Assessment of trace metal concentration in the ambient air of the Prayagraj City during Diwali festival—a case study

Namrata Kulshreshtha (ORCID) · **Sachin Kumar** ·
R. C. Vaishya

Abstract   The study evaluated the particulate matter trend and trace element concentrations, during the Diwali week for two consecutive years, November 2018 and October 2019. Diwali celebrations worsen the city's air quality from poor to a severe category of air quality index (AQI). A peak rise in PM_{10} concentration was found on Diwali day, 1.8 times more than a normal day of the same period. The concentration was 5.6-fold more than the permissible limit prescribed by National Ambient Air Quality Standards (NAAQS), India, and 11.26-fold higher than the permissible limit of World Health Organization (WHO). The more firework bursting in the year 2019 results in the rise of PM_{10} concentration by 132% compared with the previous year. Lead (Pb), a carcinogen, was found in higher levels, in Diwali samples of year 2019. The average metal concentration on Diwali day was found in the following order: Pb (396.17) > Cu (70.34) > Mn (66.34) > Cr (29.66) > Ni (4.96) in year 2019 while Ni (195.20) > Pb (149.45) > Mn (64.85) > Cu (13.44) in year 2018. A significant positive correlation between Cr and Pb, Cu and Pb, Cr and Cu, and with PM_{10} have been observed, indicating their emission from a common source and the contribution of firecrackers to particulate pollution. Principal component analysis (PCA) identified the contribution of the bursting of firecrackers and vehicular emissions towards PM_{10} pollution in the year 2019 and vehicular emissions and dust resuspension in the year 2018 over the megacity Prayagraj.

Keywords   Trace metals · Particulate matter (PM_{10}) · Diwali · Firecrackers · Air quality index (AQI)

Highlights
- First study of source apportionment of PM_{10} during Diwali week of Prayagraj city.
- PM_{10} concentration showed peak rise, violating permissible limit of both NAAQS India and WHO.
- Establishes the supportive role of firecracker bursting along with traffic emissions.

N. Kulshreshtha (✉) · R. C. Vaishya
Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad 211004, U.P., India
e-mail: rce1505@mnnit.ac.in

S. Kumar
Birbal Sahni Institute of Palaeosciences, Lucknow, India

Introduction

Diwali, a festival to signify and celebrate the goodness in a human being and burn out the evilness from one's personality. It is celebrated all over India in October or November with lots of fireworks, an integral part of the festival. Fireworks also are related to worldwide festivities like New Year's celebrations, the Las Fallas in Spain, the Lantern Festival in China, Bonfire Night in the UK, Tihar in Nepal, Skyfest in Ireland, Bastille Day in France, etc. (Verma & Deshmukh, 2014). Burning of fireworks produces gaseous pollutants such

as SO_2, NO_2, CO_2, and CO and mainly contributes to particulate pollution in the form of dense smoke cloud along with trace metals (Ravindra et al., 2003; Barman et al., 2008; Mandal & Prakash, 2012; Tiwari et al., 2012; Brahmaiah, 2015; Lin, 2016). Humans' anthropogenic activity creates lots of noise and dense smoke clouds, which intensifies noise and air pollution and degrades the city's local short-term air quality. PM emissions from various types of firecrackers, like snake tablets, garlands of 1000 sounding crackers, pulpuls, sparklers, ground spinners, and flower pots, are very harmful to children, as a child would have inhaled around 18–20 L of this extremely polluted air into the lungs over a period of 3 min (Shah et al., 2019).

Firecrackers are made up of various chemical species such as iron dust powder, sodium oxalate, aluminum, arsenic, sulfur, manganese, potassium perchlorate, strontium nitrate, and barium nitrate, etc. (Ravindra et al., 2003). The oxidants such as nitrate or perchlorate salt are added to make them burn instantly. The colorful display of firecrackers is due to electron excitation of metal ions at high temperatures during combustion. Strontium, barium, and copper metal are utilized to provide red, green, and blue fireworks, respectively (Kulshrestha et al., 2004; Lin, 2016). Some highly toxic pollutants like polychlorinated dioxins and furans were also found during the display of fireworks like "blue lighting rockets" and "Fountains" (Fleischer et al., 1999). Fireworks also generate trace elements, such as As, Cd, Co, Cr, Ni, Pb, and Se, which are carcinogens even in small amounts (ATSDR, 2003; Wang et al., 2006). A significant amount of Mn and Cr have been reported in the scalp hair of manufacturers of fireworks (Sukumar & Subramanian, 1992), leading to neurotoxic impairments (Santos-Burgoa et al., 2001).

Exposure to Pb induces severe disorders, including neurological and hematological effects. Cd, Ni, and Cr (VI) exposed the bronchial tree to toxic and carcinogenic effects. The elevated levels of Cu and Cd induce chronic lung diseases, which leads to respiratory irritancies (Lin, 2016). Smoke from fireworks also causes cough, fever, and dyspnea, leading to acute eosinophilic pneumonia (Hirai et al., 2000). The following studies indicate adverse effects of particulates on the human brain (Maher et al., 2016), stroke (American Heart Association, 2009), reduced fetal growth and delivery of premature babies (Paddock, 2016), lower

birth weight babies (Pedersen et al., 2013), and diabetes in adults and children (Zentrum, 2016). The burning of firecrackers was also associated with extremely high levels of personal exposure to $PM_{2.5}$ levels that are likely to have significant short-term and long-term adverse health effects, especially among children (Shah et al., 2019). All these studies suggest that elevated concentrations of air pollutants and associated trace metals for over a short time, like the Diwali festival, will induce a more prominent and hazardous effect on human health. Perchlorate, an essential component of firecrackers, is also adversely affecting our ecosystem, contaminating groundwater and surface water, which can have an adverse ecological impact and inhibit the iodide uptake of the thyroid gland by PM deposition through precipitation (Lin, 2016). Perchlorate was also found in Ahmedabad, Gujarat, in nearby river bodies during Diwali event (Kumar, 2020). Diwali firecracker bursting activity appears to have played a pivotal role in providing additional S and free metal inputs in the Delhi region (Sawlani et al., 2019). A study also suggested that Diwali leads to a small but statistically significant increase in air pollution (Ghei & Sane, 2018). Thus, the present study focused on determining the city's air quality status/index during Diwali week, including the pre-Diwali, Diwali, and post-Diwali period. The characterization of PM_{10} for trace metals during the festival period for the Prayagraj city was also performed to find out the harmful and elevated amount of trace metals associated with firecrackers. The present study mentions the role of firecrackers in developing air pollution episodes with the presence of harmful trace metals, so that the government could take some mitigation measures for the same.

