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Comparison of Pre-Diwali, Diwali, and Post-Diwali Levels of PM10 and PM2.5 Pollutants in Chennai City (India)

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Abstract

Introduction: The Indian festival of Diwali, which is celebrated in October/November with firecrackers, is a potential contributory factor to the rapid and transitory buildup of $PM_{2.5}$/ PM_{10} particles. This research seeks to assess the influence of Diwali firework emissions on $PM_{2.5}$/PM_{10} concentrations in Chennai, India, a tropical urban area.

Methods: This cross-sectional study aimed to examine the concentration of PM_{10} and $PM_{2.5}$ measured during Pre-Diwali, Diwali, and Post-Diwali using secondary data collected from 2017 to 2023 from the Tamil Nadu Pollution Control Board in Chennai across four stations. The data were statistically analyzed using SPSS version 24.

Results: The findings indicate that the average levels of PM_{10} and $PM_{2.5}$ during Diwali were approximately eight times and seven times greater than the established NAAQ standards, respectively. The PM_{10} mass concentration reached peak levels, ranging from 995 to 1985 μg/m^3 (2022), which is significantly above the safe limits. However, a big drop was seen in pollutant levels in 2020 across all areas due to the imposition of COVID-19 curbs. The highest PM_{10} levels were observed between 8 PM and 11 PM, and the highest $PM_{2.5}$ levels were observed between 7 PM and 9 PM in the measured years. Also, according to the Delta C (the difference between post- and pre-Diwali pollution levels) analysis, the variability in Delta C was not explained by the concentrations of PM_{10} and $PM_{2.5}$ during Diwali.

Conclusion: The Indian government should strictly enforce the use of non-polluting crackers to prevent additional environmental degradation.

Keywords: Air pollutants, Particulate matter, Environmental monitoring, Festival, COVID-19

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Introduction

Air pollution is among the leading environmental threats to human health (1–3). Air pollutants exert diverse impacts on individuals, and these impacts depend on the composition, quantity, duration, frequency, and toxicity of the pollutants to which individuals are exposed (4). An international cancer research agency has established that airborne pollutants and particulate matter (PM) are the most lethal carcinogens for humans (5,6). Additionally, other studies have indicated that annual fatalities from ambient air pollution range from 7 to 9 million (7).

Diwali, known as the festival of lights in India, is celebrated with great enthusiasm every year around late October or early November. This culturally significant event involves lighting firecrackers, which is a traditional part of the festivities. However, a serious concern during Diwali is the decline in air quality due to these fireworks. Firecrackers release various chemicals into the air, including potassium chlorate, potassium nitrate, arsenic, sulphur, sodium oxalate, manganese, ferric oxide, aluminum, barium, potassium perchlorate, strontium nitrates, and charcoal (8). Pyrotechnic exhibitions, e.g., "blue lightning rockets" and "fountains," release dangerous airborne contaminants such as poly-chlorinated dioxins and furans, alongside sulphates, potassium nitrate, charcoal, carbon monoxide and dioxide, ozone, bio-aerosols, and suspended particulates (e.g., PM_{10}, $PM_{2.5}$), all of which pose health risks, as evidenced by prior research (9–11).

To protect public health, enhance air quality, and reduce air pollution, it is crucial to know about the temporal and geographical variability of contaminants in urban settings (12). Ongoing air quality surveillance is an essential instrument for evaluating air pollution trends (13,14) and is conducted using both temporary and permanent monitors of air quality situated in industrial areas, metros, and residential regions (15,16). The urban community frequently experiences acute air pollution episodes (7,17), which escalate during significant events, such as Diwali celebrations (8,18,19), resulting in increased hospital admissions and fatality rates. The burnt firework particulates penetrate deeply into the lungs, reaching the alveolar sacs, from whence they are disseminated to other organs via the bloodstream, resulting in systemic poisoning. Air pollution predominantly induces ailments such as asthma, pulmonary illnesses, respiratory tract infections, allergic reactions, lung cancer, and, in severe instances, fatalities (16,20,21). Atmospheric air pollutants adversely affect the climate, in addition to jeopardizing human health and other life forms (22).

Several studies have investigated the impact of Diwali fireworks in different urban centers of India (15,19,23–25). During Diwali, concentrations of respirable suspended $PM_{2.5}$ and PM_{10}, heavy metals, water-soluble ions, SO_2, and NO_2 exceed the National Ambient Air Quality Standards (NAAQS), with PM_{10} concentrations increasing annually (26). Other studies (27,28) have also observed an increase in pollutants, such as SO_2, NO_2, O_3, TSP, metal traces, and bio-aerosols.

The terms PM_1, $PM_{2.5}$, and PM_{10} refer to atmospheric aerosols that have an overall median aerodynamic dimension below 1, 2.5, and 10 µm, respectively. Because of their impacts on visibility, people's health, and the environment, such aerosol particles are of concern (29,30). There is evidence that the populations of megacities are already suffering from the negative health effects caused by elevated particulate levels (31). Burning petroleum-based products in stationary sources, such as power areas and furnaces, and moving sources, such as cars and building machinery, are the primary contributors of particulate matter $PM_{2.5}$ and PM_1 in urban areas. Mechanical operations release larger particles (PM_{10}) into the atmosphere, whereas combustion releases finer particles ($PM_{2.5}$ and PM_1) (32).

In the present investigation, the levels of $PM_{2.5}$ and PM_{10} were evaluated in Chennai city (India) during Diwali over seven years (2017 to 2023). Prior research (33–35) has indicated that the daily/monthly/annual measurements of $PM_{2.5}$ and PM_{10} concentration in Chennai have exceeded the limits indicated by the World Health Organization (WHO), severely jeopardizing the city's air quality. The government of Tamil Nadu has subsequently attempted strict measures, including the outright banning of fireworks use in 2022 (25). Nevertheless, there is a sustained need to provide scholars and policymakers with additional data to enhance their understanding of $PM_{2.5}$ and PM_{10} emissions before and after Diwali in Indian megacities, such as Chennai, so that they can offer solutions for mitigating the negative impact of fireworks on the atmosphere. This research aimed to evaluate the concentrations of PM_{10} and $PM_{2.5}$ particulate matter over three distinct periods, before, during, and after Diwali, analyzing data spanning seven consecutive years, from 2017 to 2023. The particle levels and nature of pollution during the COVID-19 era were also examined. It may be noted that a recent research study (36) has conducted an environmental evaluation of $PM_{2.5}$ during the Diwali festival in Chennai using data for 2017. However, the present study presented a more comprehensive comparison as it considered data from 2017 to 2023, and included PM_{10} in the evaluation.

