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Assessment of Ambient Air Pollution Levels: A Five-Year Analysis of $PM_{2.5}$, NO, NO_2, NO_X, CO, and SO_2

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Abstract: The study conducted on the air quality of five highly polluted cities in India over the last five years (2015-2020) sheds light on the detrimental effects of air pollution and the need for monitoring and mitigation. The research focused on six major air pollutants: $PM_{2.5}$, NO, NO_2, NO_X, CO, and SO_2. The study's findings reveal that the concentrations of these air pollutants consistently exceeded the limits set by the National Ambient Air Quality Standards 2009 and the World Health Organization's Ambient Air Quality Standards. This indicates that the air quality in these cities was consistently poor and posed a significant health risk to the population. The study emphasises that certain subpopulations, such as the elderly, young children, and individuals with pre-existing health conditions like asthma, are more vulnerable to the harmful effects of air pollutants. Elevated levels of pollutants in the air can lead to severe health effects and contribute to the development of serious diseases. Furthermore, the study highlights that the air quality significantly improved in 2020 due to the nationwide lockdown imposed in response to the COVID-19 pandemic. The restrictions on mobility and industrial activities resulted in reduced emissions, leading to a temporary improvement in air quality. These conclusions underscore the critical importance of understanding the harmful effects of air pollutants and taking measures to protect human health and preserve the quality of the environment.

Keywords: Air Pollutants, $PM_{2.5}$, NO, NO_2, NO_X, CO, SO_2, Harmful effects, Ambient air quality standards

1. Introduction

Urban air pollution is a significant environmental issue, particularly in developing nations. The generation and transmission of air pollutants, which produce ambient air pollution, comprise the urban atmosphere's air pollution pathway (Liang & Gong 2020). Air pollution, including particulate matter (PM), significantly impacts public and individual health. PM refers to tiny particles suspended in the air, and its size can vary, with $PM_{2.5}$ and PM_{10} being the most commonly measured sizes.

When inhaled, PM can penetrate deep into the respiratory system, leading to various health problems. PM can cause or worsen respiratory conditions such as asthma, bronchitis, and other respiratory infections. The fine particles can irritate the airways, trigger inflammation, and impair lung function. PM exposure is linked to an increased risk of cardiovascular diseases, including heart attacks, strokes, and high blood pressure. The tiny particles can enter the bloodstream, leading to inflammation, oxidative stress, and plaque formation in blood vessels. Long-term exposure to high levels of PM has been associated with premature death due to respiratory and cardiovascular diseases. The adverse health effects are more pronounced in vulnerable populations such as the elderly, children, and individuals with pre-existing health conditions. Certain types of PM, particularly those containing toxic substances like heavy metals and polycyclic aromatic hydrocarbons (PAHs), have been classified as carcinogens. Prolonged exposure to these particles increases the risk of developing lung cancer and other respiratory cancers. PM exposure has also been linked to a range of other health problems, including reproductive and developmental disorders, neurologic effects, and adverse birth outcomes (Pandey et al. 2021).

Today's air pollution in the world is the major cause of many deadly diseases like ischemic heart disease, stroke, lung cancer etc. According to the WHO, 4.2 million people die every year because of exposure to ambient outdoor air pollution (Klopfer 1989). Around 1.67 million people died due to air pollution in India in 2019 (Indira et al. 2022).

Air pollution affects the respiratory and cardiovascular systems and has detrimental effects on eye health. Exposure to air pollutants can impact the eyes, ranging from minor irritation to chronic discomfort and more severe conditions (Kamboj & Mathur 2022). Assessing the Impact of Lockdown on Air Pollution: A Data

Analysis of India's Nationwide Restrictions. This study examines the influence of the nationwide lockdown imposed in India from March 25, 2020, to May 31, 2020, on air pollution levels. The objective is to understand the changes in air quality during the different phases of the lockdown and its potential impact on environmental and public health.The lockdown consisted of four phases, with Phase 1 lasting 21 days (March 25, 2020, to April 14, 2020), Phase 2 lasting 19 days (April 15, 2020, to May 3, 2020), Phase 3 lasting 14 days (May 4, 2020, to May 17, 2020), and Phase 4 lasting 14 days (May 18, 2020, to May 31, 2020).