Methodology

Study area and data acquisition

Prayagraj (25.44° N, 81.85° E) is a city located in the southeastern part of Uttar Pradesh, at Ganga and Yamuna's confluence with a population of 1.117 million. The city has a humid subtropical climate typical to cities in the plains of North India. Diwali is celebrated every year with lighting Diyas and burning firecrackers, followed by the winter season, which exacerbates the city's air pollution. The study is one

(*Map created using QGIS version 3.00)
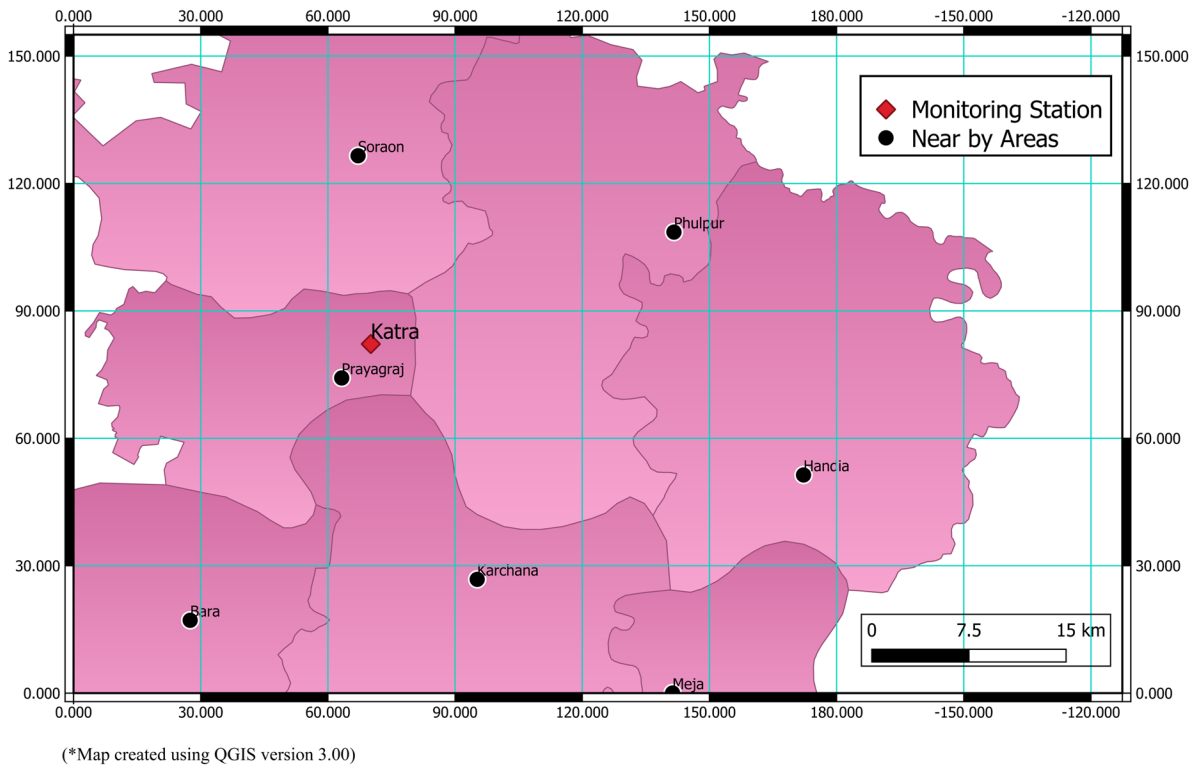
Fig. 1 Location of monitoring station in Prayagraj (Allahabad) city: Square Crossing of Laxmi Talkies, Katra

of its kind for Prayagraj city so that public awareness could be spread about the air quality status and types of hazardous metals to which they are exposed during the Diwali festival.

Data were monitored for pre-Diwali, Diwali, and post-Diwali sampling using high volume sampler APM-460 respirable dust samplers (RDS) (Envirotech, New Delhi). We have monitored the concentration of 8-hourly PM_{10} and TSPM (non-respirable particulate matter) at one of the stations of the city. It lies in the mixed area (commercial and residential) at the road intersection of Laxmi Talkies, Katra (Fig. 1). Ambient

air was drawn through the cyclone and dust particles get collected on $8'' \times 10''$ glass fiber filter paper at a flow rate of 0.8 to 1.3 m^3/min. Table 1 shows the 24-h average of meteorological parameters monitored on the Diwali day (source: www.timeanddate.com/weather/india/prayagraj). Almost very low or calm conditions were observed in the year 2019.

Sample analysis

PM_{10} particles were collected on glass fiber filters on pre-Diwali, Diwali, and post-Diwali days for both the

Table 1 Twenty-four-hour average of meteorological parameters monitored on Diwali Day in Prayagraj city	Year	Date	Air temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Wind speed (m/s)
	2018	7 November	21.0	15.0	29.0	63.0	1.0
	2019	27 October	23.3	20.0	27.0	65.4	0.0

Table 2 Specifications for the analyses with atomic absorption spectrometer (AAS)

