Study on the Impact of Firecrackers on Atmospheric Pollutants during Diwali Festival in Tamil Nadu, India

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Abstract. The current study focuses on the impact of firecrackers emission on particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), and total volatile organic compounds (TVOC) and the noise was analyzed on pre, during, and post-Diwali 2022 period (5 days) in a residential area of Tamil Nadu state of India. The findings demonstrated that, for 24-hour mean values of $PM_{2.5}$ and PM_{10} concentrations over the study period were consistently higher than the NAAQS (National Ambient Air Quality Standard) permitted limit. On the day of Diwali, the mean CO concentration reaches 2.5 mg/m^3, exceeding the NAAQS-recommended allowable limit of 2 mg/m^3. The CO_2 concentration during Diwali day is 1.8 times higher than the pre-Diwali day. In addition, the 24-hour mean concentration of TVOC during pre-Diwali, Diwali, and post-Diwali was found to be 915.21 μg/m^3, 1513.52 μg/m^3 and 1617.12 μg/m^3 respectively which is quite higher than normal days. Furthermore, the average noise level in the study site during pre, during, and post-Diwali was found to be 57.71 dB (A), 75.5 dB (A), and 63.66 dB (A) respectively which were higher than the safer limit on the residential zone. As a result of the widespread usage of firecrackers during Diwali festivities, these pollutants are significantly increased, which may have a negative influence on the general public's health.

Keywords: Air Quality; Diwali; Particulate matters; Gaseous pollutants; Noise

1. Introduction

The entire world is currently confronting significant difficulties in terms of the degradation of air quality due to an alarming rise in anthropogenic emissions brought on by rapid industrialization, motorization, urbanization, and a lack of sufficient understanding of air quality[1, 2]. High air pollution emission levels in India are a natural consequence of rising population density and rapid economic growth[3, 4]. Short-term air quality degradation events have recently attracted the attention of the scientific community and have become an important topic of discussion at all levels [5-9].India is regarded as the land of festivals due to its ancient traditions and diverse culture in its various states. Diwali is a "Festival of Lights" that is observed throughout India and often falls in October or November of a year[10]. Since firecrackers are extensively used during this festival, it has a significant negative impact on the environment[11]. Firecrackers, which are made of oxidizing chemicals (such as nitrates of barium and strontium, potassium chlorate, potassium perchlorates, potassium nitrates, and iron oxide) and fuels, are burned as part of celebrations[12, 13]. Fireworks emit loud noises and hazardous substances into both indoor and outdoor surroundings. The explosion of firecrackers releases a variety of harmful gases and particles of various sizes[14].

Atmospheric pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2),volatile organic compounds (VOC), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and benzene, toluene, and Numerous different metals, such as cadmium, manganese, and aluminium, etc discharged in enormous quantities have been had been associated with substantial health risks as a result of fireworks activities[12, 15-19]. On the day of Diwali, the day before Diwali, and the day after Diwali, people use a lot of fire-sparklers and fire-crackers primarily at night to celebrate[20]. This firework also results in an increased number of particulate matter concentrations. Particles of diameter 10μm (PM_{10}) and 2.5μm ($PM_{2.5}$) are associated with cardiorespiratory problems and mortality [21-23]. Fireworks have a huge negative impact on the environment and people's health since they include roughly 75% potassium nitrate, 15% carbon, and 10% sulfur and trace elements [20, 24, 25]. They release trace gases such (as CO, NO_x, SO_2, and O_3) as well as black carbon (BC) particulates during large-scale burning, which results in the development of dense smoke clouds[26, 27]. The dense smoke restricts human visibility in the air to a greater extent, persisting for up to several hours, depending on the prevailing climatic conditions[28].

Several researchers have examined degradation in air quality due to the Diwali celebration in various regions of India[20, 27, 29-31], and have also reported an increase in particulate matters and pollutant gases, such as $PM_{2.5}$, PM_{10},O_3, NO_2, SO_2, and trace metals during the Diwali celebration.According to Attri et al., burning and huge fireworks displays during Diwali led to the creation of the potent secondary pollutant ozone at ground level [32, 33].Research on the ambient air quality in Lucknow during the celebrations of Diwali revealed a range of PM_{10}, SO_2, and NO_x concentrations[30, 34]. When compared to their respective concentrations on pre-Diwali and regular days, the 24-hour average concentrations of NO_x, SO_2, and PM_{10} on Diwali day were found to be 6.59 times higher for NO_x, 1.95 times higher for SO_2, and 2.49 times higher for PM_{10}[30, 34]. A study conducted in Thiruvananthapuram, India, on the impact of Diwali fireworks on the mass concentration of atmospheric black carbon, showed a threefold increase over average days[35].

According to research, the aerosol from fireworks contributes up to 23-33% of the ambient PM_{10}. So, the population is impacted by the resulting acute cardiovascular ailments and chronic exposure to diseases [36, 37]. In India, the celebration of Diwali has been associated with an increase of 30–40% in cases of respiratory infections, breathlessness, and chronic obstructive pulmonary disease (COPD)[38]. The pollution that fireworks generate is diluted before it reaches people when they are set off at a higher altitude, which can improve people's health. On the other hand, ground-level fireworks immediately harm public health[39]. According to the Environmental Protection Agency (EPA), fine particulate matter ($PM_{2.5}$) poses substantial health risks to people and can premature death, cause respiratory and cardiovascular disorders, and impact the neurological system[40]. During the Diwali season, noise pollution is produced in addition to air pollution. In Haridwar, the mean noise concentration in commercial and residential areas rises by 18.1 and 29.6% in comparison to non-festive days[41]. Mahecha et al. stated that during Diwali day, the mean noise level in Jaisalmer's residential and commercial zone is 72 dB and 73.74 dB respectively[42].