Analysing data on air pollutants such as $PM_{2.5}$, NO, NO_2, NO_X, CO, and SO_2 contributes to determining the extent to which the lockdown measures contributed to changes in air pollution levels across India. This analysis will provide insights into the effectiveness of the lockdown in reducing air pollution and its potential implications for mitigating the burden of disease associated with respiratory illnesses and other health risks.

The study underscores the significance of understanding the relationship between lockdown measures and air pollution, which can inform future policy decisions and actions to improve air quality and safeguard public health (Vinti & Vaccari 2022). The changes observed in the concentration of air pollutants before and after the nationwide lockdown in 2020 can vary depending on several factors, including the specific region, local sources of pollution, and the effectiveness of the lockdown measures. However, generally, the lockdown measures implemented to combat the COVID-19 pandemic had a noticeable impact on air pollution levels.

The ambient air quality standards are shown in Table 1 and Table 2.

Table 1. Revised National Ambient Air Quality Standards 2009 (Azizan et al. 2023)

Pollutants	Annual mean [μg/m³]	24 hours mean [μg/m³]
$PM_{2.5}$	40	60
NO_2	40	80
SO_2	50	80
CO	2 (8 hours)	4 (1 hour)

Table 2. WHO Ambient Air Quality Standards (Lu 2020)

Pollutants	Annual mean [μg/m³]	24 hours mean [μg/m³]
$PM_{2.5}$	5	15
NO_2	10	25
SO_2	–	40

1.1. Particulate Matter

A mixture of solid and liquid particles suspended in the air is called particulate matter (PM). These are divided into three groups: coarse, fine, and ultrafine. Larger and relatively heavier than fine particles, coarse particles have a diameter of 2.5 micrometres to 10 micrometres (approximately 25 to 100 times thinner than human hair) and tend to settle. Examples include pollen, dust, and spores. PM2.5 refers to particles with a diameter of less than 2.5 micrometres and are suspended for a prolonged period (Schraufnagel et al. 2019, Khan et al. 2024).

1.1.1. Health effects

The fifth-leading risk factor for death is outdoor fine particles with a diameter of less than 2.5 microns, which are responsible for 4.2 million annual deaths and more than 103 million years of lost life due to disability. Numerous other mental issues have been connected to air pollution. Particulates can injure tissue directly by invading organs or indirectly through systemic inflammatory response (Sorensen et al. 2022). Even at exposure levels below the safe air quality guidelines that have been specified, negative effects may still occur (Carrington 2019, Hermansson 2023, Hrynzovskyi et al. 2023).

1.2. Sulfur dioxide (SO_2)

Sulfur and oxygen combine to form sulphur dioxide (SO_2), a gaseous air pollutant. Burning fuels containing sulphur, such as coal, oil, or diesel, produces SO_2 (Dadashi et al. 2022). Electricity production, commercial boilers, and other industrial operations, including metal processing and petroleum refining, are the main sources of sulphur dioxide emissions. Other important diesel engine sources include obsolete buses and vehicles, locomotives, ships, and off-road diesel equipment (Dadashi et al. 2022).

1.2.1. Health effects

The respiratory system, lungs, and eyes can all be impacted by SO_2 and other effects. Coughing, mucus production, asthma and chronic bronchitis flare-ups, and increased susceptibility to respiratory tract infections are all symptoms of respiratory tract inflammation (Lu 2020). On days with greater SO_2 levels, hospital admissions for heart illness and mortality rise. Acid rain contributes to deforestation and is primarily made up of sulfuric acid, created when SO_2 reacts with water (Lu 2020).

Acid rain's primary ingredient is sulfuric acid, created when SO_2 reacts with water and air. Acid rain can erode building materials and paints, induce deforestation, and acidify streams to the detriment of aquatic life (Garrett et al. 1998).

