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Research Article

Elevated $PM_{2.5}$ Levels Associated with Incense Burning in Bangalamukhi Temple, Lalitpur, Nepal

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Abstract

Incense burning is a common practice in many Asian countries, often used at homes to mask bad odors and repel insects. Pollutants released from incense burning can quickly accumulate to hazardous levels in indoor environments, particularly in poorly ventilated areas. Particulate matter (PM) emitted from incense is of great importance due to its adverse effects on human health. The study focuses on the measurement of $PM_{2.5}$, and CO_2 concentrations in Bangalamukhi temple located in Lalitpur, Nepal. The data were collected using an Air Visual Pro (IQ*Ai*r, Switzerland). The air quality parameters were measured for two days during the Navaratri (Dashain) festival designated as Peak Period I and II, and on Thursday as Peak Period III, considering the higher flow of people during these days. Non-peak Periods I and II were defined as any other days except Thursday and/or Saturday, assuming a lower flow of people. The RH levels during the sampling periods ranged from 47-72% and ambient temperature ranged from 13.7-29.0. The study showed the maximum hourly average $PM_{2.5}$ concentrations during peak and non-peak period days at Bangalamukhi temple exceeded the National Ambient Air Quality Standards 2012. Furthermore, the peak value of $PM_{2.5}$ concentration during both the peak period days (peak period I and II) was significantly higher than in the samples conducted during all the non-peak period days at the sampling site (peak value $PM_{2.5}$ concentration: 439.40-118.8 *vs* 215.1-55.4), indicating that the burning of incense was responsible for the elevated $PM_{2.5}$ concentration in the temple premises.

Keywords: Air Visual Pro, incense burning, particulate matter, peak periods

Introduction

Incense burning is a common practice in religions such as Hinduism, Buddhism, and Taoism, around the world. Burning incense for religious and ritual purposes at home is a popular practice among populations in China (Tse et al., 2011), Taiwan (Liao et al., 2006), Singapore (Friborg et al., 2008), India (Dewangan et al., 2013), and the Arabian Gulf (Chohen et al., 2013). Burning incense sticks, has long been a tradition in Nepal, a country mostly populated by followers of Hinduism and Buddhism (Shrestha, 2020).

Typically, the composition of incense sticks consists of 21% (by weight) of herbal and wood powder, 35% of fragrance material, 11% of adhesive powder, and 33% of bamboo sticks (Chang et al., 2008) but still the amount and kind of pollutants released from incense depend on the composition of the material used in making the incense sticks. Excessive usage of these incense sticks releases toxic pollutants which are leading to adverse health effects. The harmful health effects can be attributed to the various contaminants present in incense smoke, including gaseous pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x) and volatile organic compounds (VOCs) (See et al., 2007), and particulate matter (PM) and adsorbed toxic pollutants polycyclic aromatic hydrocarbons (PAHs) and toxic metals (Li et al., 1993; Lee & Wang, 2004; Mannix et al.,1996).

Burning incense releases a wide range of chemical substances, including carbon monoxide (CO), nitrogen oxides, inorganic ions, and carbonaceous aerosol (Bootdee et al., 2016; See & Balasubramanian, 2011). According to Chuang et al. (2013) and Cohen et al. (2013), incense smoke exposure has the potential to increased markers of oxidative DNA damage and cell inflammation. Acute and chronic exposure to indoor organic compounds or particles has already showed harmful effects on human and animal health such as damage of the nervous system, immune and reproduction diseases, respiratory system dysfunction, developmental problems and cancers (WHO, 2000). Some studies have found that incense smoke has even higher toxic health effects than tobacco smoke (Chen & Lee, 1996) and has been linked with higher risk of cardiovascular mortality, respiratory tract carcinomas and nasopharyngeal cancer (Chen & Lee, 1996; Pan et al., 2014).). On average, incense burning produces particulates greater than 45mg/g burned as compared to 10mg/g burned for cigarette (Chang et al., 2007). Exposure to incense smoke has been linked to several illnesses, including respiratory symptoms, asthma elevated cord blood IgE levels, contact dermatitis and cancer (Abdul & Mustafa 2007; Hijazi et al., 2002; Lin et al., 2008).