Element	Wavelength (nm)	Slit
Chromium	357.87	0.80
Copper	422.67	0.60
Lead	283.13	1.05
Manganese	279.48	0.60
Nickel	232.00	1.88

years from a commercial area of Prayagraj. The concentration of PM_{10} and SPM was monitored and analyzed as per Guidelines for the measurements of Ambient Air Pollutants (Volume I) (CPCB, 2011). All the concentrations were measured in micrograms per cubic meter ($\mu g/m^3$). A total of 18 samples were collected using Respirable Dust Sampler (Model No. APM460NL) on pre-desiccated filters (8×10 inches) for every 8 h. The sampling time was divided into the day, evening, and late-night time (6:00 AM to 2:00 PM, 2:00 PM to 10:00 PM, and 10:00 PM to 6:00 AM). All the collected filters were desiccated for 24 h and then analyzed gravimetrically. The collected filters were acid digested following the Perkin-Elmer methods for analysis of metallic air pollutants with atomic absorption spectrometer (1996). The solution obtained was filtered with syringe filters of 0.45 µm (size–25 mm) and analyzed with Atomic Absorption Spectrometer (*Model: AAnalyst 200 AA Spectrometer*) at the Environmental Laboratory of IFFCO, Phulpur, Prayagraj. The blank or unexposed filter paper was also acid digested using the same procedure. The samples were characterized for five trace metals, viz., chromium (Cr), copper (Cu), lead (Pb),

manganese (Mn), and nickel (Ni), after calibrating the instrument with standard solutions prepared with analytical reagent grade chemicals. All the samples were analyzed for three readings to achieve a low standard deviation. The specifications for the analyses are presented in Table 2 below:

Results and discussion

The high levels of pollutants in atmospheric air become hazardous to living beings due to their synergistic effect. The city is affected by high levels of PM_{10}, violating a 24-h average permissible limit of 100 µg/m³ (NAAQS) during the whole study period. Further, in this study, the monthly variation of pollutants in the Diwali month and after the month of Diwali was observed for determining the long-term effect of firecrackers. Diurnal variations were discussed for the respective days to assess the usage of firecrackers in every 8 h. Later, observations of source apportionment study were examined to determine the potential sources of particulate matter pollution in the city and determine the significant effect of firecrackers on particulate pollution.

Monthly variation

The particulate matter generated from fireworks remains suspended in the air for a week or even up to 1 month after the festival, so variation among the monitored air pollutants was observed during Diwali and post-Diwali months (Fig. 2). Post-Diwali month observed higher values for both PM_{10} and TSPM

Fig. 2 Monthly average of pollutant concentration in Diwali and post-Diwali month at mixed (square crossing of Laxmi talkies) monitoring station
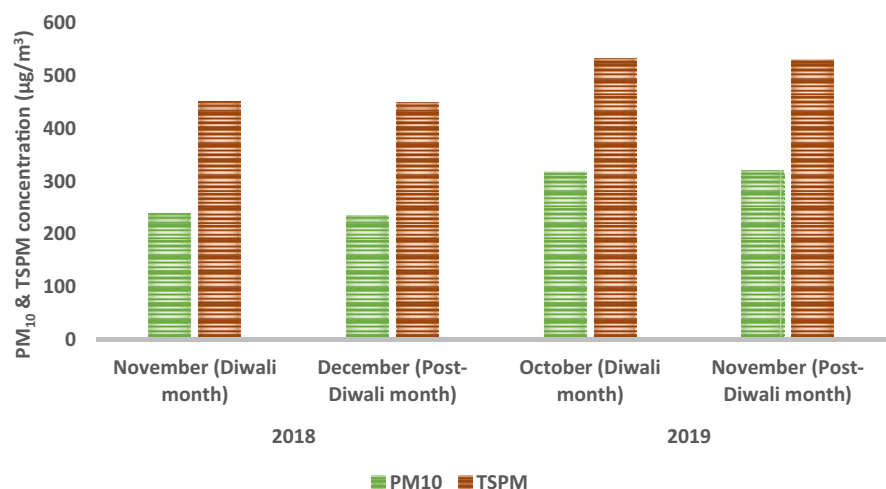
as compared with Diwali month. The trend implies short-term degradation of the city's air quality in both years, although concentrations were more in the year 2019 than in 2018. It was observed that firework emission poses a short-term effect compared with the long-term impact imposed by traffic emissions.

Diurnal variation

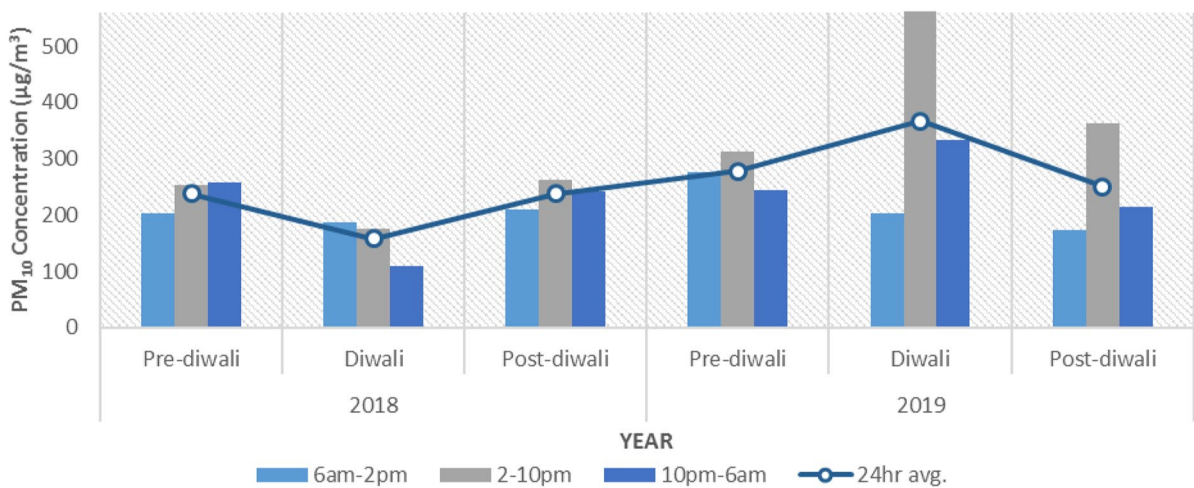### *Respirable particulate matter (RSPM/PM$_{10}$)*

Respirable particulates are a crucial part of the atmosphere. Living beings are exposed to these PMs, which can occur through various routes; inhalation of particles (< 10 μm) is one of the principal ways. The studies revealed a prominent activity of particulate pollution in cardiopulmonary morbidity and mortality in humans (Tian et al., 2014). Around 54.5% of Indians live in regions that do not comply with the Indian NAAQS for PM$_{10}$, and nearly every Indian (99.5% of the population) lives in an area with air pollution levels above the stricter guidelines of the WHO. It was found that an extra 100 μg/m^3 of "TSP" in the air was associated with a drop-in life expectancy of about 3 years (Greenstone et al., 2015). Particulate matters posed a massive troll to human life and the environment, and the display of fireworks during festive days deteriorates the conditions more (Fig. 3).

