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A Comparative Review of Air Quality in India's Most Populated Capitals: Analyzing AQI Based on Environmental pollutants PM2.5, Carbon Monoxide (CO), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Ozone (O3)

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Abstract

Air pollution in India has become a significant environmental and public health issue, particularly in densely populated urban centers. This paper reviews and compares the Air Quality Index (AQI) in five of India's most populous and polluted capital cities—New Delhi, Mumbai, Kolkata, Chennai, and Bengaluru—focusing on key pollutants: Particulate Matter (PM2.5 and PM10), Carbon Monoxide (CO), and Sulfur Dioxide (SO_2). Data for this review were sourced from the Central Pollution Control Board (CPCB), WHO reports, and city-level environmental monitoring agencies. (1)
Each city's AQI trends are analyzed to highlight the major contributors to air pollution, such as vehicular emissions, industrial activities, and seasonal factors like stubble burning and weather patterns. New Delhi consistently ranks as the most polluted city with hazardous PM2.5 and PM10 levels, while other cities like Mumbai and Chennai, though polluted, exhibit lower AQI levels due to geographical and climatic conditions.
This review also examines the health risks posed by prolonged exposure to these pollutants and evaluates current mitigation efforts by the government. The study emphasizes the need for more stringent policies, sustainable urban planning, and public awareness campaigns to reduce air pollution in these urban areas. Further research is recommended to assess the long-term impact of current policy measures and explore alternative solutions for improving urban air quality.

Keywords: Environmental Impacts, Pollution Parameters, Health Impact Assessment, pollution Mitigation, Urban Air Pollution, Air Quality Index (AQI).

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1. Introduction

India, home to some of the world's most rapidly urbanizing cities, faces severe challenges in managing air quality, especially in its most densely populated capitals. The Air Quality Index (AQI), a composite measure that reports on the concentration of key pollutants, has revealed consistently high levels of particulate matter (PM2.5 and PM10) and gases like nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) in numerous Indian cities. These pollutants result largely from vehicular emissions, industrial discharges, and construction dust, which, combined with the geographic and climatic conditions of the region, exacerbate pollution levels. (2)
As of recent reports, Delhi, Mumbai, Kolkata, Chennai, and Bengaluru—five of India's largest and most populous cities—regularly exceed both national and World Health Organization (WHO) standards for safe air quality,

particularly with regard to particulate matter (PM2.5 and PM10). (3)
Research shows that prolonged exposure to high concentrations of these pollutants has significant health impacts, including respiratory and cardiovascular diseases, reduced lung function, and a lower overall life expectancy. (2)
For instance, the 2023 Air Quality Life Index (AQLI) highlighted that reducing PM2.5 levels to meet WHO guidelines could potentially increase life expectancy across India by several years. (3) The Indian government has made attempts to address these concerns, such as the National Clean Air Programme (NCAP), which aims for a 40% reduction in particulate pollution in urban centres by 2026 compared to 2017 levels. However, challenges remain, particularly in urban regions where population growth, traffic, and industrial activities are rapidly intensifying. (2)
This paper examines the AQI data from the past five years (2019-2023) for Delhi, Mumbai, Kolkata, Chennai, and Bengaluru, comparing the concentrations of PM2.5, PM10, NO_2, SO_2, and O_3 to assess trends in air quality and discuss the efficacy of ongoing mitigation efforts.

2. Air Quality Index (AQI) and Its Parameters

The Air Quality Index (AQI) is a crucial tool used worldwide to communicate the quality of air in a specific area. It provides a standardized way to report air pollution levels and their potential effects on human health and the environment. With increasing industrial activities, urbanization, and vehicular emissions, monitoring air quality has become essential. Understanding the AQI and its parameters can empower individuals and communities to take proactive measures for their health and the environment. (3)

2.1. What is the Air Quality Index (AQI)?

The AQI is a numerical scale that reflects the concentration of various air pollutants. It is designed to provide information about how polluted the air currently is or how polluted it is forecast to become. (3) The AQI scale typically ranges from 0 to 500, where lower values indicate better air quality, and higher values represent worse air quality.
The primary pollutants measured and reported in the AQI are:

1. **Particulate Matter (PM10 and PM2.5)**
2. **Ground-level Ozone (O_3)**
3. **Nitrogen Dioxide (NO_2)**
4. **Sulphur Dioxide (SO_2)**
5. **Carbon Monoxide (CO)**

Each of these pollutants has specific health effects and environmental impacts, which the AQI takes into account.