According to a Vietnamese study, homes with incense burning had indoor $PM_{2.5}$ concentrations 61.6% higher than those without incense burning (Tran et al., 2021). According to another research done in Taiwan, burning

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incense for 30 to 60 minutes only at a time at home produced 1.79 times the levels of PM $_{2.5}$ observed outside (Lung et al., 2021). Particulate matter (PM) is of great importance due to its adverse effects on human health. Coarse particles (PM_{10}, particles with an aerodynamic diameter of 10 µm or less) and fine particles ($PM_{2.5}$, particles with an aerodynamic diameter of 2.5 µm or less) are often used as important indicators to characterize the mortality and health risk from lung cancer and cardiopulmonary deaths. However, the mortality rates and health risks were found to be greater for $PM_{2.5}$ than PM10 (Fierro, 2000). The USEPA 2004 Air Quality Criteria for Particulate Matter conclusion states that $PM_{10\text{-}2.5}$ exposure was associated with respiratory morbidity (USEPA, 2004).

Incense burning is a powerful source of a multitude of harmful constituents, including particulate matter and volatile organic compounds, which are potential air pollutants deleterious to human health (Elsayed et al., 2014; Liao et al., 2006).

Arabian incense burning is a common trigger of wheezing among asthmatic children in Oman, however it is not associated with the prevalence of asthma (AL-Rawas et al., 2008). The observations on toxicity involved; behavioral changes (autonomic responses, motor activity and central nervous system), effect on body and organ weight and rate of mortality. Micronucleus test was used to determine the genetic toxicity in Albino mice (Qureshi, 2013).

Many studies on the composition of particulate matter (PM) including $PM_{2.5}$ and PM_{10} and CO_2 emission from incense burning have identified airborne particles and associated with adverse health effects. In Nepal, urban areas are seen to have increasingly robust evidence to show that pollution normally present in our urban communities is associated with respiratory diseases, eye infatuation, pulmonary diseases and other health impacts (Saud & Paudel, 2018).

Although people are made aware of harmful effects of air pollution through many news and major studies around the world, the harmful effect of burning incense has not been given much attention. Studies regarding this topic must be conducted in Nepal as burning of incense is a very common practice. Therefore, measurement of air pollutants and estimation of $PM_{2.5}$ mass, and CO_2 emission from incense burning is the purpose of this research.

Materials and Methods

Study Area

Bangalamukhi one of the very famous temples of goddess, is located in Patan (latitude $27^0$40'36" N, longitude $85^0$19'33" E (Fig. 1) Lalitpur, Nepal. There are various other small temples inside the premises, home to many gods and goddesses. The temple is specially crowded on Thursdays as it is considered as the day of goddess . The temple is famous for its "*Kumbhamela" a religious fair* that happens during "*Janaipoornima",* a festival dedicated to "*Janai",* a traditional auspicious thread worn by men of the Brahmin and Chettri communities of Nepal.

The temple is peri-metered by concrete walls with small gully roads to each adjacent side of wall. Two-wheelers and light traffic vehicles are only access to the temple. The highway is approximately 3.5 km far from the sampling site. Hence, the influence of particles emitted from traffic sources could be nominal. However, the site is primarily influenced by incense burning from temple. The temple is usually crowded at the morning times, less crowded in the evening and least crowded in the daytime.

The festival brings huge crowds from within and outside of the valley to observe the religious fair. People also visit the temple to offer *Lakh-Batti* as shown in Figure 1, a Hindu ceremony of burning one hundred thousand lights made of cotton strands, during the "*Navaratri"* festival, nine days celebration of goddess Durga. The *Lakh-Batti* is also offered on Thursdays throughout the year.

Air Quality Data Collection

The instrument used to collect primary data was Air Visual Pro. The instrument uses light scattering laser sensor for $PM_{2.5}$ measurements. Within the sensor's measuring 'chamber', a laser light beam is shone onto particles, and this light is then irradiated in all directions from these particles (scattering). A light detector (or 'photometer detector') then measures all of this scattered light, and from this, the sensor can calculate the concentration of particles within the chamber. In this way, the sensor is able to detect near microscopic particles ranging from 0.3µm to 2.5µm. The sensor in the Air Visual Pro also has a small fan to ensure a constant flow of air through the measuring chamber (IQAir, 2015). Auto-calibration components instantly consider factors like temperature (^{0}C), relative humidity (%), $PM_{2.5}$ (µg/m³), PM_{10}(µg/m³) and CO_2 (ppm) IQ*Air* (2015). The instrument was placed 2.5 m apart, 2.6 m above the ground and at an angle of 45° from the incense station shown in Figure 2(a) and the device used shown in 2(b).

