International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 18, Number 1 (2023), pp. 27-38
© Research India Publications
https://dx.doi.org/10.37622/IJAES/18.1.2023.27-38

The Effect of Fire Cracker Burning on Ambient and Indoor $PM_{2.5}$ Levels in Jodhpur City

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Abstract

Increased air pollutants in the environment are a risk to human health. Particulate matter (PM) is one of the main factors contributing to ambient air pollution, and it becomes necessary to monitor outdoor as well as indoor PM levels to measure the risk. Diwali, the festival of lights, is one of the most celebrated festivals in India. However, it is also associated with a significant increase in air pollution levels, primarily due to the burning of firecrackers during the celebrations. Firecrackers can release large amounts of particulate matter, including PM_{10} and $PM_{2.5}$, which are tiny particles that can penetrate deep into the lungs and cause respiratory problems, aggravate asthma, and other lung diseases. A descriptive longitudinal study was carried out in Jodhpur, Rajasthan, India where data on outdoor air quality monitoring was limited especially during Diwali, and no past research has been conducted on indoor air pollution during Diwali. Air pollution (both outdoor and indoor) was monitored in selected households at four different sites namely Outer city area, Inner city area, Industrial Area and Rural area in Jodhpur district using low-cost sensor-based devices for a period of three months starting from 21st October 2021 to 1st February 2022 which included Diwali which was on 4th November 2021. The highest indoor $PM_{2.5}$ levels were recorded from residential housing in outer city area [Mean±SE=148.59±22.7µg/m^3], which was followed by rural area [145.43±6.06µg/m^3]. Highest outdoor $PM_{2.5}$ levels were found in industrial area where the mean $PM_{2.5}$ level was 131.42±6.75µg/m^3. Inner city area had least outdoor $PM_{2.5}$ [78.94±3.37µg/m^3] as well as indoor $PM_{2.5}$ [79.23±4.68µg/m^3] levels. Both indoor as well as outdoor $PM_{2.5}$ levels showed increasing trends around Diwali festival. The highest levels of indoor $PM_{2.5}$ observed were on the day of Diwali in outer city area. The levels of $PM_{2.5}$ started rising two days prior to Diwali possibly due to increased anthropogenic activity and the levels remained elevated four days post-Diwali in most of observed sites. The indoor air pollution levels in most of the sites were higher than outdoor levels except in the industrial area suggesting a requisite to formulate the strategy to lower the indoor air pollution. There was a high impact of firecracker burning as the levels of $PM_{2.5}$remained elevated several days post-Diwali.

Keywords: Particulate matter (PM), biomass, outdoor air quality, indoor air pollution ventilation, ambient air pollution, Diwali

1. Introduction

The main cause of air pollution is the introduction of dust particles, gases, and smoke into the atmosphere that exceeds the permissible limit. Anthropogenic air pollution is globally one of the biggest public health hazards and it accounts for about 9 million deaths per year [1].

Ambient air pollution affects respiratory health and increases morbidity and mortality. The particulate matters smaller than 2.5 micron in diameter has highest potential to affect the health since they can easily pass through throat and nose and lodge themselves in the lung which eventually results into both acute and chronic respiratory diseases [2, 3]. A recent study has found a link between cardiac arrests and exposure to particulate matter [4]. The World Health Organization (WHO) while assessing the different risk factors and burden of disease; found that the indoor air quality is the eighth most important risk factor, and is responsible for 2.7% of the global burden of disease [5, 6]. Mu et al have found in their study that indoor air pollution is a risk factor associated with increase in lung cancer among Chinese non-smoker females [7]. Few studies have shown that air pollutants cause a wide range of acute and chronic effects on the respiratory health in children [8].

Diwali, the festival of lights, is one of the most celebrated festivals in India. However, it is also associated with a significant increase in air pollution levels, primarily due to the burning of firecrackers during the celebrations. The bursting of firecrackers releases various pollutants such as sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter, which can cause respiratory problems, aggravates asthma, and other lung diseases. The smoke and noise generated by firecrackers can also affect the environment and wildlife. Metropolitan cities like Delhi have worsening ambient air quality especially during November which is considered to be 'smog month' for the last few years in India, with 0.5% increase in the hazardous index [9]. The effects of air pollution were found different across different areas within the city. Another study conducted in Lucknow have found that air quality worsen during Diwali and carried out chemical characterization of particulate matter [10]. A study was conducted in Prayagraj city in 2019 which concluded that on Diwali the concentration of PM_{10} was at its peak which was 1.8 times more than on a normal day of the same period [11].

