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A Closer Look at the Air Pollution Dynamics during Diwali Festival in India

Jimlee Patowary[1,4], Subrat Kishore Dutta[2,4], Anjishnu Mahanta[4] , Tara Tripura Mantha[3,4]

[1]Assam Engineering College, Department of Mechanical Engineering, Jalukbari, Assam, India
[2]Saarland University, Department of Computer Science, Saarland, Germany
[3]University of Bologna, BiGeA, Bologna, Italy
[4]Azim Premji University, Centre for Climate Change and Sustainability, Sarjapura, Karnataka, India

Correspondence to: Jimlee Patowary (jimlee.patowary5@gmail.com)

Abstract. Every year steep spikes in pollution levels are observed during the festival of Diwali in India. This worsens the already degraded air quality of the country. Ranked last in the Environmental Performance Index 2022, India needs extensive infrastructure enhancements for proper data collection and analysis of its emissions in order to improve the current scenario. The study carries out an analysis to understand the dynamics of the pollution levels around the Diwali festivities, with a particular focus on the PM2.5 air pollutants. Our analysis reveals that the northern region of India has higher pollution levels compared to the other parts of India, with Delhi as the hotspot. A close correlation is also observed between Delhi and its neighboring agricultural states. Further, in contrast to preconceived notions, an increase in emissions has been observed during the COVID-19 pandemic despite the nationwide lockdown. The study emphasizes the lack of proper monitoring setups with only one center for 9100 km^2 of the country, along with the unreliability in the analysis of the air quality in places like Delhi due to the unavailability of data from more than 60% of the monitoring centers at certain times.

Keywords: Diwali, Fireworks, Air pollution Monitoring, PM2.5, Stubble burning, Pollution center

1 Introduction

1.1 Significance of Diwali Festival in the Indian Subcontinent

Diwali which is known as the festival of light is one of the most important festivals which is celebrated all over the Indian subcontinent (Barman et al., 2008). The bursting of fireworks and crackers is an integral part of the festivities observed during Diwali (Barman et al., 2008; Chatterjee et al., 2013). It typically falls in the month of October to November every year and is celebrated majorly among the Hindu communities in India (Mahalik, 2020).

1.2 Air pollution is a significant cause of health problems

Pollutants are innate parts of the air (Lave et al., 1970). Even without the intervention of human and human activities, there would still be some amount of pollutants in the atmospheric air. For example, creatures vent carbon dioxide, Volcanic activity produces sulfur oxides, and wind development safeguards that there will be suspended particulates, therefore, there is no chance of eliminating all

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contamination from the air (Lave et al., 1970). All things being equal, the issue is one of adjusting the need of polluters to vent residuals against the harm endured by society because of the expanded contamination. Air pollution is a significant problem affecting human health worldwide. The most common air pollutants that contribute to air pollution include carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), and fine particulate matter like PM 2.5 and PM 10 (Nowak et al., 2018). The effects of air pollution can be roughly broken down into types: short-term effects and other long-term effects. It is found that Ozone is formed in the troposphere due to reactions that occur in polluted air and sunlight (Kinney, 2008). This molecule possesses the capability to trigger irritation and inflammation within the respiratory system, causing discomfort and breathing difficulties (Ambade,2018; Kinney, 2008). Aeroallergens, i.e. substances that stimulate an allergic response in sensitized individuals, are influenced by weather phenomena sensitive to atmospheric Carbon dioxide levels (Kinney, 2008). The presence of aeroallergens results in allergic diseases like asthma, hay fever, and atopic dermatitis. Short-term air pollution exposure can also be associated with problems like attention-deficit/ hyperactivity disorder (ADHD), depression, schizophrenia, epileptic seizure, and post-traumatic stress disorder (due to the bursting of firecrackers) (Mousavi et al., 2021). Considering the short-term effects of air pollution (due to festivals), the bursting of crackers releases heavy metals into the atmosphere, and subsequently their concentrations increase a number of times than the desired amount which results in crossing 0.1 (the elemental risk level) that is harmful to the children. The inhalation of such heavy metals might result in lung cancer, asthma, pneumonia, and other systemic diseases (Anderson et al., 2012; Liu et al., 2019). NO2 exposure is attributed to cough, Wheezing, and shortness of breath in atopic patients (D'Amato et al., 2014). Higher concentrations of SO2, PM10, and NOx are responsible for respiratory diseases, asthma, cardiovascular effects, lung cancer, disorders in reproduction and development, and neurological and neuropsychiatric effects (Barman et al., 2008). Short-term exposure to such harmful air quality might result in the re-emerging of diseases whereas long-term exposure would result in serious health conditions (mostly respiratory diseases like Chronic bronchitis, pulmonary heart diseases, and lung cancer) (Lave et al., 1970) specifically for children and senior citizens living in those polluted areas. A study conducted during Diwali days showed an increase in hospital admissions due to respiratory problems due to air pollution (Garaja et al., 2020). A study during the Beijing Olympics in China found that alterations in air pollution levels observed during the Beijing Olympics were linked to rapid shifts in biomarkers connected to inflammation and clotting, as well as various indicators of cardiovascular function in a group of young and healthy individuals (Rich et al., 2012). Another study conducted during the Beijing Olympics suggests that exposure to varying air pollution during the air pollution associated with this event has significant effects on respiratory functions (Mu et al., 2014).