Materials and Methods

Sampling Site

The study was conducted in Chennai, a prominent city situated on the Coromandel Coast along the eastern coastline of the Indian peninsula. Chennai is the capital of the Indian state of Tamil Nadu. Geographically, Chennai is located between 13.0843° N and 80.2705° E. The city's average elevation is 8 m above mean sea level (18).

Ambient air quality in the city is regularly monitored and measured by the Tamil Nadu Pollution Control Board (TNPCB). For this purpose, the city has eight manual National Air Quality Monitoring Programme (NAMP) stations installed in various parts of the city and seven Continuous Ambient Air Quality Monitoring Stations (CAAQMS). The NAMP and CAAQMS locations in Chennai city are listed in Table 1. Every area operates twice a week on a 24-hour basis (37).

Data Collection

The study used secondary data for the seven years from 2017 to 2023 from TNPCB. The four areas included in the study were Kodungaiyur, Perungudi, Koyambedu, and Royapuram (Figure 1). Analysis of PM_{10} and $PM_{2.5}$, the two major pollutants, was the focus of the investigation. The

Table 1. NAMP and CAAQMS locations in Chennai

NAMP		CAAQMS	
1.	Kathivakkam	1.	Kathivakkam
2.	Manali	2.	Koyambedu
3.	Thiruvottiyur	3.	Royapuram
4.	Anna Nagar	4.	Perungudi
5.	Adyar	5.	Kodungaiyur
6.	Thiyagaraya Nagar	6.	Manali
7.	Kilpauk	7.	Gummidipoondi
8.	Nungambakkam		

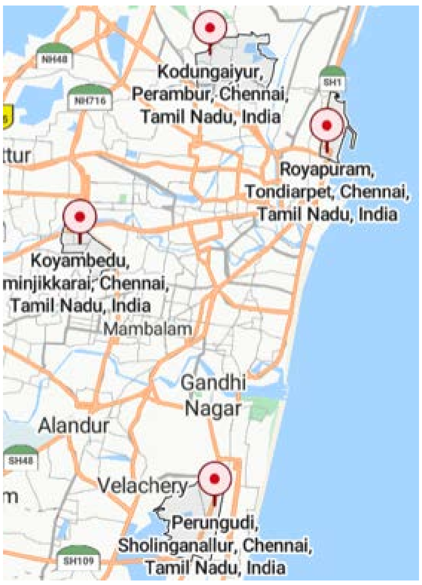


Figure 1. Study Area - Four locations in Tamil Nadu

data utilized were the levels of the two major pollutants as measured at one-hour intervals (24 hours) for the duration of the Diwali season in the respective years. The hourly average data were utilized for the study. The Diwali season was considered to comprise three segments: Pre-Diwali (the 15 days leading to Diwali), Diwali (the festival day), and Post-Diwali (the 15 days after Diwali). Daytime hours were from 6 AM to 6 PM, whereas nighttime hours were from 6 PM to 6 AM.

Statistical Analysis

The data were analyzed using the Statistical Package for Social Sciences (SPSS) version 24.0. Regression analyses, ANOVA (analysis of variance), and scatter plots were utilized for Delta C analyses to assess the difference between post- and pre-Diwali pollution levels.

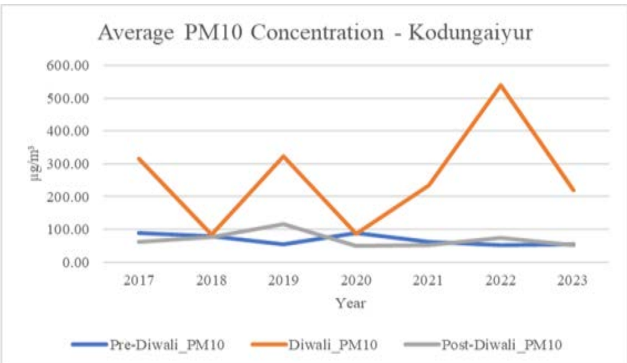
Results

PM_{10} and $PM_{2.5}$ Concentrations During Diwali

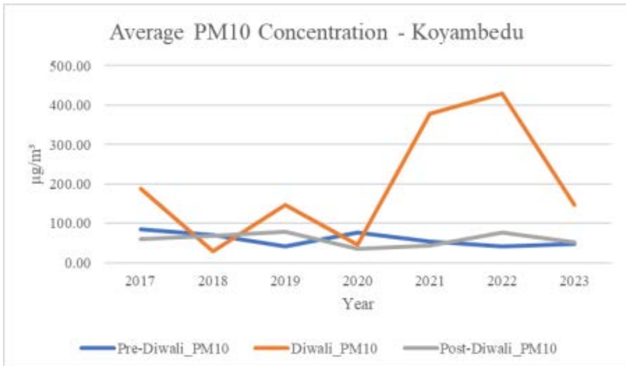
Figure 2 depicts average PM_{10} concentrations at Kodungaiyur, Koyambedu, Perungudi, and Royapuram for the study period, while Figure 3 depicts the $PM_{2.5}$ concentrations. The peak mass concentration of PM_{10} in Kodungaiyur was observed to range from 995μg/m³ (2017) to 1985 μg/m³ (2022) on Diwali day, in comparison with pre-Diwali peak concentrations of 190.40 μg/m³ to 83.80 μg/m³ and post-Diwali peak concentrations of 87.73 μg/m³ to 134.27 μg/m³ during the same period. The peak mass concentration of $PM_{2.5}$ in Kodungaiyur also shows similar trends, which could also be seen in Koyambedu, Perungudi, and Royapuram. In addition, the subsequent measure taken by the Government of Tamil Nadu in 2022, the outright ban on the use of fireworks (25). It appears to have contributed to the overall reduction of PM_{10} and $PM_{2.5}$ concentrations in 2023.