Even though there is more firework activity during the Diwali celebration in Tamil Nadu state, India, there has been less research reported in the state to understand the variations in air quality during the celebrations. The study was carried out at the residential site in Erode City which is situated in the western region of Tamil Nadu. Erode is frequently affected by air pollution caused by particle matter. For this study, continuous measurements of $PM_{2.5}$, PM_{10}, CO, CO_2, TVOC, and noise levels during the Diwali period for 5 consecutive days on October, 2022. To understand the impact of firework activities on the air quality of Erode City throughout the Diwali celebration period, the particulate matter and trace gas concentrations on pre, during, and post-Diwali day were assessed and analyzed. The findings of this study would help understand the changes in urban air quality that have taken place in Erode, a city in western Tamil Nadu,India.

2. Methodology and instrumentation

2.1. Description of study site

The study was carried out at a residential site in Erode City which is located 11.3469° North and 77.7210° East in geographical coordinates is shown in Figure 1. It has a semi-arid climate with hot to sweltering temperatures throughout the year and relatively medium rainfall. Further, the sites are only 100 m from busy

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roadways where all vehicle types—light, medium, and heavy—travel at a fairly high density. Also, the study site is surrounded by commercial complexes and marketplaces.

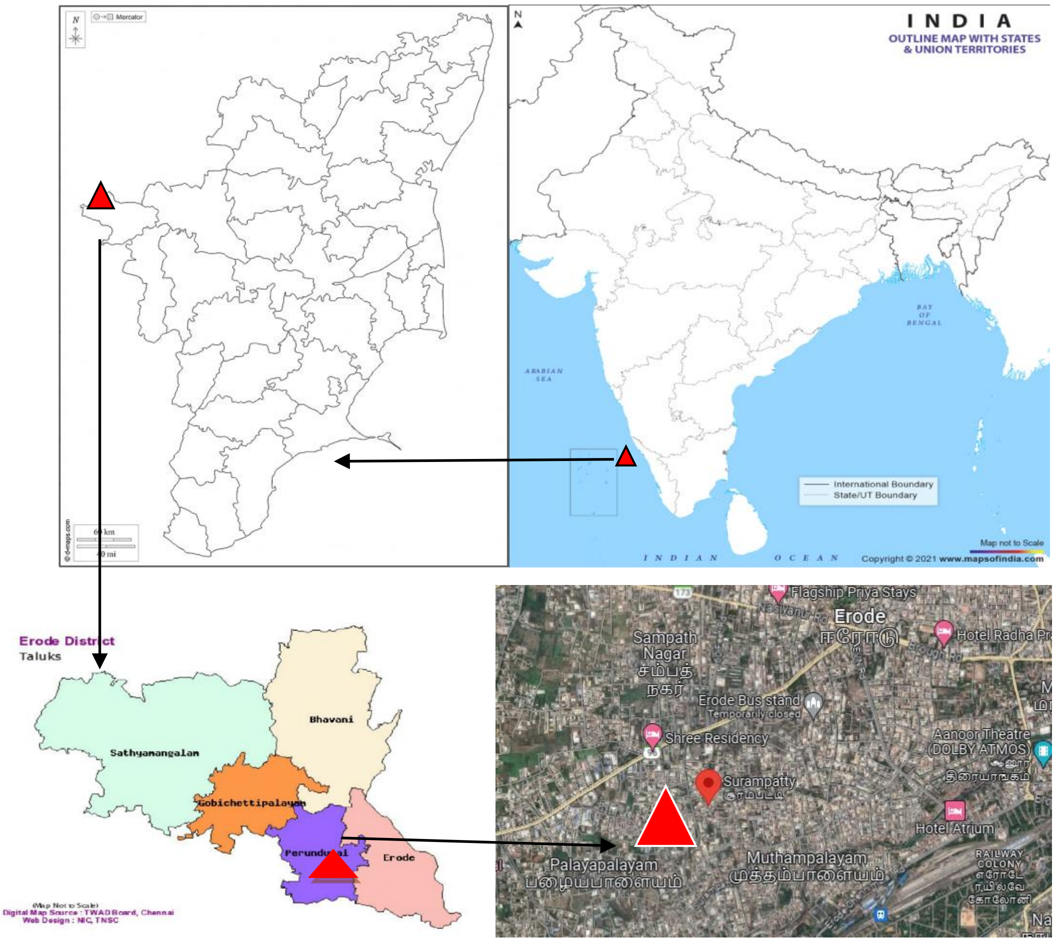

Fig.1.The map showing air sampling locations of study site (source:https,//maps.google.com)

2.2.Meterology of the site

The micro-meteorological parameters like temperature (°C), relative humidity (%), and wind speed (m/s) over Erode during the study period for pre-Diwali, Diwali, and post-Diwali days were shown in Figure 2(a), 2(b) and 2(c).It was noticed that over Erode during the study period, the wind speed, relative humidity, and temperature varied from 0.7-3.7 m/s,55-98%, and 21-37°C respectively. These data were obtained from the Tamil Nadu Pollution Control Board (TNPCB), Government of Tamil Nadu, India. As noted in Fig. 2, the mean relative humidity and temperature on the days before Diwali were nearly identical to those on Diwali and the days after Diwali. On Diwali night and the days after Diwali, the average wind speed was reported to be somewhat minimum than the previous days.