1.3 Urbanization in developing countries such as India is causing increased levels of air pollution

People living in urban areas are exposed to complex combinations of environmental pollutants. This load results from the diverse and uneven distribution of emission sources and the different meteorological conditions in these areas (Mandal et al., 2012). Due to a rise in anthropogenic activities aligned with developmental processes such as construction work and vehicle emissions (D'Amato et al., 2014), there is always an increased level of air pollution (Ganguly, 2009; Singh et al., 2010). Unplanned urbanization significantly contributes to increased levels of pollution in an area. High levels of congestion lead to pollution due to heavy traffic in an area. Traditional Transportation facilities contribute significantly to pollution levels as those vehicles are not regularized and most of the time these vehicles don't have proper pollution certificates. Also, in some cases, there are no stringent rules about air pollution, and people, therefore, don't consider it a major issue. More urbanization means more development and more people which results in much more exploitation of an area as compared to other areas. Changing human behaviors affect air quality, as seen in 2019 when carbon

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emissions were reduced due to reduced industrial and transportation activities, such as during the COVID-19 pandemic (Safarian et al., 2020).

1.4 Huge celebrations across the globe tend to use fireworks which emit toxic materials into the atmosphere

Firecrackers are a universal symbol of celebrations all over the world. They are integral to various celebrations like Chinese New Year celebrations (Yang et al., 2014), 4th July Fireworks in the USA (Mousavi et al., 2021), the Las Fellas festival in Spain, the Lantern Festival in China (Liu et al., 2019; Wang et al., 2007), Bonfire Night in the UK, Tihar in Nepal, Day of Ashura in Morocco, Sky fest in Ireland, Bastille Day in France and Diwali in India to name a few (Ambade ,2018; Kotnala et al., 2021).

1.5 Nature of firecrackers and their effect.

Fireworks are composed of a complex mixture of inorganic and organic chemicals. Upon ignition, these fireworks release a range of atmospheric pollutants, including sulfur dioxide (SO2) (Krishnan et al., 2020; Ravindra et al., 2003), nitrogen dioxide (NO2), carbon monoxide (CO), as well as particulate matter (PM2.5 and PM10), and various metals like aluminum, manganese, cadmium, and more. The fireworks create dense clouds of smoke, which lead to a temporary deterioration in air quality. This decrease is due to the increase in the concentration of total suspended particulate matter (TSP) in the atmosphere (Kumar et al., 2020). Firework powders contain higher concentrations of Chlorine content (Pervez et al., 2016). Studies reveal that burning firecrackers release high concentrations of metals like K, Al, Ba, and Sr to name a few, which suggests that these metals are used in the manufacturing of firecrackers and sparkles (Kulshrestha et al., 2004). In the field of firecracker organization, various components take on specific tasks. Sodium (Na) and Potassium (K) act as powerful metal oxidants and contribute to the energetic presentations. On the whole, components such as Aluminum (Al), Magnesium (Mg), Copper (Cu), Barium (Ba), Strontium (Sr), Sodium (Na), and Titanium (Ti) offer an intriguing variety of shapes and lustrous effects, improving the visual experience. Sulfur (S) takes on the vital task of fuel and provides the unique fuel for fireworks. Meanwhile, zinc (Zn) is pursuing its motivation to create intriguing smoke effects that add depth to the display. Inside the synthetically woven work of art, chlorides, nitrates, and sulfates intertwine in unpredictable ways, forming the basis for the ceiling's rich tones, which are attributed to the light emission of metal salts. Also, key ingredients such as potassium nitrate (KNO3), sulfur, and either potassium chlorate (KClO3) or potassium perchlorate (KClO4) form the basic combustible dark powder responsible for the amazing burn that characterizes fireworks presentation (Perrino et al., 2011). Pollutants emitted by fireworks at higher altitudes are diluted before reaching the human population, potentially mitigating health effects. However, ground-level fireworks have an immediate and direct impact on human well-being (Garaga et al., 2020). Not only humans but plants are also susceptible to chemicals emitted by firecrackers (Mahalik, 2020). A study conducted in the region of Ahmedabad stated that manufacturing of firecrackers is more dangerous than burning as Runoff resulting from the manufacture of fireworks is a significant source of perchlorate pollution in surface waters (Kumar et al., 2020).

