Air Quality Assessment with Human Health Effects for Kota Metropolis, Rajasthan (India)

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Abstract
Bad air quality is the number one environmental concern globally due to its severe impact on animals, plant life, humans and property. This study has assessed air quality and health impact on humans in Kota metropolis, Rajasthan (India), to increase the understanding of the relation between health and pollutant sources, emission characteristics, topography, and meteorological conditions. AQI and EF are also calculated to determine the pollution category and critical level of pollutants, respectively. The health effects of particulate matter on inhabitants are estimated with the AirQ+ software. The annual concentration of PM₁₀ and PM₂.₅ were more than prescribed limits by CPCB, while SO₂ and NO₂ are well below the prescribed limits. The maximum concentrations of pollutants were detected in Winter, followed by Summer and Rainy seasons. AQI varies from satisfactory to inferior category. EF was more than 1 for all monitoring stations for PM₁₀ and PM₂.₅ exhibiting High pollution, 0.5-.09 indicates Moderate pollution for NO₂, while less than .5 for SO₂ shows Low pollution. Particulate matter is the primary cause of air pollution. The PM₂.₅ induced ENACs (Estimated Number of Attributable Cases) for all causes of mortality, COPD, ALRI, LC, IHD, and stroke were 4546, 435, 255, 806,1958, and 1772, respectively. The ENACs for post neonatal infant mortality, the prevalence of bronchitis, and chronic bronchitis due to PM₁₀ increased by 326006, 716, and 13700, respectively. This study carries useful findings and suggestions for stakeholders and policymakers to control and mitigate the decrement in air quality.
Introduction

Air pollution kills about 6.9 million people worldwide, as per the World Health Organisation (WHO).\textsuperscript{1} Particulate matter (PM) is the 4\textsuperscript{th} leading cause of 85 risk factors as per the Global Burden of Disease study, leading to more than 5 million deaths in 2017.\textsuperscript{1,2} 46 Indian cities are among the 100 most polluted cities globally, attributed to the high concentration of air pollutants.\textsuperscript{3} In 2019, more than 1.13 lakh deaths in Rajasthan were due to air pollution.\textsuperscript{4} According to the literature, the primary air pollutants in the Indian scenario are Particulate matter (PM\textsubscript{2.5} and PM\textsubscript{10}), Sulphur dioxide(SO\textsubscript{2}), Nitrogen dioxide (NO\textsubscript{2}), Ozone (O\textsubscript{3}), Carbon monoxide (CO), Lead(Pb), and (NH\textsubscript{3}).\textsuperscript{5–7}

Atmospheric particulate matter (PM) is one of the key contributors to urban and rural air pollution.\textsuperscript{8} PM\textsubscript{2.5} (aerodynamic diameter ≤ 2.5 μm)\textsuperscript{9} and PM\textsubscript{10} (aerodynamic diameter ≤ 10 μm)\textsuperscript{10} with significant health problems, including chronic respiratory disease,\textsuperscript{11} premature mortality,\textsuperscript{12} aggravated asthma,\textsuperscript{13} acute respiratory,\textsuperscript{14} emergency visits, and hospital admissions symptoms,\textsuperscript{15,16} and decrease in lung function.\textsuperscript{17}

Other air pollutants include Sulphur dioxide (SO\textsubscript{2}), which adversely affects the mucous upper respiratory tract and nose membranes.\textsuperscript{17,18} 10-minute exposures at 4000 ppb reduce mean lung function values among groups of healthy individuals. It is among the most significant contributors to acid rain, which has several adverse effects on soil, water, property, and materials.\textsuperscript{19,20}

Nitrogen dioxide (NO\textsubscript{2}) concentrations in Indian cities due to increased vehicles show an alarmingly high increasing trend.\textsuperscript{7,21,22} Continuous exposure to NO\textsubscript{2} with as little concentration (0.1 ppm) for 1-3 years increases the incidence of emphysema and bronchitis and affects lung performance. Further NO\textsubscript{2} concentration exceeding 1 ppm leads to decreased lung function and increased airway responsiveness to broncho-constrictions in healthy subjects. It also contributes to acid rains.\textsuperscript{23}

The parameters to be selected for assessing air quality in Kota metropolis, Rajasthan (India), is PM\textsubscript{2.5}, PM\textsubscript{10}, SO\textsubscript{2}, and NO\textsubscript{2}. The data is collected for all air quality monitoring stations from January 2018 to December 2021 for 4 years. This study also estimates the AQI and EF to determine the pollution category and critical level of pollutants. Very few studies have estimated human health risks due to air pollutants in Kota city. Hence, AirQ+ software is employed to assess the effect of particulate matter on human beings.

Study Area & Observation Period

The study area selected for assessing air quality is Kota metropolis, Rajasthan (India). Kota comes under the category of smart cities in India, consisting of 512 square meters of the geographical area in a dumber-like shape. The topmost length and width of the Kota district are 153 kilometres from north to south and 84 kilometres from east to west, respectively. The longitude and latitude of the district lie between 75º 37' to 77º 26' and 24º 25' to 25º 51', respectively.\textsuperscript{24,25}

| Sr. No. | Station                        | Longitude | Latitude | Station Type |
|--------|--------------------------------|-----------|----------|--------------|
| 1      | Fire Station, Shrinathpuram    | 75.82     | 25.13    | Manual       |
| 2      | Municipal Corporation Building | 75.83     | 25.16    | Manual       |
| 3      | Rajasthan Technical University | 75.80     | 25.13    | Manual       |
| 4      | RSPCB, Regional Office         | 75.86     | 25.12    | Manual       |
| 5      | Samcore Glass Limited          | 75.91     | 25.17    | Manual       |
| 6      | Sewage Treatment Plant, Balita | 75.84     | 25.22    | Manual       |
| 7      | Shrinathpuram Stadium          | 75.82     | 25.14    | Continuous   |

