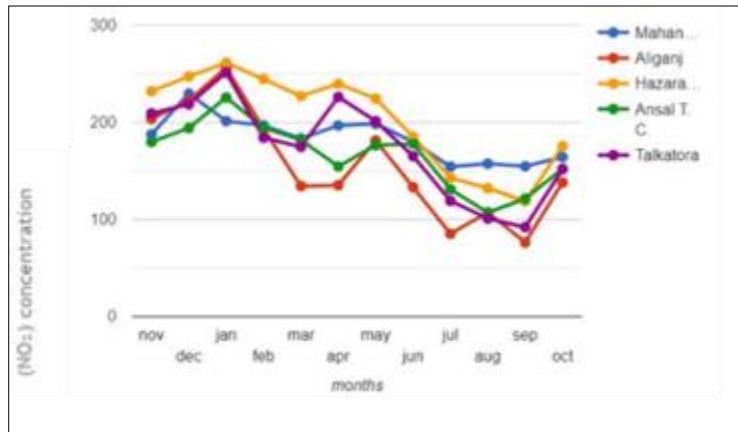
The maximum concentration of SO<sub>2</sub> was recorded 9.25 µg/m<sup>3</sup> in winter in commercial area and was minimum 5.06 µg/m<sup>3</sup> in monsoon season in industrial area. (Table-8, Fig-6).

#### Oxides of Nitrogen (NO<sub>x</sub>)

The 24 hours mean concentration of NO<sub>2</sub> was observed in Mahanagar, Aliganj, Hazaratganj, Ansal T.C., Talkatora were 28.66, 25.76, 31.36, 29.03 and 32.44 µg/m<sup>3</sup>, respectively. It was recorded maximum 32.44 µg/m<sup>3</sup> in Talkatora (industrial area) and minimum 25.76 µg/m<sup>3</sup> in Aliganj (residential area). (Table-9, Fig.7)

**Table 9** Monthly average concentration of NO<sub>2</sub> (µg/m<sup>3</sup>) in different localities of Lucknow city (2022-2023)

| Location    | Type | Month |       |       |       |       |       |       |       |       |       |       |       | Avg   |
|-------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|             |      | nov   | dec   | jan   | feb   | mar   | Apr   | may   | Jun   | Jul   | aug   | sep   | oct   |       |
| Mahanagar   | (R)  | 41.12 | 42.26 | 45.97 | 39.49 | 31.49 | 26.45 | 24.06 | 24.06 | 15.20 | 16.42 | 16.54 | 21.34 | 28.66 |
| Aliganj     | (R)  | 38.55 | 37.95 | 41.67 | 34.90 | 25.40 | 20.43 | 22.70 | 19.91 | 15.23 | 17.30 | 13.83 | 21.29 | 25.76 |
| Hazaratganj | (C)  | 42.84 | 45.89 | 48.01 | 41.46 | 30.46 | 38.31 | 28.21 | 23.31 | 18.49 | 16.92 | 19.84 | 22.58 | 31.36 |
| Ansal T.C.  | (C)  | 35.71 | 35.46 | 43.18 | 37.64 | 30.72 | 32.87 | 29.14 | 25.64 | 18.59 | 17.82 | 20.80 | 20.86 | 29.03 |
| Talkatora   | (I)  | 40.88 | 41.16 | 43.81 | 40.76 | 36.62 | 38.29 | 34.91 | 29.51 | 18.06 | 22.37 | 20.82 | 22.10 | 32.44 |
| Average     |      | 39.82 | 40.54 | 44.52 | 38.85 | 30.93 | 31.19 | 27.80 | 24.48 | 17.11 | 18.16 | 18.36 | 21.63 |       |