1.6 Meteorological Factors Affecting Air Pollution

Favorable meteorological sites aid in elevating the pollution due to the bursting of firecrackers (Pervez et al., 2016). In a study conducted in the region of Patiala during the Diwali period and in the presence of a highly polluted background atmosphere caused by emission from paddy residue burning during those days, it was seen that mass concentrations of black carbon aerosols varied from 6

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to 9 ug / m3 with the maximum on post-Diwali (Bansal et al., 2019), this shows that paddy burning has some contribution in air quality degradation in such regions at the time of Diwali. In a study conducted in an industrial site named Shahzada Bagh in Delhi, a significant correlation was identified between Total Suspended Particles (TSP), Particulate Matter with a diameter of 10 micrometers or less (PM10), Sulfur Dioxide (SO2), and Nitrogen Dioxide (NO2), and various meteorological parameters such as temperature, relative humidity, and wind speed (Singh et al., 2010). In another study, it is emphasized that the mixing level is a crucial meteorological parameter, with a lower mixing level leading to the accumulation of pollutants at lower altitudes. Consequently, this scenario leads to an increased concentration of air pollutants in the atmosphere (Mandal et al., 2012). Another study conducted in the rural areas of the Brahmaputra Valley found a noticeable impact of the Diwali fireworks on PM10 in the rural area, but it was short-lived and led to a small increase in specific chemical components in PM10 particles, such as elements and ions. Compared to urban areas (which is referred to as mainland India), Diwali had less impact on PM10 in the Brahmaputra valley. In addition, the research suggested that PM10 in the atmosphere of rural Brahmaputra Valley may not have cations, which are positively charged ions. This means that the particulate matter in this region could be acidic in nature. This suggests that the nature of particulate matter has an effect on the concentrations of the particulate matter (Deka et al., 2014). It is also seen in a study that the emissions from firecrackers burnt at night time in lower elevations are unable to disperse properly due to unfavorable meteorological conditions (Chatterjee et al., 2013). Some studies concluded that during the winter season (around the time of the Diwali celebration), there is an increase in the activity of the secondary reactions (reactions that occur in the atmosphere). In addition, during this period, the direct influence of domestic biomass combustion on particulate matter (PM) emissions, which remains noticeable throughout the year, is particularly pronounced (Perrino et al.,2011; Manchanda et al., 2020). It is stated in another study that Local meteorological conditions play a critical role in shaping trace gas concentrations by facilitating the spread of pollutants through mechanisms such as enhanced convection and strong surface winds. These factors effectively dilute emissions from fireworks (Yerramsetti , 2013). Another study indicates that under clear skies the process of haze formation has the potential to generate a significant concentration of PM2.5 particles in Delhi (Dhaka et al., 2020). A study in the semi-arid region of Udaipur, lying in the Indo-Gangetic Plain concluded that the movement of aerosols resulting from activities such as crop residue burning and fireworks events, particularly in the run-up to and during Diwali, has a significant impact on the observed changes in these parameters both in the Indo-Gangetic Plain (IGP) and in the surrounding area regions (Vyas et al., 2012). A study conducted in a region named Varanasi attributes the increased accumulation of air pollutants during Diwali to certain meteorological conditions such as low wind speed, falling temperatures, and lower nighttime boundary layer height (Pratap et al.,2021). In a region called Visakhapatnam in India, study results suggest that Diwali fireworks have an adverse effect on surrounding air quality, leading to increased levels of PM2.5, PM10, SO2, and NO2. Interestingly, the adverse effects were more evident in 2018 than in 2019. This discrepancy is attributed to the effects of rainfall, which helped remove pollutants from the atmosphere (Chandu et al., 2020). An important study points out that there is a strong location and month effect when examining air quality in Delhi (Ghei et al., 2018). Some studies suggest that pollution in Delhi is partly influenced by crop residue burning in neighboring areas [Takigawa et al., 2020; Beig et al., 2020; Saxena et al., 2021). Yet another study stated that the emissions from burning activities in the post-monsoon season in states like Punjab are carried across the Indo-Gangetic basin (IGB) by plumes. These plumes travel considerable distances across both the IGB and the central regions of India, facilitated by conducive meteorological conditions (Chauhan et al., 2017). Further in an investigation, it is found that Climate change may affect air pollutants relevant to human health, such as wildfire smoke and airborne allergens (Kinney et al.,2008). A study suggests that particulates from Haryana and Punjab might not cause the spurge of air pollution in Delhi however, they state that poor meteorological conditions and human activities play a role there (Nair et al., 2020). A study in the Chinese city of Shijiazhuang emphasizes the need to assess air quality and health effects as understanding the source of emissions health effects, and policy implications is crucial for addressing air quality issues (Peng et al., 2002).

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There has always been a hype about Diwali emissions in the media every year. The previous studies which have been done around the time of Diwali mostly considered only the aspect of air pollution due to the burning of firecrackers. While the festival is associated with increased fireworks usage, it is important to note that Diwali is not the only contributing factor to air pollution during this time. There has been some study but a thorough study to look at the nationwide emission patterns has not been carried out. With the increasing awareness about climate change and air pollution, the usage of crackers during this time has come down a lot. This has also been reported in the media. It is anticipated that the COVID lockdown in the last year reduced the usage of firecrackers as people were mostly at their homes. Therefore, a thorough study is needed to understand the patterns of emissions across the country of India during Diwali and also how the emission pattern has changed over time across the country. Studies carried out so far haven't focused on carrying out a comprehensive analysis of the emissions near the Diwali festival time.

