Assessment of particulate matter in a university campus during spring season

Saroj Kanta Behera* and Abhisek Mudgal

Department of Civil Engineering, Indian Institute of Technology (BHU), Varanasi 221 005, India

We aim to study particulate matter (PM) exposure at university campuses. The campus of Banaras Hindu University in the city of Varanasi was taken as a case study. PM concentrations were recorded using a portable aerosol monitor during peak hours for 45 days (February–March 2021) at several intersections inside the campus. PM exposure was substantially higher during the weekdays than on weekends. Due to higher humidity conditions, $PM_{2.5}$ (fine particles) exposure was higher during February than during March. March witnessed an increased PM_{10} (coarse particles) exposure because of higher atmospheric temperature, which caused greater resuspension of the coarse particles. PM concentration inside the campus was affected by traffic volume, the number of intersections, and the presence of speed breakers. $PM_{2.5}$ (54 μg m^{-3}) was lower than the limits set by the National Ambient Air Quality Standards in India (60 μg m^{-3}). In contrast, PM_{10} (115 μg m^{-3}) exceeded the standard limits (100 μg m^{-3}). Both $PM_{2.5}$ and PM_{10} surpassed the daily limit ($PM_{2.5}$: 15 μg m^{-3} and PM_{10}: 45 μg m^{-3}) set by the World Health Organization (WHO). Fine particulate matter ($PM_{2.5}$) is more hazardous to health than coarse particulate matter (PM_{10}). Consequently, the air quality on the campus was moderate as per the national norms.

Keywords: Air pollution, human exposure, particulate matter, spring season, university campus.

AIR pollution is regarded as one of the most serious environmental threats to human health. According to the World Health Organization (WHO), Geneva, Switzerland, ambient (outdoor) air pollution causes 4.2 million premature deaths every year in both cities and rural regions globally, with exposure to fine particulate matter ($PM_{2.5}$) of 2.5 μm or less in diameter being the primary cause of death[1]. As a result of its adverse health effects, airborne PM is a major worldwide concern[2]. In addition to outdoor air pollution, indoor pollution is regarded as one of the most serious environmental threats[3]. About 2.4 billion people are suffering from major health consequences due to indoor smoke produced by cooking and heating homes with biomass, coal, kerosene and fuel oil[1]. To restrict air pollution exposure, the Central Pollution Control Board (CPCB), New Delhi, India, incorporated 12 metrics (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, Pb, Ni, As, benzo(a)pyrene, and benzene) in its amended regulations in 2009 (ref. 4). However, the updated National Ambient Air Quality Standards (NAAQS) only considers lead (Pb), ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x), PM and ammonia (NH_3) when calculating the air quality index (AQI)[5]. Long-term exposure to these pollutants causes breathing and respiratory problems, aggravation of pre-existing respiratory and cardiovascular diseases, alterations in the body's defensive mechanisms against foreign chemicals, lung-tissue damage, carcinogenesis and premature mortality[6,7]. Human exposure to PM is a prominent concern in pollution exposure studies. PM exposure can cause serious effects on human health, as these pollutants can easily penetrate the lungs, heart and bloodstream. An epidemiological study revealed that ambient PM causes increased stress levels in college students[8]. The study reported that each increment of 10 μg m^{-3} in $PM_{2.5}$ exposure increased cortisol and cortisone stress hormone levels by 7.79% and 3.7% respectively[8]. PM exposure has also been associated with higher anxiety, depression and stress[9,10]. Ambient PM exposure impairs lung function[11]. Peak expiratory flow (PEF) is a measurement of lung function. An increase in 10 μg m^{-3} of short-term $PM_{2.5}$ exposure resulted in a change of –2.09 l min^{-1} in evening PEF among students[12]. In China, pneumonia hospital admission risks were 1.044 and 1.009, corresponding to an escalation in 10 μg m^{-3} of $PM_{2.5}$ and PM_{10} respectively[13].

Various studies on PM exposure have been conducted in school and residential outdoor settings, with less emphasis on university students[8,14–24]. Table 1 provides a summary of these studies.

Like school pupils and house residents, university students also spend a substantial amount of their time on different activities at the university and are exposed to PM pollutants. During the academic year at the university, most students reside in their dormitories and spend their days attending classes and participating in recreational activities. The PM exposure levels of students are determined by their campus activity patterns[25]. The present study aimed to determine the exposure of students to PM on a university campus. The main objectives of the study were: (i) To estimate the level of PM exposure on a university campus. (ii) To incorporate the effect of weekdays and weekends on PM concentration. (iii) To find the impact of meteorological conditions on different PM types.