Samples and sampling dates

The data was collected on a diurnal period: 24 hours data. Measurements of $PM_{2.5}$, PM_{10}, and CO_2 concentrations were conducted in the Bangalamukhi temple site during peak-period days(October 11 and 13, 2018, November 29, 2018) and non-peak period days (November 30 and December 3, 2018) using Air Visual Pro IO*Air*, Switzerland. Here peak periods are days where the crowd of devotees in the temple would be more while, non-peak periods are days where the case would be low. Table below shows the Maxima values of $PM_{2.5}$ at peak and non-peak period Samples, sampling dates, temperature (T°C), relative humidity (RH, %), as well as daily average mass concentration of CO_2 are given in Table.

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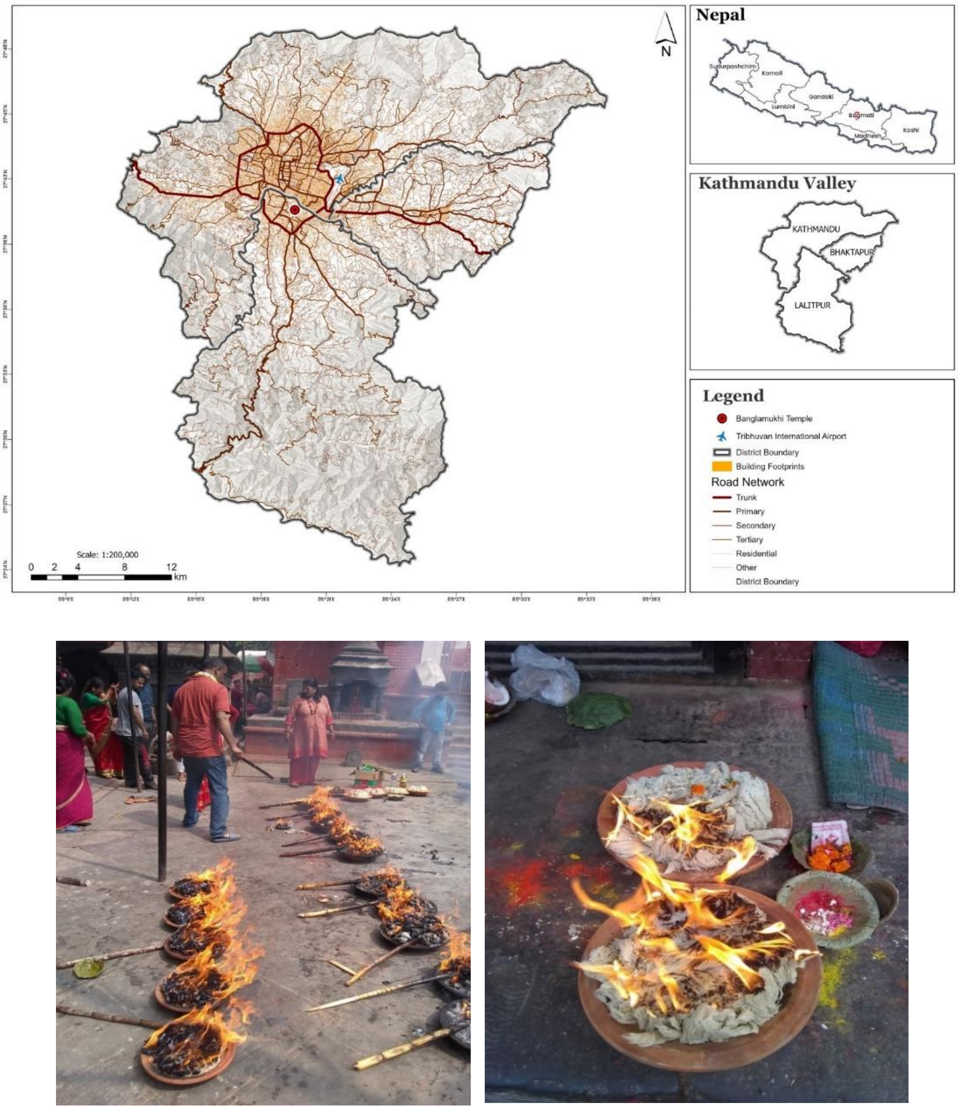