1.7 Goals and Objectives of this study:

Here we carry out a study to

- characterize the patterns of air pollution around 2021 Diwali days in a few megacities in India,
- analyze the trends of these emissions over the last few years in Delhi
- investigate the contribution of crop burning in neighboring states to Delhi air pollution
- study the functioning of the current monitoring system
- Study whether there was an increase or decrease in pollution levels during the lockdown year during Diwali

2 Science questions:

1. What are the trends of pollution parameters in Delhi during the pre-Diwali period, post-Diwali period, and Diwali period?

2. Is there any correlation between the pollution levels of Delhi during Diwali and that of neighboring states? Does stubble burning contribute to the pollution of Delhi?

3. Did the introduction of policy changes result in a reduction of pollution levels in Delhi over the successive years?

3 Study Area:

The study area for this research is pan-India. We put major emphasis on the urban areas because these areas are presumably the major sources of Diwali toxic emissions. These areas emit more Diwali emissions as it is an anthropogenic emission. Delhi, Hyderabad, Bangalore, Mumbai, Chennai, and Kolkata are among the most populous megacities of India. Delhi, the capital of India, is a massive metropolitan city lying in the north of India. Hyderabad, a major center for the technology industry lies in the northern part of South India. Bangalore, known as the Silicon Valley of India, is located on the Deccan Plateau. Mumbai, the financial capital of India, is a densely populated city lying on the Indian West Coast. Kolkata, the cultural capital of India lies in the eastern part of the country.

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4 Materials and Methods:

The study proceeds in three steps which can be summarized as follows.

4.1 Data Acquisition:

Ground observation data for these pollutants were collected from the Central Pollution Control Board of India data portal (2021). This portal provides open access to data from the stations scattered across the country which measures ambient level values for a range of pollution parameters. This study primarily considers four parameters namely, PM2.5, CO, NOx, and Ozone because of their availability and their major contributions to the overall pollution levels. The study duration has been divided into three parts: The Pre-Diwali (the day before Diwali), Diwali (on the day of Diwali), and the Post-Diwali period (the day after Diwali). For this given period an hourly measure of the concentration of the mentioned pollutants has been collected from the year 2016 to 2021 based on their availability. The frequency with which the data is collected makes sure that the pattern of change can be analyzed.
We focus our study on urban areas with high population density. In this study, we compare particulate matter (PM 2.5) for six major urban areas- Delhi, Hyderabad, Bangalore/ Bengaluru, Mumbai, Chennai, and Kolkata. We collect data from the Central Pollution Board of India where continuous monitoring of PM2.5 is available for the cities under consideration. We focus our analysis from November 3, 2021, to November 6, 2021. This is chosen such that Diwali, which was declared to fall on November 4, 2021, falls within the time span considered. We also look further into individual levels of CO, NOx, and O3 alongside general PM2.5 level variation.

Table 1: Pollutants being considered for the study and their role in air pollution

Parameters	Roles in air pollution
CO	It affects the number of greenhouse gases which cause global warming
PM2.5	It has an aerodynamic diameter of less than 2.5 μm and causes respiratory problems in human beings
NOx	These gasses contribute to the formation of smog and acid rain and also affect tropospheric ozone
O3	Surface ozone is a harmful pollutant and is linked to chronic declines in lung functions and an increased incidence of respiratory conditions such as pneumonia, influenza, and asthma (Ganguly et al., 2009)

4.2 Data collection and processing:

The data collection and processing involved the following steps:

The study accounts for the pollution level changes between the year 2016 to 2021. In the initial selection of the monitoring centers, due to the unavailability of data, the frequency of measures was minimal during the start of the mentioned period with only 3 centers

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crossing the 70% data threshold in 2016. However, over the period, the measures were more frequent with over 25 centres contributing to the measure in the year 2021.

The process starts with filtering of the observation center considered for further analysis. This decision is based on the continuous availability of data for a given parameter from the given centre. Centers with more than 30 % of their readings missing for certain parameters are not considered further for the analysis. From the centers selected, the missing values within them are replaced by the average of the values obtained from those centers whose data points are available for that hour. Further processing of the data varies from visualizations to visualization and also on the type of analysis conducted. The following gives details of the steps followed for each visualization.

4.2.1 Pollution trends during Diwali in the last five years in Delhi (Figure 6):

To evaluate the trend over the five years the data was processed in two steps. Firstly, an average over the hourly data for each centre is taken and in the second step, an average across these centres is measured giving the average values of pollutants during the Diwali period for a given year. The trend is then plotted in a stacked bar graph format where the contribution of each pollutant is shown by its covered area on the bar plotted.

4.2.2 Hourly pollution trends in major metropolitans (Figure 3):

The motivation behind this analysis is to compare the pollution levels of Delhi with other major cities in India. Five other cities considered for the comparison were Bengaluru, Chennai, Mumbai, Kolkata, and Hyderabad. For a particular city, an hourly average of all the centres is measured for all four parameters which represent the average hourly data of the city. Then the data are plotted in a scatter plot fashion which gives a clear idea about the change of a parameter with time. The colour used for each line indicates the city it represents.