*For correspondence. (e-mail: sarojkanta.behera.rs.civ18@itbhu.ac.in)

Table 1. Summary of relevant studies conducted in various types of outdoor environments

Study	Location	Environment	PM_{10}	$PM_{2.5}$
Li[14]	Taipei, Taiwan	Residential home	107	*
Tung *et al.*[17]	Hongkog, China	Residential home	73.3	*
Adgate *et al.*[18]	Minneapolis, USA	Home, work, school	*	21.6
Chao and Wong[19]	Hongkong, China	Residential home school, fire station	69.5	47
Ramachandran *et al.*[20]	Minneapolis, USA	Commercial centre	*	10.5
Diapouli *et al.*[21]	Athens, Greece	School	162.89	56.25
Pekey *et al.*[22]	Kocaeli, Turkey	Residential home[a]	59.9	23.5
Pekey *et al.*[22]	Kocaeli, Turkey	Residential home[b]	102.3	21.8
Massey *et al.*[23]	Agra, India	Residential home[e]	255	160
Massey *et al.*[23]	Agra, India	Residential home[f]	195	123
Elbayoumi *et al.*[24]	Gaza Strip, Palestine	School	102.26	20.12
Li *et al.*[8]	Sanghai, China	University	*	101.4
Osimobi and Nwankwo[15]	Port Harcourt, Nigeria	University	27.63–142.75	13.63–67.25
Majd *et al.*[16]	Mid-Atlantic, USA	School[c]	*	10
Majd *et al.*[16]	Mid-Atlantic, USA	School[b]	*	16
Majd *et al.*[16]	Mid-Atlantic, USA	School[d]	*	8.8
Cichowicz and Dobrzański[48]	Lodz, Poland	University	9.13	4.60

*Data not available. [a]Winter, [b]Summer, [c]Fall, [d]Spring, [e]Roadside, [f]Urban site. Note: All the values are in $\mu g\ m^{-3}$.

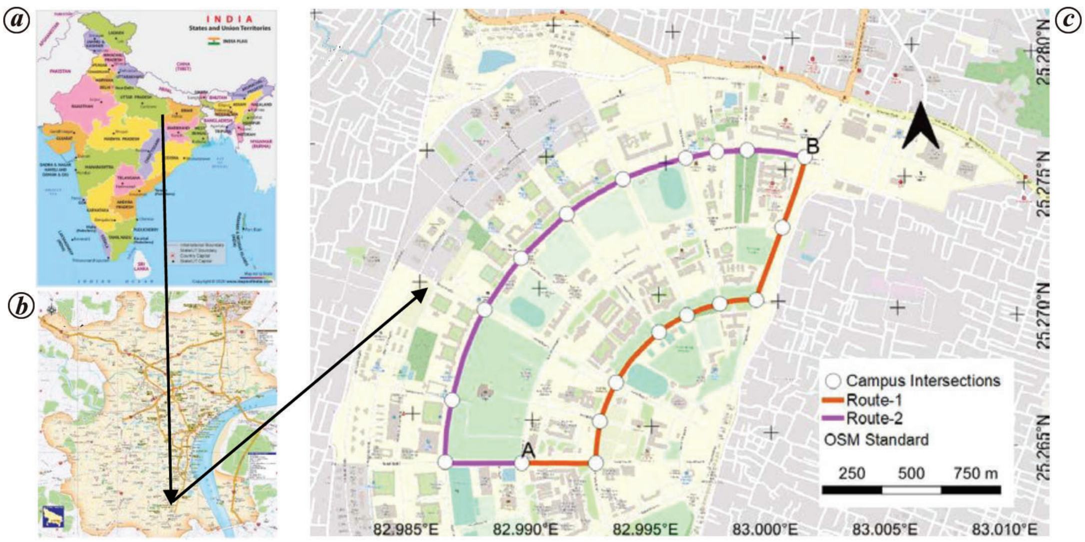

Figure 1. Monitoring locations of air pollutants inside the university campus. (Image credit: (***a***) www.mapsofindia.com, (***b***) Varanasi Development Authority and (***c***) QGIS Desktop, version 3.22.9.)