1.3. Nitrogen dioxide NO_2

One of a set of closely related gases known as nitrogen oxides, or NO_x, nitrogen dioxide, or NO_2, is a gaseous air pollutant made up of nitrogen and oxygen. When fossil fuels like coal, oil, gas, or diesel are burned at high temperatures, NO_2 is created. NO2 and other nitrogen oxides influence the ozone-forming chemical processes and particle pollution in the ambient air. It is one of six commonly occurring air pollutants for which federal air quality rules limit their presence in outdoor air. Burning fossil fuels like wood or natural gas indoors can also produce NO_2.

1.3.1. Health effects

Plant life, including trees, forests, and crops, can suffer damage from NO_2. Only exposures reaching at least 0.2 ppm for 100 hours or more during the growth season have been reported for this (Saitoh & Mizusawa 2022). Additionally, NO_2 can reduce visibility directly by selectively absorbing shorter blue wavelengths of visible light and indirectly by helping to create nitrate aerosol clouds, which also reduces visibility (Saitoh & Mizusawa 2022).

For youngsters with asthma, exposure to NO_2 is particularly detrimental. Children with asthma who reside in homes with gas stoves are more likely to experience respiratory symptoms such as wheezing, coughing, and chest tightness (Chapman et al. 2003). In addition, although this association was not discovered in males, using a gas stove was linked to worse lung function in girls with asthma (Novakovic 2023). Children with asthma may experience less respiratory symptoms if ventilation is used when using gas stoves.

1.4. Carbon monoxide (CO)

CO is a flavourless, colourless gas that results from the incomplete combustion of fuel and air. CO pollution is mostly caused by emissions from fossil fuel-powered engines, such as those found in motor cars and non-road vehicles (such as construction equipment and boats) (Schottke 2016). Generally, regions with a lot of traffic congestion tend to have higher CO levels. Other sources of carbon monoxide emissions include domestic wood burning, industrial activities (such as the processing of metals and chemical manufacture), and natural sources like forest fires. Indoor sources of CO include unvented gas and kerosene space heaters, gas stoves, cigarette smoke, and woodstoves (Schottke 2016).

1.4.1. Health effects

Inhaling large amounts of carbon monoxide (CO) is the main cause of carbon monoxide poisoning (Christensen et al. 2019). The symptoms, frequently called "flu-like," include headache, weakness, nausea, chest pain, and confusion (Guzman 2012). Large exposures may cause mortality, arrhythmias, convulsions, or loss of consciousness (Bleecker 2015, Javale et al. 2022). Rarely does "cherry red skin," as it is traditionally referred to, exist (Javale et al. 2022). Complications that last a long time include chronic fatigue, memory, and movement issues (Zhang et al. 2023).

2. Methods and Materials

2.1. Software Details

The data was analysed using Pandas software version 1.3.3, and Jupyter Notebook version 6.3.0 which runs on Python 3.7.6. The following packages were used to analyse the data and plot the graphs: matplotlib version 3.4.3 and NumPy version 1.19.5.

2.2. Dataset and Data Cleaning

The dataset for this analysis is collected from the prominent dataset website, Kaggle. Our dataset contains data from January 2015 to July 2020. Initially, our dataset contains a total of 29,531 data rows with 16 features or data columns ($PM_{2.5}$, PM_{10}, NO_x, SO_x, etc.). We have selected only a few air pollutants for this study. The selected air pollutants are "$PM_{2.5}$", "CO", "NO_2", "NO", "NO_x", "SO_2", and now we have a total of 21,592 data rows with 6 columns and zero null values. The mean values of the respective pollutants have been analysed monthly and yearly. The cities selected for analysis are Lucknow, Delhi, Ahmedabad, Patna, and Gurugram. The geographical details of the selected cities are given in Table 3.

Table 3. Geographical details of the selected cities

City	Population	Area (KM^2)	Coordinates
Lucknow	3,500,000	631	26°51′N 80°57′E
Delhi	16,787,941	1484	28°36′36″N 77°13′48″E
Ahmedabad	5,633,927	505	23.03°N 72.58°E
Patna	5,838,465	250	25.6°N 85.1°E
Gurugram	1,153,000	250	28°27′22″N 77°01′44″E

3. Results and Discussions

The average air pollution of six major air pollutants ($PM_{2.5}$, NO, NO_2, NO_X, CO, SO_2) were measured for India's five highly polluted cities (Delhi, Lucknow, Gurugram, Patna and Ahmedabad).