4.2.3 Correlation between the pollution levels (Figure 4):

To study the correlation between the pollution levels in Delhi and its neighboring states which infers the contributions of stubble burning, the hourly average of all the centres is measured for the two parameters CO and PM2.5, which represents the average hourly data of the city. The average hourly data for the two states are then plotted against the corresponding hourly measures of Delhi. The plot is a bubble plot with larger measures indicated by a larger point diameter.

4.2.4 Loopholes in the Pollution Monitoring Centres (Figure 5):

To analyze the functioning of the pollution monitoring systems in Delhi, the availability of hourly data from all the present centers has been studied. The hourly data averaged across all the available centers are then plotted against the time as shown on the top panel of the figure. The top panel also features dark circular points which indicate the high unavailability of data from the centers at a particular point in time. The values placed are the average values from the small number of available centres. The diameters of the points correspond to their PM2.5 values.

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The malfunctioning of the centres resulting in the unavailability of data at a particular point in time is depicted by a histogram in the bottom panel which shows the percentage of simultaneously non-functional data centres at a time.

4.3 Qualitative and Quantitative Analysis:

Spearman Rank Correlation:

Conditions:

1) Variables are ordinal
2) Variables can be visually inspected to be non-linearly correlated
3) Data is non-normally distributed (seen from marginal distributions of figures in Figure 1)

For Delhi-Haryana PM2.5 values,

correlation=0.9306022788931091, pvalue=8.23278879161951e-43

For Delhi-Punjab PM2.5 values,

correlation=0.7783505154639175, pvalue=1.0406434306240075e-20

H0: There is no monotonic association between the two variables

With a significance level of 0.05, the p-values are found to be significantly less, thus we can reject the null hypothesis

(a) (b)

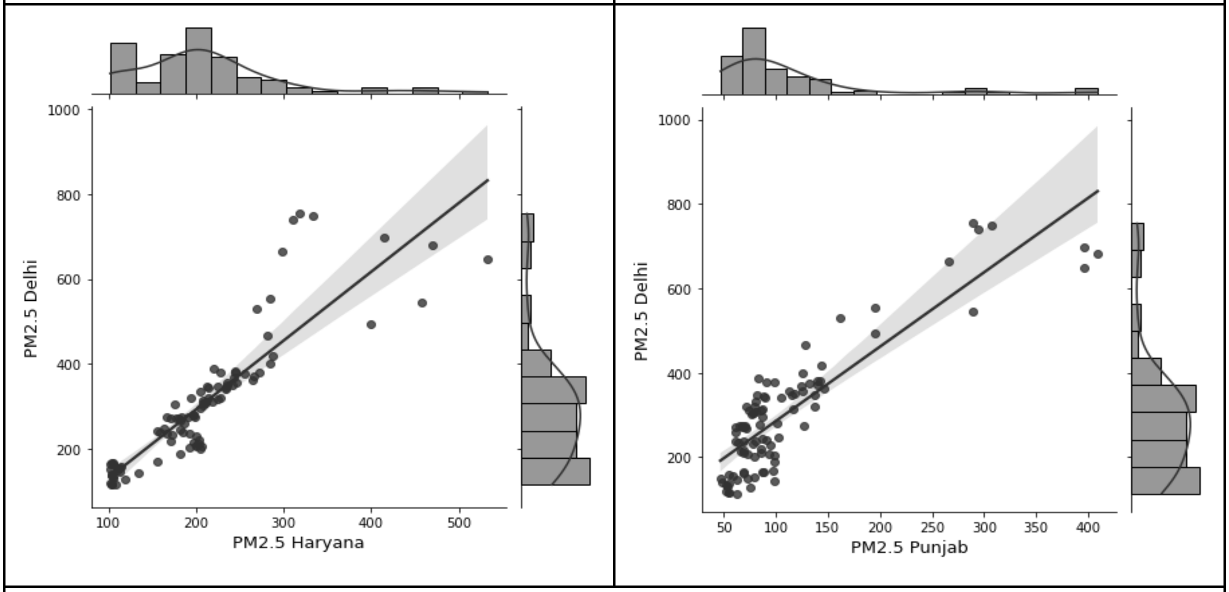

Fig. 1: The figure shows the correlation between the concentrations of PM2.5 in Delhi to that of (a) Haryana and (b) Punjab

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5 Results and Analysis:

5.1 The northern region of India has higher pollution levels compared to the other parts of India, with Delhi as the hotspot.

The hourly average of the concentrations of PM2.5 in some major cities around India During the period from 3rd November 2021 to 6th November 2021 (covering pre-Diwali, Diwali, and post-Diwali days) is shown in Figure 2. It is seen that there is a higher concentration of PM2.5 in the cities closer to Delhi. Thus, it can be inferred that the northern region of India has higher levels of pollution during Diwali than the other regions of the country.

