ORIENTAL JOURNAL OF CHEMISTRY
An International Open Access, Peer Reviewed Research Journal
www.orientjchem.org

ISSN: 0970-020 X
CODEN: OJCHEG
2024, Vol. 40, No.(3):
Pg. 728-736

Assessing the Health Impacts of Air Pollutants on and their -related Health Risks on Vulnerable Populations in Delhi

SUBHADRA RAJPOOT[1], MAMTA GAUTAM[2] and ADITI DHAMA[3]

[1]Department of Applied science and Humanities, Amity University Gr. Noida (U.P.), 201306, India.
[2]Department of Applied science and Humanities, ABES Engineering College, Ghaziabad, India.
[3]Department of Fashion Technology, Amity University Gr. Noida (U.P.), 201306, India.
*Corresponding author E-mail: srajpoot@gn.amity.edu

http://dx.doi.org/10.13005/ojc/400313

(Received: March 28, 2024; Accepted: May 01, 2024)

ABSTRACT

Airborne particulate matter (PM) is a combination of numerous chemical species rather than a single pollutant. It is a complicated mixture of solids and aerosols made up of solid cores coated in liquid, minute liquid droplets, and dry solid fragments. They can vary greatly in size, shape, and chemical makeup. When breathed into the lungs, particles having a diameter of 10 microns or smaller (known as PM_{10}) can have a negative impact on health. Particles with a diameter of no more than 2.5 microns are referred to as fine particulate matter ($PM_{2.5}$). Consequently, part of PM_{10} is contained in $PM_{2.5}$. Particulate matter exposure is linked to detrimental health effects. The topic of whether certain PM mixture components provide a bigger risk to the public's health than others has long existed to regulate the sources that release the more hazardous ones. To determine whether certain PM sources and constituents may be more hazardous than others, this study outlines an extensive epidemiologic and toxicologic research program. To safeguard public health, regulatory bodies must consider this question when establishing air quality guidelines. The findings indicate that while other factors and sources could not be completely ruled out, PM from traffic sources, the combustion of coal and oil, and other sources was linked to unfavourable health effects. Thus, based on what is now known, establishing air quality criteria for PM mass overall is probably still a good way to safeguard public health.

Keywords: Air pollution, Particulate matter, Environment, Health effect.

INTRODUCTION

Particulate matter refers to tiny particles suspended in the air, varying in size and composition. These particles can originate from various sources such as vehicle emissions, industrial processes, construction activities, and natural sources like wildfires and dust storms. PM is categorized based on size, with PM_{10} (particles with a diameter of 10 micrometres or less) and $PM_{2.5}$ (particles with a diameter of 2.5 micrometres or less) being the most monitored.

The impact of particulate matter on health is profound. When inhaled, PM can penetrate deep into the lungs and even enter the bloodstream, causing a range of health issues. Short-term exposure to elevated levels of PM can exacerbate respiratory conditions such as asthma and bronchitis, leading to increased hospital admissions and emergency room visits. Moreover, the effects of PM are not limited to respiratory and cardiovascular health; emerging research suggests potential links to neurological disorders and adverse pregnancy outcomes. Addressing the issue of particulate matter pollution requires a multi-faceted approach including stricter emissions standards, promotion of cleaner technologies, urban planning measures to reduce traffic congestion, and public awareness campaigns. By mitigating PM pollution, we can significantly improve public health and quality of life for communities worldwide.

The National Capital Region will implement and carry out all emergency measures, including a ban on commercial four-wheelers, polluting trucks, and all forms of construction, if the AQI attains 450 in accordance with the Center's air pollution management plan. $PM_{2.5}$, a tiny particulate matter that can profoundly penetrate the respiratory system and cause health difficulties, was found to be seven to eight times higher in concentration in certain parts of It was eighty to one hundred times above the safe limit of five micrograms per cubic meter established by the WHO. The air quality in Delhi-NCR has become worse over the last week due to an ongoing decline in temperature, calm winds that retain contaminants, and a rise in the burning of post-harvest paddy straw across Punjab and Haryana. The chance of death from lung cancer and cardiovascular illness increased by 8% and 6%, respectively, with every 10µg/m^3 increase in PM2.5[17]. PM's physicochemical characteristics and chemical makeup vary with time and space, which might lead to various impairments. Nevertheless, the processes behind PM's detrimental impacts on different systems remain incompletely understood and need a comprehensive integration. Furthermore, the World Health Organization changed the recommended limit of $PM_{2.5}$ in the Air Quality Guideline to 5µg/m^3, requiring the investigation of deeper and more intricate mechanisms. However, new research has revealed several novel processes, including as ferroptosis, pyro ptosis, and epigenetic changes, that are implicated in PM damage.