The parameters selected from the literature review analysis for air quality assessment in Kota are PM\textsubscript{10}, PM\textsubscript{2.5}, SO\textsubscript{2}, and NO\textsubscript{2}. There are six manual and one continuous air sampling station situated in different
localities of Kota city to measure air quality in the metropolis. The GPS coordinates of air quality monitoring stations are shown in Figure 1 and Table 1. The observation period for the study is four years, from 1st January 2018, to 31st December 2021. The data is collected from Regional Office, Rajasthan State Pollution Control Board (RSPCB), Kota.

The data are collected for PM$_{10}$, PM$_{2.5}$, SO$_2$, and NO$_2$ and then segregated for seasonal and annual analysis. The segregated data were then compared with Indian National Ambient Air Quality Standards (NAAQS), as mentioned in Table 2, to determine the pollution. The effect of the meteorological parameters such as Temperature and Rainfall is also taken into account to determine pollution. Health impacts are evaluated with the help of AirQ+ Software. The overall research methodology followed in this research work is graphically present in Figure 2.
Air Quality Index

The weighted values of each air pollutant are converted into a single number by the air quality index (AQI). The CPCB method to calculate AQI in India is a two-step process, (i) Calculation of subindex for each air pollutant, and (ii) Maximum operator system to define AQI. AQI range with respective category and colour code is tabulated in Table 3.

The governing equation to calculate the subindex \((S_i)\) is shown in equation 1.

\[
S_i = \left[ \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} \right] \cdot P_C - BP_{LO} + I_{LO} \quad \text{...(1)}
\]

Where,

- \(I_{HI}\) = AQI corresponding to \(BP_{HI}\),
- \(I_{LO}\) = AQI corresponding to \(BP_{LO}\),
- \(BP_{HI}\) = Breakpoint concentration higher or equivalent to specified air pollutant concentration,
- \(BP_{LO}\) = Breakpoint concentration lower or equivalent to specified air pollutant concentration, and
- \(P_C\) = concentration of air pollutants.

The estimation of AQI is based on the maximum operator system, as shown in equation 2.

\[
AQI = \max\{S_1, S_2, S_3, S_4, \ldots S_n\} \quad \text{...(2)}
\]

AQI range with respective category and colour code is mentioned in Table 3.

**Table 2: NAAQS for air pollutants prescribed by CPCB**

| Pollutant (µg/m³) | TWA       | Ambient air concentration |
|-------------------|-----------|---------------------------|
|                   |           | Non-sensitive area | Sensitive area |
| \(SO_2\)         | Yearly    | \(\leq 50\)            | \(\leq 20\) |
|                   | 24 hour   | \(\leq 80\)            | \(\leq 80\) |
| \(NO_2\)         | Yearly    | \(\leq 40\)            | \(\leq 30\) |
|                   | 24 hour   | \(\leq 80\)            | \(\leq 80\) |
| \(PM_{10}\)      | Yearly    | \(\leq 60\)            | \(\leq 60\) |
|                   | 24 hour   | \(\leq 100\)           | \(\leq 100\) |
| \(PM_{2.5}\)     | Yearly    | \(\leq 40\)            | \(\leq 40\) |
|                   | 24 hour   | \(\leq 60\)            | \(\leq 60\) |

\*TWA: Time-weighted average

**Table 3: AQI range with respective category and colour code.**

| AQI category | Colour  | AQI Range     |
|--------------|---------|---------------|
| Severe       | Maroon  | 401 to 500    |
| Very poor    | Red     | 301 to 400    |
| Poor         | Orange  | 201 to 300    |
| Moderate     | Yellow  | 101 to 200    |
| Satisfactory | Green   | 51 to 100     |
| Good         | Light green | 0 to 50     |

**Exceedance Factor**

The ratio of the annual average concentration of critical pollutant to the annual national standard for critical pollutant is termed as exceedance factor. EF is divided into various categories depending on the values mentioned in Table 4. The Exceedance factor is to be calculated by the following equation:

\[
EF = \frac{\bar{C}_{pp}}{\bar{S}_{pp}} \quad \text{...(3)}
\]
Where,
EF = Exceedance Factor,
AC = Annual concentration of pollutant, and
AS = Annual standard concentration of pollutant.

in this study with the help of WHO-invented software, AirQ+. This software utilises concentration-response functions to execute the assessment of human health risk.

The long-term and short-term effects of PM and PM on current concentration are analysed in this study. LTEs and STEs are evaluated on the following basis: (a) Annual PM and PM concentration, (b) Population data, (c) incidence rate per lac population or cause-specific death rate, (d) Acceptable limits of Specific pollutant, and (e) WHO prescribed relative risk (RR) values. ENACs are provided by the AirQ+ software. Relative risk (RR) values obtained through the literature survey are tabulated in Table 5.