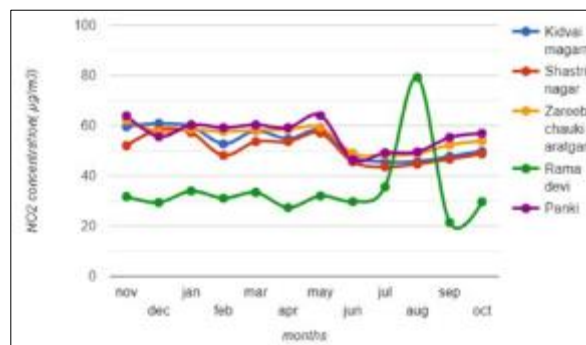


**Figure 7** Monthly average concentration of NO<sub>2</sub> (µg/m<sup>3</sup>) in different localities of Lucknow city.

It was recorded maximum 48.01 µg/m<sup>3</sup> in January in Hazarat Ganj (commercial area) and minimum 15.20 µg/m<sup>3</sup> in July in Mahanagar (residential area). (table-9Figure-7).

**Table 10** Monthly average concentration of NO<sub>2</sub> (µg/m<sup>3</sup>) in different localities of Kanpur city (2022-2023)

| Location      | Type | Month |       |       |       |       |       |       |       |       |       |       |       | Avg   |
|---------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|               |      | nov   | dec   | jan   | Feb   | Mar   | apr   | may   | Jun   | Jul   | aug   | Sep   | oct   |       |
| Kidvai Nagar  | (R)  | 59.56 | 60.90 | 59.75 | 52.73 | 57.97 | 54.76 | 58.20 | 47.64 | 45.57 | 45.73 | 47.72 | 49.81 | 53.36 |
| Shastri Nagar | (R)  | 52.04 | 58.54 | 57.23 | 48.14 | 53.64 | 53.63 | 57.03 | 45.51 | 43.59 | 44.71 | 46.62 | 48.77 | 50.78 |
| Zareeb Chauki | (C)  | 62.10 | 57.63 | 58.43 | 57.72 | 58.20 | 58.53 | 59.36 | 48.98 | 48.26 | 48.86 | 52.29 | 53.88 | 55.35 |
| Rama Devi     | (C)  | 31.75 | 29.38 | 34    | 31.07 | 33.40 | 27.36 | 32.04 | 29.75 | 35.58 | 79.23 | 21.45 | 29.67 | 34.55 |
| Panki         | (I)  | 62.92 | 55.61 | 60.28 | 59.18 | 60.30 | 59.17 | 64.02 | 46.45 | 49.19 | 49.51 | 55.29 | 56.92 | 56.65 |
| Average       |      | 53.87 | 52.40 | 53.93 | 49.76 | 52.70 | 50.69 | 54.13 | 43.66 | 44.44 | 53.60 | 44.67 | 47.81 |       |



**Figure 8** Monthly variation of NO<sub>2</sub> in different localities of Kanpur



The 24 hours mean concentration of NO<sub>2</sub> was observed in Kidvai nagar, Shastri nagar, zareeb chauki, Rama Devi and Panki were 53.36, 50.78, 55.35, 34.55 and 56.65 µg/m<sup>3</sup>, respectively. It was recorded maximum 56.65 µg/m<sup>3</sup> in Panki (Industrial area) and minimum 34.55 µg/m<sup>3</sup> in Rama devi (commercial area). (Table-10, Fig.8).

It was recorded maximum and minimum in same area, 79.23 µg/m<sup>3</sup>(maximum) in August in Rama devi (commercial area) and minimum 21.45 µg/m<sup>3</sup> in Ramadevi. (Table-10, figure-8).