The Indian government has taken several measures to control air pollution during Diwali, including imposing restrictions on the sale and use of firecrackers. However, these measures have not been entirely successful in curbing the pollution levels.

Since ambient air pollution is one of the eight risk factors for chronic health conditions and the Central Pollution Control Board (CPCB) only measures outdoor air pollution in major cities, it becomes imperative to measure both outdoor as well as indoor air pollution[12].

The most vulnerable populations consists of infants and elderly who spent most of their day time inside the homes [13]. One of the events which lead to increased air pollutions is burning of crackers.

Focus of research has mostly been on ambient air and effect of bursting of fire crackers during the festival of Diwali has been measured in ambient air only. But, given that the indoor air is affected significantly by the ambient air due to existing ventilation conditions, it is imperative to examine the impact of extreme ambient air pollution events on indoor air in households. Moreover, data on indoor air quality in smaller cities like Jodhpur during Diwali festival is limited. This study was envisaged to measure the levels of indoor and outdoor $PM_{2.5}$ in different parts of the city of Jodhpur. To our knowledge, no study has been conducted in Jodhpur Rajasthan, where indoor as well as outdoor particulate matter has been measured during Diwali festival.

2. Study area

The study was carried out in Jodhpur, a city located in the north-western part of the country, bordering the Thar Desert. The geo-coordinates of the city are 26.2638 N and 73.0089. The city is spread over 233.5 $km^2$and has a population of 10, 33,756 (Census 2011). Based on environmental conditions, Jodhpur can be divided into four zones i.e. i) inner city ii) industrial area, iii) outer city area, and iv) rural area. From each category, one locality was selected for this study. And in each locality, one household was randomly selected for the installation of air quality monitors.

3. Materials & methods

A. Instrument:

A low-cost sensor-based device, manufactured by PurpleAir® was installed in each household. One device was installed outside the selected household and the other device was installed inside the house. Air quality was monitored in real time and the machine was programmed to capture the values every minute. Data collection started on 21st October 2021 and continued up to 1st February 2022. The pre-Diwali period was November 1st and 2nd, Diwali period was 3rd and 4th November and post-Diwali period was 5th and 6th November 2021.

B. Ethical consideration:

To carry out this study ethical approval was obtained from the ethics committee on human research of the institute (Ref No: IEC-NIIRNCD-2021/trainee/7).

C. Statistical analysis:

Data was stored as Excel sheets and analysed using Statistical Package for the Social Sciences Software (SPSS, IBM Version 28.0, Armonk, NY, USA). Daily average was calculated from the data collected at each site. The Pearson correlation analysis was done to compare temperature and $PM_{2.5}$ levels.

4. Result and discussion

A. Diwali week $PM_{2.5}$ levels:

Short term exposure to the air pollution has also been associated with adverse health outcomes including respiratory and cardiovascular, mental health (cognition impairment, dementia). The levels of $PM_{2.5}$begun to rise even before the Diwali Period, possibly due to increased anthropogenic activity during this period. During Pre-Diwali period, mean $PM_{2.5}$levels varied between 57.2µg/m^3 to 162.3µg/m^3. During Diwali period the values ranged between 170.7µg/m^3 and 673.3µg/m^3. Post-Diwali the mean $PM_{2.5}$levels observed were 143.1-255.5 µg/m^3 (Figure 1, Table 1).