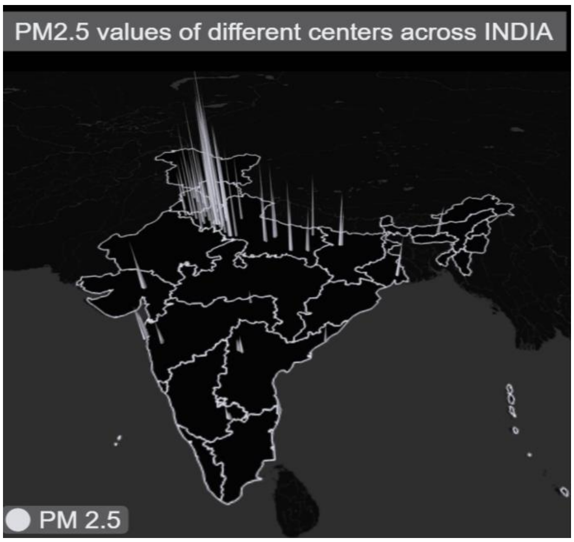

Fig. 2: PM 2.5 concentrations at some of the major cities in India. The spikes in height denote higher concentrations of PM2.5

5.2 The analysis of the four major parameters reveals that Delhi has the highest pollution levels among the major cities being selected.

From figures 3(b), 3(c), and 3(d), it is seen that during the Diwali period, Delhi had the highest pollution levels among all the major cities selected for the study. However, in figure 3(a), it is seen that the Ozone levels for Kolkata are higher than the other places.

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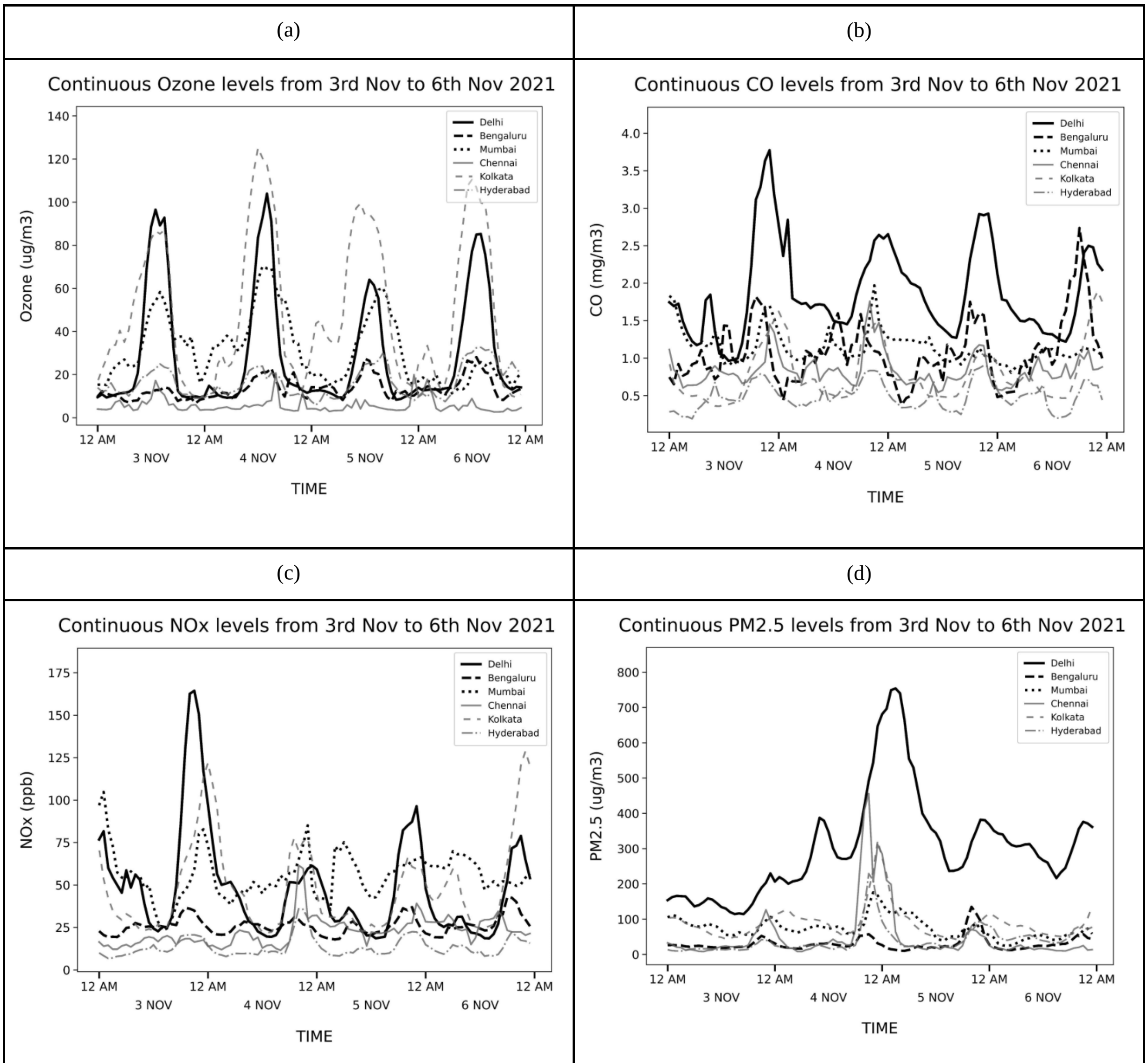

