Safety and Health at Work 10 (2019) 237–244

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Exposure to Atmospheric Particulates and Associated Respirable Deposition Dose to Street Vendors at the Residential and Commercial Sites in Dehradun City

Vignesh Prabhu [1], Sunil K. Gupta [2], Sandeep Madhwal [1], Vijay Shridhar [1,*]

[1] Department of Environmental Science and Natural Resources, Environmental Pollution Assessment Laboratory, School of Environment and Natural Resources, Doon University, Dehradun, India
[2] Department of Environmental Science and Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand, India

ARTICLE INFO

Article history:
Received 6 June 2018
Received in revised form
12 November 2018
Accepted 15 January 2019
Available online 19 January 2019

Keywords:
Alveolar
Deposition dose
Particulate matter
Street vendors

ABSTRACT

Background: Street vendors spend relatively more time near roadways and are vulnerable to air pollution related health disorders. However, there is limited information on the quality of the air they breathe. The objectives of this present study were to calculate the mass concentration of atmospheric particulate matter (PM) in eight size fractions ($PM_{0.4–0.7}$, $PM_{0.7–1.1}$, $PM_{1.1–2.1}$, $PM_{2.1–3.3}$, $PM_{3.3–4.7}$, $PM_{4.7–5.8}$, $PM_{5.8–9.0}$, and $PM_{9.0–0\mu m}$) at commercial (CML) and residential site (RSL) in Dehradun city from November 2015 to May 2016. To estimate the corresponding respiratory deposition dose (RDDs) in alveolar (AL), tracheobronchial (TB), and head airway (HD) region on street vendors working at CML and RSL. To find the association of atmospheric PM with RDDs and the incidence of respiratory related disorders among street vendors.

Methods: Andersen cascade impactor was employed for calculating the PM mass concentration. Questionnaire based health survey among street vendors were carried out through personal interview.

Results: A significant difference ($p < 0.05$; t-test) between the mean $PM_{0.4\text{-}10\mu m}$ mass concentration at CML and RSL was observed with (mean ± SD) 84.05 ± 14.5 and 77.23 ± 11.7 $\mu g\ m^{-3}$, respectively. RDDs in AL, TB and HD region at CML was observed to be 9.9, 7.8, and 7.3% higher than at RSL, respectively. Health survey revealed 1.62, 0.96, 0.04, and 0.57 times higher incidence of cold, cough, breathlessness, and chest pain, respectively with street vendors at CML compared to RSL.

Conclusion: The site characteristics plays a major role in the respiratory health status of street vendors at Dehradun.

© 2019 Occupational Safety and Health Research Institute, Published by Elsevier Korea LLC. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Air pollution is known to cause adverse effects on the human health, mainly on the functioning of respiratory system. Susceptibility toward air pollution differs with age, socioeconomic status, exposure duration, surrounding environment, and preexisting health conditions. Atmospheric particles are classified as one of the criteria pollutants [1], as they have the potential to adversely affect human health [2], visibility [3], and biogeochemical cycling in the ecosystems [4].

In most Indian cities, the chief source of atmospheric particles is attributed to vehicular emission [5]. Owing to vehicular emission, the street vendors who are often situated along the major roads, to maximize the number of customers, are at the risk of health deterioration [6]. In India, the Street Vendors Act (protection of livelihood and regulation of street vendors) was enacted in 2014. The act has defined the street vendor 'as a person, who is engaged in vending of goods to the general public, along street lanes or the footpath, from a temporary build-up structure'. However, the act does not cover any subject related to their health perspectives. At Bangkok, Noomnual and Shendell [7], conducted a health based questionnaire survey among street vendors and attributed the reason for adverse respiratory disorders to vehicular emissions and suggested that wearing an N-95 nose mask can prevent health deterioration. Jones et al [8] compared lung function parameters and respiratory symptoms between roadside vendors directly

* Corresponding author. Environmental Pollution Assessment Laboratory, School of Environment and Natural Resources, Doon University, Dehradun 248001, India
E-mail address: vs@doonuniversity.ac.in (V. Shridhar).

2093-7911/$ – see front matter © 2019 Occupational Safety and Health Research Institute, Published by Elsevier Korea LLC. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
https://doi.org/10.1016/j.shaw.2019.01.005

exposed to traffic fumes and vendors working in protected air-conditioned shops along the same road. However, in all these studies, there is no comprehensive information on the atmospheric processes such as particle chemistry and dynamics. The authors' of this study feel that it is imperative to investigate the atmospheric conditions simultaneously while performing epidemiological studies linked with outdoor air pollution. Through this approach, a holistic understanding of the cause-and-effect relationship between air pollution and health disorders can be established.

Most of the research studies involved in associating adverse health effects on humans with the atmospheric particles are restricted only to the size of atmospheric PM_1 (particulate matter) (submicron particles having aerodynamic diameter $\leq$ 1 μm) [9] and $PM_{2.5}$ (fine particles having aerodynamic diameter $\leq$ 2.5 μm) [10]. However, information on other size fractions of atmospheric PM is scarce. Therefore, in the present study, an eight-stage cascade impactor [$PM_{0.4\text{-}0.7}$ (stage-0), $PM_{0.7\text{-}1.1}$ (stage-1), $PM_{1.1\text{-}2.1}$ (stage-2), $PM_{2.1\text{-}3.3}$ (stage-3), $PM_{3.3\text{-}4.7}$ (stage-4), $PM_{4.7\text{-}5.8}$ (stage-5), $PM_{5.8\text{-}9.0}$ (stage-6), and $PM_{9.0\text{-}10.0\mu m}$ (stage-7)] was used for monitoring atmospheric PM. The cascade impactor is designed as a substitute for human respiratory tract, to collect and separate particles as per its aerodynamic size and property (Fig. S1), thereby, predicting the extent of particle penetration and the site of particle deposition in the respiratory system.

There is a reasonable number of epidemiological studies that have claimed association between atmospheric PM and respiratory health symptoms [11], and most of the studies have measured only total deposition. However, regional deposition within the respiratory system is important for assessing the potential hazards of inhaled particles [12]. Respirable deposition dose (RDD) was estimated to find the regional deposition of atmospheric PM on the workers involved in demolition of buildings [13], outdoor exercisers in Dhanbad, India [14], and elderly population in Brazil [15]. RDD are the deposition fraction estimated based on the mass of atmospheric PM, and it has strong correlation with the respiratory health symptoms [16].