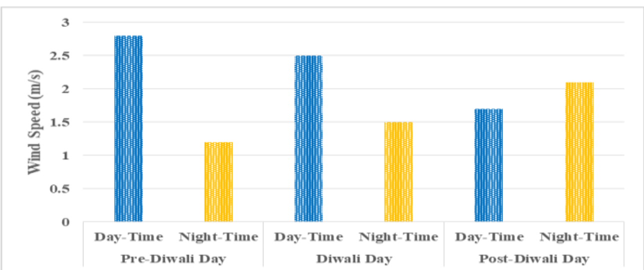

Fig.2 (a). Day and Night-time average of wind speed (m/s) over study area

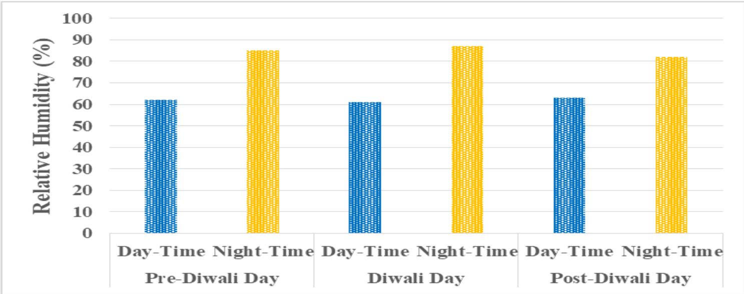

Fig.2 (b). Day and Night-time average of relative humidity (%) over study area

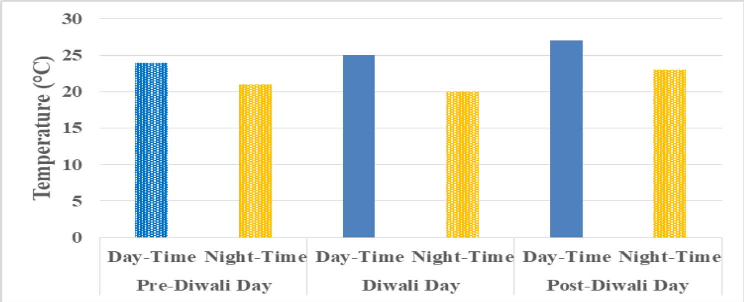

Fig.2 (c). Day and Night-time average of temperature(°C) over study area

2.3.Monitoring instrumentation

Air Quality Sensor (Oizom Polludrone Air Quality Monitor (AQM), OIZOM Limited, Gujarat, India) was used to measure such $PM_{2.5}$ (μg/m^3), PM_{10} (μg/m^3), CO (μg/m^3), CO_2 (ppm), TVOC (μg/m^3) and Noise level (dB). The particulate matter (PM) sensor operates based on the working principle of the optical particle counter and light scattering method. Its CO_2 sensor operates based on the non-dispersive infra-red principle and the CO sensor works based on the electro-chemical principle. The TVOC sensors operate based on the principle of the photoionization detector method which was used to quantify TVOCs. Air Quality Measurement (AQM) data were collected for a total of 5 days period in which 2 days before and 2 days after the Diwali Celebration.the abbrevations are elaborated for understanding purpose for the following

CO - Carbon monoxide
CO_2 - Carbon dioxide
TVOC - Total volatile Organic Compound
PM - Particle Matter

2.4.Sampling procedure

The 24-hour continuous measurements of air pollutants and noise level from October 22 to October 26, 2022, were analyzed for three different specific time intervals, viz., Pre-Diwali, Diwali, and post-Diwali day to obtain a complete picture of the urban air quality during the Diwali season in Erode city, India. The major festival day (Diwali Day) was on October 24, 2022. Thus October 22 and October 23 were considered as pre-Diwali (before Diwali) and post-Diwali (after Diwali) days were October 25 and October 26 respectively. Sampling was done by installing OIZOM Polludrone AQM at the terrace of the buildings which is 15 m from the ground level.

3.Results and discussion

3.1.Variation of particulate matter ($PM_{2.5}$ and PM_{10}) concentrations

The average night-time and day-time concentrations of $PM_{2.5}$ before, during, and after Diwali days have been shown in Figure 3.During the pre-Diwali period, the nightfall $PM_{2.5}$ concentration (230.43697µg/m³) was reported to be greater than morning time (192.72µg/m³) and hourly variations of $PM_{2.5}$ is shown in Figure 4. The higher day-time concentration of $PM_{2.5}$ was reported on Diwali (348.63µg/m³) followed by post-Diwali (331.95µg/m³) day. The daytime $PM_{2.5}$ levels before, during, and after-Diwali day were 3, 6, and 5 times higher than the permissible limit of the National Ambient Air Quality Standard (NAAQS) over residential areas (i.e., 60µg/m³). Similarly, higher night time $PM_{2.5}$ levels were observed on Diwali (497.02µg/m³) followed by post-Diwali day (395.71µg/m³). The nightfall concentration of $PM_{2.5}$ before, during, and after-Diwali day exceeds the NAAQS permissible limit by 3.8, 8, and 6 times which is extremely dangerous and can potentially cause serious lung impairments.