Although all the monitored days violate the national standard of PM$_{10}$, 60 μg/m^3 annually, and 100 μg/m^3 -24- hourly, Diwali celebrations worsen the city's air quality from *poor to a severe category of AQI*. A peak rise in concentration was found on Diwali day in duration of 2–10 PM in 2019 (563 μg/m^3), 1.8 times more than a normal day of the same period (Table 3). The concentration was 5.6-fold more than the NAAQS India's permissible limit and 11.26-fold higher than the WHO permissible limit. Similar patterns were found in various cities of India, the peak value of 900 and 950 μg/m^3 concentration of PM$_{10}$ and PM$_{2.5}$, respectively, on Diwali day of 2014 in Nagpur (Nigam et al., 2016); 2–3 times increase in PM$_{10}$, and TSP concentration was reported during Diwali festival in Hisar (Ravindra et al., 2003). A 1.3 to 4 times increase in PM$_{10}$ and a 1.6 to 25 times increase in TSP were observed during Diwali at a residential location of Delhi (Mandal & Prakash, 2012). On average, an increase of 32% was found on Diwali day as compared with a pre-Diwali day in 2019.

On the contrary, an opposite pattern was seen in the year 2018, where the 24-h average concentration of PM$_{10}$ and TSP on Diwali day was less than the pre-Diwali and post-Diwali days. This may be due to the initiative taken by the Supreme Court of India to ban the free sale of firecrackers in 2017, and thus lack of easy availability of firecrackers, lowers the impact of Diwali festival, with a decline of 34% was found on Diwali day as compared with a pre-Diwali day in 2018.

Studies have suggested that particulate matter generated from fireworks remain suspended in the atmosphere for a week or more after the festival,

Fig. 3 Temporal variation of ambient air concentration of particulate matter (PM$_{10}$) at mixed station during the study period

Table 3 Diurnal variation in RSPM (PM_{10}) and TSPM concentration ($\mu g/m^3$) in the past 2 years at square crossing of Laxmi Talkies, Katra (mixed station) Prayagraj city

| Pollutant	Year	2018			2019			Standards	
	Time	Pre-Diwali	Diwali	Post-Diwali	Pre-Diwali	Diwali	Post-Diwali	NAAQS (24 h avg)	WHO
PM_{10}	6 AM–2 PM	202	188	209	277	203	174	$100\ \mu g/m^3$	$50\ \mu g/m^3$
	2–10 PM	254	175	264	312	563	363		
	10 PM–6 AM	258	110	242	244	334	215		
	24 h avg. $\pm$ SD	238 ± 30.9	158 ± 41.8	238 ± 27.5	278 ± 34.0	367 ± 182.2	251 ± 99.4		
TSPM	6 AM–2 PM	447	387	390	499	446	413	Not available	Not available
	2–10 PM	504	359	534	462	768	563		
	10 PM–6 AM	485	379	494	483	568	452		
	24 h avg. $\pm$ SD	479 ± 28.9	375 ± 14.4	473 ± 74.3	481 ± 18.6	594 ± 162.6	476 ± 78.0		

degrading air quality with high PM concentrations for a prolonged period (Ravindra et al., 2003; Sarkar et al., 2010; Agrawal et al., 2011). The post-Diwali 24-h average concentration was found high than pre-Diwali and Diwali day concentrations (an increase of 51% compared with Diwali day) in 2018, which implies the effect of festival, vehicular traffic as well as dust resuspension. However, the post-Diwali 24-h average concentration in the year 2019 was less than Diwali day concentrations with a decline of 32%, which may be due to favorable meteorological conditions. The more firework bursting results in the rise of PM_{10} concentration by 132% in the year 2019 as compared with the previous year. As a result, an *AQI of poor to severe* category was observed *on Diwali day* in both years.

Total suspended particulate matter

The total suspended particulate matter (TSPM) concentration also follows a similar pattern as of PM_{10}, as shown in Fig. 4. TSPM comprises particles with an aerodynamic diameter of 0.1 to 100 $\mu g/m^3$, including ultrafine, fine, coarse, and coarser dust particles. These particles make a route into the atmosphere via dust resuspension by vehicles, tear and wear of tires, dust particles coming from the Ganga basin via wind (Ram & Sarin, 2010), etc. These particles also contribute to air pollution as it interrupts and disturbs the visibility, respiratory health of human beings, deteriorates the historical monuments, etc. The rise in concentration on Diwali day occurs from 2 to 10 PM and from 10 PM to 6 AM (768 and 568 $\mu g/m^3$) in 2019, while levels were low in 2018 at the station (Table 3). The highest concentration in 2019 points out the contribution of smoke dust generated from fireworks and also implying the late-night bursting of fireworks in the nearby locality. The post-Diwali 24-h average concentration was found high than pre-Diwali and Diwali day concentrations, an increase of 26% compared with Diwali day in 2018, and a decline of 20% in 2019, like PM_{10} variation.