Fig. 3: The trend graph showing the concentrations of (a) Ozone, (b) Carbon Monoxide (CO), (c) Nitrous Oxide (NOx), (d) PM 2.5 at Delhi, Bengaluru, Mumbai, Chennai, Kolkata, and Hyderabad during the pre-Diwali, Diwali and the post-Diwali period from 3rd November 2021 to 6th November 2021

5.3 Close correlation between Delhi and its neighboring agricultural states

Figures 4(a) and 4(b) establish the correlation between the PM2.5 and CO concentrations in Delhi with that of Haryana and Punjab during the Diwali period. Here as shown in Figure 4(a) the x-axis consists of PM2.5 values. Similarly, in Figure 4(b), CO values are plotted on the x-axis for Delhi during the Diwali period, and on the y- axis the PM2.5 values and CO values are plotted in both Haryana and Punjab which are the neighboring states of Delhi. It is seen that the concentration of PM2.5 and CO is almost similar in these places during the period of our study. Moreover, it is that time of the year when the practice of stubble burning is widespread in the

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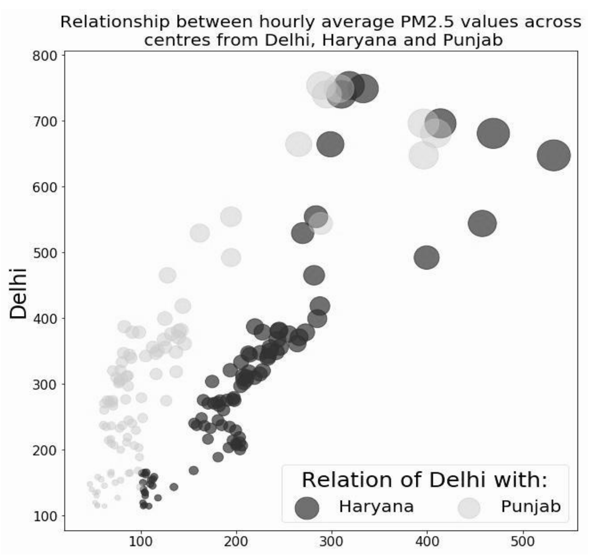
northern states of Punjab and Haryana. Therefore, it can be inferred that stubble burning might be one of the reasons why there is a rise in the levels of PM 2.5 and CO during the Diwali period.

(a)



(b)

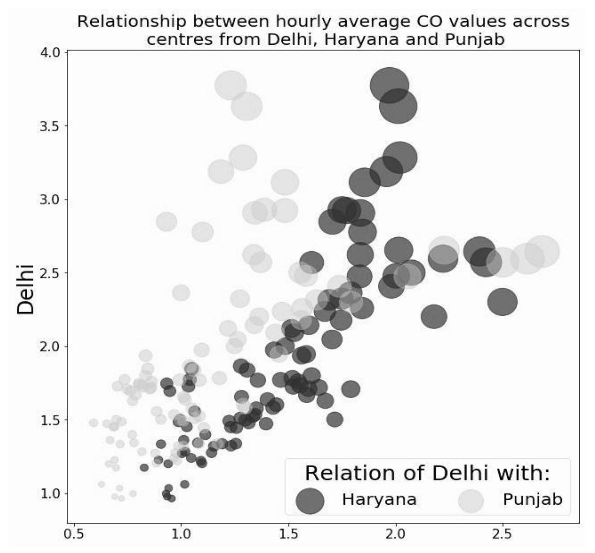


Fig. 4: The bubble plot showing the relation between the concentrations of (a) PM 2.5 and (b) CO at Haryana and Punjab to that of Delhi during the Diwali period. The x – axis represents data for Haryana and Punjab.

5.4 There is a lack of proper monitoring setups with only one center for 9100 km^2 of the country

In Figure 5, the PM2.5 hourly average during the pre-Diwali, Diwali, and post-Diwali periods have been plotted. It is seen that at around 12 am during the night of Diwali around sixty percent of the sensors stopped working. Extrapolating the data to predict approximations reveals that the sensors stopped working at that time of the day when the concentration of PM2.5 levels in the atmosphere would have increased.

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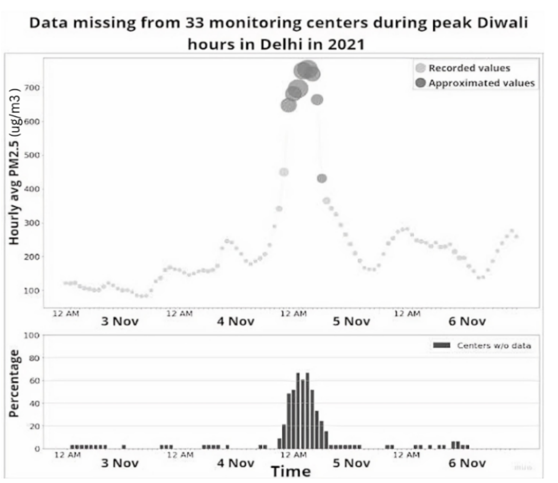