Status of air pollution in Delhi

The federal and state governments collaborate in the administration of Delhi, also known as the National Capital Territory of Delhi. About 167.5 lakh people can stay there (Indian Census, 2011) Environmental pollution primarily affects metro areas worldwide, with Delhi, India, being the worst affected. The World Bank Development Research Group funded research that examined the consequences of air pollution from 1991 to 1994.[2] The average yearly limit for total suspended particle matter (TSP) set by the World Health Organization was around five times higher in Delhi during the study period. Additionally, on 97% of the days that tests were conducted, Delhi's total suspended particle levels during this time were higher than the 24 h standard set by the World Health Organization. The study indicated that while the overall number of non-trauma deaths in Delhi was less affected by particle matter than in the US, deaths related to air pollution in Delhi resulted in a greater loss of life years since these deaths were happening at a younger age.

Concerning declining conditions, the Indian Ministry of Environment and Forests examined Delhi's environmental status in a 1997 study.[3] One of the study's highlighted areas of concern was air pollution. About 3000 metric tons of air pollutants were predicted to be released daily in Delhi, with cars accounting for most of the emissions (67%), followed by thermal power plants that burn coal (12%). From 1989 to 1997, the Central Pollution Control Board (CPCB) saw an increasing trend. Due to the rise in the number of vehicles on the road, the concentrations of carbon monoxide from vehicle emissions in 1996 were 92% higher than those in 1989. Due to constraints on lead-handling industrial units and the de-leading of gasoline, the particle lead concentrations seemed to be under control. Together with other industrial units, Delhi has the largest cluster of small-scale enterprises in India, accounting for 12% of all air pollutants. In Delhi, one major source of air pollution is vehicular pollution The PM_{10} standard is typically employed in the assessment of air quality. Particles of a diameter of 10µm or less—0.0004 inches, or one-seventh the breadth of a human hair—are included in the PM_{10} standard. Due to their small size and capacity to enter the lower respiratory system, these particles are probably the cause of harmful health effects. The effects of PM_{10} exposure on the respiratory and breathing systems, lung tissue damage, cancer, and early mortality are the main health risks to humans. Children, the elderly, and those suffering from asthma, the flu, or chronic lung illness are most vulnerable to the impacts of particulate matter. Delhi surpassed the maximum PM_{10} limit by nearly ten times, at 198 µg/m^3, according to the urban air database published by the World Health Organization in September 2011. Delhi came in third place, behind

Ludhiana and Kanpur.[5] Both indoor and outdoor air pollution in Delhi has been linked to vehicle emissions and industrial activity.

Considering the context, the main goal of this research is to investigate Delhi's environmental data to verify the city's bad state of air quality. Afterward, the GAM model will be used to evaluate the relationship between air pollutants and morbidity, or respiratory disorders. It is imperative to gain a deeper understanding of how ambient air pollution and city air quality affect respiratory illnesses. This study could give all the knowledge required to begin reducing health hazards and air pollution, developing public health guidelines, and—above overall—developing an overall-encompassing environmental management system for Delhi.

Study sites

Delhi, a densely and heavily polluted city, offers a chance to use the GAM model to determine the extent to which the current level of air pollution contributes to respiratory illnesses among city inhabitants. According to a 2011 census research, Delhi has a population of roughly 11 million people living in 1,483 km^2. Over time, Delhi became one of the nation's most important cities in terms of business, industry, healthcare, and education. Delhi has a severe climate with five distinct seasons, according to Köppen's classification. Winter is cold (December–January), and summer is hot (April–June). Summertime averages range from 25 to 45 degrees Celsius, while winter averages range from 22 to 5 degrees Celsius[33] pleasant time of year February to March is springtime, and mid-September to late November is autumn.[34]

MATERIALS AND METHODS

Air pollution data

Delhi's pollution levels are mostly determined by its climate.

During the winter, Delhi experiences low wind velocity, inversion in air strata, and chilly, dry air. Air pollution cannot disperse under such circumstances.[9] 500 million tons of crop residue burned in the wintertime in the Delhi area results in the production of haze owing to inversion.[10] Dust storms from the middle east and Thar desert worsen the state of the air throughout the summer. Because contaminants coat the dust, it becomes toxic in a contaminated atmosphere. Furthermore, Delhi cannot reduce its pollution levels through the moderating influence of the sea because it is a landlocked city. A serious environmental issue that has an impact on people's health in both developed and developing nations is air pollution.[12]

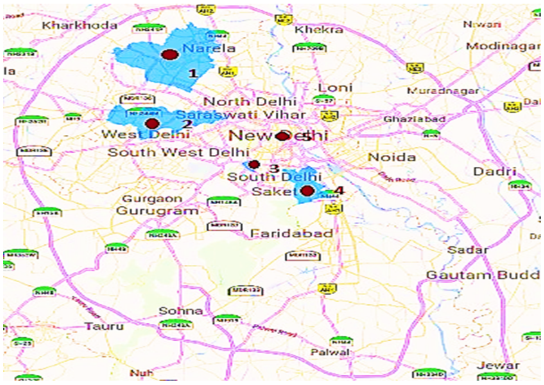


Table S2: Monitoring stations and their geographic coordinates, Delhi

Sl. No	Monitoring stations	Latitude	Longitude
1	Bawana	28.5843	77.2368
2	Punjabi Bagh	28.5902	77.2170
3	Major Dhyan Chand National stadium	28.6127	77.2363
4	Okhla Phase 2	28.5296	77.2721
5	RK Puram	28.5502	77.18518