Table 4: Pollution level related to exceedance factor (EF).

| Category | Exceedance factor | Level of pollution |
|----------|-------------------|--------------------|
| 1        | >1.5              | Critical pollution (C) |
| 2        | 1.0–1.4           | High pollution (H)   |
| 3        | 0.5–0.9           | Moderate pollution (M) |
| 4        | <0.5              | Low pollution (L)    |

Health Effects of Particulate Matter
An assessment of human health risk due to long-term exposure to a particular air pollutant is estimated

Table 5: Relative risk values for PM10 and PM2.5.

| Mortality / Morbidity | Incidences per Lac Population | RR (CI: 95 %) |
|-----------------------|-------------------------------|---------------|
| LTEs of PM2.5         |                               |               |
| Stroke Mortality      | 436                           | 1.062 (1.04 - 1.083) |
| IHDMortality          | 436                           | 1.062 (1.04 - 1.083) |
| COPD Mortality (Adults) | 101          | 1.062 (1.04 - 1.083) |
| ALRI Mortality        | 49                            | 1.062 (1.04 - 1.083) |
| Lung Cancer Mortality (Adults) | 132       | 1.062 (1.04 - 1.083) |
| All Causes Mortality (Adults) | 1013     | 1.062 (1.04 - 1.083) |
| STEs of PM2.5         |                               |               |
| All Causes Mortality (Adults) | 1013     | 1.012 (1.004 - 1.020) |
| CVD Hospital Admission | 101             | 1.009 (1.007 - 1.016) |
| Respiratory Disease Hospital Admission | 1260 | 1.019 (0.998 - 1.040) |
| LTEs of PM10          |                               |               |
| Bronchitis Prevalence in Kids | 66               | 1.117 (1.04 - 1.189) |
| Chronic Bronchitis Incidence | 1013          | 1.080 (0.98 - 1.190) |
| Infant Mortality (Post neonatal) | 497        | 1.040 (1.02 - 1.070) |
| STEs of PM10          |                               |               |
| Frequency of Asthma Symptoms | 66               | 1.028 (1.006 - 1.064) |

Results
Assessment of Air Quality
The selected monitoring period for this study was four years, from 1st January 2018 to 31st December 2021. Monthly and seasonal variations of NO2, SO2, PM10, and PM2.5 for all monitoring stations are shown in Figures 3, 4, 5 and 6, respectively. The calculated AQIs for all the monitoring stations are shown in Figure 7.
Table 6: Station-wise different air quality parameters in the Winter season.

| Year | Parameter | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 |
|------|-----------|------|------|------|------|------|------|------|
| 2018 | PM<sub>2.5</sub> | 68.33 | 62.99 | 87.58 | 92.26 | 66.35 | 66.75 | 66.18 |
|      | PM<sub>10</sub> | 172.00 | 156.00 | 209.00 | 228.00 | 166.50 | 163.50 | 163.21 |
|      | SO<sub>2</sub> | 7.26 | 7.21 | 6.86 | 8.40 | 7.39 | 7.00 | 14.37 |
|      | NO<sub>2</sub> | 28.53 | 27.70 | 27.19 | 28.41 | 27.16 | 27.70 | 25.19 |
|      | AQI       | 148  | 137  | 187  | 208  | 144  | 142  | 142  |
| 2019 | PM<sub>2.5</sub> | 62.92 | 71.63 | 95.86 | 93.61 | 70.00 | 66.64 | 64.06 |
|      | PM<sub>10</sub> | 128.25 | 145.50 | 193.25 | 190.75 | 142.00 | 135.25 | 129.80 |
|      | SO<sub>2</sub> | 7.96 | 7.18 | 8.39 | 8.05 | 7.49 | 6.97 | 8.86 |
|      | NO<sub>2</sub> | 26.32 | 25.72 | 26.84 | 25.98 | 25.24 | 24.98 | 40.62 |
|      | AQI       | 119  | 139  | 220  | 212  | 133  | 124  | 120  |
| 2020 | PM<sub>2.5</sub> | 55.03 | 71.85 | 53.54 | 87.14 | 70.81 | -    | 62.18 |
|      | PM<sub>10</sub> | 102.50 | 133.75 | 100.00 | 164.25 | 130.25 | -    | 115.26 |
|      | SO<sub>2</sub> | 6.13 | 6.35 | 6.62 | 6.44 | 6.31 | -    | 9.06 |
|      | NO<sub>2</sub> | 24.70 | 24.62 | 23.22 | 23.67 | 23.52 | -    | 27.25 |
|      | AQI       | 101  | 140  | 89   | 190  | 136  | -    | 110  |
| 2021 | PM<sub>2.5</sub> | 95.37 | 102.84 | 87.85 | 127.84 | 108.09 | -    | 92.88 |
|      | PM<sub>10</sub> | 147.75 | 161.25 | 135.75 | 199.50 | 169.75 | -    | 146.33 |
|      | SO<sub>2</sub> | 7.87 | 8.46 | 7.97 | 8.59 | 8.05 | -    | 10.08 |
|      | NO<sub>2</sub> | 31.97 | 28.96 | 29.46 | 29.61 | 28.78 | -    | 32.55 |
|      | AQI       | 218  | 243  | 193  | 306  | 260  | -    | 210  |

*AS: Air Station

Fig. 3: The monthly and annually variations in concentration of PM<sub>10</sub> from 2018 to 2021.
Fig. 4: The monthly and annually variations of PM$_{2.5}$ concentration from the years 2018 to 2021.

Fig. 5: The monthly and annually variations of SO$_2$ concentration from the years 2018 to 2021.
Fig. 6: The monthly and annually variation of NO₂ concentration from the years 2018 to 2021.