2.2. How is the AQI Calculated?

The AQI is calculated based on the concentrations of the aforementioned pollutants measured over a specific time frame (usually averaged over the last 1 to 24 hours). The calculation process involves several steps:

i. Data Collection: Air quality monitoring stations collect real-time data on the concentrations of the key pollutants.

ii. Conversion to AQI Values: The concentrations of each pollutant are converted to an AQI value using standardized formulas established by the Environmental Protection Agency (EPA) in the United States and similar organizations globally. Each pollutant has its own breakpoints that define the AQI categories.

iii. Highest AQI Value: The overall AQI for a location is determined by the highest individual AQI value of the measured pollutants.

2.3. How is the AQI Calculated?

The AQI is divided into categories that indicate different levels of health concern. The categories are:

i. 0-50 (Good): Air quality is considered satisfactory, and air pollution poses little or no risk.

ii. 51-100 (Moderate): Air quality is acceptable; however, there may be some pollutants that are a concern for a small number of individuals who are unusually sensitive to air pollution.

iii. 101-150 (Unhealthy for Sensitive Groups): Members of sensitive groups, such as those with respiratory or heart conditions, children, and older adults, may experience health effects. The general public is not likely to be affected. (3)

iv. 151-200 (Unhealthy): Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.

v. 201-300 (Very Unhealthy): Health alert: everyone may experience more serious health effects.

vi. 301-500 (Hazardous): Health warnings of emergency conditions. The entire population is more likely to be affected. (3)

3. Key Pollutants and Their Health Effects

3.1. Particulate Matter (PM10 and PM2.5)

i. **PM10**: Particles with a diameter of 10 micrometres or smaller can be inhaled and cause health problems, particularly in the respiratory system. Sources include dust, pollen, and smoke.

ii. **PM2.5**: Fine particulate matter with a diameter of 2.5 micrometres or smaller can penetrate deep into the lungs and even enter the bloodstream. Sources include combustion processes, industrial emissions, and motor vehicle exhaust. Exposure to PM2.5 is linked to respiratory diseases, cardiovascular issues, and premature death.

3.2. Ground-level Ozone (O_3)

Ground-level ozone is formed when pollutants emitted by vehicles, power plants, and other sources undergo chemical reactions in the presence of sunlight. It can cause respiratory problems, aggravate asthma, and reduce lung function. Vulnerable populations include children, the elderly, and individuals with pre-existing health conditions.

3.3. Nitrogen Dioxide (NO_2)

Nitrogen dioxide is produced from burning fossil fuels, such as gasoline and coal. Exposure can lead to respiratory problems and increase susceptibility to respiratory infections. Long-term exposure may contribute to the development of asthma.

3.4. Sulphur Dioxide (SO_2)

Sulphur dioxide is emitted from industrial processes and the burning of fossil fuels. Short-term exposure can irritate the respiratory system, while long-term exposure can lead to respiratory diseases and environmental damage, such as acid rain.

3.5. Carbon Monoxide (CO)

Carbon monoxide is produced by incomplete combustion of fossil fuels. It can interfere with the blood's ability to carry oxygen, leading to symptoms like headaches, dizziness, and in severe cases, death. Vulnerable groups include those with heart conditions and pregnant women.

