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Air Pollution in New Delhi: A Secondary Data Analysis of the Indices from 2021 to 2024

Priyanshu Rastogi[1*], Santosh Choudhary[2] and Shantanu Sharma[1]

[1]Department of Maternal, Newborn and Child Health and Nutrition, MAMTA Health Institute for Mother and Child, New Delhi, India

[2]Department of Monitoring and Evaluation, MAMTA Health Institute for Mother and Child, New Delhi, India

ABSTRACT

Background: Air pollution remains one of the most pressing environmental and public health concerns in New Delhi, often ranked among the world's most polluted cities. This study aimed to assess the trends in major air quality indicators, PM2.5, PM10, NO_2, SO_2, CO, O_3, and AQI from 2021 to 2024, using secondary data from Central Pollution Control Board (CPCB) and validated platforms.

Methods: The data were analyzed using retrospectively using descriptive statistics, ANOVA, and Kruskal-Wallis tests, supported by visualizations and statistical analysis through Tableau and STATA 16.0 respectively.

Results: The findings suggested a recurring seasonal pattern, with pollution levels peaking during winter months (November-January) across all years. PM2.5 and PM10 concentrations consistently exceeded WHO's safe limits by up to tenfold, with AQI levels frequently falling into the "very poor" to "severe" categories. While a marginal decline in AQI was observed in January 2024, pollutants like NO_2 and CO surged during winters, reflecting continuing emissions from automobiles and industries. During summers (February-June), ozone levels soared, whereas SO_2 levels remained stable then spiked in early 2024.

Conclusions: Delhi's air quality remains hazardous. There is an urgent need for evidence-based, sustainable interventions targeting major pollutants and emphasizing health-centered urban planning for a cleaner, greener and more livable city.

***Corresponding author**
Priyanshu Rastogi, Department of Maternal, Newborn and Child Health and Nutrition, MAMTA Health Institute for Mother and Child, New Delhi, India.

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Introduction

Air pollution is a critical issue in the most populous country in the world, i.e., India. India has the third-worst air quality in the world after Bangladesh and Pakistan. India's Particulate Matter PM-2.5 (54.4 µg/m3) is more than 10 times higher than the world health organization's (WHOs) PM2.5 annual guidelines [1]. Air pollution is of great concern both in urban and rural areas. The key pollutants in the air include particulate matter, oxides of nitrogen, ammonia, sulphur dioxide, and volatile organic compounds [2]. Research suggests that growing air pollution is alarming and has a drastic impact on the health of people in India. In 2019, air pollution attributed 1.67 million deaths, which is around 18% of the total deaths in India. This resulted in economic losses of USD 28·8 billion and USD 8·0 billion (5.9-10.3) due to prematurity and morbidity, respectively, in India in 2019 [3]. According to the Global Burden of Diseases 2019 study, chronic obstructive pulmonary disease (COPD), lower respiratory infections, lung cancer, ischemic heart disease, stroke, type 2 diabetes, and cataract are the major diseases attributed to air pollution [4].

The average annual particulate pollution has increased by 67.7 percent in India from 1998 to 2021. Out of the total world's increase in pollution, 59% is contributed by India alone from 2013 to 2021 [5]. Northern states in India have higher ambient air pollution and PM than the rest of India, and Delhi is India's capital and one of its most polluted cities [3,5]. Air pollution attributed to 11.5% of disability adjusted life years (DALYs) in India, which is mostly contributed by the ambient PM and household air pollution [6]. The National Clean Air Program (NCAP) was launched by the Indian government in 2019 to combat air pollution by reducing PM concentrations by 20-30 per cent by 2024 [7]. Besides, in 2015, an AQI tool was launched by the government of India for AQI monitoring, reporting, raising awareness about air pollution and its health impacts, and encouraging individuals to take preventive actions [3].