The GAM model will be sufficient to evaluate the confounding influence of meteorological circumstances on morbidity associated with respiratory disorders based on Central Control Room for Air Quality Management-All India (Central Pollution Control Board). The effects of particulate matter (PM) on heart and respiratory health are becoming more and more obvious as levels of the gas approach dangerous levels. Asthma, bronchitis, and other respiratory infections are on the rise, and people with pre-existing cardiac issues are reporting worsening symptoms. The current situation is concerning due to increasing air pollution and unfavourable predictions that the death rate for children under five will double by 2050. The moment to act is now, since Prime Minister Narendra Modi just said that India wants to reach net-zero carbon emissions by 2070.

Methods of analysis

Time series analysis and summary statistics (Table 1 and 2)

Summary Statistics has been done using

Python library Pandas which helps in reading the data and providing information about the columns, data types, and summary statistics such as mean, median, minimum, maximum, and quartiles using describe function. This enables to gain insights into the data distribution, identify patterns, and make informed decisions based on data analysis. The violin plot is particularly useful for visualizing the distribution of a numerical variable within different categories. Python's Seaborn library has been used to create the plot. When interpreting the violin plot, pay attention to the width of the "violin," which represents the density of data points at different values. Higher density is demonstrated by the wider segments, while lesser density is displayed by the narrower parts. Violin plots in Python using Seaborn, allowing you to visualize the distribution of data across different categories effectively.

Frequency analysis

Monitoring pollutants in the atmosphere is crucial for understanding environmental trends and formulating effective policies. In this analysis, we leverage Power BI's robust visualization capabilities to conduct a timeseries analysis of pollutants, providing insights into their temporal trends and patterns.

Correlation analysis using python

Correlation analysis in Python typically involves calculating correlation coefficients between pairs of variables. In the heatmap, each cell represents the correlation coefficient between two pollutants. The color and value of each cell indicate the strength and direction of the correlation. Positive values indicate a positive correlation (as one pollutant increases, the other tends to increase), while negative values indicate a negative correlation (as one pollutant increases, the other tends to decrease). Values close to zero suggest weak or no correlation. correlation analysis for pollutants using Python helps in gaining insights into the relationships between various pollutants in your dataset.

Generalized additive models

The irregular connections between the outcome variable (hospital visits for respiratory sickness) and the various separate variables (climatic variables and guidelines pollutants) in Delhi are better clarified by the (GAM) model. In this work, a non-para smoothening splines were employed to account for the potential confounding impacts of the minimal independent variables that were incorporated in the regression model.[39,40] Finally, we created the following GAM model (Eq. 1) in our current investigation using standard notations based on the explanation of the regression model building given above.

$$\text{Log}[E(Yi)]=B\chi Xi+s(time,df_1)+s(temperature,df_2)+s(humidity,df_3)+wind\ speed+DOW+ \qquad (1)$$

Where i stands for the observation day, E (Yi) for the anticipated daily hospital visits resulting from respiratory illnesses, β for the regression coefficient, and Xi for the average daily concentration of pollutants; α represents the intercept, while s is the applied smoothing spline. The independent variables, such as $PM_{2.5}$, PM_{10}, NO_2, SO_2.

RESULT AND DISCUSSION

Data distribution and time-series analyses

The distribution of criteria pollutants, climatic variables (T and RH), and daily counts of hospital from the data obtained from Annual Report from Directorate General of Health Services Government of NCT of Delhi are placed in Table 1 for 2020–23. Table 1 shows that the average PM2.5 and PM10 concentrations were much above the WHO and NAAQS recommendations. Between 2020 and 2023, they reach as high as 810.9000µg m^{-3} for PM_{10} and 650.10 µg m^{-3} for $PM_{2.5}$. Delhi's relative humidity (RH) is 97.3% on average (98.3% to 12.5% range), which is greater than the 50–70% optimum range for comfort and health. The extreme climate of Delhi is shown by the three-year mean temperature of 25.63±7.65°C, with maximum temperatures reaching 45°C and lowest temperatures of 6.2°C, and a greater relative humidity. In 2020–23, the average number of days those patients with respiratory disorders spent in the hospital was 20±23.52.

Based on information gathered from hospital records, Table 2 shows that 477,122 patients in total attended in Delhi hospitals in selected areas, between 2020 and 2023, either for an outpatient consultation or for a hospitalization for respiratory disorders. There were 176 patients in maximum attendance for respiratory conditions in a single day, and there were 0 patients in minimum and the total death count in a single day is 1394. 30% of the patients were older than 68, and 65.5% of the patients were female. In a similar vein, 55% of the male patients were over 68.