The PM_{10} and TSPM concentrations were alarmingly high in 2018 on regular days compared with Diwali, which could be attributed to ongoing construction activities for *Maha-Kumbh mela 2019*, traffic movement, and dust resuspension, and unpaved road dust. Higher concentration in TSPM was also found in other countries due to fireworks on various occasions. Vadodara has recorded a rise in PM_{10}, SO_2, and NO_2 levels of 35, 23, and 3 times, respectively, as compared with the normal day before Diwali (Brahmaiah, 2015). A study based on Lucknow also depicted higher concentration on Diwali day of the year 2005, where 24-h average concentration of PM_{10}, SO_2, and NO_x was found to be 753.3, 139.1, and 107.3 $\mu g/m^3$, respectively. During Diwali night, an
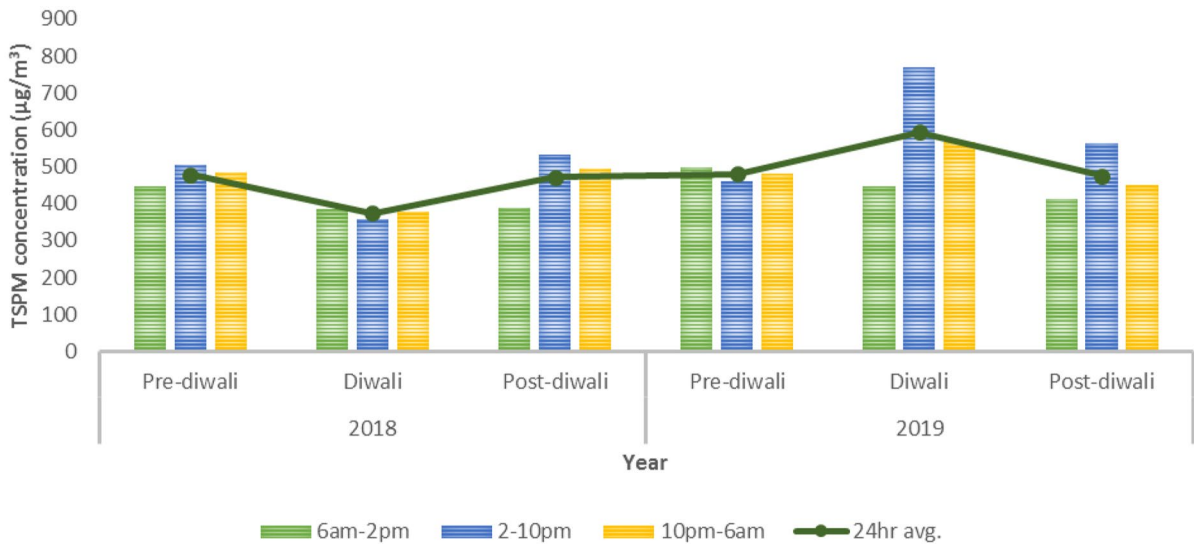
Fig. 4 Temporal variation of ambient air concentration of total suspended particulate matter (TSPM) at mixed station during the study period

increase of PM_{10} (446.8%), SO_2 (289.3%), and NO_x (121.3%) indicated that fireworks were the source of these pollutants (Barman et al., 2008). The extremely high PM concentrations may also be attributed to some meteorological factors such as low night temperature, less mixing height, low wind speed, or stable weather conditions (Thakur et al., 2010).

PM_{10} characterization

Filter papers of a normal day, Diwali, and post-Diwali day were apportioned for PM_{10} characterization with AAS. Variation in metal concentrations was observed for five trace metals in micrograms per cubic meter. During the whole study period, the average metal concentrations at mixed monitoring station were found in the following order: Pb > Mn > Ni > Cu > Cr (Fig. 5). Figure 5 shows the graphical presentation of trace metals monitored in the study period. Copper (Cu) was found in the emissions generated from diesel engines (Zhong et al., 2014). Other trace metals were mainly found from fossil fuel, wood combustion, vehicular traffic contributing Ni, Pb, Zn, Cu, or Cr (Kulshreshtha et al., 2004). With these contributing factors, Mg, Fe, Cu, Ba, Zn, Mn, Cr, Pb, and Al are also credited to the bursting of firecrackers, as they are used as fuels, oxidizers, and coloring agents in firework, making them more brightening and

colorful (Sukumar & Subramanian, 1992; Verma & Deshmukh, 2014; Zhang et al., 2019).

Copper (Cu). The concentration was ranged between 9.12 and 156.39 $\mu g/m^3$. Higher values were observed on Diwali day of the year 2019 as compared with the year 2018. The highest concentration was found on Diwali day (2 to 10 PM—156.39 $\mu g/m^3$), 10.4-fold more than normal day indicating the effect of the bursting of firecrackers. Diwali night observed 3.13-fold more concentration than regular night but 74% less than previous time due to fewer crackers bursting after 10 PM. Post-Diwali concentration was found more (1.16-fold) compared with normal night, indicating the prominent effect of regular vehicular emissions and the short-term effect of firecrackers. Diwali day observed lower concentrations than pre- and post-Diwali days in the year 2018 implying less burning of firecrackers. Diwali day marked 15.6% less and post-Diwali was 227% and 8.4% less than normal day and Diwali day, from 2 to 10 PM, respectively, although post-Diwali was 49.5% and 105% more than normal night and Diwali night, respectively, owing to vehicular traffic emissions.

Chromium (Cr). The electroplating industries, vehicular emission, and fireworks are considered as the sources of the metal. The electroplating industry was not present in a nearby area, although some steelwork occurs in the commercial area. Concentration ranged
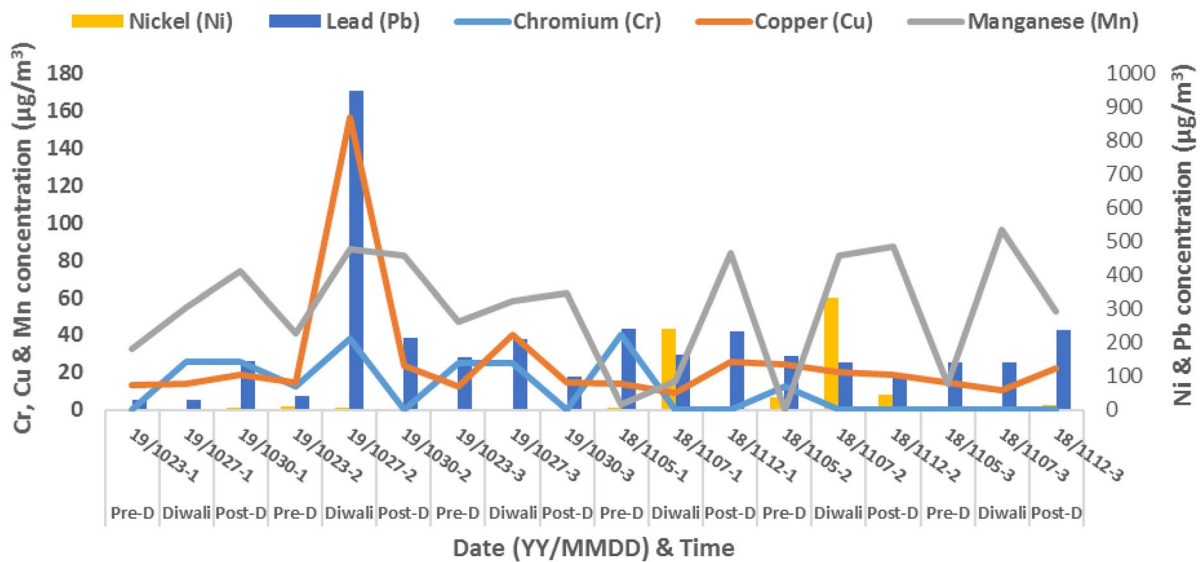
Fig. 5 Metal concentration in μg/m³ during the study period at a mixed station. *First date represents normal/pre-Diwali day, second Diwali day, third post-Diwali day with a diurnal variation where 1: 6 AM to 2 PM, 2: 2 to 10 PM, and 3: 10 PM to 6 AM