**Table 11** Monthly variation of NO<sub>2</sub> (µg/m<sup>3</sup>) in residential, commercial, and industrial area.

| Location Type | City    | Month |        |       |       |       |       |       |       |       |       |       |       | Avg   |
|---------------|---------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|               |         | Nov   | Dec    | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | oct   |       |
| Residential   | Lucknow | 39.84 | 40.105 | 43.97 | 37.19 | 28.44 | 23.24 | 23.38 | 21.98 | 15.22 | 16.86 | 15.18 | 21.32 | 27.21 |
|               | Kanpur  | 55.8  | 59.70  | 58.49 | 50.43 | 58.80 | 54.19 | 57.61 | 46.57 | 44.58 | 45.22 | 47.17 | 49.29 | 20.83 |
| Commercial    | Lucknow | 39.27 | 40.67  | 45.59 | 39.55 | 30.59 | 35.59 | 28.67 | 24.47 | 18.54 | 17.37 | 20.32 | 21.72 | 30.19 |
|               | Kanpur  | 46.92 | 43.50  | 46.22 | 44.39 | 45.8  | 42.94 | 45.7  | 39.36 | 41.92 | 64.04 | 36.87 | 41.77 | 44.95 |
| Industrial    | Lucknow | 40.88 | 41.16  | 43.81 | 40.76 | 36.62 | 38.29 | 34.91 | 29.51 | 18.06 | 22.37 | 20.82 | 22.10 | 32.44 |
|               | Kanpur  | 63.92 | 55.61  | 60.28 | 59.18 | 60.30 | 59.17 | 64.02 | 46.45 | 49.19 | 49.51 | 55.29 | 56.92 | 56.65 |

The residential areas of Lucknow (Mahanagar and Aliganj ) the 24 hours average concentration of NO<sub>2</sub> were in the range of 15.18 to 43.97 µg/m<sup>3</sup> with an average 27.21 µg/m<sup>3</sup> and the residential areas of Kanpur (Kidvai nagar and Shastri nagar) the 24 hour average concentration of NO<sub>2</sub> were in the range of 44.58 to 59.70 µg/m<sup>3</sup> with an average of 20.83 µg/m<sup>3</sup>.

In commercial areas of Lucknow ( Hazarat Ganj and Ansal T.C.) the average concentration of NO<sub>2</sub> were in the range of 17.37 to 45.59 µg/m<sup>3</sup> with an average of 30.19 µg/m<sup>3</sup> and In commercial areas of Kanpur ( Zreeb chauki and Rama Devi) the average concentration of NO<sub>2</sub> were in the range of 36.87 to 64.04 µg/m<sup>3</sup> with an average of 44.95 µg/m<sup>3</sup>.

The Industrial areas of Lucknow (Talkatora ) the 24 hours average concentration of NO<sub>2</sub> were in the range of 18.06 to 43.81 µg/m<sup>3</sup> with an average 32.44 µg/m<sup>3</sup> and the Industrial areas of Kanpur (Panki) the 24 hour average concentration of NO<sub>2</sub> were in the range of 46.45 to 64.02 µg/m<sup>3</sup> with an average of 56.65 µg/m<sup>3</sup>.(Table-11).

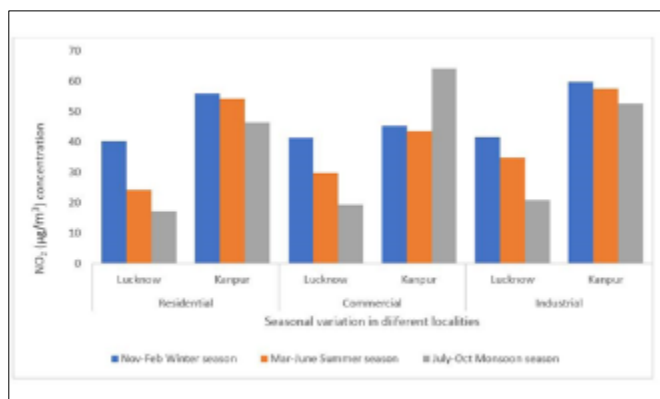
**Table 12** Seasonal variation of NO<sub>2</sub> concentration in residential, commercial, and industrial area of Lucknow and Kanpur.