As per authors' knowledge, there is no study reported on the size-segregated PM mass concentration and the associated respiratory health risks on street vendors. For this reason, the present study was framed to investigate the exposure of atmospheric PM and associated RDD with regard to the street vendors at residential and commercial site in Dehradun city. According to the World Health Organization, Dehradun city was placed at 31st rank in the list of most polluted cities in the world [17]. Therefore, the objectives of the present study were to calculate the mass concentration of PM in different size fractions, to estimate the RDD for male street vendors working at a commercial and residential site of Dehradun city, and to find the association of atmospheric PM with RDD and the incidence of respiratory-related disorders among street vendors.

2. Materials and methods

2.1. Description of the study site

Atmospheric PM measurement was carried out at Dehradun city 29°58′-31°2′ N latitude and 77°34′-78°18′ E longitude, altitude of 640 meter above mean sea level, with a total area of 300 km^2. It is geographically located in the Doon valley, situated between the middle and Shiwalik Himalayas. Dehradun district has a population density of 549 person km^{-2}, and over the period from 2001 to 2011, the population has increased by 32%. In 2018, the two-wheeler, three-wheeler, and four-wheeler count was reported to be 6,02,939; 7,674; and 2,14,688, respectively. In the present study, a commercial area (Paltan Baazar, commercial location (CML)) and a residential area (Nehru colony, residential location (RSL)) were considered for atmospheric PM measurement. Fig. 1, Fig. S2 shows the sampling locations, variation of atmospheric PM, and main road network at Dehradun city. CML is characterized by several shopping complexes and government buildings. RSL is characterized by narrow residential streets and numerous traffic intersections. The air quality at CML is mainly influenced by vehicular exhaust emission, roadside dust resuspension, commercial activities, and open burning of paper and solid waste, whereas the air quality at RSL is influenced by domestic activities, vehicular emission, and open burning of dried leaves. Detailed information about the sampling sites is summarized in Table 1. Moreover, Dehradun city is located approximately 80 km from Indo–Gangetic Plain (IGP). IGP is considered to be one of hotspots of air pollution [18].

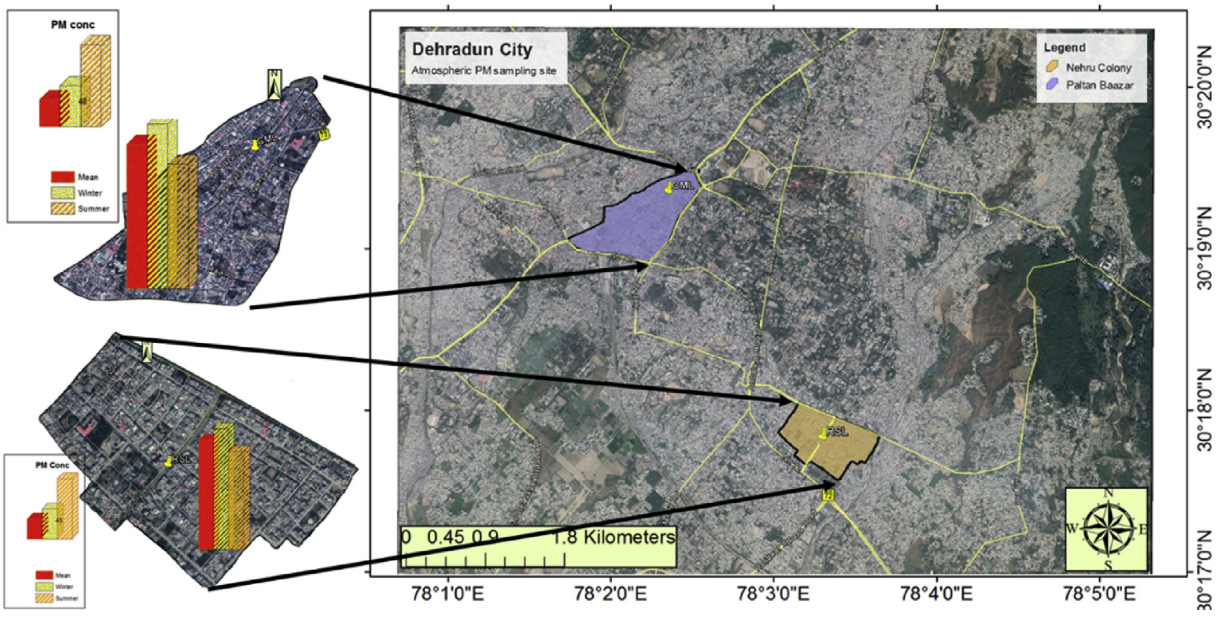

Fig. 1. A map showing the sampling locations, variation of atmospheric PM, and main road network at Dehradun city.

Table 1
24-hour average vehicular count during weekday and weekend with respect to the sampling site and the detailed information of each site characteristics

Site	Weekday				Weekend				Number of shops	Area (km^2)	Population	Road gradient	Building construction activities	Industrial activities	Road dust resuspension
	2-w	3-w	4-w	LCV	2-w	3-w	4-w	LCV							
CML	75485	3500	24015	477	65845	4154	19958	557	~4000	0.61	15525	Flat	Medium	No	High
RSL	21514	422	1845	18	16508	251	1567	11	~350	0.37	14047	Flat	low	No	Low

2-w, two-wheelers; 3-w, three-wheelers; 4-w, four-wheelers; LCV, light commercial vehicle.