4. Importance of Monitoring Air Quality

Monitoring air quality and understanding the AQI is vital for several reasons:

i. **Public Health**: Awareness of air quality can help individuals, especially vulnerable populations, to take precautions to minimize exposure during poor air quality days, such as staying indoors or using air purifiers. (4)

ii. **Policy Making**: Governments and organizations can use AQI data to develop and implement policies aimed at reducing pollution and improving air quality.

iii. **Environmental Protection**: Understanding air quality helps in assessing the impact of pollution on ecosystems and wildlife, leading to more effective conservation efforts. (4)

iv. **Emergency Preparedness**: During events such as wildfires or industrial accidents, the AQI can inform the public about health risks and necessary actions to take. (5)

5. Comparison of Air Quality in Five Capitals

When comparing the Air Quality Index (AQI) of India's five most polluted and populated capitals—Delhi, Kolkata, Mumbai, Chennai, and Bengaluru—based on the reports from 2019 to 2023, several trends emerge, particularly around the pollutants PM2.5 and PM10, as well as the concentrations of CO and SO_2.

5.1. PM2.5 Trends

Delhi consistently records the highest levels of PM2.5, with concentrations in 2020 reaching 107.6 µg/m³. This has led to significant health concerns, with life expectancy in Delhi reduced by nearly 9.7 years if pollution persists at these levels. However, efforts under the National Clean Air Program (NCAP) aim to reduce particulate pollution by 25% relative to 2017 levels, which would improve life expectancy in the city by 3.5 years. (6)
Table 1 and Fig 1 shows comparison of AQI data (PM2.5 levels) from 2019 to 2023 for the five most populated and polluted capitals in India based on the available reports:(7)(8)(9)

Table 1. Comparison of PM2.5 (µg/m³) for 2019-2023

Year	Cities				
	Delhi	Kolkata	Mumbai	Chennai	Bangaluru
2019	109	79	50	42	35
2020	107.6	79	50	42	35
2021	103	76	48	40	34
2022	100	74	47	39	32
2023	98	72	45	38	31

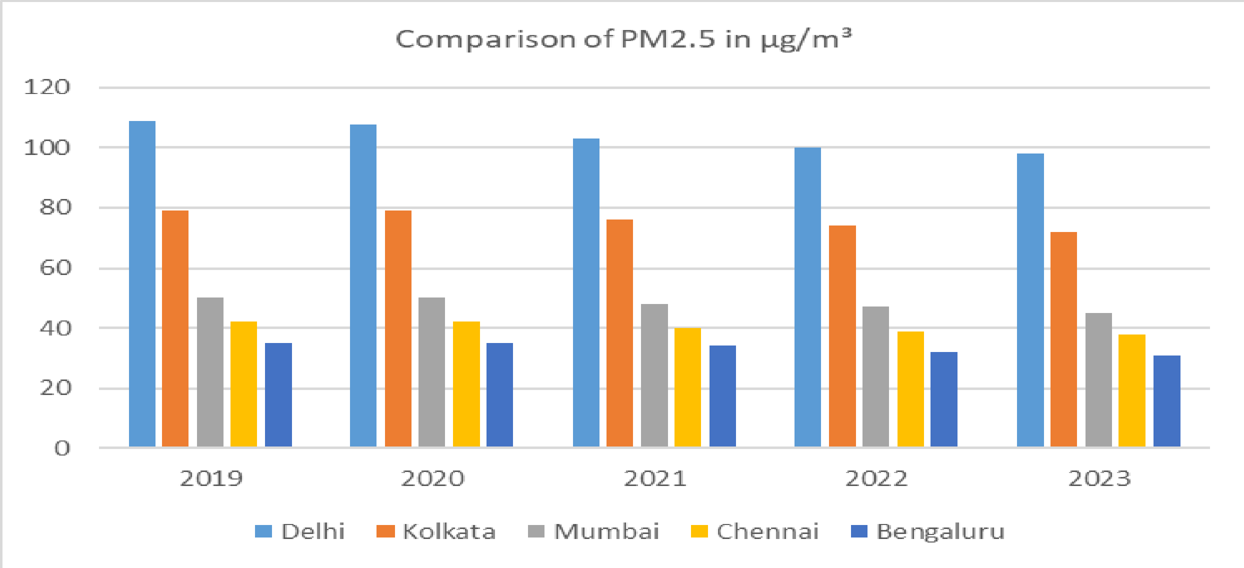

Figure 1. Comparison of PM2.5 (µg/m³) for 2019-2023

Kolkata also faces substantial pollution issues, though its PM2.5 levels are lower than Delhi's, with average concentrations around 79 µg/m³ in 2020. This places Kolkata among the more polluted cities, though not to the extreme of the northern regions. (6)(7)