| Location Type | City    | Winter (Nov-Feb) | Summer (Mar-Jun) | Monsoon (Jul-Oct) |
|---------------|---------|------------------|------------------|-------------------|
| Residential   | Lucknow | 40.27            | 24.26            | 17.14             |
|               | Kanpur  | 56.105           | 54.29            | 46.56             |
| Commercial    | Lucknow | 41.27            | 29.83            | 19.48             |
|               | Kanpur  | 45.25            | 43.51            | 46.15             |
| Residential   | Lucknow | 41.65            | 34.83            | 20.83             |
|               | Kanpur  | 59.74            | 57.48            | 52.72             |

The seasonal variation of NO<sub>2</sub> concentration were also recorded in residential area, commercial area, and industrial area. In residential areas of Lucknow 24-hour average concentration of NO<sub>2</sub> were observed 40.27, 24.26 and 17.14 µg/m<sup>3</sup> in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Lucknow average NO<sub>2</sub> concentration were recorded 41.27, 29.83 and 19.48 µg/m<sup>3</sup> in winter, summer, and monsoon season respectively and in Industrial areas of Lucknow the average NO<sub>2</sub> concentration were recorded 41.65, 34.83 and 20.83 µg/m<sup>3</sup> in winter, summer, and monsoon, respectively.

The maximum concentration of NO<sub>2</sub> was recorded 41.65 µg/m<sup>3</sup> in winter in Industrial area and was minimum 17.14 µg/m<sup>3</sup> in monsoon season in residential area of Lucknow. (Table-12, Fig-9).



**Figure 9** Seasonal variation of NO<sub>2</sub> (µg/m<sup>3</sup>) concentration in residential, commercial, and Industrial areas of Lucknow and Kanpur city.

The seasonal variation of NO<sub>2</sub> concentration were also recorded in residential area, commercial area, and industrial area. In residential areas of Kanpur 24-hour average concentration of NO<sub>2</sub> were observed 56.105, 54.29 and 46.56 µg/m<sup>3</sup> in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Kanpur average NO<sub>2</sub> concentration were recorded 45.25, 43.51 and 46.15 µg/m<sup>3</sup> in winter, summer, and monsoon season respectively and in industrial areas of Kanpur the average NO<sub>2</sub> concentration were recorded 59.74, 57.48 and 52.72 µg/m<sup>3</sup> in winter, summer, and monsoon, respectively.

The maximum concentration of NO<sub>2</sub> was recorded 59.74 µg/m<sup>3</sup> in winter in industrial area and was minimum 43.51 µg/m<sup>3</sup> in summer season in commercial area. (Table-12 Fig-9).

### 2.3. Ambient air quality (AIR)

The 24 hours mean concentration of AQI was observed in Mahanagar, Aliganj, Hazaratganj, Ansal T.C., Talkatora were 155.91, 136.08, 168.33, 144 and 149.91, respectively. It was recorded maximum 168.33 in Hazaratganj (commercial area) and minimum 136.08 in Aliganj (residential area). (Table-13, Fig.10)

It was recorded maximum 196 in February in Hazaratganj (commercial area) in the whole year and minimum 76 in September in Aliganj (residential area).

**Table 13** Monthly average of Air Quality Index (AQI) in Lucknow.

| Location    | Type | Month |       |     |       |       |       |       |       |       |       |       |       | Avg    |
|-------------|------|-------|-------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
|             |      | nov   | dec   | Jan | feb   | mar   | Apr   | may   | Jun   | jul   | aug   | sep   | oct   |        |
| Mahanagar   | (R)  | 158   | 186   | 168 | 165   | 156   | 165   | 166   | 153   | 136   | 138   | 137   | 143   | 155.91 |
| Aliganj     | (R)  | 169   | 182   | 206 | 162   | 123   | 124   | 154   | 122   | 85    | 105   | 76    | 125   | 136.08 |
| Hazaratganj | (C)  | 188   | 193   | 211 | 196   | 185   | 193   | 183   | 157   | 129   | 122   | 113   | 150   | 168.33 |
| Ansal T.C.  | (C)  | 153   | 163   | 184 | 163   | 155   | 136   | 151   | 152   | 121   | 101   | 114   | 135   | 144    |
| Talkatora   | (I)  | 173   | 179   | 201 | 156   | 150   | 184   | 168   | 144   | 113   | 105   | 92    | 134   | 149.91 |
| Average     |      | 168.2 | 180.6 | 194 | 168.4 | 153.8 | 160.4 | 164.4 | 145.6 | 116.8 | 114.2 | 106.4 | 137.4 |        |