Table 1: An overview of Delhi's daily hospital visits, climate variables, and pollution criterion distribution from 2020 to 2023

	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO	TEMP	RH%
Count	7328.000	7324.000	7246.000	7178.000	7223.000	7225.000	7260.000
Mean	106.491	209.329	39.4682	11.475	1.245	25.343	61.6016
Std	86.465	122.549	24.779	8.525	0.668	7.404	13.592
MIn	6.200	9.700	0.200	0.700	0.0000	6.200	11.400
25%	42.800	110.425	21.100	5.400	0.8000	19.300	53.600
50%	76.600	188.819	34.100	10.000	1.100	27.500	63.200
75%	146.575	285.275	54.500	15.900	1.500	31.000	70.800
Max	650.100	810.900	219.400	127.400	6.300	45.100	97.300

Table 2: Patients with respiratory disorders, by age and gender, Delhi, 2020–2023 (N=237261)

	OPD Male	OPD Female	OPD Total	IPD Male	IPD Female	IPD Total	Death Male	Death Female	Death Total
Count	4.000000	4.000000	4.000000	4.000000	4.000000	4.000000	4.000000	4.000000	4.000000
Mean	179631.000	172552.750	352183.750	13418.500	10403.250	23821.7500	617.500	370.750	988.250
Std	51443.240	52243.290	103109.960	694.489	2424.335	2195.464	234.778	96.920	327.430
MIn	123318.000	125268.000	248546.000	12495.000	8045.000	21322.000	357.000	236.000	593.000
25%	144892.500	134688.750	279581.250	13081.500	9080.000	21770.000	522.000	349.250	871.250
50%	178972.500	162541.000	341513.500	13584.500	9915.500	23109.000	593.000	390.000	983.000
75%	213711.000	200405.000	414116.000	13921.500	11238.750	25160.250	688.500	411.500	1100.000
Max	237261.0000	239861.000	477122.000	14010.000	13737.000	27747.000	927.000	467.000	1394.000

Time series charts showing, air pollutants ($PM_{2.5}$, PM_{10}, and CO), temperature, and relative humidity as well as their interactions are shown for Delhi from 2020 to 2023. In Delhi, between 2020 to 2023, there was a significant connection between $PM_{2.5}$ and PM_{10}, demonstrating their interdependency Fig. 1(a). No. pf patients connected to respiratory disorders also showed a positive association Figs. 1(b) and 1(c). A positive link between hospital visits and CO content in the urban environment is also demonstrated by Figure 1(f).

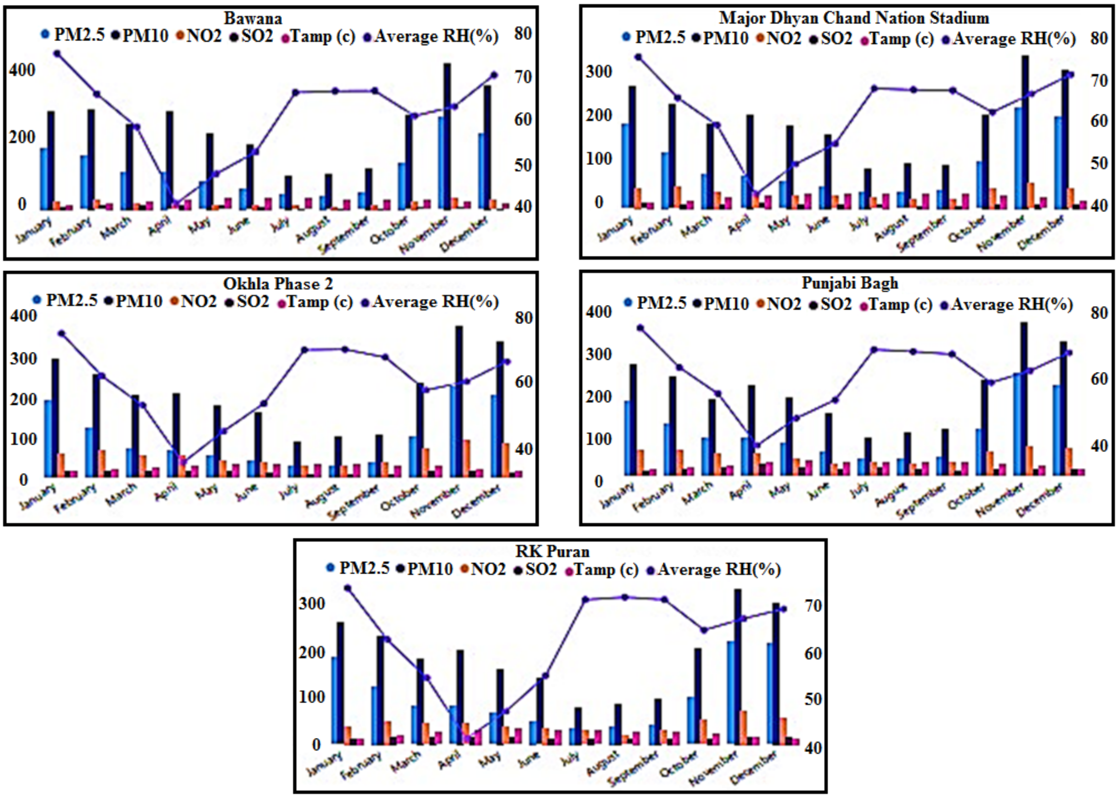
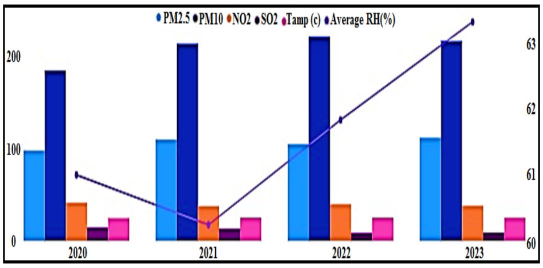
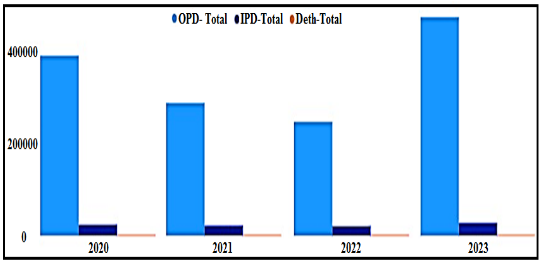