The air pollutant concentrations were calculated month-wise and annually for the above cities.

The month-wise air pollutant data over the last five years are shown in Figure 1.

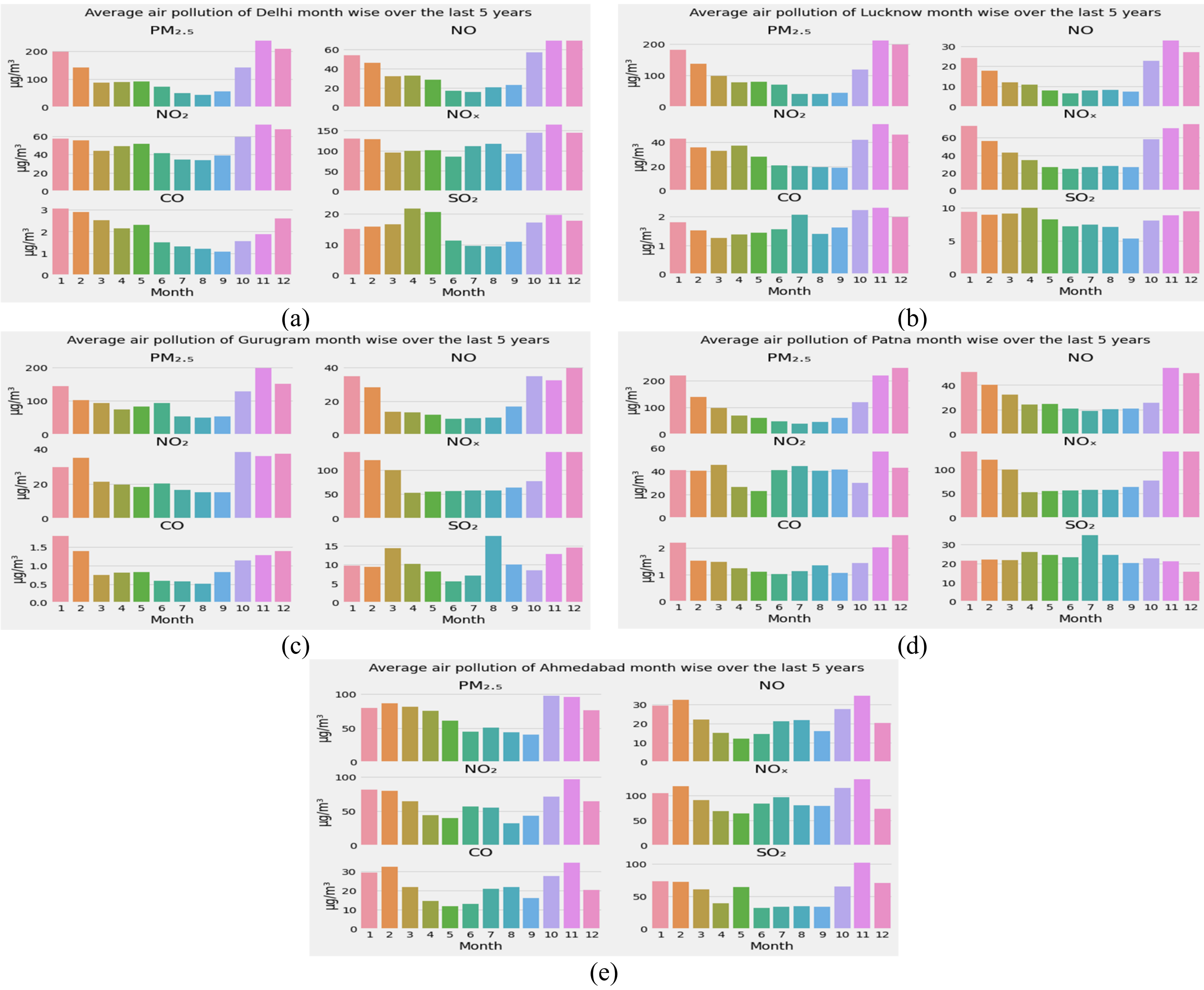

Fig. 1. Shows the monthly average air pollution for the year 2015-2020 in Delhi (a), Lucknow (b), Gurugram (c), Patna (d) and Ahmedabad (e)