2.2. Details of atmospheric PM sampling

Eight-stage nonviable Andersen cascade impactor (ACI) (Tisch Environmental, Inc, OH, U.S.A) was used for measuring the concentration of PM in 8 different size fractions within the size range 0.4–10 μm. PM sampling was conducted during the winter season (November and December of 2015, January and February of 2016) and summer season (March, April, and May of 2016) at CML and RSL. At each site, 20 samples per season, in total 80 samples (40 in CML and 40 in RSL), were collected. The ACI comprises 8 stages; therefore, in aggregate, 80 × 8 stages = 640 individual PM mass concentration samples were collected during the study period. Before sampling, the 81 mm glass fiber filter papers were placed in a vacuum desiccator for 48 hour to eliminate the effect of humidity and weighed using an electronic balance (model No: XS105DU; Mettler Toledo, USA) for presampling weight. Conditioned and weighed filter papers were transferred to the sampler and carried to the sampling location using a sealed box. After sampling, the sampler was taken to the laboratory and the particulate loaded filter papers were transferred to the vacuum desiccator using forceps. After 48 hour of desiccation, the filter papers were weighed for postsampling weight. For accurate collection of PM mass, handling and conditioning of filter papers were as per the established protocol [19,20]. Similarly, blank filter papers (n = 32; 16 from each site) were installed in ACI and brought to the respective sampling location, but no air was pumped. The filter mass obtained was corrected for field blank values. The ACI sampler is designed to work at a flow rate of 28.3 lit min^{-1}, and to make sure that there is no fluctuation in the flow rate, the sampler was checked after every sampling with a dry gas flow meter provided with the instrument. PM sampling was carried out for eight hours (10:00 to 18:00 (HH:MM) Indian Standard Time, IST). Sampling time was scheduled as per the working hour of the street vendors. Sampling time was determined through an initial survey, where it was found that the street vendors travel from home in the early morning and reach the work place before heavy traffic, setup their temporary static structure or mobile stall around 10:00, HH:MM, and leave around sunset (18:00, HH:MM). The street vendors in the city mainly depend on the daylight for selling goods. As they prefer standing during working hour, the sampler was placed at 1.5 meter above ground level (AGL) to represent breathing height [21]. Temperature (temp, °C), relative humidity (RH, %) and wind speed (WS, ms^{-1}) were measured using a portable instrument at CML and RSL, whereas wind direction (WD) and boundary layer height (BLH, meter) were obtained from an online source for the Dehradun city. Detailed information of acquisition, measurement, and result of meteorological parameters are mentioned in the supplementary text.

2.3. Street vendors' health data collection

Prior approval from the Departmental Research Ethics Committee of the School of Environment and Natural Resource, Doon University, Dehradun (certificate no: 03/2015/DREC/SENR, approval date: 01/OCT/2015) was obtained before administering the questionnaires. Street vendors were screened through four initial questions: 'Are you selling goods around the same location for the past 12 months?'; 'are you starting your work from 10:00 (HH:MM) and closing at 18:00 (HH:MM)?'; 'no known diagnosed respiratory diseases (i.e. allergies, asthma, chronic bronchitis, or tuberculosis) for the past 5 years'; 'do you involve in light activities during working hour?'. If the reply for all these pilot questions was 'yes', then he was considered for the survey. In the present study, light activity of street vendor means 'interacting with customers, arranging the goods in order, and standing continuously during the working hour'. These activities are comparable with the representative light activities mentioned in EPA [22]. To maintain uniformity in study, street vendors who performed activities that necessitate more energy (such as lifting heavy loads, making street foods stuffs using flame, etc) were excluded from the survey. Thereby, a total of 130 street vendors were requested to attend the health survey. However, 3.8% denied to attend the survey, owing to their busy work schedule. The survey consists of several questions pertaining to information on general characteristics (age, height, weight, and educational qualification), respiratory-related disorders (cold, cough, breathlessness, and productive cold), additional health issues (chest pain, eye irritation, hip and knee pain), and usage of a nose mask. The questionnaires were developed from peer-reviewed literature [6,7,23,24]. The research data were collected with informed consent on the basis of direct interview and the responses were handwritten in a paper by our research team. As there were not enough women street vendors in the study location, only male street vendors were included, and among male street vendors, those who were aged between 18 and 70 years were selected as the sample.

2.4. Details of vehicular count

The traffic vehicular count was performed twice in a week (once in a weekday and weekend) during the sampling months at CML and RSL. Two-hour vehicular count was taken 4 times a day at 05:00–07:00 (HH:MM), 09:00–11:00 (HH:MM), 14:00–16:00 (HH:MM), and 19:00–21:00 (HH:MM) during both weekday and weekend. The resultant value is averaged to 24 hour. Although PM sampling was carried out for 8 hours in the present study, 8-hour traffic details were not reported. As the PM released from the vehicles gets suspended for a long time in the atmosphere, the authors feel that 24-hour traffic information is imperative for substantiating the research outcome.

2.5. Respirable deposition dose

The atmospheric particles inhaled during the breathing process get settled onto the respiratory tract lining and do not get exhaled, causing severe respiratory disorder [14]. To determine the extent of particulate deposition in various regions of the respiratory tract, we estimated the RDD using the equation (1).

$$RDD = V_T \times f \times DF_i \times PM_i \quad (1)$$

where V_T is the tidal volume (m^3 $breath^{-1}$), f is breathing frequency (breath min^{-1}), and V_T and f depend on the physical activity. For light activity, V_T and f were considered as 12.5 $\times 10^{-4}$ m^3 $breath^{-1}$ and 20 breath min^{-1}, respectively. DFi is deposition fraction of a size fraction i, and PMi is the mass concentration in different size fractions. The deposition fractions in various regions were estimated using the methodology given in Hinds [12]. DF_{HD} is the deposition fraction in head airways and is estimated using the equation (2), and dp is the mean particle size in μm

$$DF_{HD} = IF\left[\left(\frac{1}{1+\exp(6.84+1.183\ \ln d_p)} + \frac{1}{1+\exp(0.924+1.885\ \ln d_p)}\right)\right] \quad (2)$$

The inhalation fraction (IF) used in the above mentioned equation is calculated using the equation (3).

$$IF = 1 - 0.5\left(1 - \frac{1}{\left(1+0.00076 d_p^{2.8}\right)}\right) \quad (3)$$

DF_{TB} is the deposition fraction in the tracheobronchial region and is estimated using the equation (4).

$$DF_{TB} = \left(\frac{0.00352}{d_p}\right)\left[\exp\left(-0.234(\ln d_p + 3.40)^2\right) + 63.9\exp\left(-0.819(\ln d_p - 1.61)^2\right)\right] \quad (4)$$

DF_{AL} is the deposition fraction in the alveolar region and is estimated using the equation (5).

$$DF_{AL} = \left(\frac{0.0155}{d_p}\right)\left[\exp\left(-0.416(\ln d_p + 2.84)^2\right) + 19.11\exp\left(-0.482(\ln dp - 1.362)^2\right)\right] \quad (5)$$

2.6. Statistical analysis

SPSS, version 16.0 (SPSS Inc., Chicago, IL, USA), was used for statistical analysis. Independent sample Student t-test was used to compare the age, weight (kg), height (cm), and body mass index (BMI) of the street vendors at CML and RSL. Fisher's exact test of independence was used to test whether there is a significant site-wise variation in the occurrence of respiratory-related health disorders. A p value of less than 0.05 was considered to be statistically significant for all the performed tests.