Fig. 7: The variation in Air quality index (AQI) on a monthly and annual basis from the years 2018 to 2021.
It is clear from Table 6 that the AS-4 (Regional Office, RSPCB) air quality monitoring station is in the top most position in the Winter season among all stations. It is observed from the analysis of monitored data that the air quality of this area is continuously deteriorating. Particulate matter is the leading cause of the worst air quality in this area. This area’s PM$_{2.5}$ and PM$_{10}$ concentrations were 87.58 and 209 µg/m$^3$ in 2018, 62.92 and 128.25 µg/m$^3$ in 2019, 53.54 and 100 µg/m$^3$ in 2020, and 87.14 and 164.25 µg/m$^3$ in 2021, respectively. The variation in concentration of PM$_{10}$ and PM$_{2.5}$ on a monthly and annual basis for all monitoring stations is shown in Figures 3 and 4. The CPCB permissible limits of PM10 and PM$_{2.5}$ are 100 and 60 micrograms per meter cube, respectively. Not a single location follows the CPCB standards for PM$_{10}$ providing significant evidence of being an air pollutant. A similar scenario is observed for PM$_{2.5}$ except for two stations (AS-1 and AS-3) in 2020. It has been observed that the station with a high PM$_{2.5}$ concentration also has a higher concentration of PM$_{10}$ and vice versa in the Winter season.

Shreenathpuram stadium (AS-7) always has a high concentration of SO$_2$, but the concentrations were almost seven times lower than the prescribed limit of 80 µg/m$^3$ mentioned in Indian NAAQS. All other stations have almost similar trends for SO$_2$ in the Winter season each year during the observation period of 4 years. The highest and lowest concentration of SO$_2$ were 14.37 and 6.86 µg/m$^3$ in 2018, 8.86 and 6.97 µg/m$^3$ in 2019, 9.06 and 6.13 µg/m$^3$ in 2020, and 10.08 and 7.87 µg/m$^3$ in 2021, respectively. The variation in concentration of SO$_2$ on a monthly and annual basis for all monitoring stations is shown in Figure 5.

Monitoring station AS-7 also has a high concentration of NO$_2$, but the concentration is almost two times lower than the prescribed limit of 80 micrograms per meter cube set by the CPCB India. The maximum and minimum concentrations of NO$_2$ were 28.53 and 25.19 µg/m$^3$ in 2018, 40.62 and 24.98 µg/m$^3$ in 2019, 27.25 and 23.22 µg/m$^3$ in 2020, and 32.55 and 28.78 µg/m$^3$ in 2021, respectively. The variation in concentration of NO$_2$ on a monthly and annual basis for all Sampling locations is shown in Figure 6.

Air Quality Index (AQI) is also calculated from the method given by the Central Pollution Control board, India. The AQI results exhibit a high dependency on the amount of particulate matter. Stations with a higher concentration of particulate matter (PM$_{2.5}$ and PM$_{10}$) also have higher AQI and Vice Versa values. The largest and lowest concentration of AQI were 208 and 137 in 2018, 220 and 119 in 2019, 190 and 89 in 2020, and 306 and 193 in 2021, respectively. The AQI varied from 89 (satisfactory) to 306 (very poor) during the observation period during the Winter seasons. The variation in AQI on a monthly and annual basis for all monitoring stations is shown in Figure 7.

| Parameters | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 |
|------------|------|------|------|------|------|------|------|
| PM$_{2.5}$ | 65.79| 59.66| 72.93| 79.38| 60.30| 60.70| 54.71|
| PM$_{10}$  | 138.25| 123.50| 179.25| 187.00| 163.75| 145.00| 163.71|
| SO$_2$     | 7.25 | 9.33 | 6.51 | 7.07 | 7.65 | 6.19 | 11.74|
| NO$_2$     | 29.86| 32.43| 28.94| 31.56| 24.22| 32.35| 11.62|
| AQI        | 126  | 116  | 153  | 158  | 143  | 130  | 142  |

Table 7: Station-wise air quality parameters in the Summer season.

2018
It is clear from Table 7 that the AS-4 (Regional Office, RSPCB) air quality monitoring station is again in the topmost position in the Summer season among all stations. It is observed from the analysis of monitored data that the air quality of this area is continuously deteriorating. Particulate matter is the leading cause of the worst air quality in this area. This area's PM$_{2.5}$ and PM$_{10}$ concentrations were 58.67 and 187 µg/m$^3$ in 2018, 79.38 and 165 µg/m$^3$ in 2019, 41.66 and 94.54 µg/m$^3$ in 2020, and 146.13 and 69.31 µg/m$^3$ in 2021, respectively. The variation in concentration of PM$_{10}$ and PM$_{2.5}$ on a monthly and annual basis for all monitoring stations is shown in Figures 3 and 4.

The CPCB standards for PM$_{10}$ and PM$_{2.5}$ are 100 and 60 micrograms per meter cube, respectively. Not a single location follows the CPCB standards for PM10 except in 2020, providing significant evidence of being an air pollutant in Summers. A different scenario is observed for PM$_{2.5}$. The PM$_{2.5}$ concentration is within prescribed limits in Summers except in 2020. It has been observed that the station with a high PM$_{2.5}$ concentration also has a higher concentration of PM$_{10}$ and vice versa in the Summer season.

The concentrations of SO$_2$ were almost seven times lower than the prescribed limit of 80 µg/m$^3$ mentioned in Indian NAAQS for all stations in Summers during the observation period of 4 years. All stations have almost similar trends for SO$_2$ in the Winter season each year during the observation period. The highest and lowest concentration of SO$_2$ were 11.74 and 6.19 µg/m$^3$ in 2018, 9.74 and 6.05 µg/m$^3$ in 2019, 9.04 and 7.38 µg/m$^3$ in 2020, and 10.06 and 7.14 µg/m$^3$ in 2021, respectively. The variation in concentration of SO$_2$ on a monthly and annual basis for all monitoring stations is shown in Figure 5.