In 2018, there was a limited restriction on igniting firecrackers during Diwali. In 2019, a complete ban was imposed on all firecrackers, save for green crackers, which were permitted (38). Therefore, there was a decrease in pollutants in 2018, followed by a smaller increase in 2019. Also, a big dip is seen in pollutant levels in 2020 across all areas, due to the imposition of COVID-19 curbs. The PM levels experienced a substantial decline, resulting in all areas meeting the Indian air quality requirement of 60 μg/m³ for a 24-hour average. Kolkata exhibited the highest decrease in $PM_{2.5}$ levels at 61%, while Mumbai experienced a reduction of 50%, followed by Chennai and New Delhi (25%) (39).

Tiwari et al. (40) found that lower temperatures contributed to increased levels of pollutants. This could explain why there was an elevated level of pollutants during the pre-Diwali period in 2020 compared to 2019. Rising air temperature results in an unpredictable atmosphere, facilitating rapid dilution of pollutants (41). The humidity level in Chennai during Diwali in 2020 was lower than that in 2019. Reduced air moisture promotes the amplification of pollutants, and conversely, increased air moisture inhibits their spread (42). During Diwali in the epidemic year, Delhi reported a high level of relative humidity. The elevated humidity levels should have considerably diminished the amounts of pollutants present. Nevertheless, the rise in pollutant levels from before Diwali to Diwali, despite the presence of high moisture, suggests widespread burning of fireworks in Chennai before 2023.



Kodungaiyur



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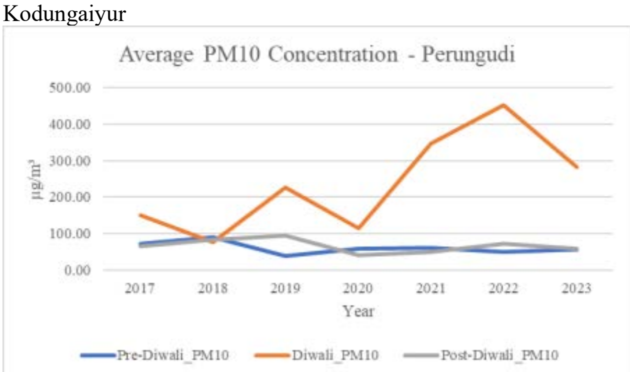

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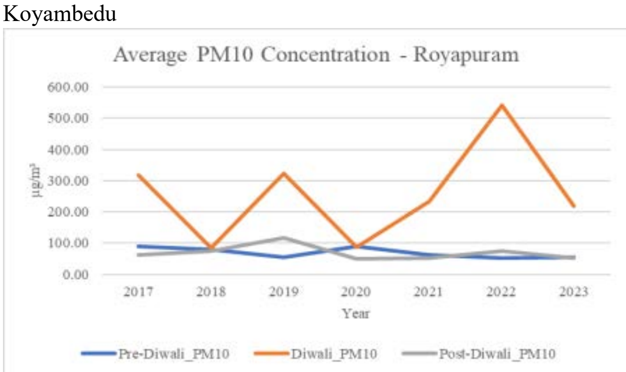
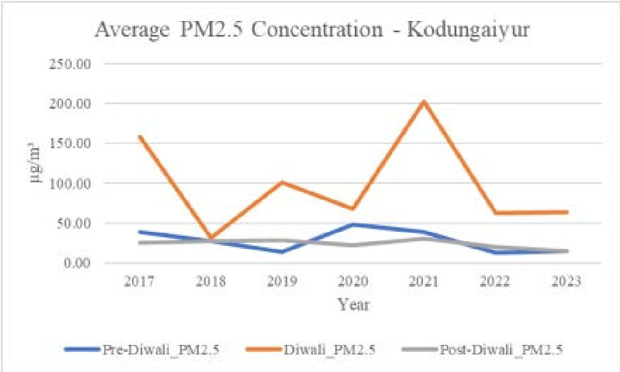
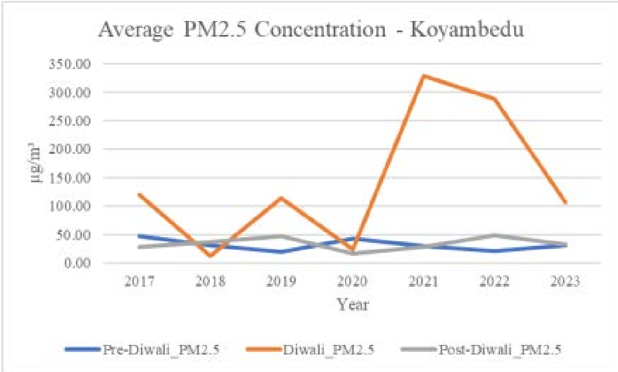


Royapuram

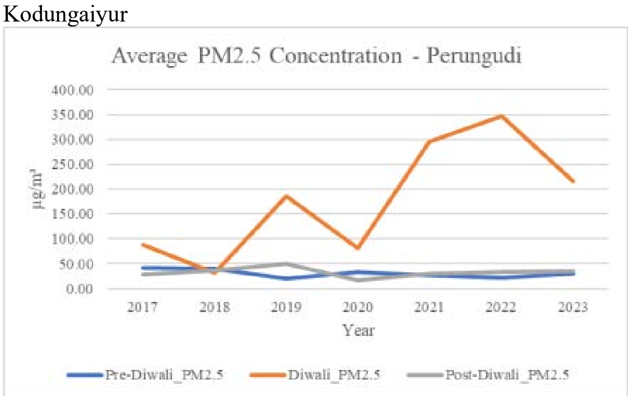
Figure 2. PM_{10} Concentrations at four monitored locations