Figure 1 Location map of Bangalamukhi temple at Lalitpur District in Nepal (upper); and Lakh batti offering by a devotee (lower two photos)

Figure 2 (a) installation of device in the temple (b) the instrument used: Air Visual Pro

Results and Discussion

Time series of hourly average $PM_{2.5}$ concentration during peak period and non-peak period days at Bangalamukhi temple, Patan are shown in figures 3 and 4, respectively. In the figures, red dotted lines represent the WHO Air Guideline value of PM_{10} i.e., 45 μg/m³ and the purple dotted line represent the WHO Air Guideline value of $PM_{2.5}$ i.e., 15 μg/m³ for ambient air quality.

The $PM_{2.5}$ mass concentrations show different patterns in peak and non-peak period days. During the observation period, the maximum $PM_{2.5}$ concentration in all the peak period days were significantly higher than in the samples conducted during all the non-peak period days at the sampling site ($PM_{2.5}$ concentration: 305.1~439.40, indicating that the burning of incense was responsible for the elevated $PM_{2.5}$ concentration, as in Figure 3.

The elevated concentration of $PM_{2.5}$ were observed in the morning and evening (peaked values at: 7:00~8:00 and 18:00 ~20:00, respectively) during the peak period-I ($PM_{2.5}$ concentration: 305.10 and 118.75 μg/m³, respectively) and both the non-peak periods ($PM_{2.5}$ concentration: 75.03~ 217.10 and 55.35~97.91 μg/m³, respectively), while the concentration decreased ($PM_{2.5}$ concentration: 21.7~32.7 μg/m³) in the afternoon (at 14:00 ~16:00).

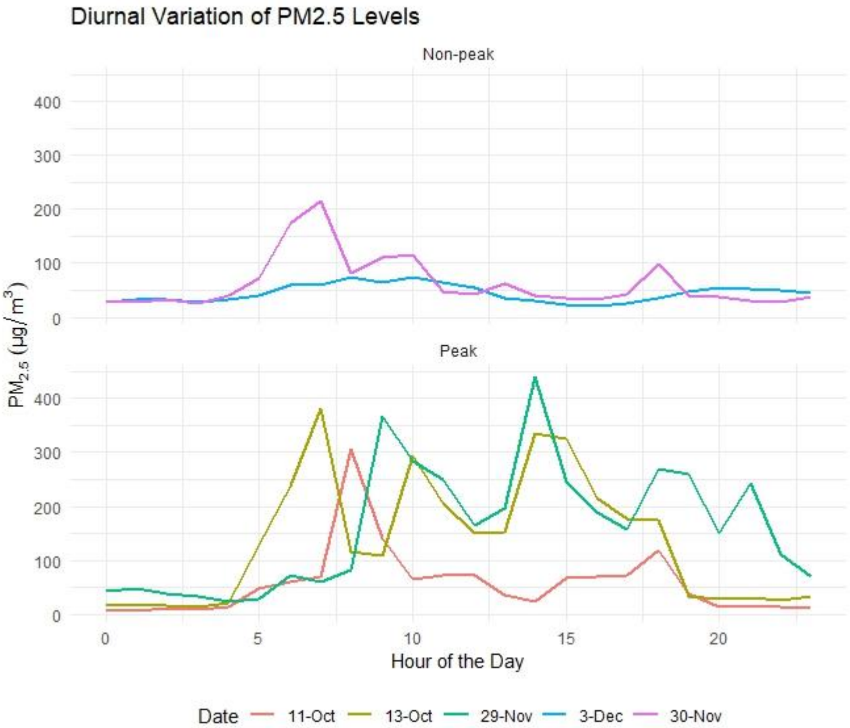

Figure 3. Diurnal variations of hourly averages of $PM_{2.5}$ concentrations in: non-peak period and peak period (b) at Bangalamukhi temple, Patan, Lalitpur

The elevated concentration of $PM_{2.5}$ were observed (peaked values at: 8:00~9:00, 10:00 ~14:00 and 14:00 ~18:00, respectively) during the peak period II ($PM_{2.5}$ concentration: 380.74, 334.87 and 294.15 μg/m³, respectively) and peak period III ($PM_{2.5}$ concentration: 365.76, 439.40 and 269.75 μg/m³, respectively). The values of peaks were observed at different times of the day due to hundred thousand lights. Naturally, peak periods had more flow of people, and hence peaks were seen as shown in Figure 2.