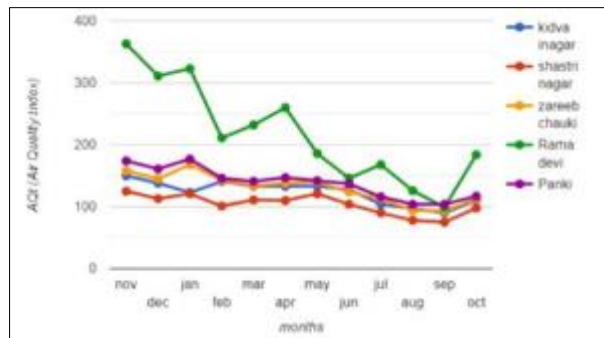


**Figure 10** Monthly variation of AQI in different localities of Lucknow.

**Table 14** Monthly variation of AQI in the different localities of Kanpur

| Location      | Type | Month |       |       |       |       |       |       |       |       |      |      |       | Average |
|---------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|-------|---------|
|               |      | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug  | Sep  | Oct   |         |
| Kidvai nagar  | (R)  | 150   | 138   | 123   | 141   | 133   | 133   | 133   | 128   | 104   | 97   | 90   | 111   | 123.41  |
| Shastri nagar | (R)  | 125   | 113   | 121   | 101   | 111   | 110   | 121   | 104   | 90    | 78   | 75   | 98    | 103.91  |
| Zareeb chauki | (C)  | 158   | 145   | 168   | 143   | 134   | 138   | 140   | 124   | 113   | 94   | 93   | 113   | 130.25  |
| Ramadevi      | (C)  | 363   | 311   | 323   | 211   | 232   | 260   | 186   | 146   | 168   | 126  | 99   | 184   | 217.41  |
| Panki         | (I)  | 174   | 161   | 177   | 146   | 141   | 147   | 142   | 137   | 116   | 104  | 104  | 117   | 138.83  |
| Average       |      | 194   | 173.6 | 182.4 | 148.4 | 150.2 | 157.6 | 144.4 | 127.8 | 118.2 | 99.8 | 92.2 | 124.6 |         |

The 24 hours mean concentration of AQI was recorded in Kidvai nagar, Shastri nagar, Zareeb chauki, Rama Devi and Panki were 123.41, 103.91, 130.25, 217.41 and 138.83, respectively. It was recorded maximum 217.41 in commercial area (Rama devi) and minimum 103.91 in Shastri nagar (residential area). (Table-14, Fig-11).



**Figure 11** Monthly variation of AQI in different localities of Kanpur.

It was recorded maximum 363 in November in Rama devi (commercial area) and minimum 75 September in Shastri nagar (residential area), (Table-14, figure-11).

**Table 15** Monthly variation of AQI in residential, commercial, and industrial area of Lucknow and Kanpur city.

| Location Type | City    | Month |       |       |       |       |       |     |       |       |       |       |       | Avg    |
|---------------|---------|-------|-------|-------|-------|-------|-------|-----|-------|-------|-------|-------|-------|--------|
|               |         | Nov   | Dec   | Jan   | Feb   | Mar   | Apr   | May | Jun   | Jul   | Aug   | Sep   | oct   |        |
| Residential   | Lucknow | 163.5 | 184   | 187   | 163.5 | 139.5 | 144.5 | 160 | 137.5 | 110.5 | 121.5 | 106.5 | 134   | 145.99 |
|               | Kanpur  | 144   | 125.5 | 122   | 121   | 122   | 121.5 | 127 | 116   | 97    | 87.5  | 82.5  | 104.5 | 113.66 |
| Commercial    | Lucknow | 170.5 | 178   | 197.5 | 179.5 | 170   | 164.5 | 167 | 154.5 | 125   | 111.5 | 113.5 | 142.5 | 156.16 |
|               | Kanpur  | 260.5 | 28    | 245.5 | 177   | 183   | 199   | 163 | 135   | 140.5 | 110   | 96    | 148.5 | 173.83 |
| Industrial    | Lucknow | 173   | 179   | 201   | 156   | 150   | 184   | 168 | 144   | 113   | 105   | 92    | 134   | 149.91 |
|               | Kanpur  | 174   | 161   | 177   | 146   | 141   | 147   | 142 | 137   | 116   | 104   | 104   | 117   | 138.83 |