The NO$_2$ concentration is almost four times lower than the prescribed limit of 80 micrograms per meter cube set by CPCB India. The maximum and minimum concentrations of NO$_2$ were 32.43 and 11.62 micrograms per cubic meter in 2018, 24.95 and 22.50 micrograms per cubic meter in 2019, 18.87 and 16.32 µg/m$^3$ in 2020, and 24.43 and 22.40 µg/m$^3$ in 2021, respectively. The variation in concentration of NO$_2$ on a monthly and annual basis for all monitoring stations is shown in Figure 6.

Air Quality Index (AQI) is also calculated from the method given by the CPCB, India. The AQI results exhibit a high dependency on the amount of particulate matter. Stations with a higher concentration of particulate matter (PM$_{2.5}$ and
PM, also have higher AQI and Vice Versa values. The largest and lowest concentration of AQI were 158 and 116 in 2018, 165 and 110 in 2019, 95 and 67 in 2020, and 131 and 88 in 2021, respectively. The AQI varied from 67 (satisfactory) to 165 (moderate) during the observation period during the Summer seasons. The variation in AQI on a monthly and annual basis for all monitoring stations is shown in Figure 7.

Table 8: Station-wise air quality parameters in the Rainy season.

| Parameter | 2018 | 2019 | 2020 | 2021 |
|-----------|------|------|------|------|
|           | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 |
| PM,      | 41.38 | 34.33 | 52.72 | 42.71 | 39.55 | 42.42 | 35.34 | 54.75 | 54.25 | 69.75 | 84.75 | 55.75 | 60.25 | 76.31 | 55 | 54 | 70 | 85 | 56 | 60 | 76 |
| PM,      | 121.25 | 93.50 | 159.00 | 123.50 | 109.50 | 120.50 | 103.26 | 123.50 | 109.50 | 120.50 | 103.26 | 106 | 114 | 102 | 106 | 114 | 102 | 106 | 114 | 102 | 106 | 114 | 102 |
| SO,      | 6.86 | 6.79 | 6.57 | 7.19 | 7.10 | 6.36 | 8.84 | 6.36 | 6.07 | 5.77 | 6.50 | 6.33 | 5.86 | 9.13 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 | 6.76 |
| NO,      | 25.84 | 23.60 | 25.17 | 25.64 | 22.61 | 25.89 | 24.81 | 22.61 | 25.89 | 24.81 | 24.81 | 22.34 | 22.49 | 13.53 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 |
| AQI,     | 114 | 94 | 139 | 116 | 106 | 114 | 102 | 116 | 106 | 114 | 102 | 116 | 106 | 114 | 102 | 116 | 106 | 114 | 102 | 116 | 106 | 114 | 102 |

It is clear from Table 8 that the AS-4 (Regional Office, RSPCB) air quality monitoring station is in the top most position during the Rainy season among all stations. It is observed from the analysis of monitored data that the air quality of this area is continuously deteriorating. Particulate matter is the leading cause of the worst air quality in this area. This area's PM, and concentrations were 42.71 and 123.50 micrograms per cubic meter in 2018, 43.92 and 84.75 micrograms per cubic meter in 2019, and 67.14 and 121.50 µg/m in 2020, and 54.77 and 104.50 µg/m in 2021, respectively. The variation in concentration of PM, and PM, on a monthly and annual basis for all monitoring stations is shown in Figures 3 and 4.

The CPCB standards for PM, and PM, are 100 and 60 micrograms per meter cube, respectively.
All monitoring location follows the CPCB standards for PM\(_{10}\) except for the 2018 Rainy season, providing significant improvement in the air quality. A different scenario is observed for PM\(_{2.5}\). All monitoring location follows the CPCB standards for PM\(_{2.5}\). It has been observed that the station with a high PM\(_{2.5}\) concentration also has a higher concentration of PM\(_{10}\) and vice versa in the Rainy season.

Shreenathpuram stadium (AS-7) always has a high concentration of SO\(_2\), but the concentrations were almost seven times lower than the prescribed limit of 80 µg/m\(^3\) mentioned in Indian NAAQS. Rest all stations have almost similar trends for SO\(_2\) in the Winter season each year during the observation period of 4 years. The highest and lowest concentration of SO\(_2\) was 8.84 and 6.36 micrograms per cubic meter in 2018, 9.13 and 5.77 micrograms per cubic meter in 2019, 9.22 and 5.90 µg/m\(^3\) in 2020, and 9.95 and 6.30 µg/m\(^3\) in 2021, respectively. The variation in concentration of SO\(_2\) on a monthly and annual basis for all monitoring stations is shown in Figure 5.

Monitoring station AS-2 (Municipal Corporation) has a high concentration of NO\(_2\) during the observation period. Still, the concentration is almost three times lower than the prescribed limit of 80 micrograms per meter cube set by the CPCB India for all stations. The maximum and minimum concentrations of NO\(_2\) were 25.89 and 22.61 micrograms per cubic meter in 2018, 23.11 and 22.29 micrograms per cubic meter in 2019, 24.96 and 13.53 µg/m\(^3\) in 2020, and 26.08 and 20.36 µg/m\(^3\) in 2021, respectively. The variation in concentration of NO\(_2\) on a monthly and annual basis for all sampling locations is shown in Figure 6.