On the contrary, non-peak periods I and II shown in Figure 2, both had more than 3 peaks during the 24-hour period. For both the days considered for Non-peak period, a similar pattern can be noticed, at least 2 peaks in the morning time and at least one in the evening which could be attributed to the burning of high inflow of people at different time slots in the temple throughout the day. These peaks are evidently at concentrations way above the WHO standard and emitting abundant amounts of detrimental pollutants including particulate matter

Diurnal Variation Analysis

The diurnal variation of $PM_{2.5}$ levels, presented in Figure 2 , illustrates the hourly changes in particulate matter concentrations across different dates categorized as peak and non-peak periods. The line plots in these figures depict clear patterns in $PM_{2.5}$ levels, with notable fluctuations corresponding to different times of the day.

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Conversely, the non-peak periods (30-Nov and 3-Dec) show relatively lower and more stable $PM_{2.5}$ levels throughout the day. The absence of significant spikes suggests reduced anthropogenic activities, possibly due to fewer vehicles on the road and lower industrial outputs during these dates.

To facilitate a straightforward comparison between peak and non-peak periods, a box plot of $PM_{2.5}$ concentrations was constructed (Fig. 3). This box plot vividly demonstrates the disparity in $PM_{2.5}$ levels, where the median concentration during peak periods is substantially higher than that of non-peak periods. The interquartile range (IQR) and the presence of outliers further highlight the variability and elevated pollution levels experienced during peak days.

For the peak periods (11-Oct, 13-Oct, and 29-Nov), we observe distinct peaks in $PM_{2.5}$ concentrations during early morning and late evening hours. These peaks are likely associated with increased vehicular emissions and industrial activities during rush hours. The concentrations during these periods reach their maximum around 8 AM and again in the evening around 6 PM, indicating a bimodal distribution commonly seen in urban pollution studies.

In comparison to the NAAQS 2012, the maximum $PM_{2.5}$ concentration among the observed data exceeds the national standards by at least 7 times and the minimum $PM_{2.5}$ concentration also exceeds the national standard. At the same time the maximum $PM_{2.5}$ concentration greatly exceeds the WHO standards. A study conducted in Thailand yielded comparable results, suggesting that on special occasions, $PM_{2.5}$ concentrations within temples could reach as high as 184-625 μg/m³ (Hien et al., 2022).