Based on the analysis of the graphs, two conclusions were drawn:

1. Air Pollutant Concentration Exceeding Allowed Limits: The concentration of air pollutants measured in the five highly polluted cities (Delhi, Lucknow, Gurugram, Patna and Ahmedabad) consistently exceeded the limits set by the National Ambient Air Quality Standards and the World Health Organization. This indicates that the air quality in these cities was consistently poor and posed a risk to human health and the environment.
2. Seasonal Variation: The results also revealed that the maximum concentration of air pollutants occurred during the winter months compared to the summer months. This seasonal variation suggests that the winter season, characterised by factors such as temperature inversions and increased emissions from various sources like heating and combustion, may contribute to higher pollution levels. The summer months may have relatively lower pollutant concentrations due to increased temperature and pollutant dispersion.

These conclusions emphasise the need for comprehensive measures to address air pollution, especially during winter when pollution levels tend to be higher. Implementing strategies to reduce emissions from various sources, improving ventilation, and promoting sustainable practices can help mitigate the adverse effects of air pollution and protect public health.

The air pollutants were also measured annually over the last five years and are shown in Figure 2.

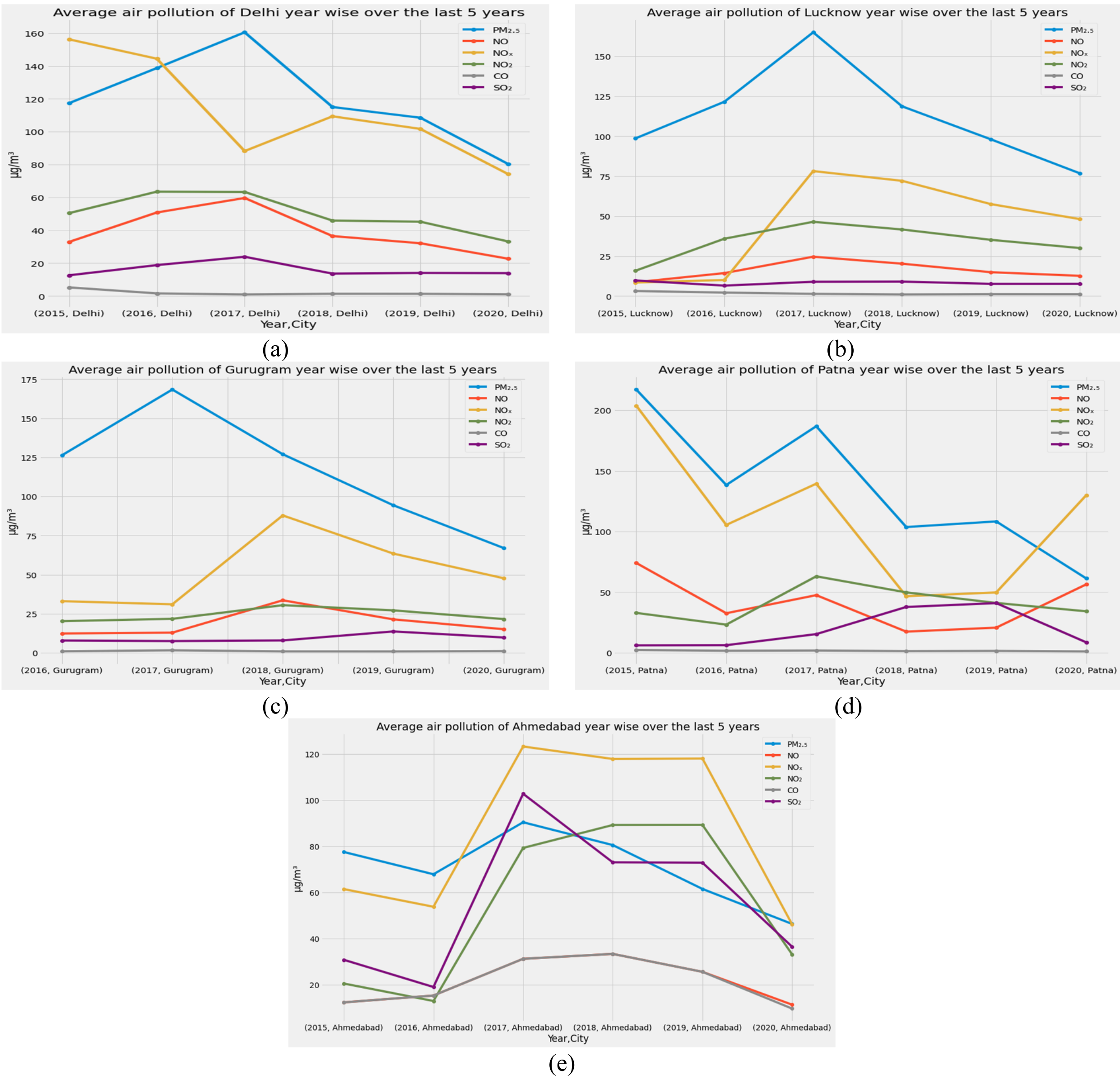

Fig. 2. Shows the annual average air pollution for year 2015-2020 Delhi (a), Lucknow (b), Gurugram (c) Patna (d) and Ahmedabad (e)

Based on the analysis of the graphs, two conclusions were drawn:

1. Air Pollutant Concentration Exceeding Allowed Limits: The concentration of air pollutants measured in the five highly polluted cities (Delhi, Lucknow, Gurugram, Patna and Ahmedabad) consistently exceeded the limits set by the National Ambient Air Quality Standards and the World Health Organization. This indicates that the air quality in these cities consistently poses a risk to human health and the environment.