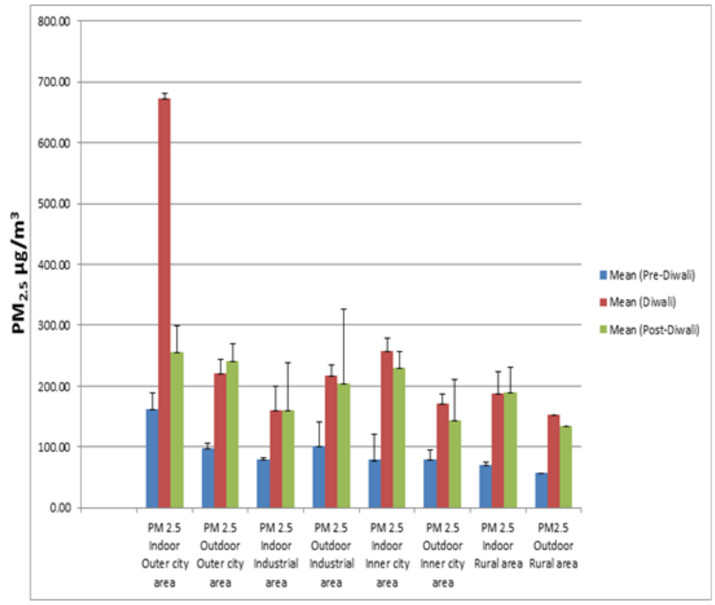

Figure 1: Mean $PM_{2.5}$ levels Pre-Diwali (1st and 2nd November) During Diwali (3rd and 4th November and post-Diwali(5th and 6th November)

Table 1: Mean $PM_{2.5}$ levels Pre-Diwali (1st and 2nd November) During Diwali (3rd and 4th November and post-Diwali(5th and 6th November)

$PM_{2.5}$ (µg/m^3)	Mean (SD) Pre-Diwali	Mean (SD) Diwali	Mean (SD) Post-Diwali
Indoor Outer city area	162.3 (73)	673.3 (564)	255.5 (101)
Outdoor Outer city area	97.6 (26)	221.8 (7)	241.8 (43)
Indoor Industrial area	78.8 (8)	160.8 (21)	159.8 (27)
Outdoor Industrial area	101.3 (3)	217.4 (39)	204.5 (77)
Indoor Inner city area	78.5 (39)	256.9 (17)	231 (121)
Outdoor Inner city area	79.3 (42)	170.7 (21)	143.1 (26)
Indoor Rural area	69.6 (15)	188.3 (16)	190.2 (67)
Outdoor Rural area	57.2 (4)	153.4 (36)	135.2 (40)

Existing research on the impact of Diwali on air quality in India has focused on measuring the concentration of pollutants in the air around Diwali [14]. For example, it was found that on Diwali day, 24 hour average concentrations, in Lucknow, to be 2.49 and 5.67 times higher when compared with the concentration of pre-Diwali and normal day respectively [15].

In the outer city area, the levels of Indoor $PM_{2.5}$ remained elevated for four days and baseline and (pre-Diwali) levels were achieved on 8th November 2021 suggesting exposure of poor quality of air for extended period of time. The increase in the levels of $PM_{2.5}$ was attributable to the celebration as there was no change in the temperature during Diwali week. Since the vehicular emission also rises due to traffic during festival, the levels of $PM_{2.5}$ started increasing from 30th October onwards. In first week of November (Diwali) the levels of outdoor $PM_{2.5}$ were between 36.4µg/m^3 and 204.4µg/m^3 with indoor levels varying between 84.6-176.2 µg/m^3. The highest recorded value was on Diwali day which was found to be 1072.7µg/m^3. The possible explanation for the increased indoor value was due to no ventilation on the Diwali day in this household. As there were increased fireworks outside, people of the household kept the windows and doors shut throughout the day.

Post-Diwali $PM_{2.5}$levels were higher for outdoor (204.5µg/m^3) compared to indoor levels (159.8µg/m^3) only in the Industrial area. The baseline (pre-Diwali) levels were achieved on 10th November 2021 which was a gradual decline in the levels primarily due to cumulative effect of bursting of crackers along with increased vehicular emission due to people travelling back after celebrating the festival with their family. In the industrial area the levels were elevated also due to background levels on account of industrial emission. Similar to the Outer City area, increase in the levels of $PM_{2.5}$ was attributable to the celebration as there was no change in the temperature during Diwali week.