The PM2.5, PM10, Sulphur dioxide, Nitrogen dioxide, ammonia, carbon monoxide, lead, and ozone are the major air quality indices mandated by the government of India to be measured either 24-hourly or on an hourly basis [8]. The AQI is the highest sub-index among these pollutants, each with its own calculation based on concentration. AQI categories range from Good (0-50) to Severe (401-500), helping assess health risks. Understanding air pollution levels, their sources, and prevention techniques is critical for public health, urban planning, and policy advocacy [9]. This is even crucial from the lens of transforming cities into smart and green, a commitment made by the Indian government [10].

The present study aimed to assess the trend in the rate of change in the various air quality indices in Delhi in the past four years, i.e., from 2021 to 2024. We assessed the seven primary indices, including AQI, PM2.5, PM10, C0, Ozone, Nitrous oxide, and Sulphur dioxide.

Methods

Study Design

We employed a quantitative, retrospective, secondary data analysis design for assessing the trends and variations in the air quality parameters of New Delhi from 2021 to 2024. Our study focused on comparing the key Air Quality Index (AQI) parameters of New Delhi over 4 years. We selected New Delhi as it has been cited as the most polluted city in the world multiple times in recent years.

Data Source

We obtained secondary data on AQI parameters for New Delhi from the AQI platform, which is an open-source air quality monitoring platform that displays real-time air quality data. The AQI App by Purelogic Labs aggregates data from over 10,500 monitoring stations worldwide, including those in India. It sources information from both government-operated stations and private networks. It is suggested that the AQI app data is primarily obtained from publicly available datasets provided by the CPCB and other validated government and environmental monitoring portals (such as SAFAR-system of air quality and weather forecasting and research).

AQI Parameters Analyzed

We analyzed six AQI parameters, including air quality index, PM2.5, PM10, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3). According to the AQI estimates, the 24-hourly values were averaged to calculate the average daily values for each parameter.

Data Cleaning and Preparation

The day-wise raw data of 6 AQI parameters over 4 years were entered manually in Microsoft Excel sheet. The data of single or two-day missing values was imputed using the median value of the month. However, there was a complete missing data set between 11th and 29th August 2022, which was left blank and not imputed.

Data Analysis

Descriptive statistical analysis was conducted to summarize the trends of AQI parameters across the years 2021 to 2024. Year-wise comparisons of mean values for each parameter were performed using Analysis of Variance (ANOVA) for normally distributed parameters and Kruskal-Wallis H test for non-normally distributed parameters. The analyses were done in STATA version 16.0. However, the area charts for the AQI parameters were drawn using Tableau. Seasonal variations were also analyzed to observe changes across different seasons (winter, summer, monsoon, and post-monsoon).

Ethical Considerations

As this study was based entirely on secondary, publicly available data, no ethical approval was required. However, all data sources were properly cited to ensure academic integrity.

Results

The AQI varied from 309 in 2021 to 256 in 2024 in the month of January (Table 1). The AQI levels remain increased during the peak winter months, including November, December, and January every year. The maximum monthly average was recorded in the month of November 2024. Though the carbon monoxide levels have been constant throughout the year 2021 and 2022. However, in 2023 and 2024, their values are at their highest levels between December and January (Table 2).

The levels of nitrogen oxides are persistently high between November and April across all four years (Table 3). In 2024, the nitrogen oxide levels were more than 20 ppb. It's only during the monsoon season that the levels go down.

On the contrary, the levels of ozone rise between February and June every year (Table 4). The PM10 values tended to increase after October until Feb the next year, between 2021 and 2024, except in 2022 (Table 5). The PM10 values remained high until June 2022 and started to rise from September onwards. Likewise, PM2.5 values remained high during winter months (Table 6). SO2 levels were nearly similar throughout year (Table 7).