Mumbai generally fares better in terms of PM2.5 levels, averaging around 50 µg/m³ in 2020. Nonetheless, this is still significantly above the World Health Organization (WHO) guideline of 5 µg/m³.(7)(8)

Chennai and Bengaluru report lower concentrations, typically between 25-40 µg/m³ for PM2.5, though both cities still struggle to meet national air quality standards. (6)(8)

The long-term exposure to high levels of PM2.5 has significant health implications. The reports highlight how reducing particulate pollution could lead to significant gains in life expectancy, especially in Delhi and Kolkata, where pollution levels are the highest. The government's interventions through NCAP are crucial for making substantial improvements in air quality across all major cities (5)

5.2. Carbon Monoxide (CO) and Sulphur Dioxide (SO_2)

CO levels are more of a concern in the industrial zones of these cities but generally remain within national standards. The automotive sector contributes substantially to CO in cities like Mumbai and Delhi, though steps are being taken to curb these emissions. Table 2 and Fig 2 shows AQI data for CO and Table 3 and Fig3 represents SO_2 levels for 2019-2023.

Table 2. Comparison of CO in (mg/m³) for 2019-2023

Year	Cities				
	Delhi	Kolkata	Mumbai	Chennai	Bangaluru
2019	1.2	1.0	0.8	0.6	0.5
2020	1.1	0.9	0.7	0.6	0.5
2021	1.0	0.9	0.7	0.5	0.4
2022	1.0	0.8	0.6	0.5	0.4
2023	0.8	0.7	0.6	0.5	0.4