The residential areas of Lucknow (Mahanagar and Aliganj) the 24 hours average AQI were in the range of 106.5 to 187 with an average 145.99 and the residential areas of Kanpur (Kidvai nagar and Shastri nagar) the 24-hour average of AQI were in the range of 82.5 to 127 with an average of 20.83 113.66.

In commercial areas of Lucknow (Hazarat Ganj and Ansal T.C.) the average of AQI were in the range of 111.5 to 197.5 with an average of 156.16 and in commercial areas of Kanpur (Zreeb chauki and Rama Devi) the average of AQI were in the range of 96 to 245.5 with an average of 173.83.

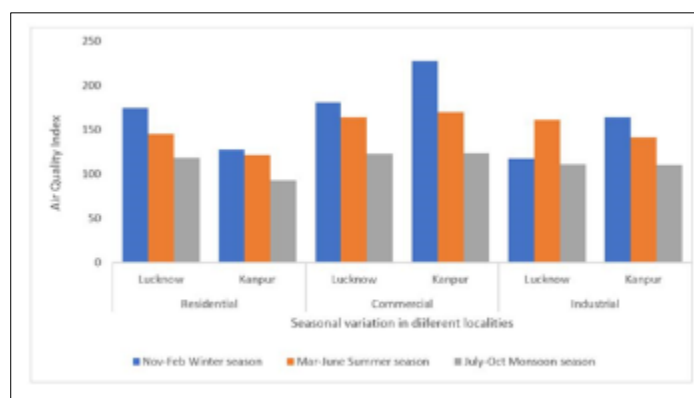
The Industrial areas of Lucknow (Talkatora) the 24 hours average of AQI were in the range of 92 to 201 with an average 149.91 and the Industrial areas of Kanpur (Panki) the 24-hour average of AQI were in the range of 104 to 177 with an average of 138.83.(Table-15).

**Table 16** Seasonal variation of AQI in residential, commercial, and industrial area of Lucknow and Kanpur.

| Location Type | City    | Winter (Nov-Feb) | Summer (Mar-Jun) | Monsoon (Jul-Oct) |
|---------------|---------|------------------|------------------|-------------------|
| Residential   | Lucknow | 174.5            | 145.37           | 118.12            |
|               | Kanpur  | 128.12           | 121.62           | 92.87             |
| Commercial    | Lucknow | 181.37           | 164              | 123.12            |
|               | Kanpur  | 227.75           | 170              | 123.75            |
| Industrial    | Lucknow | 177.25           | 161.5            | 111               |
|               | Kanpur  | 164.5            | 141.75           | 110.25            |

The seasonal variation of AQI were also recorded in residential area, commercial area, and industrial area. In residential areas of Lucknow, 24-hour average of AQI were observed 174.5, 145.37 and 118.12 in winter (Nov-Feb), summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Lucknow average AQI were recorded 181.37, 164 and 123.12 in winter, summer, and monsoon season respectively and in industrial areas of Lucknow the average AQI were recorded 177.25, 161.5 and 111 in winter, summer, and monsoon, respectively.



**Figure 12** Seasonal variation of AQI in residential, commercial, and Industrial area of Lucknow and Kanpur city.

The maximum AQI was recorded 181.37 in winter in commercial area and was minimum 111 in monsoon season in Industrial area of Lucknow. (Table-16, Fig-12).