Fig. 1(a). The time series of Delhi from 2020–2023 between different particulate matters and pollutants at selected sites month wise





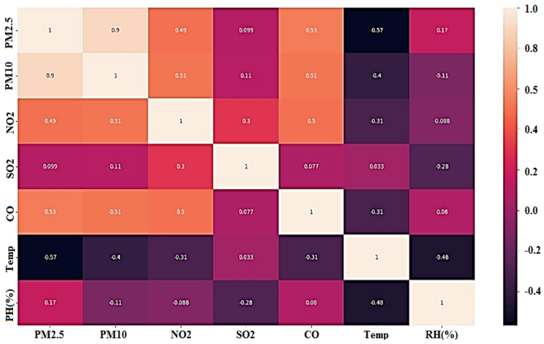


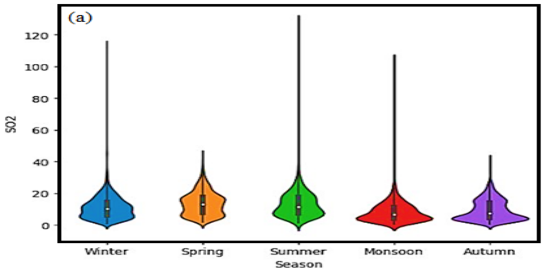
Fig. 1(b). Pollutant and meteorological variables correlations

There was a minor positive connection (r=0.281) between PM_{10} and SO_2, but there was a positive correlation (r=0.341) between the two important gaseous pollutants, SO_2 and NO_2. Table 3 and Fig. 2 demonstrate the almost linear positive association that PM_{10} exhibited with both NO_2 (r=0.783) and CO (r=0.733). Furthermore, $PM_{2.5}$ displayed positive linear correlations with CO (r=0.757), NO_2 (r=0.673), and SO_2 (r=0.137). Moreover, there was an encouraging correlation among PM_{10} and $PM_{2.5}$.

Table 3: Correlation analysis of different pollutants with respect to each other

	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO	Temp	RH%
$PM_{2.5}$	1.0000	0.89869	0.49085	0.098773	0.53004	-0.57056	0.16626
PM_{10}	0.89869	1.0000	0.50950	0.105216	0.51257	-0.39653	-0.11386
NO_2	0.49085	0.50950	1.0000	0.29963	0.49532	-0.30765	-0.08777
SO_2	0.09877	0.10521	0.29963	1.0000	0.07692	0.03319	0.28410
CO	0.53004	0.51257	0.49532	0.076925	1.0000	-0.10488	0.07994
Temp	-0.57056	-0.39653	-0.30765	0.033190	-0.31048	1.0000	0.47576
RH%	0.16626	-0.11386	0.08777	-0.28410	0.07994	-0.47576	1.0000

Violin plots of different air pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2), two meteorological variables (T, RH), and hospital visits of patients were drawn for the five distinct seasons of Delhi have been provided in Fig. 2(a)–3(g) above. Fig. a and b shows that in the winter and autumn NO_2 predominates in the city and SO_2 predominates in city air in both the winter and summer. Fig. 2(e) shows that in the winter and autumn, $PM_{2.5}$ predominates in the urban environment. Fig. 2(c) shows that PM_{10} predominates in city air in both the winter and summer, but wintertime median PM_{10} concentrations were greater. During the winter, the amount of CO in the air stays high, and during the monsoon season, it decreases Fig. 2(g). With the greatest median value during the monsoon, Fig. 2f makes it abundantly evident that the city has somewhat greater RH during the summer and monsoon. According to Fig. 2(d), summer and autumn are the hottest seasons in the city. Finishing points are shown by the rectangles inside the violin.