2. Yearly Variation: The results also revealed that 2017 had the highest concentration of air pollutants compared to other years, while 2020 showed lower concentrations. The decrease in pollution levels in 2020 can be attributed to the nationwide lockdown imposed in response to the COVID-19 pandemic. The restrictions on mobility and industrial activities during the lockdown reduced emissions and improved air quality.

These conclusions highlight the urgent need for effective measures to address air pollution and maintain air quality within acceptable limits. While 2020 demonstrated that drastic measures such as lockdowns can temporarily impact air quality, it is essential to implement sustainable solutions to ensure long-term improvements. This may involve adopting cleaner technologies, promoting renewable energy sources, implementing stricter emission standards, and fostering awareness and behavioral changes among the population to reduce pollution levels consistently.

3.1. Pollution Rate Calculation

Pollution rates of all the above pollutants were also calculated and are shown in Table 4.

Table 4. Rate of Pollution of cities from 2015-2020. Taking base concentration as of year 2015 (+ = percent increase in concentration of pollutants and (-) = decrease in pollutant concentration)

	City	2016	2017	2018	2019	2020
$PM_{2.5}$	Delhi	0.74	15.68	-28.32	-5.67	-25.98
	Lucknow	24.86	35.72	-28.04	-17.39	-21.64
	Ahmedabad	12.93	33.22	-10.95	-23.62	-24.69
	Patna	-70.64	35.04	-44.50	4.46	-43.40
	Gurugram	5.55	-24.57	-25.68	-29.00	-100.00
NO	Delhi	370.80	17.00	-38.83	-12.01	-29.34
	Lucknow	1819.28	71.18	-17.68	-26.27	-15.14
	Ahmedabad	910.09	104.30	6.80	-23.31	-55.77
	Patna	-40.53	45.71	-63.89	20.85	172.00
	Gurugram	744.09	160.35	-36.27	-29.46	-100.00
NO_2	Delhi	149.69	-0.28	-27.49	-1.49	-26.60
	Lucknow	1508.87	14.28	-10.33	-15.51	-14.59
	Ahmedabad	207.57	514.79	12.55	0.04	-62.90
	Patna	114.78	171.54	-21.03	-17.48	-16.76
	Gurugram	429.98	40.22	-10.87	-20.53	-100.00
NO_X	Delhi	13.03	-38.92	24.00	-7.14	-26.95
	Lucknow	1296.35	674.87	-7.78	-20.20	-16.26
	Ahmedabad	42.53	129.27	-4.40	0.16	-60.92
	Patna	-74.61	32.24	-66.54	6.64	161.20
	Gurugram	184.52	183.17	-27.77	-24.86	-100.00
SO_2	Delhi	1084.68	26.94	-42.89	2.85	-0.84
	Lucknow	587.62	36.96	1.22	-15.59	0.36
	Ahmedabad	100.39	441.82	-28.94	-0.20	-50.01
	Patna	1564.60	146.04	145.45	8.41	-78.98
	Gurugram	1114.76	5.44	72.72	-28.36	-100.00