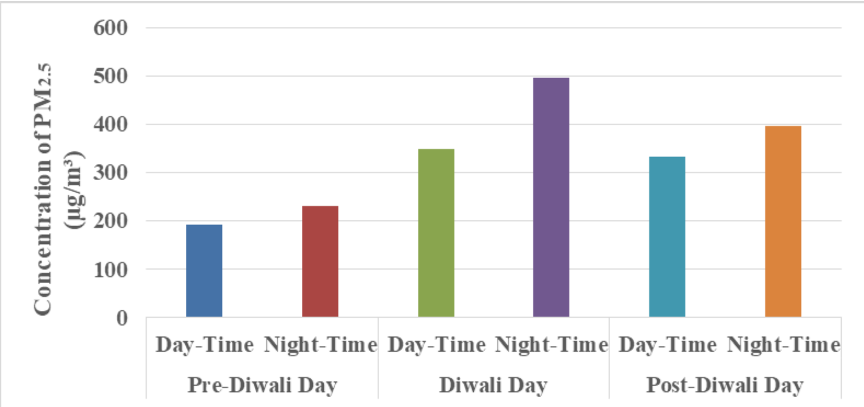

Fig.3. Day-time and night-time $PM_{2.5}$ concentration over study period

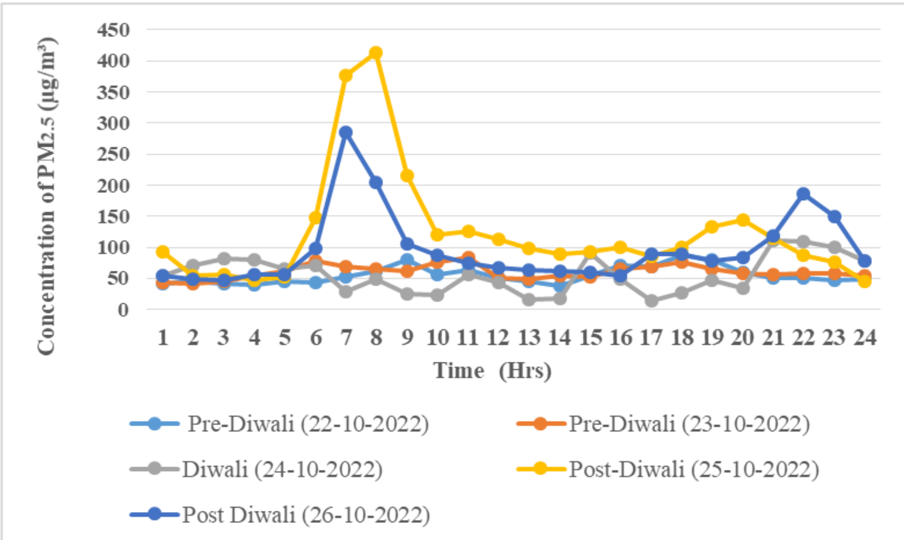

Fig.4. Hourly Variations of $PM_{2.5}$ Concentrations during study period

The average night-time and day-time concentrations of PM_{10} before, during, and after Diwali days have been shown in Figure 5. Further, the night-time concentration of PM_{10} was reported to be 799.43µg/m³ which was higher than the daytime concentration (652.48µg/m³) during before-Diwali day.Further, a higher amount of day-time PM_{10} agglomerations were reported on Diwali (958.92µg/m³) followed by post-Diwali (937.57µg/m³) day and hourly variation of PM_{10} is shown in Figure 6. The daytime agglomeration of PM_{10} before, during, and after-

Diwali day were found to be 6.52, 9.58, and 9.37 times higher than the NAAQS threshold limit over a residential area (i.e., 100µg/m³).In addition, the maximum night-time PM_{10} level was reported on Diwali (1005.76µg/m³) followed by post-Diwali day (964.71µg/m³). The nightfall concentration of PM_{10} before, during, and after-Diwali day was very higher than the threshold limit of NAAQS by 7.9, 10.05, and 9.64 times which is extremely threatening to public health and exacerbates cardiac and respiratory disorders[43]. The higher particulate matter agglomeration during pre-Diwali and post-Diwali might be due to the general populace beginning to celebrate two days before Diwali and continuing for two days.