Fig. 5: The figure highlights the time frame during which most of the monitoring centers were not recording data for PM 2.5

5.5 An increase in emissions has been observed during the COVID-19 pandemic despite the nationwide lockdown

To prevent the further spread of the COVID-19 virus the government of India imposed a lockdown initially for 21 days from 24th March 2020. Diwali was celebrated on 14th November 2020. An analysis of the trend of the concentration of the PM2.5 levels as shown in Figure 6, in the atmosphere revealed that compared to 2019 in 2020 there was an increase in the level of PM2.5 in the atmosphere despite the successive periods of lockdown and unlock periods. Even another study conducted around the same time supports that despite the ongoing pandemic, Diwali in 2020 did not result in a significant drop in air pollutant levels. Unexpectedly, most pollutants had higher concentrations during Diwali 2020 than during Diwali 2019 (Mandal et al., 2022).

5.6 Judicial Prohibitions in the year 2016 resulted in a drastic drop in the pollution levels in the consequent years

From figure 6, it is seen that there is a drastic drop in the levels of PM2.5 from 2016 to successive years. It can be attributed to the fact that there have been some judicial prohibitions in Delhi to improve air quality which has resulted in the improvement of the pollution levels during that time. The Supreme Court of India banned the sale of fireworks in Delhi in 2017 during Diwali.

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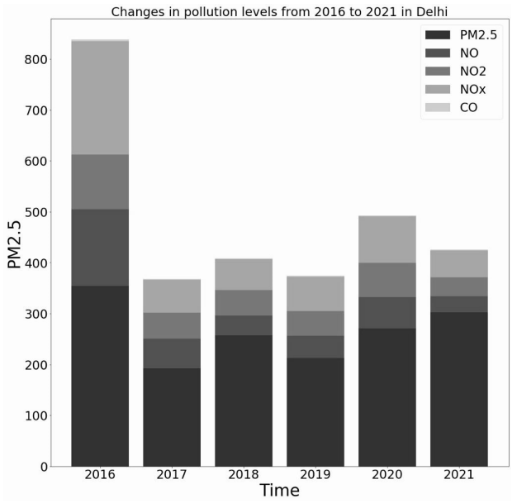

Fig. 6: Variations in concentrations of PM 2.5, NO, NO2, NOx and CO at Delhi during Diwali from 2016 to 2021

6 Discussions and Conclusion:

1. In general, the pollution level is the highest across the northern belt of the country during Diwali Nights compared to other parts of the country even though Diwali is celebrated across India.

2. Among the major cities, the concentrations of PM2.5, CO, and NOx in the atmosphere are the highest in Delhi while Kolkata showed the highest concentrations of O_3 in the atmosphere.

3. During the time when Diwali is being celebrated, the neighboring areas of Haryana and Punjab have extensive rounds of stubble burning. It is seen that the levels of CO and PM2.5 in Haryana and Punjab are similar to that in Delhi. Moreover, a study states that In the Indian context, the prevailing rice-wheat rotation system produces a significant 352 million tonnes of stubble annually, with 22% coming from wheat and 34% from rice. Tragically, about 84 million tonnes (23.86%) of this stubble is burnt in the field after harvest, significantly exacerbating air quality concerns. This practice has a major impact on air pollution, especially during the winter months (October-November), resulting in heavy pollution in cities like Delhi and causing adverse health effects (Abdurrahman et al., 2020).

4. It is seen that at around 12 a.m. during Diwali night, around sixty percent of the sensors stopped working. Extrapolating the data to predict approximations reveals that the sensors stopped working at that time of the day when the concentration of PM2.5 levels in the atmosphere would have increased. This highlights that the monitoring systems need to be upgraded and more sensors need to be installed.

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5. It is anticipated that there should have been a reduction in the air pollution levels during the covid 19 period during Diwali as people were mostly at their homes and there have been significant restrictions on the use of firecrackers. However, it is seen that even during those times, the pollution levels didn't come down. This suggests that burning firecrackers is not the only reason why the Delhi air is polluted.

6. Judicial Prohibitions in 2016, may have resulted in a drastic drop in pollution levels in the consequent years. A similar study spanning two consecutive years (2015-2016 and 2017-2018) with different fireworks regulations found that in 2017-2018 when court bans went into effect, concentrations of common pollutants in the atmosphere were reduced (Yadav et al., 2022). Increased public awareness and implementing measures such as increasing the cost of fireworks have proved effective in reducing the pollution caused by fireworks, as shown in the case of Hyderabad (Yerramsetti et al., 2013). Initiatives to improve urban green spaces and plant trees could positively impact air quality and public health during the festive season. Urban greenery and planting more trees to an extent might help in mitigating pollution control in Delhi as seen as an effective way in Canada (Nowak et al., 2018).

Data Availability

The dataset used in this study are available at Zenodo under DOI (https://doi.org/10.5281/zenodo.11390165)

Author Contribution

All authors contributed equally to this study. All authors have read and approved the final version of the manuscript.

Competing Interest

The authors declare no competing interest.

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