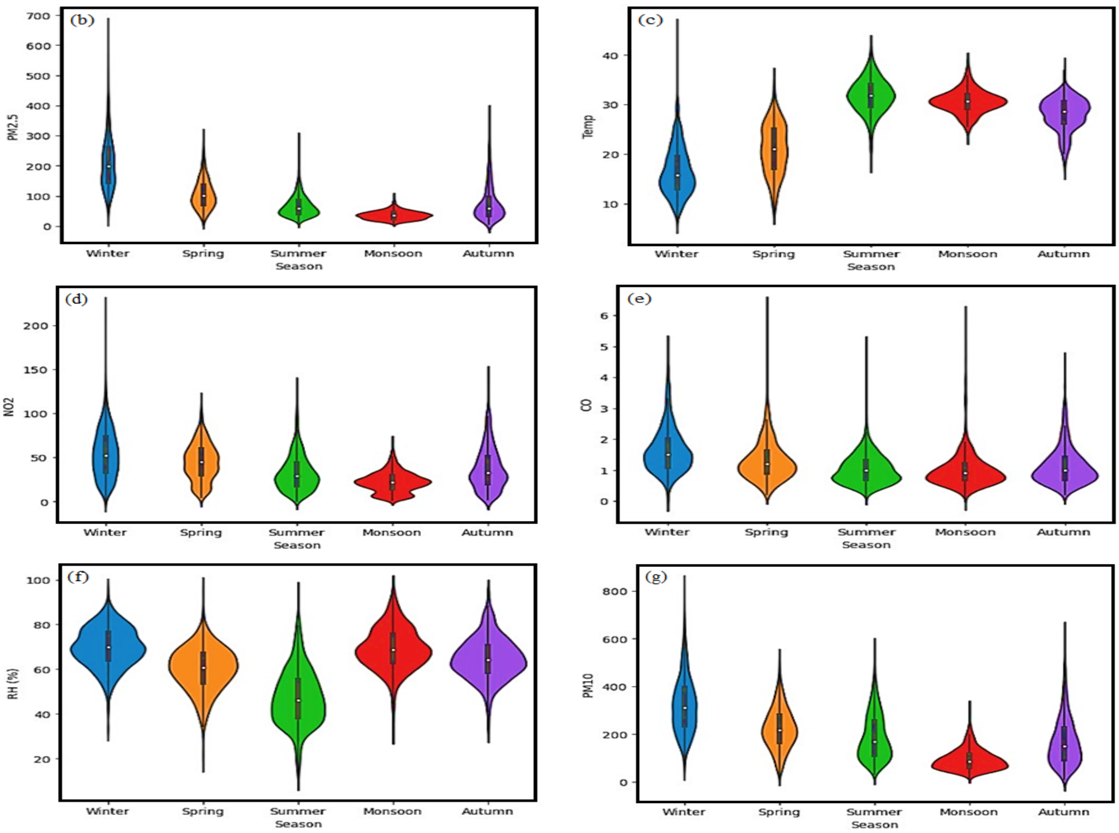


Fig. 2(a)-3(g). Violin plots of three air pollutants, two metrological variables, and hospital visits in five seasons of Delhi. (a) NO_2, (b) SO_2, (c) PM_{10}, (d) TEMP, (e) $PM_{2.5}$, (f) RH (g) CO

RESULT AND CONCLUSION

The study first investigated Delhi's air pollution levels before evaluating how air pollution affected respiratory illnesses. The outcome implies that Delhi has been finding it difficult to deal with the growing types of criterion pollutants in the first place. Delhi's air pollution has been a longstanding issue, particularly during the winter months when a combination of factors exacerbates the problem. These factors include vehicular emissions, industrial pollution, construction activities, agricultural burning in neighbouring states, and geographical factors such as temperature inversions which trap pollutants close to the ground. The primary pollutants of concern include particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NOx), sulphur dioxide (SO_2), carbon monoxide (CO).

- ❖ Respiratory Problems
- ❖ Increased Hospitalizations
- ❖ Reduced Lung Function
- ❖ Risk of Respiratory Infections

Between 2020 and 2023, 22, 253 individuals with respiratory illnesses were admitted to the Delhi hospital or saw an outpatient consultation. According to the study, Delhi's mean $PM_{2.5}$ and PM_{10} concentrations for the years 2020–2023 were 109.32±71.06 µg/m^{-3} and 210.61±95.90 µg/m^{-3}, respectively. These values were significantly higher than the WHO and NAAQS guidelines. Frequency analysis showed that, of Delhi's five seasons, $PM_{2.5}$ and PM_{10} pollution predominate most during the winter. According to preliminary time series analysis, hospital visits in Delhi between these selected durations were positively correlated with CO, $PM_{2.5}$, and PM_{10}, while hospital visits were positively correlated with CO. According to a Pearson correlation analysis, PM_{10} in Delhi displayed a high positive association with $PM_{2.5}$ but only almost positive linear relationships with NO_2 and CO. It's interesting to note that SO_2 continued to have a strong positive association with CO, NO_2, $PM_{2.5}$, and PM_{10}. Previous research conducted in Mumbai, India, revealed a substantial positive association between $PM_{2.5}$ and NO_2, designating $PM_{2.5}$ as a dummy indicator of air pollution caused by emissions from the city's transportation sector[34]. According to air pollution data, there are noteworthy positive relationships between PM concentrations and gaseous pollutants. These correlations suggest that causes of pollution include waste disposal, solvent evaporation, and transportation-related pollution.