3. Results

3.1. General characteristics of street vendors

Street vendors subjected to questionnaires were primarily involved in selling vegetables, fruit juices, cosmetics, snacks, flowers, and electronic accessories. It was taken care to exclude those street vendors who use wooden/gas-based fire source for cooking food items. The physical characteristics and respiratory health status of street vendors at CML and RSL in Dehradun city is presented in Table 2. The mean height (cm), mean weight (kg), and BMI was observed to be 156.68, 58.34, and 23.8 at CML and 155.46, 56.06, and 23.3 at RSL, respectively. Student t-test revealed a nonsignificant difference ($p > 0.05$) in the general characteristics such as age ($p = 0.10$, $t = -1.28$), height ($p = 0.21$, $t = 0.80$), weight ($p = 0.06$, $t = 1.51$), and BMI ($p = 0.20$, $t = 0.83$) between the street vendors at CML and RSL. At CML and RSL, around 55.1% and 65.1%, respectively, of the street vendors were smokers. Fisher's exact test of independence revealed a nonsignificant difference ($p > 0.05$) in the prevalence of cold, cough, breathlessness, and chest pain of the street vendors with sites. However, respiratory symptoms reported by the street vendors at CML was 1.62, 0.96, 0.04, and 0.57 times higher for cold, cough, breathlessness, and chest pain, respectively, compared with that reported at RSL.

3.2. Spatiotemporal variation of size segregated PM

The mean ± SD of $PM_{0.4\text{-}10\mu m}$ mass concentration observed at CML and RSL was 84.05 ± 14.5 and 77.23 ± 11.7 μgm^{-3}, respectively. On examining the size segregated variation of PM mass concentration at CML, $PM_{9.0\text{-}10\mu m}$ (20.18 ± 3.84 μgm^{-3}) revealed high

Table 2
Physical characteristics and respiratory health status of street vendors at commercial (CML) and residential area (RSL) in Dehradun city

Characteristics		Commercial area	Residential area
Total surveyed (n)		86	44
Rejected survey (n)		4	1
Smokers (%)		55.1	65.1
Education	Primary level (%)	48.8	
	Secondary level (%)	11.2	
Demographic characteristics (mean ± SD)*	Age (years)	37.37 ± 12.6	40.39 ± 12.3
	Height (cm)	156.68 ± 8.8	155.46 ± 7.5
	Weight (kg)	58.34 ± 7.33	56.06 ± 7.7
Respiratory health status n (%)†	No symptoms	51 (62.1)	33 (76.7)
	Breathlessness	6 (7.3)	3 (6.9)
	Cold	5 (6.0)	1 (2.3)
	Cough	15 (18.2)	4 (9.3)
	Productive cold	2 (2.4)	1 (2.3)
	Chest pain	3 (3.6)	1 (2.3)
Other information, n (%)	Nose mask	0	0
	Hip pain	4 (4.8)	2 (4.8)
	Knee pain	8 (9.7)	3 (6.9)
	Eye irritation	11 (13.4)	1 (2.3)

* Independent sample t test ($p > 0.05$).
† Fisher exact test of independence ($p > 0.05$).

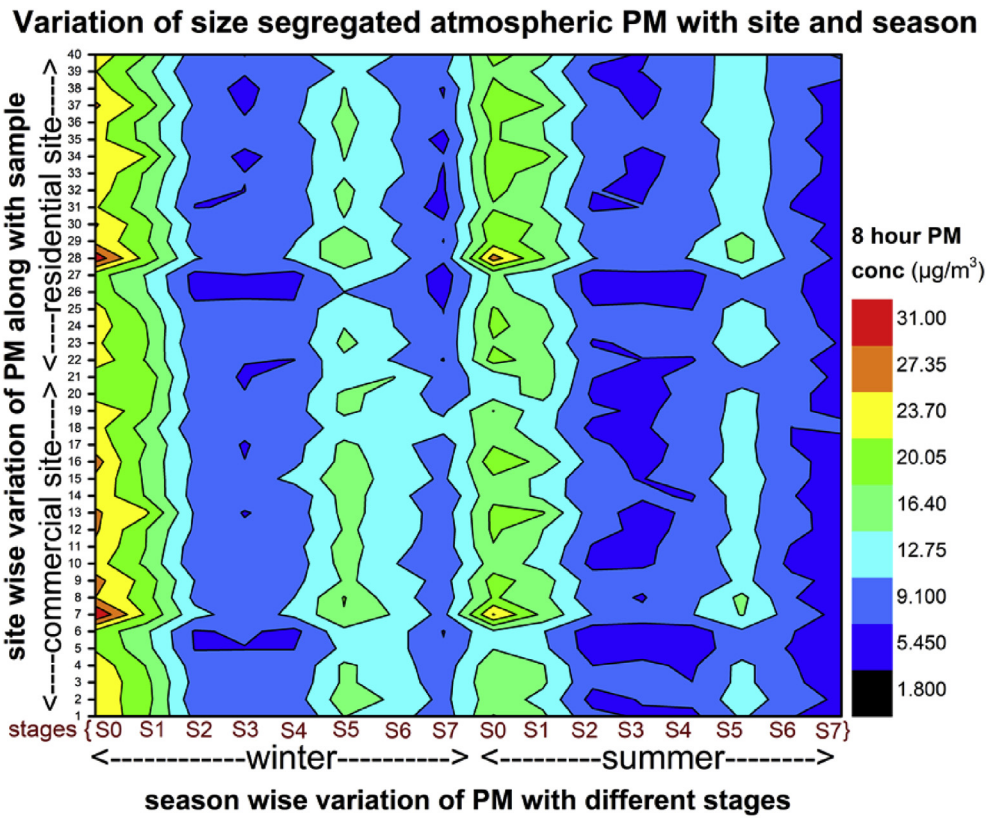

Fig. 2. Variation of size-segregated atmospheric PM with site and season [$PM_{0.4\text{-}0.7}$ (S7), $PM_{0.7\text{-}1.1}$ (S6), $PM_{1.1\text{-}2.1}$ (S5), $PM_{2.1\text{-}3.3}$ (S4), $PM_{3.3\text{-}4.7}$ (S3), $PM_{4.7\text{-}5.8}$ (S2), $PM_{5.8\text{-}9.0}$ (S1), and $PM_{9.0\text{-}10\mu m}$ (S0)].