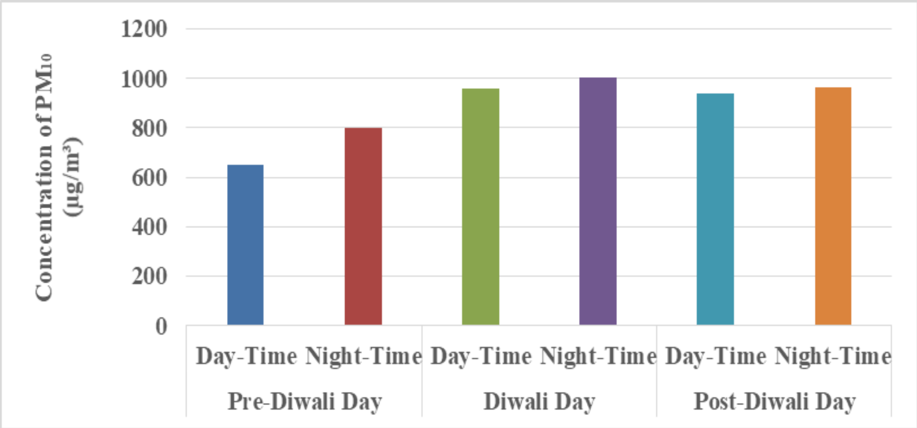

Fig.5. Day-time and night-time PM_{10} concentration over study period

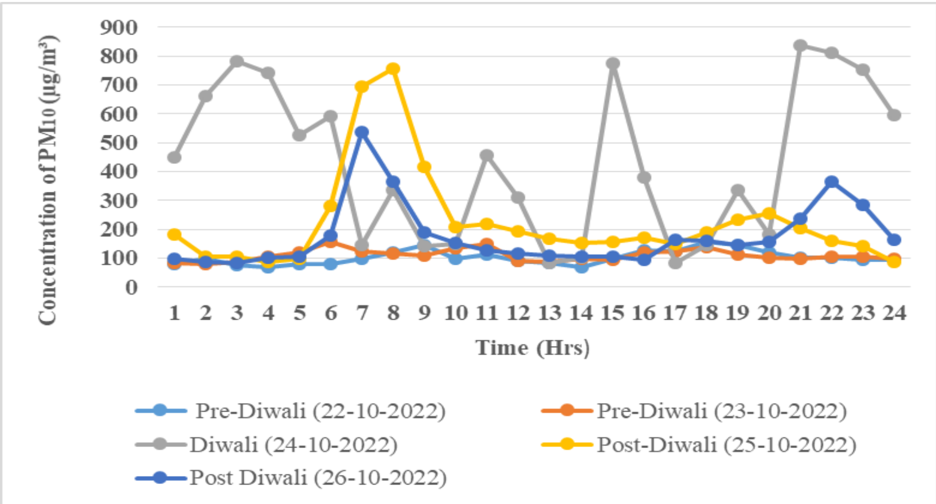

Fig.6. Hourly Variations of PM_{10} Concentrations during study period

The concentration of $PM_{2.5}$ and PM_{10} on Diwali day was 3 to 4 times higher than pre-Diwali period. On Diwali day, the aerosol mass increases since it is discharged into the air because of the spontaneous emissions from firecrackers and remains in the atmosphere for a maximum duration[44]. This is the reason $PM_{2.5}$ and PM_{10} values were found to be greater in the post-Diwali days than pre-Diwali period. Thus, it is evident that the night-time use of fireworks had a significant impact on the particulate concentration over the next day[45-49].However, it is important to highlight that the cause of the increased particle concentration is not just firecrackers; other local activities including vehicle emissions and human activities are also to be responsible[50]. Similar studies were conducted in Varanasi, where Kumar et al. observed that the significant use of firecrackers on festival days increased aerosol surface mass loading by 56–121% for the year 2014 which is compatible with the current study[51]. Another important study done by Barman et al. in the year 2008 reported higher concentrations of PM_{10} particles over Lucknow during the Diwali celebration which showed a similar trend with this investigation[52].

In this study, both $PM_{2.5}$ and PM_{10} concentrations were higher at night time and minimum in daytime which is consistent with the findings of Chatterjee et al. over residential place in Brahmaputra plain[45]. As a result of the mixing height decreasing by 6°C along with a 6°C drop in temperature, the wind speed is reduced at night. During the night, the wind blows at a lesser speed, which prevents the particles from dispersing, increasing the concentration of particulate matter on the surface[53].On the contrary, stronger thermal convection during the daytime increases mixing height, and greater wind speed permits the aerosol particles to be dispersed, which in turn reduces surface particulate concentrations[54]. The observance of minimum particulate matter during daytime might be due to the meteorological condition of daytime being impeditive to the formation of the thermal inversion layer[54, 55].

3.2. Variation of gas pollutants (CO, CO_2& TVOC) concentrations

On burning, firecrackers release toxic compounds in the form of smoke which contains carbon monoxide (CO) and carbon dioxide (CO_2). The 24-hour concentration of CO in the study site during pre-Diwali, Diwali, and post-Diwali were found to be 1568.48µg/m³, 2507.82µg/m³, and 2017.45µg/m³ respectively and hourly variation of CO concentrations is shown in Figure 7. On Diwali day, the mean concentration of CO reaches 2.5 mg/m^3 which is higher than the safer limit (2 mg/m^3) recommended by NAAQS. The CO concentration gradually increases from pre-Diwali and it reaches peak concentration during Diwali day, again starting to decrease in trend which shows the influence of firework activities on ambient air quality during the Diwali celebration.The average night-time and day-time CO concentrations before, during, and after Diwali days have been shown in Figure 8. The highest daytime CO levels were recorded on post-Diwali (2955.45 $\mu g/m^3$), Diwali (2132.12 $\mu g/m^3$), and pre-Diwali (1706 $\mu g/m^3$) days. During nightfall, the maximum level of CO concentration was determined on Diwali (7265.35µg/m³) followed by post-Diwali (2505.48µg/m³) and pre-Diwali (1829.13µg/m³) respectively.Thus, it is evident that the nightly use of fireworks had a significant impact on the next daytime CO concentration[38]. On Diwali day, an alarmingly high concentration of CO (7.2 + 1.3 mg/m^3) was reported which is 3.6 times greater than the NAAQS threshold limit. This large amount of CO concentration emitted during Diwali day from the burning of crackers may result in several health issues like headaches, shortness of breath, loss of consciousness, and chest pain[56, 57].