Table 1: Distribution of AQI Values Across 12 Months of the last four Years (2021-2024)

Months	2021 AQI (μ/m3), median (IQR)	2022 AQI (μ/m3), median (IQR)	2023 AQI (μ/m3), median (IQR)	2024 AQI (μ/m3), median (IQR)
January	309 (285, 393)	206 (185, 273)	240 (186, 273)	256 (239, 283)
February	283.5 (228, 307)	142.5 (122.5, 204)	181 (163, 206.5)	167 (153, 192)
March	178 (138, 201)	180 (166, 208)	153 (134, 165)	162 (145, 169)
April	130.5 (112, 167)	198.5 (190, 207)	146.5 (123, 166)	149.5 (137, 168)
May	94 (71, 108)	168 (154, 200)	140 (107, 173)	171 (156, 188)
June	92 (74, 114)	156.5 (124, 180)	107.5 (101, 127)	130 (115, 146)
July	79 (63, 90)	92 (72, 109)	91 (78, 108)	98 (82, 116)
August	78 (69, 100)	98 (81, 113)	100 (91, 115)	77 (67, 85)
September	74 (64, 85)	105.5 (80, 128)	101 (84, 121)	98 (80, 129)
October	171 (117, 219)	167 (134, 195)	158 (137, 188)	177 (134, 209)
November	433 (386, 467)	223.5 (203, 263)	300 (240, 330)	250.5 (234, 347)
December	366 (320, 450)	236 (204, 267)	251 (214, 291)	196 (174, 300)

*Abbreviations: AQI: Air Quality Index; IQR: Interquartile Range

Table 2: Distribution of CO Values Across 12 Months of the Last Four Years (2021-2024)

Months	2021 CO (ppb), median (IQR)	2022 CO (ppb), median (IQR)	2023 CO (ppb), median (IQR)	2024 CO (ppb), median (IQR)
January	1 (1, 2)	1 (1, 1)	0.75 (0.65, 0.89)	1.12 (0.92, 1.41)
February	1 (1, 2)	1 (1, 1)	0.71 (0.61, 0.86)	0.66 (0.52, 0.84)
March	1 (1, 1)	1 (1, 1)	0.63 (0.53, 0.70)	0.69 (0.54, 0.80)
April	1 (1, 1)	1 (1, 1)	0.67 (0.58, 0.80)	0.67 (0.59, 0.77)
May	1 (1, 1)	1 (1, 1)	0.63 (0.56, 0.81)	0.78 (0.66, 0.95)
June	1 (1, 1)	1 (1, 1)	0.63 (0.58, 0.67)	0.57 (0.52, 0.65)
July	1 (1, 1)	1 (1, 1)	0.59 (0.50, 0.62)	0.50 (0.47, 0.52)
August	1 (1, 1)	1 (1, 1)	0.53 (0.48, 0.59)	0.49 (0.47, 0.54)
September	1 (1, 1)	1 (1, 1)	0.59 (0.55, 0.64)	0.59 (0.55, 0.66)
October	1 (1, 1)	1 (1, 1.14)	0.73 (0.61, 0.81)	0.85 (0.75, 1.08)
November	2 (1, 2)	1.01 (0.88, 1.13)	1.21 (0.92, 1.52)	1.23 (1.07, 1.44)
December	1 (1, 2)	0.93 (0.81, 1.09)	1.09 (0.91, 1.21)	1.08 (0.85, 1.21)

*Abbreviations: CO: Carbon Monoxide; IQR: Interquartile Range; ppb: Parts per Billion

Table 3: Distribution of NO Values Across 12 Months of the last Four Years (2021-2024)

Months	2021 NO (ppb), median (IQR)	2022 NO (ppb), median (IQR)	2023 NO (ppb), median (IQR)	2024 NO (ppb), median (IQR)
January	23 (18, 30)	18 (15, 24)	17 (16, 22)	32 (22, 43)
February	29 (25.5, 31)	17.5 (16, 22)	20 (19, 22)	26 (16, 36)
March	22 (20, 25)	24 (20, 26)	15 (14, 18)	36 (30, 39)
April	22 (17, 26)	27.5 (22, 30)	19 (15, 22)	35.5 (31, 40)
May	12 (10, 15)	19 (15, 25)	16 (13, 19)	25 (20, 32)
June	14.5 (13, 16)	15.5 (13, 22)	12.5 (11, 14)	10 (9, 13)
July	14 (13, 15)	11 (10, 13)	9 (9, 11)	9 (8, 12)
August	13 (11, 14)	10 (9, 13)	8 (7, 8)	10 (8, 11)
September	11 (10, 14)	12 (10, 14)	11 (9, 12)	14 (11, 15)
October	19 (15, 22)	22 (17, 49)	16 (14, 19)	23 (17, 26)
November	35.5 (32, 41)	25 (24, 28)	20 (19, 25)	26 (22, 29)
December	31 (27, 33)	23 (19, 27)	27 (23, 37)	28 (24, 22)