The seasonal variation of AQI were also recorded in residential area, commercial area, and industrial area. In residential areas of Kanpur, the 24-hour average of AQI were observed 128.12, 121.62 and 92.87 in winter (Nov-Feb), Summer (Mar-Jun) and monsoon (Jul-Oct) respectively.

Similarly in commercial areas of Kanpur average AQI were recorded 227.75, 170 and 123.75 in winter, summer, and monsoon season respectively and in Industrial areas of Kanpur the average AQI were recorded 164.5, 141.75 and 110.25 in winter, summer, and monsoon, respectively.

The maximum AQI was recorded 174.5 in winter in residential area and was minimum 92.87 in monsoon season in residential area. (Table-16 Fig-12).

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### 3. Discussion

According to a report released by Swiss air quality monitoring body IQAir, the majority of air pollution ploughing the largest cities is from vehicle, industrial and construction emission. Dust and construction contribute about 59% to the air pollution in India. In the big metro cities, the major cause of air pollution happens to be the vehicular exhaust containing the oxides of carbon and nitrogen, Sulphur and particulate matter, volatile organic compounds (VOCs).

Almost all the cities of India having higher concentration of PM<sub>10</sub> in year of Indian mega cities such as Delhi (Trivedi et al, 2014), Kolkata (Das et al, 2015), Raipur (Giri et al, 2013), Kanpur (Singh and Gupta, 2015) and Lucknow (Lawrence and Fatima 2014, Saini et al, 2022).

Respirable particulate matter has been identified as the major air pollutant of the urban air environment. The vehicles fitted with latest technology engines, usage of CNG in vehicles, other combustion sources and formation as secondary pollutant has resulted in higher level of fine and ultrafine particles in the urban air environment. There are more likely chances in the increase of incidences of respiratory and mutagenic disease due to high levels of finer particulates. Therefore, in the revised National Ambient Air Quality Standards (NAAQS) November 2009 suspended particulate matter (SPM) was excluded and fine particulate fraction PM<sub>2.5</sub> was included with existing PM<sub>10</sub>. (Verma et al.,2016)

The level of 24-hour average concentration of PM<sub>10</sub> In Lucknow and Kanpur were reported higher than the prescribed level of NAAQ. Only the residential area of Kanpur has an average value of PM<sub>10</sub> concentration in monsoon season. Winter season reported worse in the whole year in both Lucknow and Kanpur than summer season. In residential areas the concentration of PM<sub>10</sub> is least in comparison to commercial and industrial areas in both cities and highest in the commercial areas. In comparison, the air quality of Kanpur is better than the Lucknow in consideration of PM<sub>10</sub> concentration.

The AQI for Kanpur city have shown that air quality worsens (extremely poor to severe) in winter months and during the early summer months (March, April, and part of May). These months are characterized by dusty winds resulting in high SPM. The air quality generally improves in monsoon and post-monsoon period (good to moderate) as rain washes out the pollutants. (Mukesh et al., 2003)

Sulphur dioxide affects the respiratory system, particularly lung function and can irritate the eyes and increase the risk of tract infections. It causes coughing mucus secretion and aggravates conditions such asthma and chronic bronchitis. SO<sub>2</sub> contributes to the formation of thick haze and smog. Most of the Sulphur dioxide released from power plants, oil refineries, some motor vehicles and domestic boilers and fires. The 24 hours average concentration of Sulphur dioxide were reported highest in the season of winter and lowest in the monsoon. The level of Sulphur dioxide in industrial and vegetation area of Kanpur slightly higher than Lucknow but the average value of SO<sub>2</sub> in commercial area is much higher in Lucknow than Kanpur. 24-hour average concentration of SO<sub>2</sub> were reported under the prescribed level throughout the year. One option to reduce SO<sub>2</sub> emission use coal that contains less Sulphur, another is to "wash" the cold to remove some of the Sulphur. The power plant can also install equipment called scrubbers which remove the SO<sub>2</sub> from gases leaving the smokestack.