between 0.0 to 40.16 μg/m³. Higher values were observed on Diwali day of the year 2019 as compared with the year 2018, where concentration was below the detection limit due to less traffic on the day (Sarkar et al., 2010). During 2 to 10 PM duration, Diwali observed 3.06-fold more as compared with normal day but remain not detected on post-Diwali day (2 PM to 6 AM). Diwali night observed 1.15% less concentration than normal night and 35% less than the previous time. Concentration was found only in normal day samples while the rest of the samples remain below the detection limit in the year 2018. The main sources contributing to Cr in the ambient air of the commercial area were mainly traffic emissions and fireworks in the year 2019.

Manganese (Mn). The metal concentration was ranged between 0.0 and 96.54 μg/m³. Higher values were observed on Diwali and post-Diwali days of both years as compared with a normal day. The variation among concentrations was as follows: Diwali day, 1.7-fold more than a normal day, attributed to the previous night burning of firecrackers from 6 AM to 2 PM. During 2 to 10 PM duration, the highest concentration was found on Diwali day, which was 2.1-fold more as compared with normal day and 3.9% less on post-Diwali day as compared with Diwali, indicating the effect of the bursting of firecrackers, as concentration was 2.02-fold more than a normal day. Diwali

night observed 1.23-fold more levels than normal night but 31.6% less than the previous time. Post-Diwali concentration was found more (1.32-fold) as compared with normal night and 1.07-fold more than Diwali night indicating the short-term air quality change due to the Diwali festival. Concentration on a normal day of the year 2018 was found very low, unlike the year 2019. The variation among concentrations was as follows: Diwali day, 5.5-fold more, attributed to previous night burning of firecrackers from 6 AM to 2 PM duration. Diwali day observed 82.67 μg/m³ (metal on a normal day was not detected), and post-Diwali was 5.6% more than Diwali day from 2 to 10 PM. Diwali night observed 6.8-fold more, and post-Diwali was 3.7-fold more and 45% less than normal night and Diwali night, respectively.

Nickel (Ni). The metal was mainly found in vehicular traffic emissions. Concentration was ranged between 0.0 and 332.4 μg/m³. We have found no significant difference on Diwali day of the year 2019. Concentration was 1.52-fold more on post-Diwali day as compared with Diwali day. During the 2 to 10 PM duration, the highest level was found on a normal day. Diwali day experienced 18.4% less metal concentration than normal day and remained undetected on post-Diwali day. All 3 days observed almost similar metal concentrations in night samples. Concentration on all days of the year 2018 was found high,

Table 4 Correlation coefficient among metals and PM_{10} at mixed station of Prayagraj city

Pearson Correlation	Cr	Cu	Mn	Ni	Pb	PM_{10}
Cr	1.000	0.468*	− 0.161	− 0.296	0.464	0.356
Cu		1.000	0.294	− 0.116	0.953**	0.832**
Mn			1.000	− 0.001	0.241	0.110
Ni				1.000	− 0.079	− 0.276
Pb					1.000	0.740**
PM_{10}						1.000

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

unlike the year 2019. The variation among concentrations was as follows: Diwali morning, 31-fold more, attributed to the previous night's burning of firecrackers. Diwali day observed 9.31-fold more concentration than a normal day, and post-Diwali was 7.4-fold less than Diwali day from 2 to 10 PM. Diwali night observed more concentration and post-Diwali was 1.14-fold more than Diwali night. All the patterns indicate the primary source as traffic to nickel concentration. Similar observations were found where the concentrations of Zn, Ni, V, and Cr were considered as vehicular (fuel combustion, brake, and tire abrasion) and industrial tracers and found less on Diwali (Sarkar et al., 2010).

Lead (Pb). The primary sources of the metal are fossil fuel or wood combustion and vehicular traffic emissions and also used in firework to achieve a steady and reproducible burning rate (Kulshrestha et al., 2004; Zhang et al., 2019). Concentration was ranged between 28.74 and 949.72 μg/m³. Higher values were observed on Diwali day of the year 2019 as compared with the year 2018, wherein normal and post-Diwali day observed high concentration. The highest concentration was found on Diwali day (949.72 μg/m³), 22.43-fold more, and 5.7-fold more on post-Diwali day than a normal day from 2 to 10 PM duration. Diwali night observed 1.35-fold more concentration than normal night but 77.9% less than previous time owing to fewer firecrackers bursting during late night. Diwali day observed lower concentrations as compared with pre-and post-Diwali days in the year 2018 implying less burning of firecrackers. The temporal variation among concentrations was as follows: Diwali day observed 11.2% less and post-Diwali was 36.4% and 28.3% less than a normal and Diwali day, respectively, from 2 to 10 PM, implying

the prominent effect of vehicular emissions in comparison with firecrackers.

Statistical analysis

Intercorrelations of the measured metal concentration with monitored PM_{10} were calculated for the study period, and the correlation matrix is presented in Table 4 for a mixed station. Cr was found significant and positively correlated with Cu and Pb, and Cu was strongly correlated with Pb (significant at $p < 0.01$). A weak correlation between Cu and Mn and Mn and Pb was found. These metals are used to create colorful and smoky effects of fireworks (Sukumar & Subramanian, 1992; Verma & Deshmukh, 2014). A strong positive correlation was found between PM_{10} with Cu and Pb (highly significant at $p < 0.01$) and a moderate correlation with Cr while the weak correlation with other metals of consideration. The correlation study implies the contribution of fireworks in the presence of a higher concentration of PM_{10} and harmful trace metals. The contribution of Ni can be attributed to vehicular emissions.