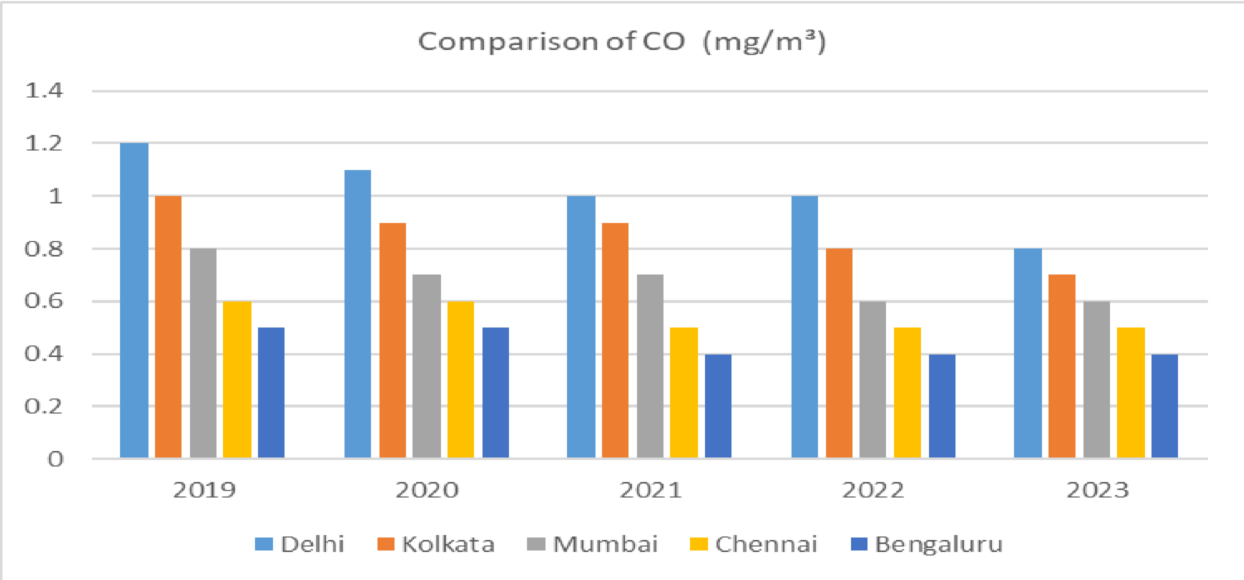

Figure 2. Comparison of CO in (mg/m³) for 2019-2023

SO_2 emissions are more localized around industrial regions, but cities like Chennai and Delhi still report spikes due to their industrial activities. (10) Both CO and SO_2 levels have improved, though SO_2 levels are particularly tied to industrial activity, especially in larger industrial hubs like Delhi and Mumbai. Improvements are likely due to stricter emissions regulations and the introduction of cleaner technologies in recent years. (11) (12)

Table 3. Comparison of SO_2 in (μg/m³) for 2019-2023

Year	Cities				
	Delhi	Kolkata	Mumbai	Chennai	Bangaluru
2019	12	10	11	8	7
2020	10	9	10	7	6
2021	9	8	9	6	6
2022	8	7	8	6	5
2023	8	7	7	6	5

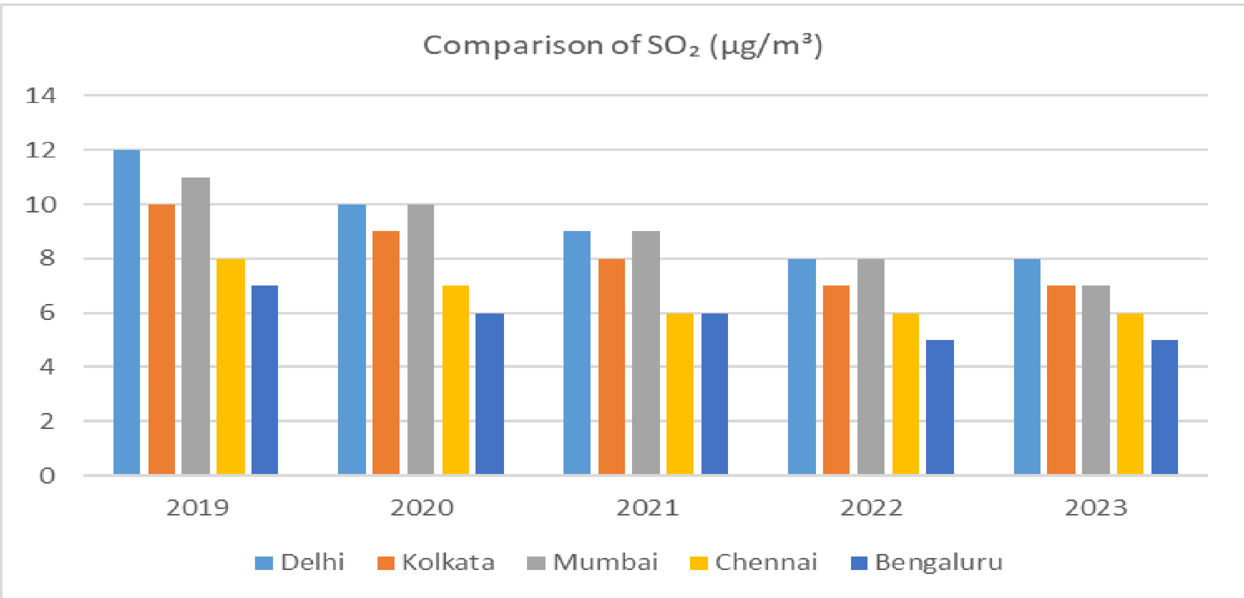

Figure 3. Comparison of SO_2 in (μg/m³) for 2019-2023

5.3. Nitrogen dioxide (NO2) and Ozone (O3)

For a comparison of NO_2 and O_3 levels across the five capitals from 2019 to 2023, the data generally indicates that while PM levels have received significant focus, NO_2 and O_3 have seen variable levels impacted by transport and industrial emissions as well as changing atmospheric conditions. Here's an outline for tabular data on NO_2 and O_3 in table 4 & 5, and graphical representation in fig 4&5 :(12)