Efforts to mitigate Delhi's air pollution include measures such as vehicle emissions standards, restrictions on industrial emissions, promoting cleaner cooking fuels, and implementing policies to reduce agricultural burning. However, addressing the problem requires coordinated efforts at the local, regional, and national levels, as well as long-term sustainable solutions to reduce pollution sources and improve air quality for the health and well-being of Delhi's residents.

ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The author declare that we have no conflict of interest.

REFERENCES

1. Schwartz J. Air pollution and hospital admissions for heart disease in eight US counties., *Epidemiology.,* **1999**, *10*(1), 17–22.
2. Dominici F.; Samet JM.; Zeger SL. Combining evidence on air pollution and daily mortality from the twenty largest US cities: a hierarchical modelling strategy (with discussion)., *J R Stat Soc Ser* A., **2000**, *163*, 263–302.
3. Lee JT.; Kim H.; Hong YC.; Kwon HJ.; Schwartz J.; Christiani DC. Air pollution and daily mortality in seven major cities of Korea, 1991–1997., *Environ. Res.*, **2000**, *84*(3), 247–254. doi: 10.1006/enrs.2000.4096.
4. Yang CY.; Chang CC.; Chuang HY.; Tsai SS.; Wu TN.; Ho CK. Relationship between air pollution and daily mortality in a subtropical city: Taipei, Taiwan., *Environ. Int.*, **2004**, *30*(4), 519–523. doi: 10.1016/j.envint.2003.10.006.
5. Zeka A.; Zanobetti A.; Schwartz J. Short term effects of particulate matter on cause specific mortality: effects of lags and modification by city characteristics., *Occup. Environ. Med.*, **2005**, *62*(10), 718–725. doi: 10.1136/oem.2004.017012.
6. Kan H.; London SJ.; Chen G.; Zhang Y.; Song G.; Zhao N., Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China., *Environ. Int.*, **2007**, *33*(3), 376–384. doi: 10.1016/j.envint.2006.12.001.
7. Schwartz J. Air pollution and hospital admissions for the elderly in Birmingham, Alabama., *Am. J. Epidemiol.*, **1994**, *139*(6), 589–598. doi: 10.1093/oxfordjournals.aje.a117048.
8. Schwartz J. Air pollution and hospital admissions for respiratory disease. *Epidemiology.,* **1996**, *7*(1), 20–28. doi: 10.1097/00001648-199601000-00005.
9. Zanobetti A.; Schwartz J.; Dockery DW. Airborne particles are a risk factor for hospital admissions for heart and lung disease., *Environ. Health Perspect.*, **2000**, *108*(11), 1071–1077. doi: 10.1289/ehp.001081071.
10. Atkinson RW.; Anderson HR.; Sunyer J.; Ayres Baccini M.; Vonk JM.; Boumghar A.; Acute effects of particulate air pollution on respiratory admissions results from APHEA 2 Project., *Am. J. Respir. Crit. Care Med.*, **2001**, *164*(10 Pt 1), 1860–1866. 10.1164/ajrccm.164.10.2010138.
11. Wilson AM.; Wake CP.; Kelly T.; Salloway JC. Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological timeseries study., *Environ. Res.*, **2005**, *97*(3), 312–321. doi: 10.1016/j.envres.2004.07.010.
12. Ravindra K.; Rattan P.; Mor S.; Aggarwal AN. Generalized additive models: Building evidence of air pollution, climate change and human health., *Environ. Int.*, **2019**, *132*, 104987. doi: 10.1016/j.envint.2019.104987.
13. Peng RD.; Dominici F.; Barriuso RP.; Zeger SL.; Samet JM. Seasonal Analyses of Air Pollution and Mortality in 100 US Cities., *American Journal of Epidemiology.*, **2005**, *161*(6), 585–594, doi: 10.1093/aje/kwi075.
14. Medina-Ramón M.; Zanobetti A.; Schwartz J. The effect of ozone and PM10 on hospital admissions for pneumonia and chronic obstructive pulmonary disease: a National Multicity Study., *Am. J. Epidemiol.*, **2006**, *163*(6), 579–588. 10.1093/aje/kwj078.