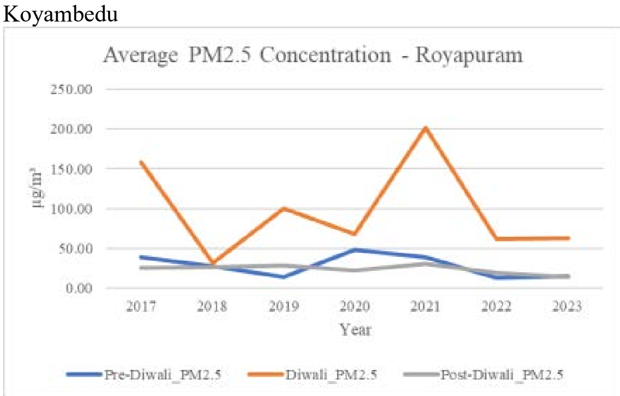
Kodungaiyur



Koyambedu



Perungudi



Royapuram

Figure 3. $PM_{2.5}$ Concentrations at four monitored locations

Minimum and Maximum Particulate Levels

The average values of the minimum and maximum concentrations of $PM_{2.5}$ and PM_{10} during 2017–2023 are shown in Table 2. The mean and standard deviations for the data are explained in Table 3. During Diwali, the average PM_{10} level was nearly 8 times the prescribed NAAQ level of 100 μg/m³, while that of $PM_{2.5}$ was around 7 times the prescribed NAAQ level of 60 μg/m³. Both these values are very dangerous and could cause severe lung impairments. The average particulate levels would have been much higher but for the low concentration levels during COVID-19 curbs, thereby indicating the need for strict measures to limit pollution.

It is crucial to note that the heightened particulate concentration is not solely due to firecrackers. Additional local events, such as vehicular emissions along with human activity, also contribute to this rise (43). Kumar et al. (39) performed similar research and found that the usage of crackers on festivals led to a 55%-120% spike in particulate surface mass enrichment in 2014, which aligns with the findings of the present research. Barman et al. (44) observed increased levels of PM_{10} during the Diwali festival, and this finding also aligns with the results of the present study.

Post-Diwali, Koyambedu and Perungudi reported the highest PM_{10} and $PM_{2.5}$ levels in 2020 (995 and 622 μg/m³, respectively), while Koyambedu reported the highest levels in 2021 (1985 μg/m³). The maximum PM_{10} value prescribed by the NAAQS and WHO is 100 and 45 μg/m³, respectively, while that of $PM_{2.5}$ is 60 and 15 μg/m³, respectively (45). It was observed that in 2022, the PM_{10} levels in Kodungaiyur were the highest at 1985 μg/m³, i.e., nearly 20 times the NAAQS recommended limit and nearly 44 times the WHO recommended limit. Likewise, in 2021, the $PM_{2.5}$ levels in Kodungaiyur were the highest at 862 μg/m³, i.e., nearly 14 times the NAAQS recommended limit and nearly 57 times the WHO recommended limit. These trends are visible in all the other three areas.

Table 2. PM_{10} and $PM_{2.5}$ average levels variation before Diwali, during Diwali, and after Diwali for all years and locations

	PM_{10} (μg/m³)		$PM_{2.5}$ (μg/m³)	
Period (2017-2023)	**Min**	**Max**	**Min**	**Max**
Pre-Diwali (4 locations)	50.139	87.171	21.84619	42.7881
Diwali (4 locations)	76.536	772.429	34.39286	428.0643
Post-Diwali (4 locations)	57.676	77.736	25.04286	35.89592
WHO Standard (24 hour)	45		15	
NAAQS (24 hour)	100		60	

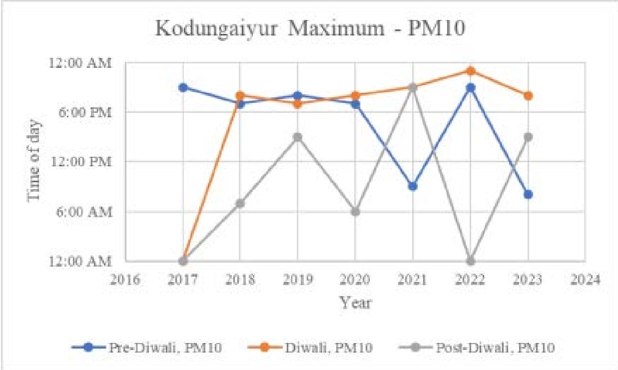
Occurrence of Maximum Pollution

Figures 4 and 5, respectively, illustrate the daily timeframes during which PM_{10} and $PM_{2.5}$ concentrations reached their highest levels across the four monitored locations - during the festive celebrations before Diwali, during Diwali, and after Diwali. For instance, in Kodungaiyur, peak PM_{10} concentrations typically occurred between 8 PM and 11 PM, while maximum $PM_{2.5}$ levels were recorded between 7 PM and 9 PM across the observed years. Similar trends were observed in all the other three areas monitored. Thus, the concentration of PM in the air was found to be greater at night compared to the day. At night time, the mixing altitude diminishes as the temperature drops

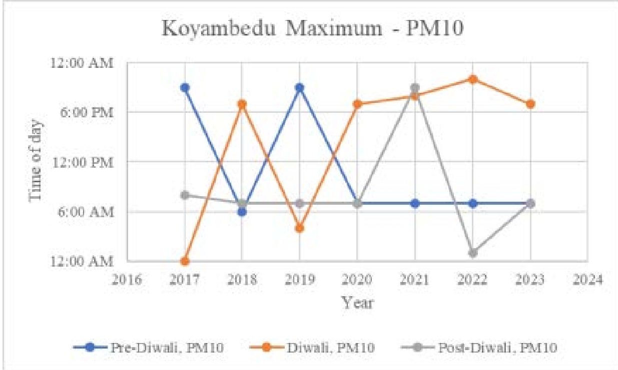
Table 3. Levels of PM_{10} and $PM_{2.5}$ before Diwali, during Diwali, and after Diwali for all years and locations