* Abbreviations: NO: Nitrous Oxide; IQR: Interquartile Range; ppb: Parts Per Billion

Table 4: Distribution of the Ozone Values Across 12 Months Over 4 Years (2021-24)

Months	2021 Ozone (ppb), median (IQR)	2022 Ozone (ppb), median (IQR)	2023 Ozone (ppb), median (IQR)	2024 Ozone (ppb), median (IQR)
January	10 (7, 13)	8 (7, 9)	6 (5, 8)	16 (11, 35)
February	13 (12, 15)	10 (8, 12)	11 (9, 12.5)	25 (8, 36)
March	16 (14, 18)	16 (14, 17)	12 (11, 14)	17 (15, 29)
April	21 (18, 23)	19 (16, 22)	14 (12, 16)	21.5 (19, 24)
May	21 (19, 25)	23 (20, 27)	17 (12, 19)	30 (28, 34)
June	18.5 (16, 20)	16.5 (14, 20)	10 (9, 15)	14 (11, 18)
July	12 (10, 15)	10 (8, 12)	9 (8, 13)	9 (8, 10)
August	10 (9, 11)	9 (7.5, 11.5)	7 (6, 8)	7 (7, 9)
September	10.5 (10, 11)	11 (9, 12)	8 (7, 10)	12 (9, 14)
October	13 (11, 15)	14 (10, 18)	10 (8, 11)	16 (14, 19)
November	13 (12, 14)	10 (9, 11)	8 (7, 10)	14 (11, 16)
December	10 (7, 11)	8 (6, 9)	7 (7, 28)	14 (10, 16)

*Abbreviations: IQR: Interquartile Range; ppb: Parts Per Billion

Table 5: Distribution of the PM10 Values Across 12 Months Over 4 Years (2021-24)

Months	2021 PM10 (μ/m3), median (IQR)	2022 PM10 (μ/m3), median (IQR)	2023 PM10 (μ/m3), median (IQR)	2024 PM10 (μ/m3), median (IQR)
January	233 (176, 303)	212 (181, 332)	271 (192, 306)	264 (233, 299)
February	216 (176.5, 232)	178.5 (134.5, 241.5)	221 (179, 268)	139 (124, 188)
March	152 (122, 168)	233 (184, 276)	154 (130, 196)	172 (142, 209)
April	124 (106, 152)	297 (272, 310)	178 (144, 239)	201.5 (174, 229)
May	81 (58, 91)	234 (179, 294)	160 (101, 242)	245 (193, 269)
June	84 (62, 106)	228.5 (139, 282)	117.5 (91, 152)	160.5 (125, 205)
July	67 (51, 81)	80 (58, 99)	69 (58, 73)	84 (72, 95)
August	74 (61, 106)	76.5 (72, 99.5)	109 (82, 134)	58 (49, 75)
September	70 (59, 84)	109.5 (66, 131)	93.5 (65, 119)	77 (68, 126)
October	183 (119, 207)	189 (139, 235)	202 (162, 230)	230 (160, 282)
November	391.5 (320, 425)	270.5 (227, 316)	354 (300, 434)	321.5 (284, 379)
December	285 (232, 374)	276 (223, 322)	271 (244, 311)	232 (192, 327)

*Abbreviations: PM: Particulate Matter; IQR: Interquartile Range

Table 6: Distribution of the PM2.5 Values Across 12 Months over 4 Years (2021-24)