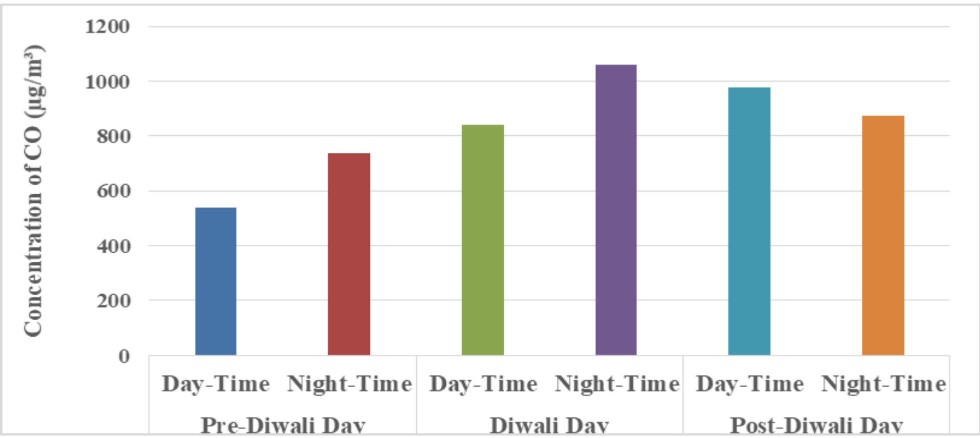

Fig.7. Day-time and night-time CO concentration over study period

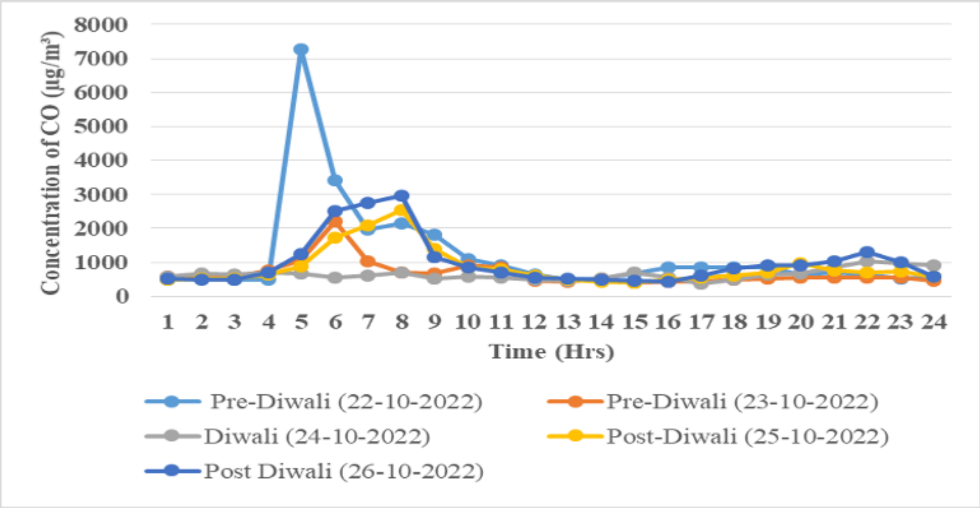

Fig.8. Hourly Variations of CO concentrations during study period

Generally, firecrackers are mainly made from black powder which is carbon and these components emit CO_2 in the environment after the combustion of fireworks[18]. In this study, the 24-hour average concentration of CO_2 in the study site during pre-Diwali, Diwali, and post-Diwali were found to be 910.12 ppm, 1715.54 ppm, and 1257.17 ppm respectively and hourly variation of CO_2 concentrations is shown in Figure 9. The CO_2 concentration during Diwali day is 1.8 times higher than the pre-Diwali concentration of CO_2 which depicted the influence of firework activities on ambient air quality over the study region. The maximum day-time concentration of CO_2 emission appeared on Diwali (1544.05 ppm) followed by post-Diwali (1481.84 ppm) and pre-Diwali (813.69 ppm). Similarly, the maximum night-time concentration of CO_2 level was higher on Diwali (1867.85 ppm) and post-Diwali (1391.52 ppm) than pre-Diwali (978.81 ppm) days. On the other hand, the day-time concentration of CO_2 emission was higher than the night-time during the post-Diwali day. This may be because the night-time use of fireworks had a significant impact on the CO_2 concentration the next day.The average night-time and day-time CO_2 concentrations before, during, and after Diwali days have been shown in Figure 10.