Period	Year	Std. Error	Min	Max	Mean ± Std. Deviation
Pre-Diwali_PM_{10}	2017	4.07	41.07	190.40	83.51 ± 39.88
	2018	1.81	49.93	134.40	79.02 ± 17.70
	2019	2.20	16.80	106.60	47.03 ± 21.51
	2020	1.73	48.53	121.53	78.49 ± 16.94
	2021	1.34	32.88	114.69	60.05 ± 13.13
	2022	1.52	25.53	92.27	49.13 ± 14.94
	2023	0.84	34.73	74.60	53.51 ± 8.20
Diwali_PM_{10}	2017	21.05	73.00	952.00	243.15 ± 206.23
	2018	7.25	12.00	337.00	69.17 ± 71.06
	2019	30.79	7.00	1577.00	254.90 ± 301.65
	2020	13.23	16.00	769.00	83.23 ± 129.59
	2021	51.12	5.00	1985.00	298.41 ± 500.90
	2022	68.91	60.00	1985.00	490.98 ± 675.19
	2023	18.54	73.00	985.00	216.40 ± 181.62
Post-Diwali_PM_{10}	2017	0.99	43.20	87.73	62.15 ± 9.67
	2018	1.75	50.36	123.50	76.00 ± 17.18
	2019	2.48	59.93	186.71	101.01 ± 24.32
	2020	0.92	24.36	66.34	42.89 ± 9.03
	2021	0.81	31.16	81.13	49.28 ± 7.92
	2022	2.60	47.44	178.01	74.51 ± 25.46
	2023	0.99	32.86	69.64	53.48 ± 9.73
Pre-Diwali_$PM_{2.5}$	2017	2.64	18.33	114.73	41.28 ± 25.85
	2018	1.10	19.53	78.52	31.43 ± 10.77
	2019	0.73	7.69	39.48	16.77 ± 7.17
	2020	1.05	26.93	73.07	42.972 ± 10.33
	2021	0.94	16.20	59.47	33.37 ± 9.19
	2022	0.86	9.73	58.60	17.17 ± 8.40
	2023	0.97	11.33	50.53	22.87 ± 9.52
Diwali_$PM_{2.5}$	2017	17.10	35.00	856.00	130.88 ± 167.57
	2018	2.93	4.00	115.00	26.87 ± 28.72
	2019	13.76	1.00	678.00	125.31 ± 134.87
	2020	12.20	3.00	622.00	60.34 ± 119.49
	2021	44.26	1.00	1916.00	257.23 ± 433.64
	2022	35.78	13.00	1901.00	189.80 ± 350.52
	2023	14.93	22.00	981.00	112.01 ± 146.29
Post-Diwali_$PM_{2.5}$	2017	0.44	19.50	41.57	26.93 ± 4.32
	2018	1.03	23.50	69.50	31.74 ± 10.10
	2019	1.13	23.93	67.43	38.56 ± 11.12
	2020	0.61	9.79	40.09	19.26 ± 6.02
	2021	0.55	21.96	61.49	30.10 ± 5.34
	2022	2.19	13.50	138.53	30.34 ± 21.50
	2023	1.10	10.43	48.71	24.13 ± 10.78

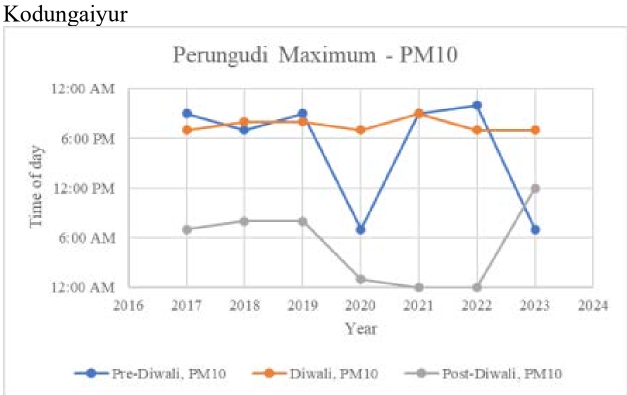
by around 6°C, causing the aerosol particulates to gather close to the surface. The reduced nocturnal wind speed inhibits the dispersion of particles, hence increasing the density of aerosol particulates on the surface. Heightened heat convection throughout the day leads to a rise in the mixing height, while stronger wind speeds contribute to the dispersion of aerosol particles, resulting in decreased surface aerosol levels. The daytime density of PM_{10} on the day before Diwali was nearly similar to that of a typical day due to the absence of any variation in human activity during the day between a regular day and the day before Diwali. The highest level of PM_{10} aerosol throughout the night was observed on Diwali; this was followed by levels after Diwali and before Diwali. This provides clear evidence