The main source of NO<sub>2</sub> resulting from human activities is the combustion of fossil fuel (coal, gas, and oil) especially fuel used in cars. It is also produced from making nitric acid, welding, and using explosives, refining of petrol and metals commercial manufacturing and food manufacturing. Elevated levels of an auto can cause damage to the human respiratory track and increase a person's vulnerability to, and the severity of respiratory infections and asthma. Long

term exposure to high levels of NO<sub>2</sub> dioxide can cause chronic lung disease. The 24-hour average concentration of NO<sub>2</sub> maximum in industrial areas of Lucknow and Kanpur and recorded minimum in commercial areas of both cities. The level of NO<sub>2</sub> concentration recorded higher in Kanpur in comparison to Lucknow throughout the entire year. In Lucknow, the average concentration of NO<sub>2</sub> were found under prescribe level of NAAQ in summer and monsoon season but in winter it was recorded slightly above than prescribe level of NAAQ. Concentration of NO<sub>2</sub> level higher than prescribed minimum level of NAAQ which was reported highest in winter season and at lowest in monsoon season. The minimum concentration of SO<sub>2</sub> and NO<sub>2</sub> were reported in monsoon period maybe attributed due to rainfall which washout pollutants from air similar observations and finding the earlier reported by Mumtaz et al (2017) and Saini et al (2022).

India has experienced a sharp rise in air pollution as a result of industrialization, population development, an increase in the number of vehicles on the road, the usage of fuels, inadequate transportation infrastructure, and, most importantly, insufficient environmental legislation. With an increased pace of industrialization, especially in developing countries, environmental problems have also increased. In tandem with population growth and economic expansion, there has been a sharp increase in the sources of air pollution. In addition to making, it more difficult to breathe, air pollution can also make pre-existing respiratory and heart diseases worse. (KM Mansi 2022)

According to the World health organization (WHO), air pollution is 92% global burden of diseases of the world's population, currently about 3 million annual deaths were reported over the world where the level air quality exceed from the WHO guideline (WHO, 2016). Cohen et al.(2005) were reported the higher concentration of PM causes 8 lakhs premature death and 6.4 million people last per year over the world.

The result indicate that the AQI of Kanpur ranges between unhealthy for sensitive group to very unhealthy and Air quality index of Lucknow indicate and healthy air quality of Lucknow. In comparison to both cities Kanpur always had lower AQI than Lucknow that indicates Kanpur had much better air quality than Lucknow the entire year. Both cities need to maintain and reduce the air quality index (AQI). The minimum AQI recorded in monsoon season and most polluted season was winter having highest AQI.

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#### 4. Conclusion

The study was conducted to access the comparative study of current air quality of Lucknow and Kanpur city. For this purpose, secondary data were collected from Uttar Pradesh Pollution Control Board website and analyzed monthly and seasonally variation of PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub> in 5 representative locations of both cities. The studies revealed that there is higher concentration of PM<sub>10</sub> occurs throughout the year in both cities from the prescribed NAAQ standard and WHO guidelines, but it was less than the previous year. Its peak concentration was reported in the month of January 2023 in Lucknow (Hazarat Ganj) and in Kanpur (Rama Devi). The concentration of SO<sub>2</sub> and NO<sub>2</sub> were observed below the prescribed level throughout the year in Lucknow and Kanpur. In monsoon season the concentration level of SO<sub>2</sub> and NO<sub>2</sub> was found to be lower than the summer and winter season. The result indicate that the AQI of Kanpur ranges between unhealthy for sensitive group to very unhealthy and Air quality index of Lucknow indicate and healthy air quality of Lucknow. In comparison to both cities Kanpur always had lower AQI than Lucknow that indicates Kanpur had much better air quality than Lucknow the entire year. The minimum AQI recorded in monsoon season and most polluted season was winter having highest AQI.

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#### Compliance with ethical standards

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No conflict of interest to be disclosed.

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