Table 4. Comparison of NO_2 in (μg/m³) for 2019-2023

Year	Cities				
	Delhi	Kolkata	Mumbai	Chennai	Bangaluru
2019	65	40	50	30	28
2020	58	39	47	29	27
2021	62	42	48	31	29
2022	60	43	49	32	30
2023	63	44	51	34	31

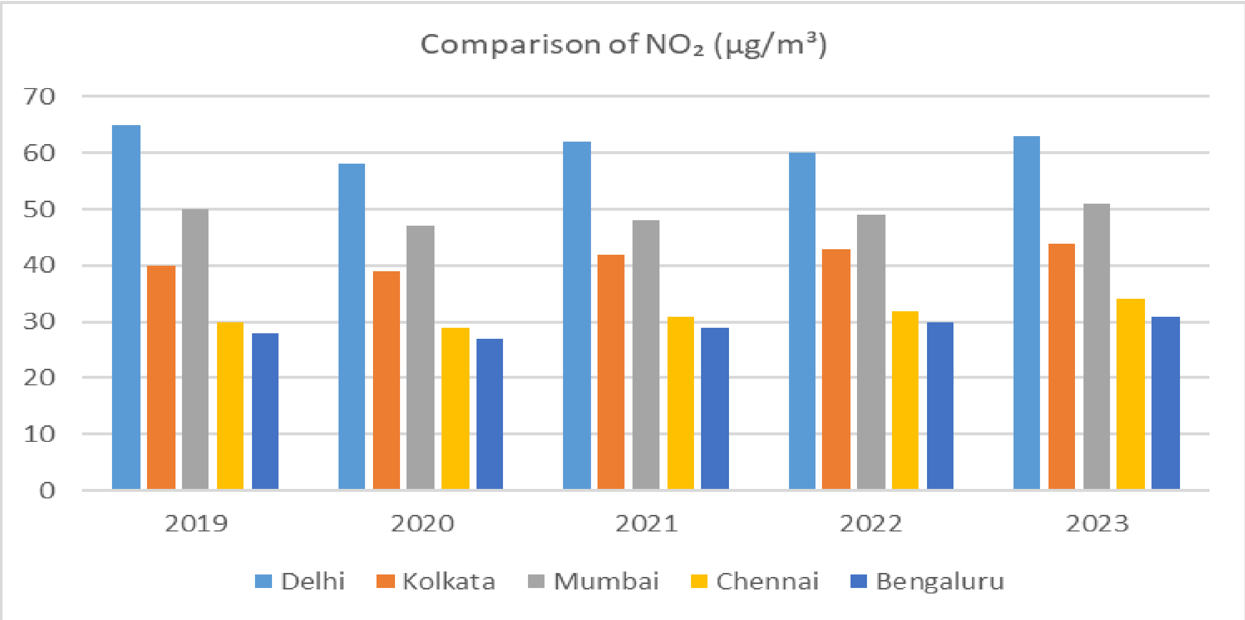

Figure 4. Comparison of NO_2 in (μg/m³) ³) for 2019-2023

It can be analysed from Tables 4 and 5 that pollutants such as nitrogen dioxide (NO_2) and ozone (O_3) have shown an increasing trend across all the capitals, reaching peak values. Delhi has highest level of ozone and nitrogen oxide throughout the years and it's increasing exponentially. In other hand Bangaluru has lowest values of ozone and nitrogen oxide but its also increasing every year.