As the festivity began in the early November, there was a sharp increase in the indoor $PM_{2.5}$ levels with value of 256.9µg/m^3 (Diwali). On 5th of November (Post-Diwali) when levels increased to 316.8µg/m^3 for indoors, the outdoor level was 143.1 µg/m^3

for inner city area. The baseline (pre-Diwali) levels were reached on 10th November 2021 in inner city area. In this area $PM_{2.5}$levels were elevated possibly due to the congested radial grid street pattern with narrow paths and additional effect of bursting of crackers along with moderate vehicular emission during festival. No variation was found in terms of temperature, but $PM_{2.5}$ levels were increased during Diwali week.
In the rural area, baseline (Pre-Diwali) $PM_{2.5}$ was 59.0µg/m^3 which elevated to 198.8µg/m^{3}for indoor, and 179.0µg/m^{3}for outdoor a day before Diwali. On Diwali day indoor $PM_{2.5}$ values were around 176.8µg/m^3 and value for the outdoor $PM_{2.5}$ was 127.8µg/m^3. The highest recorded value was 238.0µg/m^3 for indoor on 5th of November which was post-Diwali and for the outdoor it was 163.6µg/m^3. The baseline (pre-Diwali) levels were achieved on 7thNovember 2021 for one day, from 8thNovembervalues started increasing again could be due to increase in traffic on highways with people going back to work after festival. Similar to the observation a study conducted in Lucknow, India has found that the $PM_{2.5}$ levels were higher during post-Diwali period [16].

B. Diwali Day:

As bursting of crackers is night event with most activity occurring at 10 PM on Diwali day, it was important to assess the $PM_{2.5}$ levels at night. When the $PM_{2.5}$ levels during peak hours were evaluated separately, it was found that the highest recorded $PM_{2.5}$ was from outer city area, where mean $PM_{2.5}$ levels was 1072.70 µg/m^3, followed by industrial area where mean $PM_{2.5}$level was 403.60 µg/m^3, lowest recorded levels were from rural area where $PM_{2.5}$level was 209.39 µg/m^3. The indoor $PM_{2.5}$levels were higher than outdoor levels in outer city area. The levels were comparable in rural and industrial area. There was slight increase in indoor levels in inner city area compared to outdoor levels (Figure 2, Table 2).

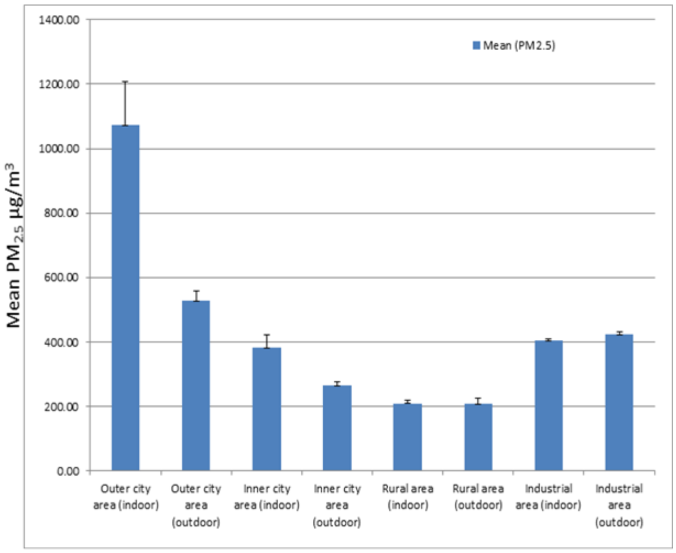

Figure 2: Mean $PM_{2.5}$ levels were obtained from observation made on the day of Diwali between 11 PM and 12 PM when the firecracker burning is highest.

Table 2: Mean $PM_{2.5}$ levels on Diwali

Sites	Mean ($PM_{2.5}$)	Std. Error
Outer city area (indoor)	1072.70	133.56
Outer city area (outdoor)	526.61	33.10
Inner city area (indoor)	381.54	40.94
Inner city area (outdoor)	264.97	10.56
Rural area (indoor)	209.39	10.98
Rural area (outdoor)	207.59	18.56
Industrial area (indoor)	403.60	5.83
Industrial area (outdoor)	423.72	8.62

When both indoor as well as outdoor $PM_{2.5}$ levels were compared it was found that indoor $PM_{2.5}$ levels were higher than the outdoor $PM_{2.5}$ levels in most of the study sites during entire study period (Figure 3 andTable 3).In most of sites the $PM_{2.5}$ levels were much higher than the respective outdoor levels on the same day.