Table 4. cont.

	City	2016	2017	2018	2019	2020
CO	Delhi	483.62	-40.24	46.20	-2.50	-22.91
	Lucknow	2065.20	-34.69	-27.24	17.22	-2.70
	Ahmedabad	910.09	104.30	6.80	-23.31	-62.43
	Patna	3153.10	11.37	-24.55	11.54	-27.33
	Gurugram	16419.39	-40.97	-3.66	24.00	-100.00

Based on the values of pollution rates, several conclusions can be drawn from the research:

1. Overall Trend: The pollution levels of $PM_{2.5}$, NO, NO_2, NO_X, CO, and SO_2 exhibited an initial increase from 2016 to 2017, followed by a decreasing trend from 2018 to 2020. This suggests that efforts to reduce pollution may have been implemented during this period, gradually improving air quality.
2. Patna and Gurugram: In the case of Patna and Gurugram, the pollution rates of CO and SO_2 show an increase from 2015 to 2018. However, starting in 2019, there has been a decrease in the pollution levels of these two pollutants. This indicates that specific measures may have been implemented in these cities to target the reduction of CO and SO_2 emissions, leading to a subsequent improvement in air quality.
3. Impact of National Lockdown: The pollution rates across all cities and pollutants show lower values in 2020. This can be attributed to the nationwide lockdown in response to the COVID-19 pandemic. The restrictions on mobility and industrial activities reduced emissions, improving air quality temporarily.

These conclusions highlight the potential effectiveness of pollution control measures and the impact of significant events, such as lockdowns, on air quality. However, sustained efforts are necessary to maintain and further improve the air quality in these cities, as the pollution rates were still found to exceed the permissible limits in previous years.

4. Conclusion

The study of the levels of air pollutants in five of the most affected cities (Delhi, Lucknow, Gurugram, Patna and Ahmedabad) produces some of the following conclusions. Initially, based on the findings of the levels of air pollutants, it was realised that the air pollutants were above the National Ambient Air Quality Standards of the USA and the World Health Organization Standards, which had dire consequences on human health and the environment. Secondly, the analysis of the variation of the parameters revealed annual fluctuations: No must admit that the highest levels of pollution were detected in 2017, and the lowest ones – in 2020, which can be explained by the impact of the pandemic restrictions that limited people's movement and industrial output. Such a temporary relief further cements the argument of the necessity for long-lasting solutions to the problem of air pollution. Furthermore, looking at the data from 2016 to 2020, one would identify a direct trend where Pollutants like $PM_{2.5}$, NO, NO_2, NO_X, CO and SO_2 levels were high and decreased gradually. This suggests that some measures have been taken to control pollution. Specifically, the trends of CO and SO_2 have been observed to decrease since 2019 in both Patna and Gurugram, which points to specific measures being taken. However, the excesses observed in previous years point to the need to continue the efforts in cleaning up the air through the use of cleaner technologies, better emission standards, and continued public sensitisation.

Conflict of interest

The authors declare no competing interests.

Declaration

All the authors of the manuscript have no conflict of interest to declare. This manuscript has Integral University Manuscript Communication Number: IU/R&D/2024-MCN0002848.

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