Table 5 Rotated component matrix of factors extracted with PCA rotated with Varimax with Kaiser normalization

	Component		
	1	2	3
Cr	0.650		
Cu	0.955		
Mn		0.935	
Ni			0.982
Pb	0.959		

Table 6 Factors extracted with principal component analysis (PCA)

Component	Initial Eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.388	47.759	47.759	2.388	47.759	47.759	2.289	45.778	45.778
2	1.238	24.766	72.525	1.238	24.766	72.525	1.144	22.882	68.660
3	0.909	18.177	90.702	0.909	18.177	90.702	1.102	22.042	90.702
4	0.421	8.411	99.113						
5	0.044	0.887	100.000						

Source identification of PM_{10} with principal component analysis

The exploratory factor analysis was performed to extract the factors for the present study. Kaiser-Meyer-Olkin's test has shown average sampling adequacy (0.575), and Bartlett's test of sphericity has shown significance at $p < 0.05$. Based on Varimax rotation with Kaiser normalization, three factors have been extracted. Each factor is constituted of those variables that have factor loadings greater than 0.5 (Table 5). Five variables, viz, Cr, Cu, Mn, Ni, and Pb, were clubbed/reduced into three factors and used in the study. These three extracted factors explained 90.702% of the variability (Table 6).

Factor 1 explained 45.778% of the variance with higher loadings of Cr, Cu, and Pb attributed to firecrackers. Factor 2 explained 22.882% of the variance with higher loadings of Mn, indicating the contribution from the burning of firecrackers (Table 6). Factor 3 explained 22.042% of the variance with higher loadings of Ni only, a trace element generated from oil and coal combustion (Sukumar & Subramanian, 1992; Kulshrestha et al., 2004; Ram & Sarin, 2010; Saxena et al., 2014; Zhong et al., 2014). Cr was found in samples of Diwali 2019 but BDL during Diwali and Post-Diwali of 2018, which implies the role of combustion processes.

Conclusion

A peak rise in PM_{10} concentration was observed, violating permissible limit of both NAAQS India and WHO. Post-Diwali concentration was found 51% more (year 2018) and 32% less (year 2019) compared with a festive day resulting in short-term degradation of the air quality of the city. The high rise in TSPM concentration on Diwali day was also observed in 2019 compared with the year 2018. PM_{10} concentration shows a 132% rise in the year 2019 compared with 2018, which implies more firework usage in the former year. Still, the concentrations were found alarmingly high on normal days of the year 2018 compared with Diwali due to ongoing construction activities for *Maha-Kumbh mela 2019*, traffic movements, dust resuspension, and unpaved road dust.

The average metal concentration in characterized air samples of Diwali day was found in the following order (mean ± SD): Pb (396.17 ± 398.35) > Cu (70.34 ± 61.78) > Mn (66.34 ± 13.73) > Cr (29.66 ± 6.22) > Ni (4.96 ± 1.79) in year 2019 and Ni (195.20 ± 135.29) > Pb (149.45 ± 11.02) > Mn (64.85 ± 35.46) > Cu (13.44 ± 4.96) > Cr (ND) in year 2018. A strong positive and significant correlation between PM_{10} and Cu and Pb indicates firecrackers' contribution to ambient air pollution (significant at $p < 0.01$). Cr was detected only during the festive day. The late-night bursting of firecrackers was not found at the monitoring station. Three factors explained the 90% of data variance with higher loadings of Cr, Cu, Pb, and Mn attributed to the bursting of firecrackers. The study establishes the supportive role of firecracker bursting along with traffic emissions in Prayagraj city. Thus, we need to find alternatives or choose a less polluting firecracker, especially for kids, or we need to alter the way of bursting them. We should follow the mega-events of New Year's celebrations in London, Tokyo, or Sydney, where bursting occurs at a much higher height to prevent local environment pollution. Thus, bursting at the surface level could be controlled to prevent the development of nasty air-pollution episodes, and the selection of firecrackers should be monitored and regulated by the governments by prescribing age or on the basis of related health issues.

Declarations

Conflict of interest   The authors declare that they have no conflict of interest.

References

Agrawal, A., Upadhyay, V. K., & Sachdeva, K. (2011). Study of aerosol behavior on the basis of morphological characteristics during festival events in India. *Atmospheric Environment, 45*(21), 3640–3644.

American Heart Association. (2009). "Traffic Exposure may Trigger Heart Attacks." Science Daily. 14 March 2009. www.sciencedaily.com/releases/2009/03/090313171310.htm

ATSDR (Agency for Toxic Substances and Disease registry). (2003). Toxicological profile information sheet. http://www.Atsdr.cdc.gov/toxiprofiles

Barman, S. C., Singh, R., & Negi, M. P. S. (2008). Ambient air quality of Lucknow City (India) during use of fireworks on Diwali Festival. *Environmental Monitoring and Assessment, 137,* 495–504. https://doi.org/10.1007/s10661-007-9784-1

Brahmaiah, U. P. N. D. (2015). Impact of fireworks on ambient air quality: A case study. *International Journal of Environmental Science and Technology, 12,* 1379–1386. https://doi.org/10.1007/s13762-014-0518-y

CPCB. (2011). http://indiaenvironmentportal.org.in/files/NAAQSManualVolumeI-1.pdf

Fleischer, O., Wichmann, H., & Lorenz, W. (1999). Release of polychlorinated dibenzo-p-dioxins and dibenzofurans by setting off fireworks. *Chemosphere, 39,* 925–932.

Ghei, D., & Sane, R. (2018). Estimates of air pollution in Delhi from the burning of firecrackers during the festival of Diwali. *PLoS ONE, 13*(8), e0200371. https://doi.org/10.1371/journal.pone.0200371

Greenstone, M., Nilekani, J., Pande, R., Ryan, N., Sudarshan, A., & Sugathan, A. (2015). Lower pollution, longer lives: Life expectancy gains if India reduced particulate matter to air-quality standards. *Economic and Political Weekly, 8,* 40–46.

Hirai, K., Yamazaki, Y., & Okada, K. (2000). Acute eosinophilic pneumonia associated with smoke from fireworks. *Internal Medicine (Japan), 39*(5), 1999–2001.