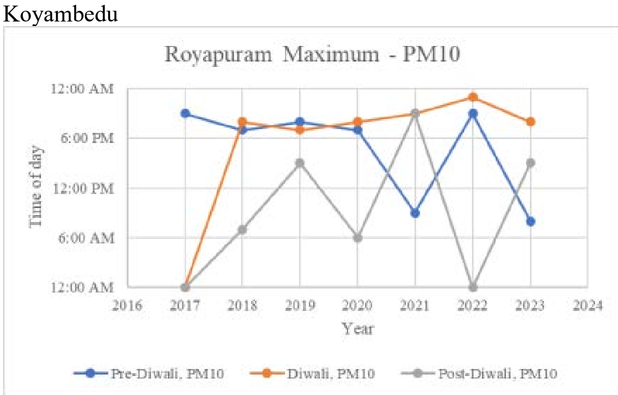
Kodungaiyur



Koyambedu

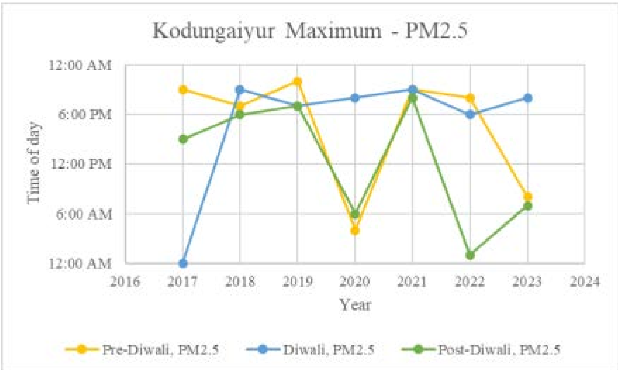


Perungudi

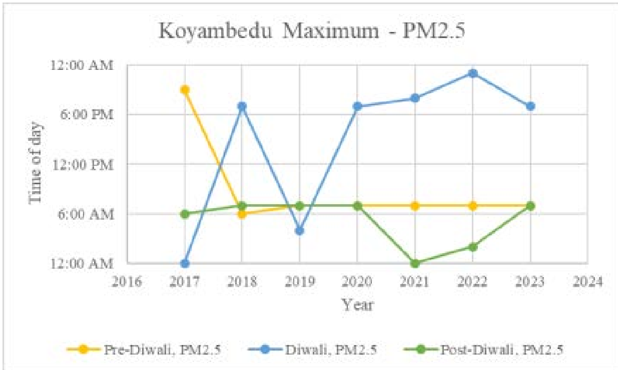


Royapuram

Figure 4. Time of day for occurrence of maximum PM_{10} pollution



Kodungaiyur



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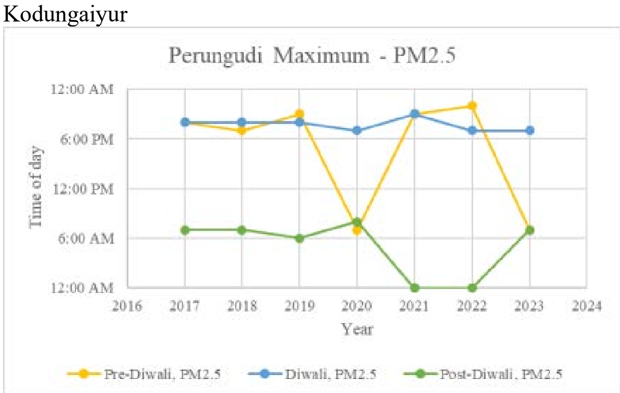

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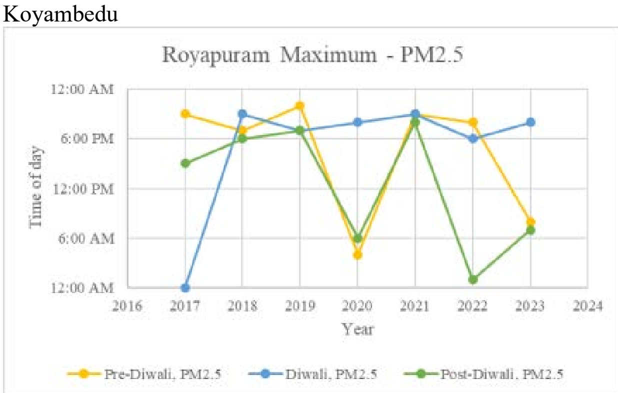

Royapuram

Figure 5. Time of day for occurrence of maximum $PM_{2.5}$ pollution

of the influence of fireworks on the amount of PM_{10} and $PM_{2.5}$ aerosols in the atmosphere during nightfall on those specific days. Nocturnal fireworks events had a significant impact on the subsequent day aerosol levels.

Comparison of Pollutant Levels

ANOVA was used to statistically assess differences in the levels of pollutants before, during, and after Diwali during the study period (Table S1). The study found that the differences were significant for all periods ($P = 0.00$). In other words, the levels of PM_{10} and $PM_{2.5}$ before, during, and after Diwali differed during the years across all locations and also within the same location at different times of day.

Delta C Analysis

Delta C (ΔC) represents the difference between post- and pre-Diwali pollution levels, i.e., the change in concentration of a specific pollutant or parameter between the period before Diwali and after Diwali. The scatter plots illustrate the relationship between PM_{10} concentrations (in μg/m³) and ΔC (the change in concentration of a specific pollutant or parameter) during three different periods: before, during, and after Diwali (Figure 6). In addition, Figure 7 illustrates the scatter plots between $PM_{2.5}$ concentrations (in μg/m³) and ΔC across three different periods: before, during, and after Diwali.