Table 3
Pearson's correlation coefficient between size-segregated atmospheric PM.

Size-segregated atmospheric PM	$PM_{9.0\text{-}10\mu m}$	$PM_{5.8\text{-}9.0\mu m}$	$PM_{4.7\text{-}5.8\mu m}$	$PM_{3.3\text{-}4.7\mu m}$	$PM_{2.1\text{-}3.3\mu m}$	$PM_{1.1\text{-}2.1\mu m}$	$PM_{0.7\text{-}1.1\mu m}$	$PM_{0.4\text{-}0.7\mu m}$
$PM_{9.0\text{-}10\mu m}$	1.00	*0.79*	*0.82*	*0.01*	*0.04*	*0.71*	*0.76*	*0.69*
$PM_{5.8\text{-}9.0\mu m}$	**0.76**	1.00	*0.74*	*−0.15*	*0.04*	*0.56*	*0.80*	*0.68*
$PM_{4.7\text{-}5.8\mu m}$	**0.86**	**0.78**	1.00	*0.09*	*0.36*	*0.53*	*0.51*	*0.51*
$PM_{3.3\text{-}4.7\mu m}$	**0.68**	**0.53**	**0.48**	1.00	*0.14*	*0.19*	*−0.19*	*−0.03*
$PM_{2.1\text{-}3.3\mu m}$	**0.79**	**0.69**	**0.71**	**0.59**	1.00	*0.17*	*−0.21*	*0.06*
$PM_{1.1\text{-}2.1\mu m}$	**0.63**	**0.60**	**0.62**	**0.65**	**0.77**	1.00	*0.49*	*0.56*
$PM_{0.7\text{-}1.1\mu m}$	**0.78**	**0.73**	**0.57**	**0.76**	**0.72**	**0.54**	1.00	*0.78*
$PM_{0.4\text{-}0.7\mu m}$	**0.70**	**0.63**	**0.51**	**0.73**	**0.76**	**0.54**	**0.84**	1.00

The values in bold represent CML and values in italics represent the RSL.

loading followed by $PM_{5.8\text{-}9.0\mu m}$ (15.47 ± 2.35 μgm^{-3}), and $PM_{0.4\text{-}0.7\mu m}$ (5.64 ± 1.90 μgm^{-3}) showed low PM mass concentration. Similarly at RSL, $PM_{9.0\text{-}10\mu m}$ (18.87 ± 4.01 μgm^{-3}) revealed high loading followed by $PM_{5.8\text{-}9.0\mu m}$ (14.65 ± 2.61 μgm^{-3}), and $PM_{0.4\text{-}0.7\mu m}$ (4.55 ± 1.26 μgm^{-3}) showed low PM mass concentration. A significant seasonal difference ($p < 0.05$, t-test) in the $PM_{0.4\text{-}10\mu m}$ mass concentrations was observed at CML and RSL. Moreover, a significant difference ($p < 0.05$, t-test) was observed between PM mass concentration at CML and RSL in the size fractions of $PM_{4.7\text{-}5.8\mu m}$, $PM_{3.3\text{-}4.7\mu m}$, $PM_{1.1\text{-}2.1\mu m}$, $PM_{0.7\text{-}1.1\mu m}$, and $PM_{0.4\text{-}0.7\mu m}$.

Fig. 2 presents the variation of size-segregated atmospheric PM with site and season. Seasonal variation in the mean $PM_{0.4\text{-}10\mu m}$ revealed high concentration during winter (95.70 ± 8.59 μgm^{-3} at CML; 85.34 ± 8.49 μgm^{-3} at RSL) compared with summer (72.45 ± 8.61 μgm^{-3} at CML; 69.13 ± 8.47 μgm^{-3} at RSL). During the winter season, a significant difference ($p < 0.05$, t-test) in the PM mass concentrations at CML and RSL was observed in the size fractions of $PM_{3.3\text{-}4.7\mu m}$, $PM_{2.1\text{-}3.3\mu m}$, $PM_{0.7\text{-}1.1\mu m}$, and $PM_{0.4\text{-}0.7\mu m}$. However, during the summer season, significant difference ($p < 0.05$, t-test) in the PM mass concentrations at CML and RSL was observed in the size fractions of $PM_{9.0\text{-}10\mu m}$, $PM_{5.8\text{-}9.0\mu m}$, $PM_{3.3\text{-}4.7\mu m}$, $PM_{2.1\text{-}3.3\mu m}$, $PM_{1.1\text{-}2.1\mu m}$, and $PM_{0.7\text{-}1.1\mu m}$. Weekly variation in mean $PM_{0.4\text{-}10\mu m}$ revealed high concentration during weekdays (82.97 ± 14.35 μgm^{-3} at CML; 78.15 ± 11.25 μgm^{-3} at RSL) compared with weekends (69.94 ± 10.90 μgm^{-3} at CML; 68.97 ± 14.46 μgm^{-3} at RSL). A significant difference ($p < 0.05$, t-test) was observed in the $PM_{0.4\text{-}10\mu m}$ mass concentrations between weekdays and weekends at CML, whereas a nonsignificant difference was observed at RSL ($p = 0.15$, $t = 1.36$).

Pearson's correlation test used between various size fraction of PM revealed a strong correlation between $PM_{9.0\text{-}10\mu m}$ and $PM_{4.7\text{-}5.8\mu m}$ ($r = 0.86$ at CML, $r = 0.82$ at RSL), $PM_{5.8\text{-}9.0\mu m}$ and $PM_{4.7\text{-}5.8\mu m}$ ($r = 0.78$ at CML, $r = 0.74$ at RSL), and $PM_{0.7\text{-}1.1\mu m}$ and $PM_{0.4\text{-}0.7\mu m}$ ($r = 0.84$ at CML, $r = 0.78$ at RSL) (Table 3). The ratio of fine

($PM_{0.4\text{-}2.1\mu m}$) to coarse ($PM_{2.1\text{-}10\mu m}$) fraction was observed to be 0.47 and 0.44 at CML and RSL, respectively, indicating prevalence of coarse PM. Earlier, several researchers have reported the ratio of fine-to-coarse PM to be less than 0.5, indicating substantial contribution from primary sources such as resuspension of road dust, waste burning, and mechanical activities [25,26].