Months	2021 PM2.5 (μ/m3), median (IQR)	2022 PM2.5 (μ/m3), median (IQR)	2023 PM2.5 (μ/m3), median (IQR)	2024 PM2.5 (μ/m3), median (IQR)
January	164 (140, 244)	147 (117, 244)	182 (114, 233)	204 (185, 232)
February	139.5 (108, 157)	82.5 (68.5, 141)	104.5 (82.5, 134.5)	94 (72, 124)
March	82 (58, 89)	102 (84, 119)	71 (56, 90)	76 (64, 93)
April	57.5 (47, 74)	107 (93, 115)	63 (45, 83)	66.5 (58, 82)
May	45 (35, 52)	74 (65, 89)	56 (35, 88)	76 (64, 102)
June	40.5 (35, 49)	57 (51, 73)	38.5 (33, 48)	46.5 (38, 53)
July	36 (32, 41)	33 (26, 40)	32 (27, 38)	35 (27, 44)
August	34 (27, 43)	39.5 (32.5, 43)	37 (29, 42)	25 (20, 28)
September	30 (25, 38)	37.5 (24, 52)	35 (28, 45)	34.5 (26, 49)
October	67 (51, 100)	94 (52, 129)	85 (55, 117)	95 (60, 140)
November	243 (203, 287)	160.5 (133, 201)	249 (176, 297)	184 (156, 215)
December	196 (156, 264)	177 (140, 208)	197 (155, 240)	115 (88, 176)

*Abbreviations: PM: Particulate Matter; IQR: Interquartile Range

Table 7: Distribution of the Sulphur-Di-Oxide Values Across 12 Months over 4 Years (2021-24)

Months	2021 SO2 (μ/m3), median (IQR)	2022 SO2 (μ/m3), median (IQR)	2023 SO2 (μ/m3), median (IQR)	2024 SO2 (μ/m3), median (IQR)
January	5 (4, 5)	3 (2, 3)	3 (2, 4)	11 (5, 17)
February	6 (5, 7)	3 (2, 3)	3 (2, 3)	5 (3, 9)
March	7 (6, 8)	5 (5, 6)	3 (3, 3)	7 (5, 7)
April	8 (6, 9)	7 (6, 7)	3 (2, 4)	6 (6, 7)
May	4 (3, 5)	4 (4, 5)	3 (2, 3)	6 (5, 7)
June	3 (3, 4)	3 (2, 3)	2 (2, 3)	3 (2, 3)
July	3 (2, 3)	2 (2, 2)	2 (2, 2)	2 (2, 2)
August	2 (2, 3)	2 (2, 2)	2 (2, 2)	2 (2, 5)
September	3 (3, 3)	2 (2, 2)	2 (2, 2)	3 (3, 3)
October	3 (3, 3)	3 (2, 14)	2 (2, 3)	4 (3, 4)
November	4 (4, 4)	3 (3, 3)	3 (3, 3)	5 (4, 5)
December	4 (3, 4)	3 (2, 3)	3 (3, 13)	6 (5, 6)

*Abbreviations: SO2: Sulphur-di-oxide; IQR: Interquartile Range

Discussion

The present study examined the alarming state of air pollution in New Delhi, resulting in seasonal and annual alterations in critical pollutants such as PM2.5, PM10, CO, NO_2, SO_2, and ozone from 2021 to 2024. The findings of the current study are in alignment with the existing literature, stating Delhi as one of the most polluted city in the world, especially during winters between November and January where AQI peak acutely due to residential and commercial biomass burning, agricultural stubble burning, waste burning, construction activities, transport vehicles, light air, coal burning, industrial emission, and temperature anastrophe [1-3].

The research suggested that crop residue burning is a periodic problem, between October and November in the Punjab, Haryana, and western Uttar Pradesh of India. The first 15 days of November recorded as the most impacted period when the air transported the burning residues and alter the ambient air quality over these parts of India [4].

The premature deaths and diseases due to air pollution are the largest environmental health threat globally.3 The premature deaths are associated with various polluting sectors, suggesting the necessity for an emission mitigation strategy that addresses each industry and any interlinkages that exist. The Ministry of Environment, Forest and Climate Change launched an initiative for the National Clean Air Programme (NCAP) in 2019 to achieve a 20-30% reduction in PM levels by 2024. The AQI, PM2.5, and PM10 levels were consistently categorized as “Very Poor” to “Severe” particularly from October to January. This clearly depicts the limited effectiveness of the mitigation policies and the implementation of the tailored interventions [5].