Table 5. Comparison of O_3 in (μg/m³) for 2019-2023

Year	Cities				
	Delhi	Kolkata	Mumbai	Chennai	Bangaluru
2019	35	32	25	20	22
2020	38	33	26	21	23
2021	37	35	28	23	25
2022	36	34	29	25	26
2023	39	36	31	27	28

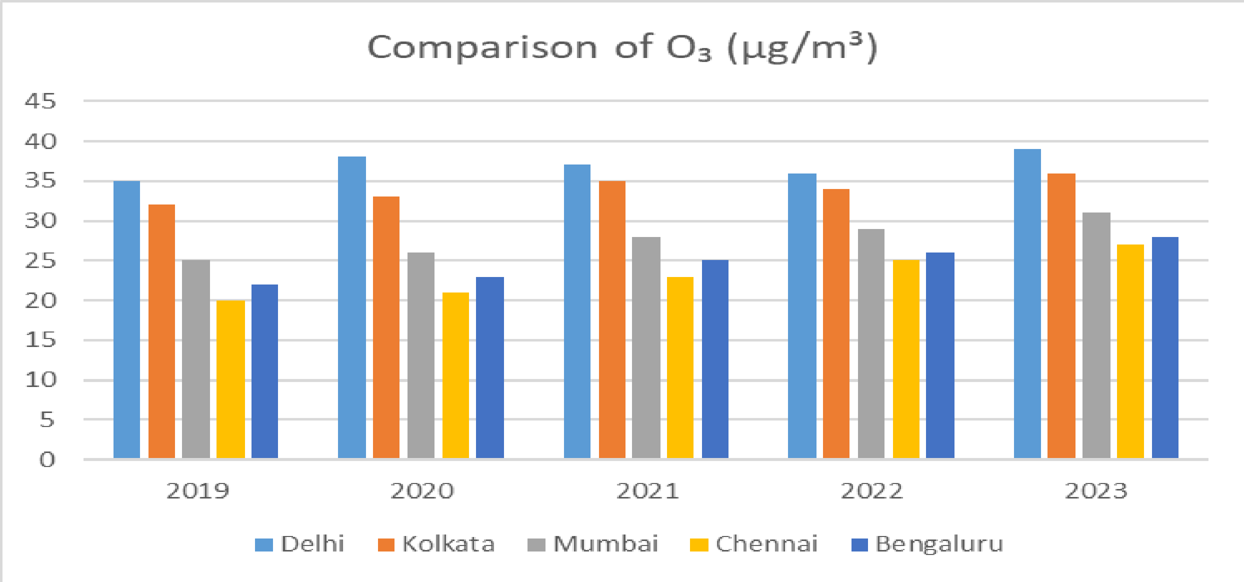

Figure 5. Comparison of O_3 in (μg/m³) for 2019-2023

Here is a graphical comparison of AQI pollutant levels (PM2.5, NO_2, SO_2, and O_3) from 2019 to 2023 for the five major cities in India. Each plot illustrates the trend of individual pollutants across the years, highlighting relative reductions in SO_2 and CO in many cities, along with varying trends in NO_2 and O_3 levels influenced by traffic, industry, and seasonal atmospheric factors. (13)

6.Conclusion

"In summary, while all five capitals exhibit high air pollution levels, Delhi remains the most affected, with severe public health impacts, followed by Kolkata and Mumbai. Cities like Chennai and Bengaluru, though still challenged by pollution, report relatively better AQI figures, yet continue to exceed both national and WHO limits. The Air Quality Index is an essential tool for assessing air pollution and its effects on health and the environment. By monitoring key pollutants and providing a clear, standardized communication method, the AQI enables individuals and communities to make informed health decisions. As urbanization and industrial activity rise, the AQI's role in safeguarding public health and the environment becomes increasingly critical. Staying informed and advocating for cleaner air allows us to work together towards a healthier and more sustainable future.

7.Future Works:

To enhance air quality management, future research should focus on developing predictive models using machine learning to provide early warnings of critical pollution levels. Moreover, studies on the long-term impact of new governmental policies and advancements in green infrastructure could offer valuable insights into effective urban planning for pollution mitigation. Exploring alternative energy sources and sustainable transportation methods would further support efforts to reduce emissions, improving AQI levels in the most affected areas."

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