3.3. Influence of meteorological conditions on the variation of atmospheric PM

The mean value of temperature, RH, and WS was 20.93 (°C), 66.11 (%), and 1.12 (ms^{-1}) at CML and 21.41 (°C), 66.21 (%), and 1.12 (ms^{-1}) at RSL, respectively. At CML, during the winter season, the mean value of temperature, RH, and WS was 18.36 (°C), 69.78 (%), and 1.02 (ms^{-1}). Whereas, during the summer season, the mean value of temperature, RH, and WS was 25.23 (°C), 60 (%), and 1.3 (ms^{-1}), respectively. At RSL, during the winter season, the mean value of temperature, RH, and WS was 18.46 (°C), 68.88 (%), and 1.06 (ms^{-1}). Whereas, during the summer season, the mean value of temperature, RH, and WS was 26.33 (°C), 61.76 (%), and 1.23 (ms^{-1}), respectively. Variation of temperature, RH, and WS at CML and RSL during the study period is presented in Fig. S3. The WD data are essential to interpret whether PM emission from CML influence the air quality at RSL. On analyzing the WD data, it was found that 1% of the wind movement toward Dehradun city was from north, 24% from north-east, 3% from east, 9% from south-east, 6% from south, 22% from south-west, 25% from west, and 10% from north-west. WD information indicates that there exists high dynamism in the wind movement at Dehradun city. The influence of PM emissions from one site over the air quality of other site is complex to understand. Therefore, in-depth analysis should be carried out in future to understand the influence of PM from one site on the other.

3.4. Variation of RDD

Street vendors working at CML and RSL were assessed for the PM exposure through RDD in the head airway (HD), tracheobronchial (TB), and alveolar (AL) region of the human respiratory system (Table 4). We observed higher RDD at CML than at RSL. At CML, RDD on the AL, TB, and HD region were observed to be 54, 55, and 469 ng min^{-1} for $PM_{0.4\text{-}10\mu m}$, respectively, whereas, at RSL, the RDD in the AL, TB, and HD region were observed to be 49, 51, and 437 ng min^{-1}, respectively. Deposition in the AL and TB region was impacted more by PM contribution from the $PM_{1.1\text{-}2.1\mu m}$. Whereas RDD in the HD region was impacted more by the PM contribution from $PM_{9.0\text{-}10\mu m}$.

3.4.1. RDD in the HD region

The RDD in the HD region was contributed substantially by the size fraction $PM_{9.0\text{-}10\mu m}$ (149 ng min^{-1} for CML, 139 ng min^{-1} for RSL). The RDD in the HD region at CML during the winter season was observed to be 28% higher than in the summer season. Similarly, the RDD in the HD region at RSL during the winter season were observed to be 21% higher than during the summer season. At CML, as the particle size decreases from 9.0 to 0.4 μm, corresponding RDD in the HD region also reduced from 149 to 5.9 ng min^{-1}. Similarly at RSL, deposition in the HD region revealed a decreasing trend, as the particle size decreased from 9.0 to 0.4 μm. However, there was a slight increase in RDD in the size range 2.1–3.3 μm, before decreasing further until 0.4 μm (Table 4).

3.4.2. RDD in the TB region

Deposition in the TB region was contributed maximum by $PM_{1.1\text{-}2.1\mu m}$ (5.45 ng min^{-1} for CML, 5.06 ng min^{-1} for RSL). At CML and RSL, the RDD in TB region contributed from coarse fraction ($PM_{2.1\text{-}10.0\mu m}$) was 17.1 ng min^{-1} and 16.1 ng min^{-1}, respectively, and the RDD contributed from fine fraction ($PM_{0.4\text{-}2.1\mu m}$) was 7.7 ng min^{-1} and 7.0 ng min^{-1}, respectively. At CML and RSL, the RDD in TB contributed by fine PM ($PM_{0.4\text{-}2.1\mu m}$) was 31.0% and 30.2%, respectively, of the total RDD contributed by $PM_{0.4\text{-}10\mu m}$. At CML, the RDD were 29% higher during winter than during summer, whereas, in the case of RSL, the RDD was observed to be 15% higher during winter than during summer.

3.4.3. RDD in the AL region

Interestingly, the RDD in the AL region were contributed substantially by $PM_{1.1\text{-}2.1\mu m}$ (14.1 ng min^{-1} for CML, 13.1 ng min^{-1} for RSL). Proportion of RDD in the AL region contributed by $PM_{1.1\text{-}2.1\mu m}$ was 27.2% and 27.8%, respectively, at CML and RSL. Contribution of fine size fraction of PM toward the deposition in the AL region was observed to be 18.0% and 11.2% higher than the contribution by coarse size fraction of PM at CML and RSL, respectively. Moreover, it is well known that the residence time of fine size PM in the human lungs can extend up to several months and can become hazardous causing lung injury [12].

4. Discussion

It is evident from the present study that the spatiotemporal variation of PM plays a major role in the respiratory health status of street vendors. Although the percentage of smokers at RSL was higher than that at CML, incidence of respiratory-related disorders was higher for street vendors at CML than for those reported at RSL, revealing the adverse effect of traffic-related PM on the functioning of respiratory system. The vehicular count recorded at CML was

Table 4
Respirable deposition dose (RDD) (ng min^{-1}) in the head region, tracheobronchial region, and alveolar region at CML and RSL during the winter and summer season