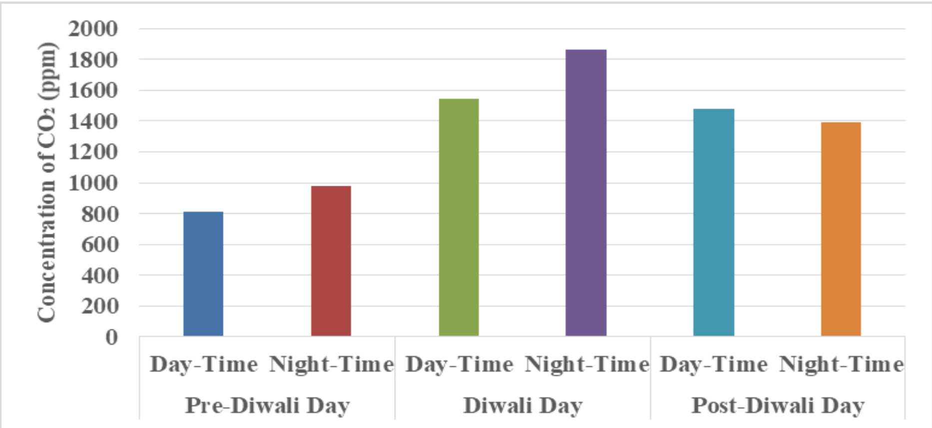

Fig.9. Day-time and night-time CO_2 concentration over study period

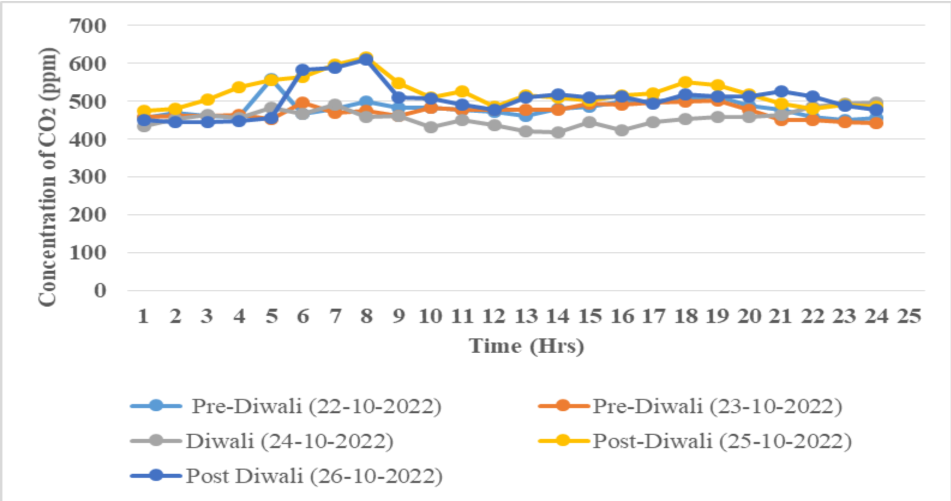

Fig.10. Hourly Variations of CO_2 Concentrations during study period

Furthermore, fireworks contain about 10% sulfur, 15% carbon, and 75% potassium nitrate and trace elements. On burning, these elements release the vapours of toxic organic chemicals in the form of volatile organic compounds (VOCs) into the atmosphere. During the study period, the 24-hour concentration of (Total Volatile Organic Compounds) TVOC during pre, during, and post-Diwali days were found to be 915.21µg/m³, 1513.52µg/m³, and 1617.12µg/m³ respectively and hourly variation of TVOC concentrations is shown in Figure 11. The results show that a gradual increase in TVOC concentration was reported from pre-Diwali to post-Diwali days which indicates the extensive of firecrackers.This could be due to the effect of Diwali night fireworks, which lasted till the next morning (post-Diwali day).Similar to $PM_{2.5}$ and PM_{10}, the concentration of TVOC was higher during night-time and minimum in the daytime except for post-Diwali day. The average night-time and day-time TVOC concentrations before, during, and after Diwali days have been shown in Figure 12. Because during the daytime of post-Diwali day, the wind speed was minimum than night time. Higher TVOC concentration during the night time may be due to climatic factors like high humidity, decreasing temperature, and calm winds during night-time which prevents the dispersion of pollutants, which eventually leads to higher concentration of pollutants combined with firecrackers emissions.The burning of firecrackers also emits harmful volatile organic chemicals and particulate particles, according to recent studies [36, 58-60]. According to a study by Fleischer et al., the use of sparklers like "Fountains" and "Blue lightning rockets" causes the production of highly harmful organic pollutants such as polychlorinated dioxins and furans[61]. Kulshrestha et al. found that numerous flying firecrackers generate highly toxic volatile organic compounds like dibenzofurans and polychlorinated dibenzodioxins into the lower troposphere during combustion[13]. In addition, the study conducted by Chatterjee et al. reported that organic carbon,VOCs, and Polycyclic aromatic hydrocarbons (PAHs) have also been found in fireworks emissions during Diwali celebrations[45]. Altogether, the volatile organic compounds were emitted due to the burning of firecrackers during Diwali celebrations which exacerbate the risks of cardio-pulmonary illness and central nervous systems (CNS) disorders[62].

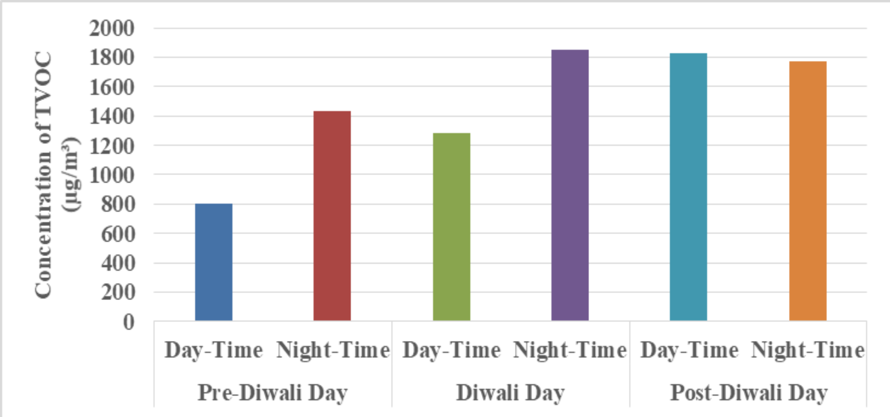

Fig.11. Day-time and night-time TVOC concentration over study period

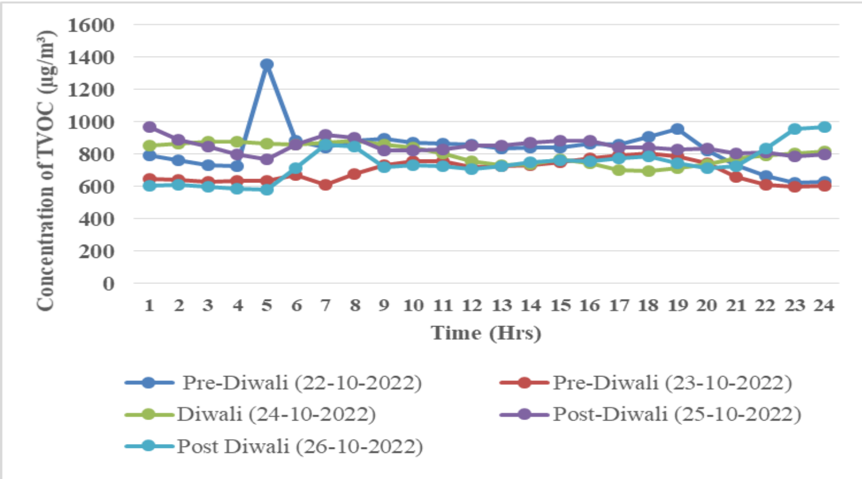

Fig.12. Hourly Variations of TVOC Concentrations during study period

3.3.Variation of noise level

The average noise level in the study site during pre-Diwali, Diwali, and post-Diwali were found to be 57.71 dB, 75.5 dB, and 63.66 dB respectively and hourly variations of noise level study period is shown in Figure 13. The results indicate that noise level starts to increase from pre-Diwali days and reached a higher level during Diwali day and again starts to decline in trend. Thus it indicates that the bursting of firecrackers increased noise pollution during the Diwali celebration. The average night-time and day-time noise concentrations before, during, and after Diwali days have been shown in Figure 14. The maximum night-time noise level was reported on Diwali (91.29 dB) followed by post-Diwali (71.34 dB) day and pre-Diwali (62.09 dB) day. The noise level during night-time on pre, during, and post-Diwali days were respectively 2.02, 1.58, and 1.37 times higher than the permissible limit (45 dB) of ambient noise over residential areas during night-time. In addition, the maximum noise level in the daytime was reported on Diwali (85.02 dB) followed by post-Diwali day (65.98 dB) and pre-Diwali (53.34 dB) day. Furthermore, the noise level during the daytime on Diwali and post-Diwali days were 1.5 and 1.18 times higher than the permissible limit (55 dB) of ambient noise over residential areas during night time. The present findings are consistent with the study of Chanchpara et al. reported that noise level was reported to be maximum during night-time compared with the morning time[36]. This indicates that fireworks activities are extensively carried out during the night time.An increase in noise levels during Diwali celebrations can lead tosleep disturbance, high blood pressure, and temporary or permanent hearing loss [63].