Nonetheless, PM 2.5 and PM10, remains a major concern. Our research found that the PM2.5 levels exceeded the World Health Organization’s annual safe limit (5 μg/m³) by tenfold in several months. The results were consistent with global findings by IQAir (2023), which ranked Delhi as one of the most polluted cities in the world.2 Our study showed a modest decrease trend in annual average PM 2.5 and PM10 values in 2024, reflecting minor progress in initiatives under NCAP. However, the levels remain substantially greater than acceptable limits, outlining the need for stronger and lasting actions. Furthermore, evidence suggested that Delhi had the highest per capita economic loss (USD 62·0 [46.6-79.9]) from air pollution [6].

The levels of Nitrogen dioxide (NO_2) in the analysis were high between November and April, maybe due to vehicle emissions, industrial activities, and fossil fuel combustion for heating. The elevated NO_2 levels are reported to be associated with increased respiratory infections and long-term lung damage, airway inflammation.2,4 Similarly, carbon monoxide (CO) levels remain stable throughout 2021 and 2022, but the levels elevated in the winters between December and January in 2023 and 2024, affecting the heart and brain [7]. In addition, the levels of Sulphur-dioxide (SO_2) remained relatively uniform throughout the year; however, the levels rose at the beginning of 2024. Studies suggested that exposure to a higher concentration for 15-20 minutes can cause severe obstructive syndrome. Evidence depicted that exposure to SO_2 at less than 25 ppm may cause irritation in the eyes and throat and respiratory health issues among the population [8].

The overall declining trend in AQI values from 2021 to 2024 in certain months, like January, demonstrated a slight but insufficient improvement in air quality. This could be due to periodic government actions such as the odd-even vehicle scheme, the firecracker ban, the temporary industries, and construction work closures during high-pollution days. However, the persistence of poor air quality throughout the year indicates that these interventions may not be long-term or evenly implemented [9,10]. Research showed that the deaths from continued exposure to poor air quality contributed to the risk of non-communicable diseases (NCDs), including chronic obstructive pulmonary disease (COPD), ischemic heart disease, stroke, and even type 2 diabetes, lower respiratory infections, as prioritized in the Global Burden of Disease Study 2019. Air pollution is identified as the second leading risk factor in India. Household air pollution (HAP) and outdoor air pollution were responsible for 5% and 6% of the total disease burden in India, respectively, in 2016 [2,6].

The present study did an extensive four-year analysis of seven major pollutants using secondary data from reliable sources such as the CPCB and other validated platforms, ensuring data integrity.

The findings of the present study indicate that current pace of development needs improvement, despite Delhi’s inclusion under the Smart Cities Mission and the implementation of various mitigation policies. Thus, community-level awareness, real-time air quality monitoring, and mobile AQI applications that give timely and easily accessible information to the public, helping people take preventive actions, are required. However, technological solutions must be combined with policy enforcement, inter-sectoral partnership, and structural reforms such as encouraging electric vehicles, controlling industrial emissions, and improving urban green infrastructure [10].

Limitations

The study has some limitations as well. Since the analysis only focused on New Delhi, the findings may not reflect the air quality trends in the Delhi NCR regions, which also face similar pollution challenges. There may be gaps or inconsistencies resulting from uncontrolled missing values or issues in air pollution measuring device calibration [11-13].

Conclusion

Delhi’s air quality still poses a serious environmental and health threats, especially during the winter months when pollution levels are at their highest. The present study observed marginal improvement in certain pollutants between 2021 and 2024, whereas the overall air quality remains hazardous. Despite the introduction of numerous initiatives such as National Clean Air Programme (NCAP), they still have not produced sustainable impact. Our study highlighted winters as the season of highest risk, a depicting recurring trend. To address this, sustainable interventions are important to target key pollutants such as PM2.5, PM10, and NO_2. Additionally, a collaborative, multi-sectorial initiative involving health, urban development, transport, and industry sectors is essential to establish greener and liveable cities.

The future research must prioritize the localized adverse health impacts of air pollution and critically assess the long-term effectiveness of the urban air quality policies and action plans.

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