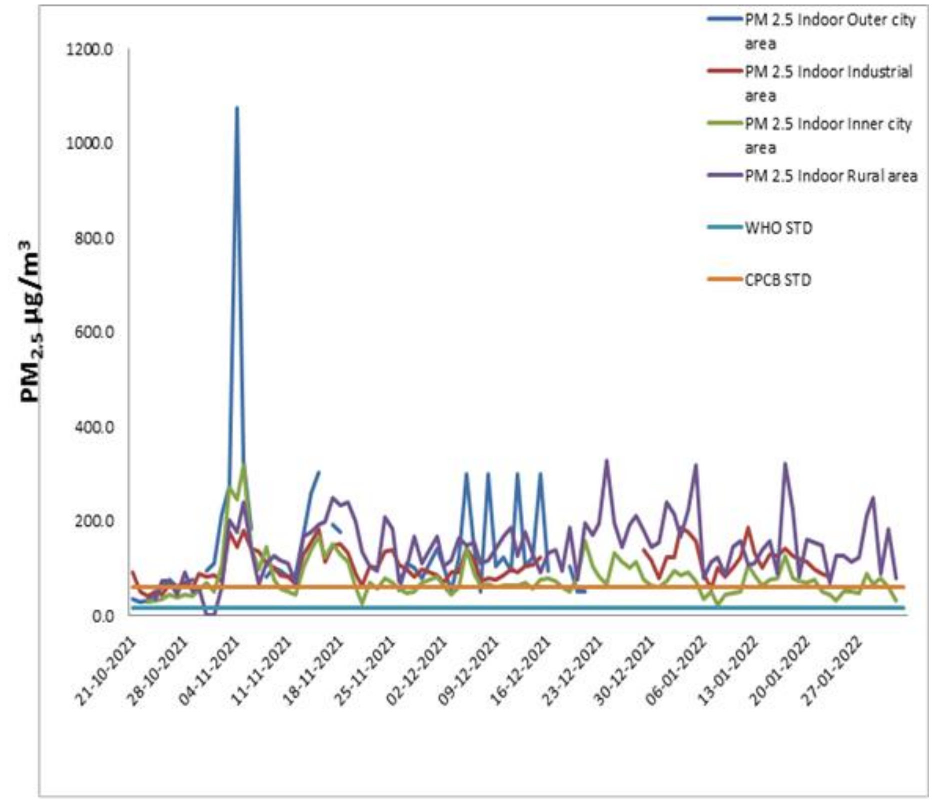

Figure 3: Indoor as well as outdoor $PM_{2.5}$ levels during entire study period. (CPBP=Central pollution control board).

Table 3: Average $PM_{2.5}$ levels during study period at all sites (N= number of day's of data collection)

$PM_{2.5}$ levels/Site	**N**	**Mean(µg/m³)**	**Std. Error**
$PM_{2.5}$ Indoor/Outer City Area	49	148.5954	22.75142
$PM_{2.5}$ Outdoor/Outer City Area	92	116.5617	5.64453
$PM_{2.5}$ Indoor/Industrial Area	81	106.3211	3.87883
$PM_{2.5}$ Outdoor/Industrial Area	75	131.4272	6.75334
$PM_{2.5}$ Indoor/Inner City Area	101	79.2338	4.68345
$PM_{2.5}$ Outdoor/Inner City Area	101	78.9467	3.37479
$PM_{2.5}$ Indoor/Rural Area	100	145.4374	6.06078
$PM_{2.5}$ Outdoor/Rural Area	70	99.0193	4.82483