Air Quality Index (AQI) is also calculated from the method given by the CPCB, India. The AQI results exhibit a high dependency on the amount of particulate matter. Stations with a higher concentration of particulate matter (PM\(_{2.5}\) and PM\(_{10}\)) also have high AQI and Vice Versa. The largest and lowest concentration of AQI were 139 and 94 in 2018, 85 and 54 in 2019, 124 and 98 in 2020, and 103 and 65 in 2021, respectively. The AQI varied from 54 (satisfactory) to 139 (moderate) during the observation period during the Rainy seasons. The variation in AQI on a monthly and annual basis for all monitoring stations is shown in Figure 7.

### Table 9: Station-wise air quality parameters annually.

| Parameter | 2018 | 2019 | 2020 |
|-----------|------|------|------|
| PM\(_{2.5}\) | 50.85 | 52.18 | 42.17 |
| PM\(_{10}\)  | 143.83 | 106.58 | 81.92 |
| SO\(_2\)    | 7.12 | 7.02 | 6.47 |
| NO\(_2\)    | 28.08 | 24.15 | 22.57 |
| AQI         | 129 | 104 | 82  |

| Parameter | 2018 | 2019 | 2020 |
|-----------|------|------|------|
| PM\(_{2.5}\) | 50.85 | 52.18 | 42.17 |
| PM\(_{10}\)  | 143.83 | 106.58 | 81.92 |
| SO\(_2\)    | 7.12 | 7.02 | 6.47 |
| NO\(_2\)    | 28.08 | 24.15 | 22.57 |
| AQI         | 129 | 104 | 82  |
It is clear from Table 9 that the AS-4 (Regional Office, RSPCB) air quality monitoring station is in the topmost position on an annual basis among all stations. It is observed from the analysis of monitored data that the air quality of this area is continuously deteriorating. Particulate matter is the leading cause of the worst air quality in this area. This area's PM$_{2.5}$ and PM$_{10}$ concentrations were 64.55 and 179.50 micrograms per cubic meter in 2018, 72.30 and 146.83 micrograms per cubic meter in 2019, 65.31 and 126.80 µg/m$^3$ in 2020, and 83.97 and 150.04 µg/m$^3$ in 2021, respectively.

The AS-1 (Fire Station) air quality monitoring station is lower in particulate matter concentrations than other stations. The monitored PM$_{2.5}$ and PM$_{10}$ concentrations were 50.85 and 143.83 micrograms per cubic meter in 2018, 52.18 and 106.58 micrograms per cubic meter in 2019, 42.17 and 81.92 µg/m$^3$ in 2020, and 61.23 and 108.04 µg/m$^3$ in 2021, respectively. The variation in concentration of PM$_{10}$ and PM$_{2.5}$ on a monthly and annual basis for all monitoring stations is shown in Figures 3 and 4.

The CPCB standards for annual PM$_{10}$ and PM$_{2.5}$ are 60 and 40 micrograms per meter cube, respectively. Not a single location follows standards for PM$_{10}$ and PM$_{2.5}$, providing significant evidence of being air pollutants. It has been observed that the station with a high PM$_{2.5}$ concentration also has a higher concentration of PM$_{10}$ and vice versa in the Winter season.

Shreenathpuram stadium (AS-7) always has a high concentration of SO$_2$, but the concentrations were almost four times lower than the prescribed limit of 50 µg/m$^3$ mentioned in Indian NAAQS. All other stations have almost similar trends for SO$_2$ each year during the observation period of 4 years. The highest and lowest concentration of SO$_2$ were 11.65 and 6.52 micrograms per cubic meter in 2018, 9.25 and 6.29 micrograms per cubic meter in 2019, 9.11 and 6.47 µg/m$^3$ in 2020, and 10.03 and 7.26 µg/m$^3$ in 2021, respectively. The variation in concentration of SO$_2$ on a monthly and annual basis for all monitoring stations is shown in Figure 5.

The NO$_2$ concentration is almost 1.5 times lower than the prescribed limit of 40 micrograms per cubic meter set by CPCB India. The maximum and minimum concentrations of NO$_2$ were 28.64 and 20.54 micrograms per cubic meter in 2018, 29.24 and 23.27 micrograms per cubic meter in 2019, 22.57 and 21.76 µg/m$^3$ in 2020, and 27.32 and 25.10 µg/m$^3$ in 2021, respectively. The variation in concentration of NO$_2$ on a monthly and annual basis for all sampling locations is shown in Figure 6.

Air Quality Index (AQI) is also calculated from the method given by the Central Pollution Control Board, India. The AQI results exhibit a high dependency on the amount of particulate matter. Stations with a higher concentration of particulate matter (PM$_{2.5}$ and PM$_{10}$) also have high AQI and vice versa. The largest and lowest concentration of AQI were 155 and 116 in 2018, 141 and 104 in 2019, 118 and 82 in 2020, and 180 and 97 in 2021, respectively. The AQI varied from 82 (satisfactory) to 155 (moderate) during the observation period each year. The variation in AQI on a monthly and annual basis for all monitoring stations is shown in Figure 7.