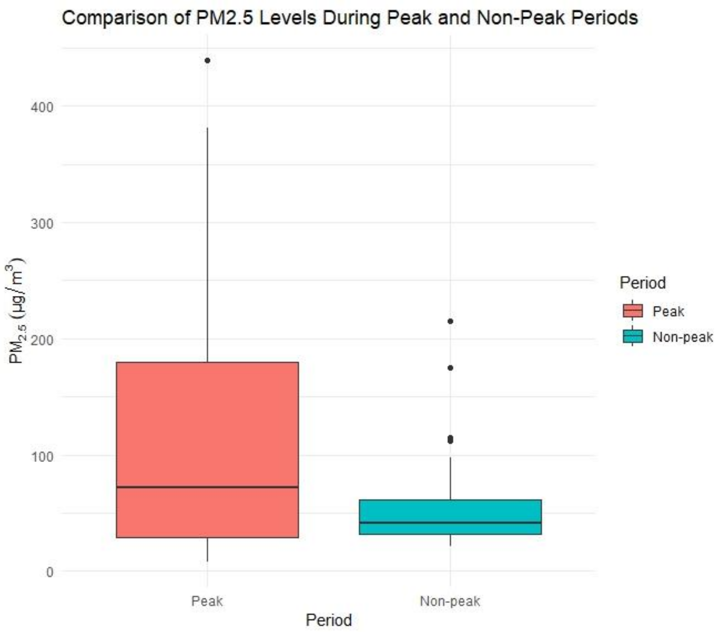

Figure 4. Comparison of $PM_{2.5}$ during both Peak and Non-Peak periods

The Figure 2 clearly shows the difference in $PM_{2.5}$ levels between peak and non-peak periods. From the plot, one can observe that $PM_{2.5}$ levels are generally higher during peak periods compared to non-peak periods. This suggests that specific days and times significantly contribute to overall air pollution levels. $PM_{2.5}$ levels may show a peak during morning and evening rush hours due to traffic emissions, and a trough during the night when activities are minimal.

The box plot (Fig. 3) compares $PM_{2.5}$ levels between peak and non-peak periods, enabling readers to easily evaluate the differences. The median $PM_{2.5}$ concentration during peak periods is notably higher than during non-peak periods, emphasizing the impact of increased human activities on air quality. The spread of the data, indicated by the IQR, also shows greater variability in $PM_{2.5}$ levels during peak periods, with several outliers pointing to exceptionally high pollution events.

Overall, these visualizations and analyses underscore the significant influence of peak traffic and industrial activities on diurnal air pollution patterns, highlighting the necessity for targeted pollution control measures during these critical times.

In a study conducted in a domestic setting, particles released by a source of burning incense spread throughout space, even in closed rooms and even in rooms that are on the next story away (Xi et al., 2010). This merely scratches the surface of the damage that burning incense can bring to areas like temples that are used frequently and to those who have continuous access to them. According to a pilot-scale study conducted in France, burning an incense stick could release up to 25,500 particles cm^3, and indoor $PM_{2.5}$ concentrations might reach 197 µg/m³ (Ji et al., 2010). This is 13 times higher than the WHO 24-hour limit of 15 µg/m³.

Studies show that, on an average, incense burning produces particulates greater than 45mg/g burned as compared to 10 mg/g burned for cigarette (Chang et al., 2007). Several studies have indicated that incense smoke can pose greater health risks than tobacco smoke (Chen & Lee, 1996). These risks include increased chances of cardiovascular mortality, respiratory tract carcinomas, and nasopharyngeal cancer (Chen & Lee, 1996; Pan et al., 2014). Moreover, additional research has reinforced these findings, associating incense smoke with heightened toxic effects compared to tobacco smoke, along with elevated risks of cardiovascular mortality, respiratory tract carcinomas, and nasopharyngeal cancer (Friborg et al., 2007; Pan et al., 2014).

Incense burning is a powerful source of a multitude of harmful constituents, including particulate matter and volatile organic compounds, which are potential air pollutants deleterious to human health (Liao et al., 2006; Elsayed et al., 2014). Particulate matter (PM) is of great importance due to its adverse effects on human health. Coarse particles (PM_{10}, particles with an aerodynamic diameter of 10 µm or less) and fine particles ($PM_{2.5}$, particles with an aerodynamic diameter of 2.5 µm or less) are often used as important indicators to characterize the mortality and health risk from lung cancer and cardiopulmonary deaths. However, the mortality rates and health risks were found to be greater for $PM_{2.5}$ than PM_{10} (Fierro, 2000).

The USEPA 2004 Air Quality Criteria for Particulate Matter conclusion states that PM_{10} and $PM2_{2.5}$ exposure was associated with respiratory morbidity (USEPA, 2004). Acute and chronic exposure by indoor organic compounds or particles have already showed harmful effects on human and animal health such as damage of the nervous system, immune and reproduction diseases, respiratory system dysfunction, development problems or cancers (WHO, 2000). The research can further be carried out to find out the effects on health through passive sampling (in-vitro culture).

The maxima values of $PM_{2.5}$ at the peak and non-peak periods are shown in *Table*. There are two distinct peaks observed during Peak period I and both the non-peak periods while three peaks were observed during peak period II and four during peak period III. The occurrence of two peaks in a day corresponds to morning and evening puja offerings in the temple, while maxima of more than two peaks are associated with the burning of lakh batti'- a ceremony of lighting hundred thousand cotton wicks burning at different times of the day. A similar result was observed in a study by Hien et al. (2022) showing that incense burning contributed to increased PM_{10} and $PM_{2.5}$ concentrations, with higher concentrations during religious events.