As a study suggests, a human spends 80% of their lives indoors rather than outdoors [17]. The indoor exposure scenarios like cooking, biomass burning, room heating, refurbishment activities, remodelling, and new furniture which emits toxic gases and ultrafine particles which is an additive to the air pollution level and have a severe impact on human health [18].
WHO recommends 24 hourly $PM_{2.5}$ levels should not exceed 15µg/m^3 [19]. During the study period, levels of indoor as well as outdoor $PM_{2.5}$ never reached the WHO-recommended values in any of the study sites. In fact, the indoor $PM_{2.5}$ levels were as high as 20-times during the study period.
The central pollution control board (CPCB) recommends 24 hourly average of $PM_{2.5}$ levels should be below 60µg/m^3 [18]. The above result suggests very poor air quality in most of the areas in Jodhpur City.
There has been much scientific evidence that indicates that the air in the residential area can be more polluted than outdoor air in the urbanised cities [20, 21]. In most of the developing countries, the women of the household seem to bear the highest risk of disease development due to the longer duration of exposure to these pollutants in the households [22].

C. $PM_{2.5}$ Correlation with temperature:

There have been studies where the $PM_{2.5}$levels showed variation with temperture and Chen PCet.al. in their study have found that lower ambient temperature elevates $PM_{2.5}$ concentrations, and the high $PM_{2.5}$ levels coincided with low temperature levels [23], temperature and $PM_{2.5}$ levels were correlated to find if there is any association. There was only small significant negative correlation found for the indoor $PM_{2.5}$ levels and temperture in Rural area ($r = -0.372$, $p < 0.001$). and Industrial area ($r = -0.274$, $p < 0.006$)Table 4).

Table 4: 2-tailed Pearson correlation in between Indoor $PM_{2.5}$ in Industrial area and temperature and also Indoor $PM_{2.5}$ Rural area and it's temperature.

Indoor temperature Industrial area	Pearson Correlation	-.372**	1
	Sig. (2-tailed)	0.001	
	N	80	82
$PM_{2.5}$ Indoor Rural area	Pearson Correlation	1	-.274**
	Sig. (2-tailed)		0.006
	N	100	100
**. Correlation is significant at the 0.01 level (2-tailed).			

Overall, in all the sites, industrial, rural as well as outdoor city area had 2.5-20 times higher than the CPBP recommended safe $PM_{2.5}$ levels. The indoor levels were higher than outdoor levels in outer city area and rural area and comparable in inner city area and slightly lower in industrial area. As mentioned in the beginning, two third of the time spent by infant, elderly and women are indoor and indoor levels in most of the sites were alarmingly high with highest levels recorded on the eve of Diwali in outer city area, there is an urgent need to device plan to control the indoor levels.

Poor ventilation and increased anthropogenic activities result in higher particulate matter and measures should be adopted by Government, Industries as well as general public in reducing these activities.

Overall, reducing air pollution during Diwali in Jodhpur requires a combination of regulatory, educational, and awareness-raising measures. A concerted effort involving the government, non-governmental organizations, and the general public can help in reducing pollution levels during Diwali and ensuring a safer and healthier environment for all.

D. Limitation:

As this being a pilot study, the number of air samplers installed in each area were insufficient to generalize the conclusion. A study with more devices installed in each area for real time monitoring of $PM_{2.5}$ levels as well as assessing the impact of air pollution on health especially respiratory health of the residents is needed.

5. Conclusion

Within the limitations of the study, it can be concluded that the indoor air pollution was highest in areas where higher or middle-income groups reside suggesting that the poor ventilation plays a key role in increasing the indoor air pollution levels. Both indoor and outdoor $PM_{2.5}$levels were increased in the rural area for most number of days. During festival season increased anthropogenic activity and poor ventilation added to increased indoors as well as outdoor $PM_{2.5}$ levels which remained elevated for 4-8 days. It becomes imperative to raise public awareness coupled with a multidisciplinary approach to address the emergence of particulate matter as threat and propose sustainable solutions. These findings may influence public debate and future policy at the state and national levels to improve air quality in tier II cities. There is also a need to assess the impact of increased $PM_{2.5}$ levels on the severity of Chronic Obstructive Pulmonary Disease (COPD), asthma, bronchiolitis, lung cancer, cardiovascular events, central nervous system dysfunctions, and cutaneous diseases in Jodhpur.

6. Acknowledgement

The air quality monitoring devices were provided by the Embassy of United States of America in India. Mr. Ravi Srivastava and Ms. Priya Ghosh of the US Embassy in India are being acknowledged for their support in conducting the study.

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