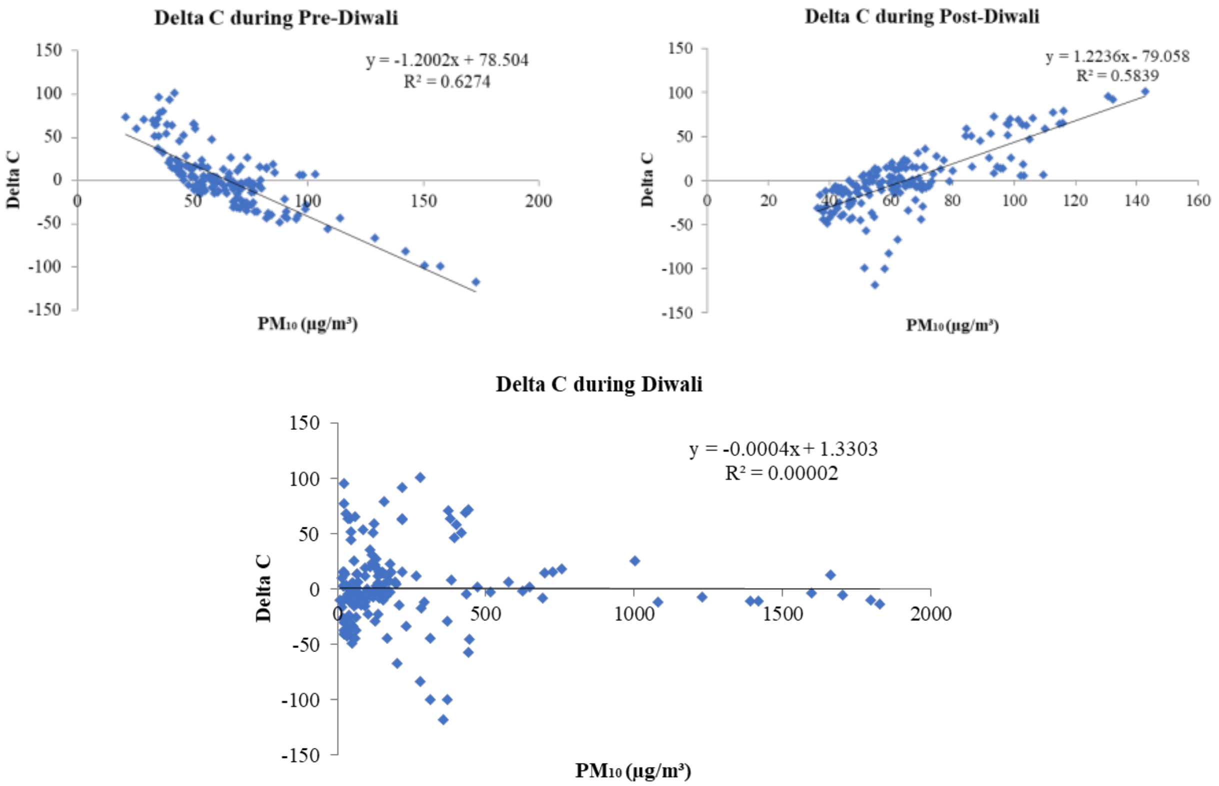

Figure 6. Scatter plot between PM_{10} and Delta C

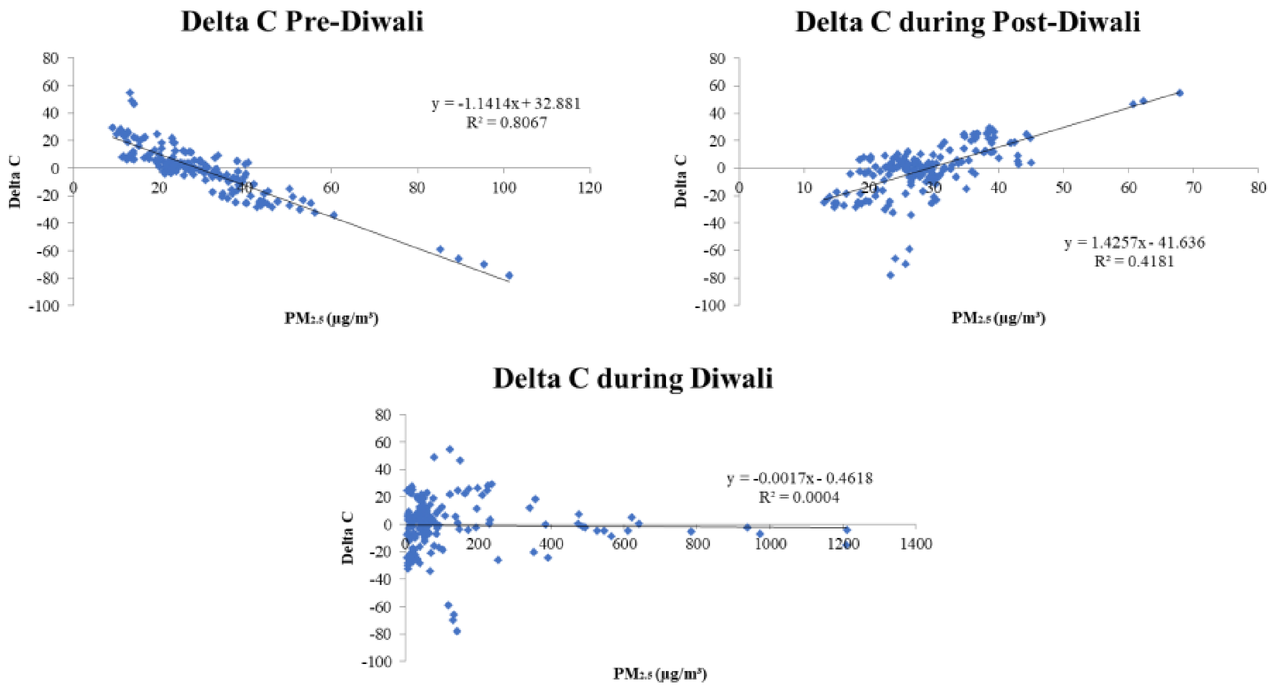

Figure 7. Scatter plot between $PM_{2.5}$ and Delta C

Pre-Diwali

The regression equations for PM_{10} and $PM_{2.5}$ before Diwali are $y = -1.2002x + 78.504$ and $y = -1.1414x + 32.881$, respectively, indicating a negative correlation between Delta C and the concentrations of $PM_{10}/PM_{2.5}$ before Diwali, implying that as the $PM_{10}/PM_{2.5}$ concentration increases, Delta C decreases. The R^2 values of 0.6274 and 0.8067, respectively, indicate a moderate to strong relationship, suggesting that around 62.74% and 80.67% of the variability in Delta C can be explained by the levels of PM_{10} and $PM_{2.5}$, respectively, before Diwali.

During Diwali

The regression equations for $PM_{2.5}$ and PM_{10} during Diwali are $y = -0.0004x + 1.3303$ and $y = -0.0017x - 0.4618$, with R^2 values of 0.00002 and 0.0004, respectively, indicating an almost negligible negative association between Delta C and the concentrations of $PM_{10}/PM_{2.5}$ during Diwali. The slope of the lines is very close to zero, indicating little to no linear relationship. The extremely low R^2 values (0.00002 and 0.0004, respectively) indicate that $PM_{10}/PM_{2.5}$ concentrations during Diwali do not explain the variability in Delta C, suggesting that perhaps other factors, such as wind speed and humidity levels, might be influencing Delta C during this period.

Post-Diwali

The regression equations for PM_{10} and $PM_{2.5}$ in this period are $y = 1.2236x - 79.058$ and $y = 1.4257x - 41.636$, with R^2 values of 0.5839 and 0.4181, respectively, indicating a positive association between Delta C and the concentrations of $PM_{10}/PM_{2.5}$ after Diwali, implying that as the $PM_{10}/PM_{2.5}$ concentration increases, Delta C also increases. The R^2 values of 0.5839 and 0.4181 indicate a moderate to strong relationship, suggesting that around 58.39% and 41.81% of the variability in Delta C, respectively, can be explained by the levels of $PM_{10}/PM_{2.5}$ after Diwali.

Discussion

There has been considerable focus on $PM_{2.5}$ and PM_{10} air pollution brought on by growing cities and industrialization (46,47). Major events, such as festivals, offer significant opportunities to analyze the effects of control policy strategies on environmental issues. Although several studies have investigated the features and divergences of $PM_{2.5}$ and PM_{10} levels during short-term events, few research works on their behavior over longer timeframes exist in the literature (48). Thus, our research can be regarded as one of the first to create a comprehensive picture using data collected over an extended period of time.

As anticipated, the findings in this study demonstrated that local governments' implementation of control policies during festivals (as was the case during the COVID pandemic) can significantly affect PM concentrations and result in a sharp drop during the course of the festivities. Conversely, traditional festivals involving the use of fireworks result in a notable increase in PM concentrations. Research indicates that due to strict government regulations during significant events, like international sporting competitions or conferences, the level of air pollutants in host cities tends to improve relative to baseline pollution levels, thereby enhancing the health of the public (49–51). Thus, with government-enforced restrictions, pollution can be greatly reduced.