Size-segregated atmospheric PM	CML		RSL		CML		RSL		CML		RSL	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
	Head region				Tracheobronchial region				Alveolar region			
$PM_{9.0\text{-}10\mu m}$	171.70	131.77	164.26	119.42	38.65	29.66	36.98	26.88	4.83	3.71	4.62	3.36
$PM_{5.8\text{-}9.0\mu m}$	132.79	110.35	129.01	101.21	5.80	4.82	5.63	4.42	7.21	5.99	7.01	5.50
$PM_{4.7\text{-}5.8\mu m}$	58.02	48.02	52.76	44.76	3.23	2.68	2.94	2.49	4.20	3.48	3.82	3.24
$PM_{3.3\text{-}4.7\mu m}$	51.73	37.78	40.00	42.47	3.92	2.86	3.03	3.21	5.86	4.28	4.53	4.81
$PM_{2.1\text{-}3.3\mu m}$	51.30	37.88	39.04	46.20	4.82	3.56	3.67	4.34	9.78	7.22	7.44	8.80
$PM_{1.1\text{-}2.1\mu m}$	39.45	32.97	37.25	30.04	3.84	3.21	3.62	2.92	15.24	12.73	14.39	11.60
$PM_{0.7\text{-}1.1\mu m}$	16.87	10.71	14.17	9.39	1.40	0.89	1.17	0.78	10.28	6.52	8.63	5.72
$PM_{0.4\text{-}0.7\mu m}$	4.48	2.54	3.36	2.30	0.33	0.19	0.25	0.17	4.48	2.54	3.36	2.29

3.60 times higher than that at RSL. Among the street vendors who suffer breathlessness and chest pain, 44% and 25%, respectively, of them felt that their symptoms aggravated during the winter season. This can be attributed to the meteorological conditions in Dehradun city (viz.), low boundary layer (winter season: 230.8 m AGL; summer season: 665.6 m AGL), and low wind movement (winter season: 1.04 ms^{-1}; summer season: 1.26 ms^{-1}). However, the remaining percentage pointed out that high temperature during the summer season (summer season: 25.78°C; winter season: 18.41°C) causes discomfort and stress. Through questionnaires, it was found that none of the vendors preferred to wear nose masks during working hours. Owing to long standing hour, other health issues such as hip and knee pain were common among street vendors. Eye irritation can be attributed to the frequent movement of vehicles that induce turbulence of road dust.

4.1. Variation of size-segregated PM

The PM mass concentration observed at CML was considerably higher than that observed at RSL in the present study. Among the analyzed size-segregated PM, $PM_{9.0\text{-}10\mu m}$ showed maximum concentration, whereas $PM_{0.4\text{-}0.7\mu m}$ showed least mass concentration. This indicates predominance of coarse-sized PM compared with fine-sized PM. The chief sources of coarse-sized PM are from roadside dust resuspension, open burning of waste, and particles from mechanical sources. Frequent movement of vehicles induces the process of dust resuspension. Owing to irregular cleaning activity of the road, the roadside dust loading is usually high throughout the year in the study location.

The fine PMs are chiefly emitted from combustion sources. The major combustion source is vehicular activity. It is reported that, in Dehradun, the vehicles involved in mass transportation are found to be using inefficient engines and they release substantial quantity of PM and gaseous pollutants. Conclusively, it can be stated that the atmospheric PM are multicomponent mixtures originating from a wide range of sources, and it evolves through several microphysical processes such as coagulation, condensation, and nucleation [5]. To arrive at a decision on the sources of PM loading in various size fractions, the chemical species associated with each size fraction of PM should be investigated in future.

Significant seasonal difference ($p < 0.05$) was observed in the mass concentration of $PM_{0.4\text{-}10\mu m}$, with high values during the winter season and low values during the summer season. The wintertime maxima are associated with increased fuel consumption, biomass burning, and unfavorable meteorological conditions for pollution dispersion. On examining the weekly variation in the PM mass concentration, it was observed that the PM mass concentration during weekday was higher than the weekend PM mass concentration. The weekly variation of PM at CML can be substantiated from the traffic information data (Table 1), indicating the influence of vehicular activity on temporal variation of PM between weekday and weekend. However, at RSL, a nonsignificant ($p > 0.05$) difference was observed, which suggests continuous emission source from vehicular movement and road dust resuspension throughout the week.

Correlation study between the size-segregated PM revealed a high correlation coefficient between various size fractions. High correlation between few coarse size range of PM indicates that there were similar or common PM sources, which may be dust resuspension, open burning of waste, and particles from mechanical sources, while high correlation observed among few fine size range of PM indicate analogous source, which may be exhaust emission from vehicles. At CML, the correlation coefficient value ranged between r = 0.48 and 0.86, which indicates that the PM loading in all the size fractions were contributed by one dominant source that can be assumed as vehicular emission. However, at RSL, the correlation coefficient value ranged between r = −0.21 and 0.82, which indicate that there are more than one significant sources of PM. Further insight into the relationship between size-segregated particles is discussed in the supplementary text.

4.2. Association of RDD with atmospheric PM and incidence of respiratory-related disorders among street vendors

The RDD were observed to be high in the HD region compared with the TB and AL region. Total RDD in the HD region at CML and RSL was observed to be 503.6 and 469.1 ng min^{-1}, respectively. Deposition of foreign particles in the airway region may stimulate cough to expel the particles from the body [27]. The particles in the size range of $PM_{9.0\text{-}10\mu m}$ have contributed substantially toward deposition in the HD region. At Nairobi [28], the contribution of PM in the size range of $PM_{2.0\text{-}16\mu m}$ on HD deposition reported to be 87% of the total deposited mass.

Deposition in the TB and AL region was contributed substantially by the fine size particles in the size range of 1.1-2.1 μm. And, high deposition in the TB and AL region was observed at CML compared with RSL. Street vendors at CML are exposed to high level of fine particles that can adversely affect the respiratory health condition. Earlier epidemiological research shows that the fine particles can reach the AL region and possess greater potential to penetrate into the blood stream and cause illness [29]. This research work can be associated with the hospital records on respiratory ailments to establish an in-depth understanding of the adverse health effects of air pollution on the street vendors at Dehradun city. Furthermore, to understand the association between atmospheric PM and respiratory health disorders is complex. However, future studies should be carried out with viable cascade impactor to find the role of bioaerosols in the incidence of health symptoms. This present research work can be referred by the concerned authorities, and the administration can take steps in preventing traffic congestion in the commercial area and regulate cleaning of the roadside dust to prevent resuspension of dust particles. With regard to personal protective measures, the government can provide nose masks and health insurance for the street vendors.