15. Lu X.; Zhang S.; Xing J.; Wang Y.; Chen W.; Ding D.; Progress of air pollution control in China and its challenges and opportunities in the ecological civilization era., *Engineering*., **2020**, *6*(12), 1423–1431. 10.1016/j.eng.2020.03.014.
16. Dutta A.; Jinsart W. Risks to health from ambient particulate matter ($PM_{2.5}$) to the residents of Guwahati city, India: An analysis of prediction model., *Hum. Ecol. Risk Assess*., **2021a**, *27*(4), 1094–1111. doi: 10.1080/10807039.2020.1807902.
17. Zhao Y.; Hu J.; Tan Z.; Liu T.; Zeng W.; Li X.; Ambient carbon monoxide and increased risk of daily hospital outpatient visits for respiratory diseases in Dongguan., *China. Sci. Total Environ*., **2019**, *668*, 254–260. doi: 10.1016/j.scitotenv.2019.02.333.
18. Song J.; Lu M.; Zheng L.; Liu Y.; Xu P.; Li Y.; Acute effects of ambient air pollution on outpatient children with respiratory diseases in Shijiazhuang, China., *BMC Pulm. Med*., **2018**, *18*(1), 150. doi: 10.1186/s12890-018-0716-3.
19. Cai J.; Peng C.; Yu S.; Pei Y.; Liu N.; Wu Y.; Association between $PM_{2.5}$ Exposure and All-Cause, Non-Accidental, Accidental, Different Respiratory Diseases, Sex and Age Mortality in Shenzhen., *China. Int. J. Environ. Res. Public Health*., **2019**, *16*, 401. 10.3390/ijerph16030401.
20. Liang L.; Cai Y.; Barratt B.; Lyu B.; Chan Q.; Hansell AL.; Associations between daily air quality and hospitalizations for acute exacerbation of chronic obstructive pulmonary disease in Beijing, 2013–17: an ecological analysis., *Lancet Planet Health*., **2019**, *3*, 270–279. 10.1016/S2542-5196(19)30085-3.
21. Wang X.; Xu Z.; Su H.; Ho HC.; Song Y.; Zheng H., Ambient particulate matter (PM_1, $PM_{2.5}$, PM_{10}) and childhood pneumonia: The smaller particle, the greater short-term impact Sci., *Total Environ*., **2021**, *772*, 145509. doi: 10.1016/j.scitotenv.2021.145509.
22. IQAir. World Air Quality Report 2020: Region and city $PM_{2.5}$ ranking., **2019**.
23. Gurjar BR.; Van Aardenne JA.; Lelieveld J.; Mohan M. Emission estimates and trends (1990–2000) for megacity Delhi and implications., *Atmos Environ*., **2004**, *38*, 5663–5681. doi: 10.1016/j.atmosenv.2004.05.057.
24. Gurjar BR.; Sharma A.; Agarwal A.; Sharma A.; Gupta P.; Nagpure AS.; Human health risks in megacities due to air pollution., *Atmos. Environ*., **2010**, *44*, 4606–13. 10.1016/j.atmosenv.2010.08.011.
25. Yadav S.; Satsangi PG. Characterization of particulate matter and its related metal toxicity in an urban location in Southwest India., *Environ. Monit. Assess*., **2013**, *185*(9), 7365–7379. doi: 10.1007/s10661-013-3106-6.
26. Panda S.; Sharma SK.; Mahapatra PS.; Panda U.; Rath S.; Mahapatra M.; Organic and elemental carbon variation in $PM_{2.5}$ over mega city New Delhi and Bhubaneswar, a semi-urban coastal site in India., *Natural Hazards*., **2016**, *80*, 1709–1728 10.1007/s11069-015-2049-3.
27. Guttikunda SK.; Nishadh KA.; Gota S.; Singh P.; Chanda A.; Jawahar P.; Air quality, emissions, and source contributions analysis for the Greater Bengaluru region of India, Atmos., *Pollut. Res*., **2019**, *10*(3), 941–953. doi: 10.1016/j.apr.2019.01.002.
28. Chen Y.; Wild O.; Ryan E.; Sahu SK.; Lowe D.; Archer-Nicholls S.; Mitigation of $PM_{2.5}$ and ozone pollution in Delhi: a sensitivity study during the pre-monsoon period, Atmos., *Chem. Phys*., **2020**, *20*, 499–514, 10.5194/acp-20-499-2020.
29. Sreekanth V.; Mahesh B.; Niranjan K. Gradients in $PM_{2.5}$ over India: Five city study., *Urban Climate*., **2018**, *25*, 99–108. 10.1016/j.uclim.2018.06.001.
30. Khilnani GC.; Tiwari P. Air pollution in India and related adverse respiratory health effects: past, present, and future directions., *Curr. Opin. Pulm. Med*., **2018**, *24*(2), 108–116. doi: 10.1097/MCP.0000000000000463.
31. Sharma AK.; Baliyan P.; Kumar P. Air pollution and public health: the challenges for Delhi, India., *Rev Environ. Health*., **2018**, *28,33*(1), 77–86. doi: 10.1515/reveh-2017-0032.
32. Balyan P.; Ghosh C.; Sharma AK.; Banerjee BD. Health Effects of Air Pollution among Residents of Delhi: *A Systematic Review, International Journal of Health Sciences and Research*., **2018**, *8*(1), 273–282.
33. Mahato S.; Pal S.; Ghosh KG. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi., *India. Sci. Total Environ*., **2020**, *730*, 139086. doi: 10.1016/j.scitotenv.2020.139086.
34. Impact Assessment of Diwali Fireworks Emissions on the Air at Special Locations in Delhi During Three Consecutive Years. S RAJPOOT-*Oriental Journal of Chemistry*., 2023ISSN: 0970-020 X CODEN: OJCHEG **2023**, *39*(2), 417-426.