Table 1. Maxima values of $PM_{2.5}$ at peak and non-peak period

Samples	Maxima I		Maxima II		Maxima III		Maxima IV	
	(µg/m³)	Time	(µg/m³)	Time	(µg/m³)	Time	(µg/m³)	Time
Peak period I	305.1	08:00	118.8	18:00	---------		---------	
Peak period II	380.7	07:00	334.9	10:00	294.1	14:00	---------	
Peak period III	365.8	09:00	439.4	14:00	269.8	18:00	243.2	21:00
Non-peak period I	215.1	07:00	97.9	18:00	---------		---------	
Non-peak period	75.0	08:00	55.4	20:00	---------		---------	

The maximum and minimum values of temperature in centigrade, relative humidity in percentage and daily average concentrations of CO_2 in ppm are depicted in Table. From Tables 1 and 2 we can observe that the concentration of $PM_{2.5}$ is high during peak periods II, while the maximum ambient temperature was recorded during the same period. This observation shows as the temperature increases the concentration of $PM_{2.5}$ also increases. A study conducted in Japan by Wang and Ogawa (2015) shows contradicting results, where the production of $PM_{2.5}$ shows a negative correlation with temperature. Similar suggestions about temperature and $PM_{2.5}$ having negative correlation were made by Yang et al. (2017) .

Table 2. Samples, sampling dates, meteorological conditions (T and RH), and daily average

Samples	Sampling Date	Ambient Temperature (°C)		Relative Humidity (%)		Daily average concentration of CO_2 (ppm)
		max	min	max	min	average
Peak period-I	October 11, 2018, Thursday	26.8	17.2	70.1	56.0	436.61
Peak period-II	October 13, 2018, Saturday	29.0	17.1	71.0	47.0	450.79
Peak period-III	November 29, 2018, Thursday	21.0	14.5	72.0	48.0	491.47
Non-peak period I	November 30, 2018, Friday	20.0	13.9	72.0	49.0	448.26
Non-peak period II	December 3, 2018, Monday	17.4	13.7	71.0	55.0	516.54

Burning incense releases a significant amount of PM_1, which has a considerably smaller aerodynamic diameter than $PM_{2.5}$ and might cause more serious health issues because it enters the lungs deeper Kumar et al. (2014). This could perhaps be of interest to study for further research. Hien et al. (2022) also agrees that although PM_1 is of greater importance to studying emissions from incense burning, very limited studies on it have been conducted so far.

A limitation of the study is that an environment unaffected by incense burning could not be included as a reference site for comparison due to the limited availability of instruments. The study focused solely on the Bangalamukhi temple, where incense burning was the primary source of $PM_{2.5}$ emissions. Without a reference site that was not influenced by incense burning, it is difficult to isolate the effect of incense from other confounding factors for elevated $PM_{2.5}$ levels.

Conclusions

The study demonstrated that there are fine particles ($PM_{2.5}$) released from incense burning that can accumulate quickly to hazardous levels in environments. The PM concentrations at Bangalamukhi temple in Patan, Nepal were measured during the peak and non-peak periods to compare $PM_{2.5}$ concentrations . The peak value of $PM_{2.5}$ concentration during the peak period days (peak period I, II, and III) were significantly higher than during the non-peak period days at the sampling site, indicating that t incense burning was responsible for the elevated $PM_{2.5}$ level. During both peak and non-peak periods, the $PM_{2.5}$ level aerosol were significantly above the National Ambient Air Quality Standards as given in the Environment Statistics of Nepal, 2013. Further study is recommended to fully characterize the chemical constituents in the environment affected by incense burning. Additionally, in vitro and in vivo studies are needed to elucidate the adverse health effects of incense burning and the specific mutagenic and genotoxic components.

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Author Contributions: BS and SM conceptualized the study, BS and SH carried out sampling and analysis, SM contributed to the methodology, provided supervision, and reviewed and edited the manuscript. BS and SH wrote the draft manuscript and performed statistical analysis contributed to the investigation, provided resources, and developed the methodology. All authors read and revised the manuscript.

Conflict of Interests: The authors declare no conflict of interest.

Data Availability Statement: The data of this study are available from the corresponding author, upon reasonable request.

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