4.3. Limitations

This study has reported that the street vendors working in highly polluted commercial areas are more vulnerable toward incidence of the respiratory-related disorders compared with the street vendors working at the residential area. However, the authors feel that there are few limitations in the study. First, for understanding the association between RDD and specific respiratory symptoms/health issues, long-term data on PM mass concentration and health status of the concerned individuals are important. Second, the influence of PM emissions from one site on the air quality of other site could not be well established in the present study. The third limitation is that there is lagging of site-wise data on the number of days lost by the street vendors due to respiratory illness, ratio of amount spend on medical expense to the amount earned by vendors. This information may be essential to have an idea on demarcating safe zones for street vendors.

Conflict of interest

The authors declare that there is no conflict of interest related to this outcome reported in the manuscript.

Acknowledgments

The authors are grateful to Dr. Kusum Arunachalam, Head of Department, School of Environment and Natural Resources (SENR), Doon University for providing necessary support for their work. The authors are thankful to M.N Chamoli, Technical assistant, SENR Department, Doon University for aiding in technical support.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2019.01.005.

References

[1] Gurjar BR, Ravindra K, Nagpure AS. Air pollution trends over Indian megacities and their local-to-global implications. Atmos Environ 2016;142:475–95.
[2] Vega E, Eidels S, Ruiz H, López-Veneroni D, Sosa G, Gonzalez E, Gasca J, Mora V, Reyes E, Reyna GS, Villasenor R, Chow JC, Watson JG, Edgerton SA. Particulate air pollution in Mexico city: a detailed view. Aerosol Air Qual Res 2010;10:193–211.
[3] Tsai YI, Cheng MT. Characterization of chemical species in atmospheric aerosols in a metropolitan basin. Chemosphere 2004;54:1171–81.
[4] Rinaldi M, Emblico L, Decesari S, Fuzzi S, Facchini MC, Librando V. Chemical characterization and source apportionment of size-segregated aerosol collected at an urban site in Sicily. Water Air Soil Pollut 2007;185:311–21.
[5] Banerjee T, Murari V, Kumar M, Raju MP. Source apportionment of airborne particulates through receptor modeling: Indian scenario. Atmos Res 2015;164–165:167–87.
[6] Kongtip P, Thongsuk W, Yoosook W, Chantanakul S. Health effects of metropolitan traffic-related air pollutants on street vendors. Atmos Environ 2006;40:7138–45.
[7] Noomnual S, Shendell DG. Young adult street vendors and adverse respiratory health outcomes in Bangkok, Thailand. Saf Health Work 2017;8:407–9.
[8] Jones AY, Lam PK, Gohel MDI. Respiratory health of road-side vendors in a large industrialized city. Environ Sci Pollut Res 2008;15:150–4.
[9] Schneider IL, Teixeira EC, Agudelo-Castañeda DM, Silva GS, Balzaretti N, Braga MF, Oliveira LFS. FTIR analysis and evaluation of carcinogenic and mutagenic risks of nitro-polycyclic aromatic hydrocarbons in $PM_{1.0}$. Sci Total Environ 2016;541:1151–60.
[10] Zhao Y, Song X, Wang Y, Zhao J, Zhu K. Seasonal patterns of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ concentrations in a naturally ventilated residential underground garage. Build Environ 2017;124:294–314.
[11] Pope CA, Dockery DW. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manag Assoc 2006;56:709–42.
[12] Hinds W. Aerosol technology: properties, behaviour and measurement of airborne particles. John Wiley; 1999.
[13] Azarmi F, Kumar P. Ambient exposure to coarse and fine particle emissions from building demolition. Atmos Environ 2016;137:62–79.
[14] Gupta SK, Elumalai SP. Size-segregated particulate matter and its association with respiratory deposition doses among outdoor exercisers in Dhanbad City, India. J Air Waste Manag Assoc 2017;67:1137–45.
[15] Segalin B, Kumar P, Micadei K, Fornaro A, Gonçalves FLT. Size-segregated particulate matter inside residences of elderly in the Metropolitan Area of São Paulo, Brazil. Atmos Environ 2017;148:139–51.
[16] Heal MR, Kumar P, Harrison RM. Particles, air quality, policy and health. Chem Soc Rev 2012;41:6606–30.
[17] WHO. Ambient air pollution 2016; 2016.
[18] Kumar M, Raju MP, Singh RS, Banerjee T. Impact of drought and normal monsoon scenarios on aerosol induced radiative forcing and atmospheric heating rate in Varanasi over middle Indo-Gangetic Plain. J Aerosol Sci 2017;113:95–107.
[19] USEPA. Quality assurance guidance document 2.12: monitoring $PM_{2.5}$ in ambient air using designated reference or class I equivalent methods; 1998. NC.
[20] RTI. Standard operating procedure for particulate matter gravimetric analysis; 2008. North Carolina.
[21] Barman SC, Singh R, Negi MPS, Bhargava SK. Ambient air quality of Lucknow city (India) during use of fireworks on Diwali festival. Environ Monit Assess 2008;137:495–504.
[22] Exposure EPA. Factors Handbook 2011 edition (final); 2011. Washington.
[23] Vichit-Vadakan N, Ostro BD, Chestnut LG, Mills DM, Aekplakorn W, Wangwongwatana S, Panich N. Air pollution and respiratory symptoms: results from three panel studies in Bangkok, Thailand. Environ Health Perspect 2001;109:381–7.
[24] Mohanraj R, Azeez P. Health effects of airborne particulate matter and the Indian scenario. Curr Sci 2004;87:741–8.
[25] Mahapatra PS, Sinha PR, Boopathy R, Das T, Mohanty S, Gurjar BR. Seasonal progression of atmospheric particulate matter over an urban coastal region in peninsular India: role of local meteorology and long range transport. Atmos Res 2017;199:145–58.
[26] Deshmukh D, Deb MK, Mkoma SL. Size distribution and seasonal variation of size-segregated particulate matter in the ambient air of Raipur city, India. Air Qual Atmos Heal 2013;6:259–76.
[27] Mccallion P, de Soyza A. Cough and bronchiectasis. Pulm Pharmacol Ther 2017;47:77–83.
[28] Gaita SM, Boman J, Gatari MJ, Wagner A, Jonsson SK. Characterization of size-fractionated particulate matter and deposition fractions in human respiratory system in a typical African city: Nairobi, Kenya. Aerosol Air Qual Res 2016;16:2378–85.
[29] Tran DT, Alleman LY, Coddeville P, Galloo JC. Indoor-outdoor behavior and sources of size-resolved airborne particles in French classrooms. Build Environ 2014;81:183–91.