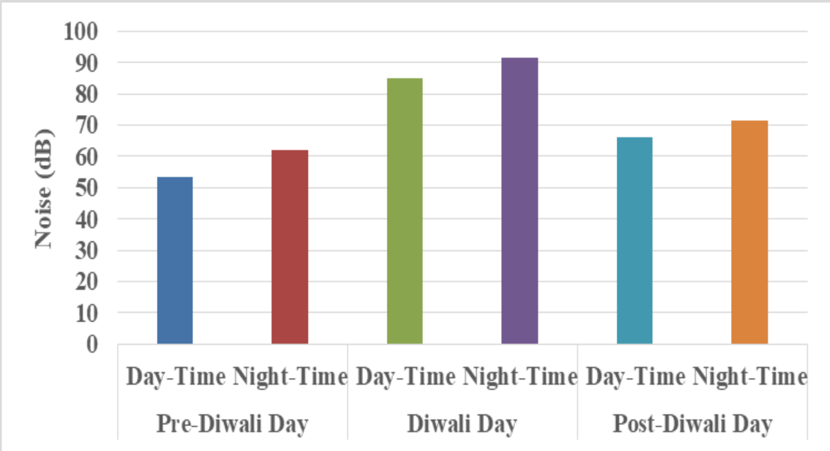

Fig.13. Day-time and night-time noise (dB) level over study period

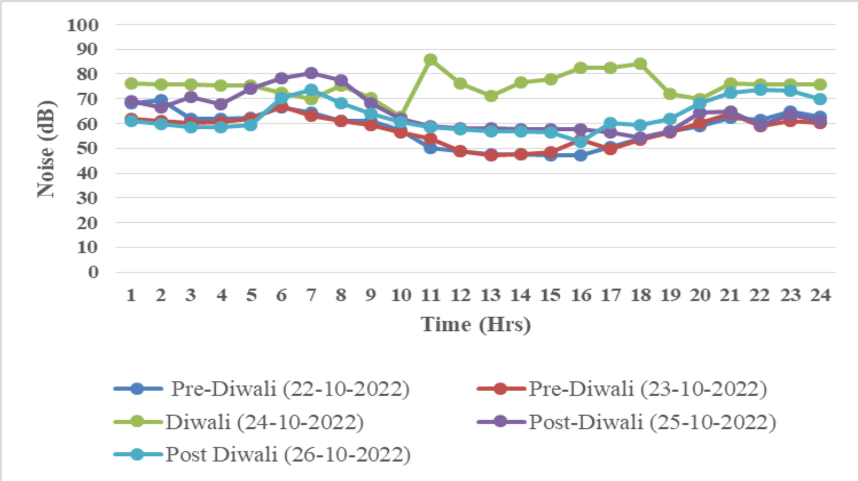

Fig.14. Hourly Variations of noise level during study period

4.Conclusion

The current study investigates the impact of Diwali fireworks activities on air quality over a residential site at Erode City, Tamil Nadu state of India for five consecutive days from October 22 to October 26, 2022. This study shows that the fireworks activities had a strong effect in increasing particulate matter and gaseous pollutants concentration over the study site. Both $PM_{2.5}$ and PM_{10} concentrations during pre, during, and post-Diwali days exceed the NAAQS permissible limit on the residential area. Furthermore, the night-time concentration of particulate matter was higher than daytime concentrations. This study shows that the nightfall concentration of PM_{10} before, during, and after-Diwali day was very higher than the threshold limit of NAAQS by 7.9, 10.05, and 9.64 times. Additionally, the nightfall concentration of $PM_{2.5}$ before, during, and after-Diwali day exceeded the NAAQS permissible limit by 3.8, 8, and 6 times in the current study.The short-term high accumulation of $PM_{2.5}$ and PM_{10} is a matter of serious issue for people because it can infiltrate deeply into the lungs and cause many respiratory and cardiovascular problems.On Diwali day, an alarmingly high concentration of CO (7.2 + 1.3 mg/m^3) was found which is 3.6 times greater than NAAQS permissible limit. In this study, the 24-hour average concentration of CO_2 in the study site during pre, during, and post-Diwali days were found to be 910.12 ppm, 1715.54 ppm, and 1257.17 ppm respectively.The maximum concentration of TVOC was observed to be 1849 µg/m^3 during the night time of Diwali day.During the Diwali season, the accompanying climatic conditions (lowered night-time boundary layer height, lowering temperature, and low wind speed) cause an unwanted deposit of air pollutants close to the surface layer at the study location. During the study, the noise concentration was reported to be higher at in the night-time than daytime. The noise level during the night-time on pre, during, and post-Diwali days were respectively 2.02, 1.58, and 1.37 times higher than the permissible limit and thus depicted a higher amount of crack bursting during the night.A noteworthy finding from this study is that the average concentration of the air pollutants it observed remained high even on the day after Diwali, indicating that it may take longer than a day to clear the atmosphere after igniting firecrackers.Diwali celebrations result in the discharge of gaseous and particle pollutants that dwell in the atmosphere for a longer period, harming the ecosystem and the public's health. Thus, people should raise awareness to celebrate Diwali in an environmentally friendly manner.

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