Kulshrestha, U. C., Rao, T. N., Azhaguvel, S., & Kulshrestha, M. J. (2004). Emissions and accumulation of metals in the atmosphere due to crackers and sparkles during Diwali festival in India. *Atmospheric Environment, 38,* 4421–4425.

Kumar, M. (2020). Runoff from firework manufacturing as major perchlorate source in the surface waters around Diwali in Ahmedabad. *India. Journal of Environmental Management, 273,* 111091.

Lin, C.-C. (2016). A review of the impact of fireworks on particulate matter in ambient air. *Journal of the Air & Waste Management Association, 66*(12), 1171–1182. https://doi.org/10.1080/10962247.2016.12192802016.1219280

Maher, B. A., Ahmed, I. A. M., Karloukovski, V., Maclaren, D. A., & Foulds, P. G. (2016). Magnetite pollution nanoparticles in the human brain. *PNAS Early Edition*, 3–7. https://doi.org/10.1073/pnas.1605941113

Mandal, P., & Prakash, M. (2012). Impact of Diwali celebrations on urban air and noise quality in Delhi City, India. *Environmental Monitoring and Assessment,* 209–215. https://doi.org/10.1007/s10661-011-1960-7

Nigam, S., Kumar, N., Mandal, N. K., Padma, B., & Rao, S. (2016). Real time ambient air quality status during Diwali Festival in Central India. *Journal of Geoscience and Environment Protection, 4,* 162–172.

Paddock, C. (2016). "Air pollution tied to premature birth." *Medical News Today*, Retrieved from http://www.medicalnewstoday.com/articles/305638.php

Pedersen, M., et al. (2013). Ambient air pollution and low birthweight: A European cohort study (ESCAPE). *Lancet Respiratory Medicine, 1,* 695–704.

Ram, K., & Sarin, M. M. Ã. (2010). Spatio-temporal variability in atmospheric abundances of EC, OC and WSOC over Northern India. *Journal of Aerosol Science, 41*(1), 88–98. https://doi.org/10.1016/j.jaerosci.2009.11.004

Ravindra, K., Mor, S., & Kaushik, C. P. (2003). Short-term variation in air quality associated with firework events : A case study. *Journal of Environmental Monitoring, 5,* 260–264. https://doi.org/10.1039/b211943a

Santos-Burgoa, C., Rios, C., Nercadi, L. A., Arecguga-Serrano, R., Cano-Vall, F., Eden-Wynter, R. A., et al. (2001). Exposure to manganese; health effects on the general population, a pilot study in central Mexico. *Environ Res. Sect A, 85,* 90–104.

Sarkar, S., Khillare, P. S., Jyethi, D. S., Hasan, A., & Parween, M. (2010). Chemical speciation of respirable suspended particulate matter during a major firework festival in India. *Journal of Hazardous Materials, 184*(1–3), 321–330. https://doi.org/10.1016/j.jhazmat.2010.08.039

Sawlani, R., Agnihotri, R., Sharma, C., Patra, P. K., Dimri, A. P., Ram, K., & Verma, R. L. (2019) The severe Delhi SMOG of 2016: A case of delayed crop residue burning, coincident firecracker emissions, and atypical meteorology. *Atmospheric Pollution Research 10*(3):868–879

Saxena, M., Sharma, S. K., Mandal, T. K., Singh, S., & Saud, T. (2014). Source apportionment of particulates by receptor models over Bay of Bengal during ICARB campaign. *Atmospheric Pollution Research, 5,* 729–740.

Shah R, Limaye S, Ujagare D, Madas S, Salvi S. (2019). Personal exposures to particulate matter <2.5 μm in mass median aerodynamic diameter (PM2.5) pollution during

the burning of six most commonly used firecrackers in India. *Lung India 36,* 24–9.

Sukumar, A., & Subramanian, R. (1992). Trace elements in scalp hair of manufacturers of fireworks from Sivakasi, Tamil Nadu. *Science of the Total Environment, 114,* 161–168.

Thakur, B., Chakraborty, S., Debsarkar, A., Chakrabarty, S., & Srivastava, R. C. (2010). Air pollution from fireworks during festival of lights (Deepawali) in Howrah. *India - a case study. Atmosfera, 23*(4), 347–365.

Tian, G., Qiao, Z., & Xu, X. (2014). Characteristics of particulate matter (PM10) and its relationship with meteorological factors during 2001–2012 in Beijing. *Environmental Pollution, 192,* 266–274. https://doi.org/10.1016/j.envpol.2014.04.036

Tiwari, S., Chate, D. M., Srivastava, M. K., Safai, P. D., Srivastava, A. K., Bisht, D. S., & Padmanabhamurty, B. (2012). Statistical evaluation of PM10 and distribution of PM1, PM2.5, and PM10 in ambient air due to extreme fireworks episodes (Deepawali festivals) in megacity Delhi. *Natural Hazards, 61,* 521–531. https://doi.org/10.1007/s11069-011-9931-4

Verma, C., & Deshmukh, D. K. (2014). The ambient air and noise quality in India during Diwali festival: A review. *Recent Research in Science and Technology, 6*(2), 203–210.

Wang, X., Bi, X., Sheng, G., & Fu, J. (2006). Hospital indoor PM10/PM2.5 and associated trace elements in Huangzhou. *China. Science of the Total Environment, 366,* 124–135.

Zentrum, H. (2016). Air pollution a risk factor for diabetes, say researchers. ScienceDaily, 8 September 2016. http://www.sciencedaily.com/releases/2016/09/160908084041.htm

Zhang, J., Huang, X., Chen, Y., Luo, B., Luo, J., Zhang, W., et al. (2019). Characterization of lead-containing atmospheric particles in a typical basin city of China: Seasonal variations, potential source areas, and responses to fireworks. *Science of the Total Environment, 661,* 354–363. https://doi.org/10.1016/j.scitotenv.2019.01.079

Zhong, J. M., Latif, T., Mohamad, N., Wahid, N. B. A., Dominick, D., & Juahir, H. (2014). Source apportionment of particulate matter (PM_{10}) and indoor dust in a university building. *Environmental Forensics, 15,* 8–16.