Fireworks, unfortunately, represent a significant contributor to acute air pollution. Besides the studies in our database, there are other studies indicating a significant rise in PM levels during fireworks shows, e.g., in Chinese cities celebrating the Lunar New Year (52), a firecracker celebration in Queretaro, Mexico, to mark New Year's Eve (26), etc. Firework events are prevalent worldwide; however, studies conducted in developing countries such as China and India are more frequent (due to the numerous mega festivals celebrated in these countries), revealing elevated ambient $PM_{2.5}$ and PM_{10} concentrations and significant relative risk values. Understanding the mechanisms of emissions control may yield important insights for assessing the quality of air in major urban areas, particularly in developing nations.

The impacts of mega-events on the levels of $PM_{2.5}$ are shaped by various determinants. Both large-scale festivals and conferences are affected by the existing PM concentration, which significantly governs the extent of the influence of such events (53). Governments should implement more stringent control measures in areas with higher levels of ambient pollution to effectively mitigate pollution to safe environmental levels.

Government measures to limit pollution are typically categorized into three approaches. The first approach is the conditional burning of firecrackers, which entails the regulated use of fireworks in designated locations and times. The Indian Supreme Court's order to restrict firecracker bursting to two hours during Diwali (54) or the State government's outright ban on firecrackers in 2022 (25) were ignored, as Chennai's air quality fell to "poor" thresholds on the day of Diwali in 2023. The second approach involves prohibiting the use and sale of fireworks in urban areas. South Africa implemented a ban on the lighting and sale of firecrackers during festivities in Cape Town to mitigate air pollution (55). As another illustration, the Italian government decided to restrict or outright forbid fireworks in all of the country's major cities before New Year's Eve due to smog (56). This approach is a harsh one, considering the sentiments of the revelers. The third approach involves the use of green firecrackers. Green crackers are an ideal way to cut down on pollution without compromising enjoyment. The development of such eco-friendly crackers in India is attributed to the efforts of the National Environmental Engineering Research Institute and the Council for Scientific and Industrial Research (CSIR). Green crackers are less likely to include barium nitrate, the most harmful component in regular crackers. In place of magnesium and barium, green crackers employ aluminum and potassium nitrate, as well as carbon, rather than arsenic and other dangerous contaminants (57).

$PM_{2.5}$ and PM_{10} dispersal and buildup are greatly influenced by meteorological factors such as temperature, precipitation, temperature inversion, wind velocity, humidity levels, and atmospheric pressure (58). Relevant research has demonstrated that the effects of various meteorological factors on $PM_{2.5}$ and PM_{10} vary. Particulate matter levels were identified to be negatively correlated with precipitation, RH, air temperature, wind velocity, and atmospheric pressure, but positively correlated with PM concentrations and variations in meteorological variables, according to research by Li et al. (59). This implies that a better understanding of the impacts of variations in meteorological factors aids in the analysis of variations in PM levels. Also, depending on the extent to which traffic is a contributing factor in local air pollution, different locations will experience different effects from local transport-focused regulations, as well as further effects from emissions associated with transportation (60).

Particulate matter and Delta C readings are clearly significantly different on Diwali days. There is a steep increase in PM_{10} and $PM_{2.5}$ with Delta-C readings. Wang et al. (61) also noted a boost in the correlation between Delta-C and black carbon particles after any fireworks activity. There must be more UV-absorbing aromatic organic substances present because the UV-absorbing signal is enhanced.

Conclusion

Extensive use of crackers and loud explosives with fireworks during the Diwali celebration causes significant, albeit short-lived, air pollution. The present study statistically evaluated correlations between levels of pollutants PM_{10} and $PM_{2.5}$ in different areas in Chennai during the pre-Diwali, Diwali, and post-Diwali periods in 2017 to 2023. The study found that the peak mass concentration of PM_{10} and $PM_{2.5}$ was observed on the day of Diwali for all four studied regions compared to before and after Diwali periods. Moreover, the maximum concentration of PM_{10} and $PM_{2.5}$ was recorded at night time on the festival day in relation to non-festive days. The present study demonstrated that during Diwali, the average PM_{10} and $PM_{2.5}$ levels were nearly 8 times and 7 times higher than the prescribed NAAQ level, respectively. A big drop was seen in pollutant levels in 2020 across all areas, due to the imposition of COVID-19 curbs, which brought down the average figures for the entire period. In addition, pollutant levels were found to decrease significantly in 2023, probably due to the government's ban on firecrackers in Tamil Nadu.

To prevent additional environmental degradation, the government should strictly enforce the use of non-polluting crackers as soon as possible. Aside from Diwali, there are a few other occasions where firecrackers are lit. In densely populated urban settings, such actions can contribute to enhancing the quality of the surrounding air in the days ahead and ensure a sustainable atmospheric climate.

However, this study has some limitations. Firstly, more data across other regions need to be analyzed to make the results generalizable. Secondly, the data collected by the authors may contain errors associated with measuring, calibration, and instrument maintenance. The authors lack information concerning the collected data of the devices, flow verification, and checks at the network stages. However, personal interactions with the relevant technical officers indicated that the verification procedures followed are precisely as outlined in the manual for the monitoring devices utilized at each monitoring station.

Some avenues for future work are as follows:

- Satellite measurements on a global scale can be utilized to assess the temporal and spatial fluctuations in pollutant levels that are linked to firework events.
- Future research can examine and contrast pollutant levels across various regions in India using real-time $PM_{2.5}$ and PM_{10} analyzers.
- In areas where specific interventions, such as policy or legal measures, are introduced, studies can be undertaken to evaluate the impact of such policies on the quality of air during fireworks. This approach would help build a comprehensive evidence foundation for regulating pollution caused by fireworks.

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Competing Interests

The authors declare no competing interests.

Ethical Approval

The authors confirm that the research is their original study. It has not been published, nor is it under review in another journal, and it is not submitted for publication elsewhere.

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Supplementary Files

Supplementary file 1 contains Table S1.

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