**Exceedance Factor**

EF was more than 1 for all monitoring stations for PM10 and PM$_{2.5}$, exhibiting High pollution (H), 0.5-.09 indicates Moderate pollution (M) for NO$_2$, while less than .5 for SO$_2$ exhibits Low pollution (L). The exceedance Factor (EF) for air quality parameters at each monitoring station is shown in Figure 8 and tabulated in Table 10.
Table 10: Exceedance Factor (EF) for air quality parameters at each monitoring station.

| Parameter | Year | AS-1 | AS-2 | AS-3 | AS-4 | AS-5 | AS-6 | AS-7 |
|-----------|------|------|------|------|------|------|------|------|
| PM$_{2.5}$ | 2018 | 1.27 | 1.15 | 1.63 | 1.61 | 1.31 | 1.29 | 1.29 |
|          | 2019 | 1.30 | 1.32 | 1.70 | 1.81 | 1.33 | 1.32 | 1.32 |
|          | 2020 | 1.05 | 1.40 | 1.07 | 1.63 | 1.26 | -    | 1.06 |
|          | 2021 | 1.53 | 1.70 | 1.38 | 2.10 | 1.83 | -    | 1.51 |
| PM$_{10}$ | 2018 | 2.40 | 2.07 | 3.04 | 2.99 | 2.44 | 2.38 | 2.39 |
|          | 2019 | 1.77 | 1.80 | 2.31 | 2.45 | 1.80 | 1.79 | 1.78 |
|          | 2020 | 1.36 | 1.81 | 1.39 | 2.11 | 1.62 | -    | 1.37 |
|          | 2021 | 1.80 | 2.03 | 1.62 | 2.50 | 2.19 | -    | 1.81 |
| SO$_2$   | 2018 | 0.14 | 0.16 | 0.12 | 0.15 | 0.13 | 0.13 | 0.23 |
|          | 2019 | 0.14 | 0.12 | 0.15 | 0.14 | 0.13 | 0.14 | 0.19 |
|          | 2020 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 | -    | 0.18 |
|          | 2021 | 0.14 | 0.15 | 0.16 | 0.16 | 0.16 | -    | 0.20 |
| NO$_2$   | 2018 | 0.70 | 0.70 | 0.68 | 0.71 | 0.62 | 0.72 | 0.51 |
|          | 2019 | 0.60 | 0.59 | 0.62 | 0.60 | 0.60 | 0.58 | 0.73 |
|          | 2020 | 0.56 | 0.57 | 0.54 | 0.55 | 0.54 | -    | 0.50 |
|          | 2021 | 0.68 | 0.66 | 0.65 | 0.66 | 0.64 | -    | 0.63 |

Fig. 8: Exceedance Factor (EF) for each monitoring station.

Health Effect of Particulate Matter
The average concentrations of PM$_{10}$ and PM$_{2.5}$ obtained from the Shreenathpuram station (AS-7) for Kota during the observation period are 110.2 and 51.8 µg/m$^3$. LTEs and STEs of particulate matter pollution are estimated with these average values of PM$_{10}$ and PM$_{2.5}$. The estimated long-term impact of current PM$_{2.5}$ concentration on human health is shown in Table 11. The PM$_{2.5}$-induced long-term ENACs for all causes of mortality, COPD, ALRI, LC, IHD, and stroke were 4546, 435, 255, 806, 1958, and 1772, respectively. Whereas the short-term ENACs for CVDHA (cardiovascular disease), RDHA (respiratory disease hospital admission), and all-cause mortality (adults) were 49, 1251, and 659, respectively. The estimated short-term impact of current PM$_{2.5}$ concentration on human health is shown in Table 12.
Table 11: The estimated long-term impact of current PM$_{2.5}$ concentration on human health.

| All CausesMortality (Adults) | Mean ENACs | Confidence Interval (CI) |
|------------------------------|------------|--------------------------|
| Lung Cancer Mortality (Adults) | 806        | 403 - 1124               |
| ALRI Mortality                | 255        | 162 - 332                |
| COPD Mortality (Adults)       | 435        | 281 - 647                |
| IHD Mortality                 | 1958       | 1321 - 3756              |
| Stroke Mortality              | 1772       | 1055 - 2826              |

The ENACs (long-term) for postneonatal infant mortality, the prevalence of bronchitis, and chronic bronchitis due to PM$_{10}$ increased by 326,006, 716, and 13,700, respectively, Whereas the ENAC (short-term) for asthma symptoms in kids, was 322. The estimated LTEs and STEs of current PM$_{10}$ concentration on human health are shown in Table 13.

Long-term effects of PM$_{10}$ and PM$_{2.5}$ are compared with National Capital Territory (NCT) Delhi (India), Alwar (India), and Tehran (Iran). The maximum number of cases was for NCT Delhi, followed by Alwar, Kota, and Tehran. It is due to the difference between the annual concentration of particulate matter (PM$_{10}$ and PM$_{2.5}$) among these cities. The annual concentration of PM$_{10}$ and PM$_{2.5}$ were 292 and 73.53 micrograms per cubic meter at NCT Delhi, 158.75 and 73.53 µg/m$^3$ at Alwar, and 110.2 and 51.8 µg/m$^3$ at Kota, respectively. The annual PM$_{2.5}$ concentration in Tehran (Iran) was 34.5 µg/m$^3$.

Table 12: Estimated short-term impact of current PM$_{2.5}$ concentration on human health.

| Respiratory Disease Hospital Admission | Average | CI   |
|---------------------------------------|---------|------|
| ENACs                                 | 1251    | 0 - 2549 |
| CVD Hospital Admission                | 49      | 9 - 88  |
| ENACs                                 | 659     | 245 - 1062 |
| All Causes Mortality                  | ENACs    | 659     | 245 - 1062 |
Table 13: Long-term effects (LTEs) and short-term effects (STEs) of PM10 for Kota.

|                      | Mean     | CI                |
|----------------------|----------|-------------------|
| **Infant Mortality (Post Neonatal) (LTEs)** |          |                   |
| ENACs                | 32606    | 180553 - 493915   |
| Chronic Bronchitis Incidences (Adults) |          |                   |
| ENACs                | 13700    | 6645 - 16839      |
| Prevalence of Bronchitis in Kids |          |                   |
| ENACs                | 716      | 0 - 1099          |
| Asthma Symptoms Kids (STEs) |          |                   |
| ENACs                | 322      | 78 - 523          |

Fig. 9: Average health effects on inhabitants of Kota associated with particulate matter exposure.

Table 14: Comparison of Long-term effects among different cities.14,32,33

| Long Term Effect          | Kota, India | Alwar, India | NCT, Delhi | Tehran, Iran |
|---------------------------|-------------|--------------|------------|-------------|
| **PM$_{2.5}$**           |             |              |            |             |
| All natural causes mortality | 4546        | 12867        | 72254      | 6710        |
| COPD for adults           | 435         | 1089         | 6545       | 172         |
| Lung cancer               | 806         | 2225         | 7568       | 135         |
| Stroke                    | 1772        | 4353         | 28233      | 1145        |
| **PM$_{10}$**            |             |              |            |             |
| All natural causes mortality | 326006     | 878494       | 150110     | -          |
| Chronic bronchitis in adults | 13700      | 32698        | 50810      | -          |
| Bronchitis in children    | 716         | 1799         | 1189       | -          |

Discussion
The main reasons behind low concentrations of SO$_2$ and NO$_2$ are the absence of a source of their primary production, such as burning fossil fuels, and other reduction initiatives taken by the Government.18,20,34,35 The leading causes of higher PM$_{10}$ and PM$_{2.5}$ are natural dunes,36 cement plants,37 stone cutting industries,37 crushing industries,38 municipal incineration, power plants, chemical plants,39 diesel and petrol stations,19 natural dust,9 stuble burning,40 vehicular population,36 etc.
Air quality varies enormously from day to day at a particular location due to the dynamics of the atmosphere, even though emissions may remain relatively constant. The factors affecting the atmosphere's dynamics are temperature, pressure, wind, moisture, and relative humidity.\(^{18}\)

The maximum concentration of air pollutants was observed in the Winter season, followed by the Summer and Rainy seasons of the observation period except the year 2020. High-pressure systems are generally encountered during Winter. High-pressure systems are related to clear sky, light winds, and atmospheric stability. When such a system becomes stagnant over an area for several days, air contaminants can cause air pollution problems.

While low-pressure systems (usually associated with cloudy skies, gusty winds, atmosphere instability, and the formation of fronts) and other meteorological parameters significantly contribute to the lower concentration of pollutants in the Summer and Rainy seasons.

The minimum concentration was detected during the Rainy season. The main reason behind it is that the precipitation occurred due to the study area's southwest monsoon and a low-pressure system. Rain always serves as a cleaning agent for the atmosphere, removing soluble gases and particulate matter in a washout process.\(^{41}\)

The Summer season in 2020 has the lowest concentrations of air pollutants compared to the Rainy season. It may be because India was affected by the outbreak of Coronavirus Disease of 2019 (Covid-19), the global-level infectious disease declared as a pandemic by WHO (World Health Organization).\(^7\)

Many countries had started imposing complete lockdown across the globe resulting in full closure of business, trade, cultural, tourist, educational, and socio-economic activities. India went for a complete lockdown starting from 25th March 2020, which continued till 17th May 2020, as imposed by the Government of India.\(^{42,43}\)

This lockdown resulted in the complete halting of transportation, business activities, shops and malls, tourist and recreational centres, and other economic activities. This resulted in a significant decrease in fuel demand by almost 70% due to the non-movement of transport and domestic vehicles, regularly used for movement.\(^{44}\)

There are varied reasons which may be attributed to improvement in air quality in lockdown. Closure of industrial and transportation activities, reduced mining, and lesser economic activities have significantly reduced particulate matter concentrations. This also concurs that traffic pollution and industrial activities which are major point source contributors to deteriorating air quality. Sustainable remedial measures are to be considered as a major step towards reducing air pollution and having a proper balance with economic activities. However, it is noteworthy that the lockdown was also forced in 2021, but it had less impact on air quality improvement compared to the lockdown in 2020 in India.

**Conclusion**

This study concludes that Kota metropolis is subjected to particulate matter pollution and inhabitants of the city are extremely susceptible to the adverse effects of PM\(_{10}\) and PM\(_{2.5}\). Urbanised areas are the prime hotspots that contribute significantly toward particulate matter concentrations. Lifestyle patterns, culture, land use patterns, and the presence of heavy industries are other socio-cultural factors contributing to air quality.

The absence of primary production sources of NO\(_2\) and SO\(_2\), such as burning fossil fuels, and other reduction initiatives taken by the Government, have a very significant impact on maintaining low levels of these pollutants.

Temperature and rainfall have significant impacts on the air quality of the Kota metropolis. Minimum concentration of pollutants was observed in the Rainy followed by Summer and Winter seasons. The range of AQI varies between the satisfactory to very poor category. EF was more than 1 for all monitoring stations for PM\(_{10}\) and PM\(_{2.5}\), exhibiting High pollution (H), 0.5–0.9 exhibiting Moderate pollution (M) for NO\(_2\), while less than 0.5 for SO\(_2\) exhibits Low pollution (L). Human health risk assessment results reveal that cardiovascular and respiratory disease principally contributes to total mortality caused by particulate matter pollution.
Therefore, particulate matter pollution is a critical factor to be considered by the policymakers to ensure sustainability coupled with environmental concerns. Improving solid waste management, increasing green beltway, restricting open burning, planting some new species of plants in internal sources, prohibiting old vehicles, and shifting vehicles towards clean energy would be adequate to mitigate the effect of particulate matter on inhabitants.

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Conflict of Interest
There is no conflict of interest between the authors.

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