Materials and methods

Study area

Varanasi, Uttar Pradesh, is one of the most polluted cities in India. In 2017, its AQI even crossed that of the most polluted city in India, viz. Delhi[26]. Varanasi has three predominant seasons: winter (November to February), summer (March to June) and monsoon (June to October)[27]. The region experiences cold weather during winter (December–February, 3°–15°C), extreme summer (March–June, 37°–46°C), and intense rainfall during monsoon (July–September, annual average 963.5 mm)[28]. The pollution exposure study was conducted on the Banaras Hindu University (BHU) campus in Varanasi, which spans 1300 acres and has a total enrollment of over 30,000 students across six institutions, including one hospital (Sir Sunderlal Hospital). Field experiments were used to conduct the study at 19 different junctions (depicted by blank circles in Figure 1) on the university campus. The intersections are on two specified routes, viz. route 1 and route 2. The academic buildings and office complexes are located on both sides of route 1, while dormitories and playgrounds can be found on both sides of route 2. The presence of a sufficient number of trees on the campus is expected to limit students' exposure to PM[29]. The trees also help reduce the temperature on campus[30]. The various motorized trips that arrive on campus are spread throughout the academic departments, offices, dormitories and playgrounds. Students also ride motorized two-wheelers, which adds to vehicular traffic on the campus.

These motorized trips are primarily responsible for particulate pollution on the campus.

Instrumentation and data collection

PM concentrations were measured using a portable aerosol monitor (DustTrakTM DRX, Desktop Model 8533, TSI Inc, USA). The instrument works on the principle of light scattering. It has been calibrated to ISO 12103-1, A1 test dust at 29% relative humidity (RH). The instrument can measure four types of PM pollutants (PM_1, $PM_{2.5}$, PM_4 and PM_{10}). Here, PM_X refers to particulate matter with an aerodynamic diameter $\leq X$ µm. PM measurements were taken at 1 Hz frequency. The aerosol monitor was carried in a backpack, with the sampling tube extending outside and attached to the handle of the bag. The opening of the sampling tube was kept at the average adult's breathing level. PM data were collected from February 2021 to March 2021 (~45 days) between 4 and 5 pm (peak hour).

For collecting PM data on the campus, the backpack was carried by a surveyor who cycled at an average speed of 14 km/h along a 4.5 km closed loop made up of routes 1 and 2. The bicycle rode through the 19 intersections that represented different levels of exposure on the campus. The locations of the bicycle were simultaneously recorded using a cellphone GPS application (Geo-Tracker). Kumar and Goel[31] used mobile measurements along a 6 km-long closed loop to determine PM exposure at and near ten intersections in Guildford, UK. Polednik[32] also used a similar methodology for measuring 5 min fixed-site measurements at 11 stop points evenly spaced along a 2.1 km long route in Lublin, Poland. The present study was conducted between 4 and 5 pm to ensure no temporal change in concentration. To avoid accumulation errors, the instrument was zero-calibrated using a zero filter before each measurement. The data collection started with riding a bicycle on route 1 (from *A* to *B*), followed by measuring PM concentration on route 2 (from *B* to *A*; Figure 1). For analysis, meteorological data such as RH, atmospheric temperature (AT), wind speed (WS) and wind direction (WD) were obtained from the CPCB website.

Data pre-processing

The DustTrak data is prone to errors as a result of instrument malfunction. As a result, there may be missing data, unexpectedly higher values and negative concentrations. The data were pre-processed to address these issues. The processed data still had errors inherent to the measurement based on the light scattering principle. Under changing humidity levels, hygroscopic development and agglomeration of aerosol particles affect the measuring accuracy of light scattering principle-based instruments[33]. The average RH during the study was observed to be 47.5% and 42% for February and March, respectively. To minimize the effect of RH on concentration, the $PM_{2.5}$ concentration was corrected using the approach developed by Laulainen[34], as shown in eqs (1) and (2). The correction factor (CF) depends upon RH at the time of data collection. This method has been used to correct $PM_{2.5}$ in numerous exposure studies conducted in Delhi[20,35,36]. RH correction did not significantly change (with a 95 percentile error of 5%) the value of raw $PM_{2.5}$ concentration since the range of RH lies between 34% and 59%. Hence, further analysis was carried out using the original (uncorrected) data.

$$PM_{2.5\_RH\ corrected} = \frac{PM_{2.5\_Raw}}{CF}, \tag{1}$$

$$CF = 1 + 0.25\frac{RH^2}{1 - RH}. \tag{2}$$

The GPS traces from each trip as well as the PM exposure data, were imported into a database and merged based on time. The merged file contained both GPS coordinates and PM exposure data. PM concentration at the 19 intersections was estimated by averaging PM measurements (taken while riding the bicycle) recorded within 50 m of the intersections. QGIS was used to clip the points spatially. The data collected on the campus at these intersections were used for exposure analysis.

Results and discussion

PM exposure

Table 2 summarizes the measured PM concentration on the campus. PM exposure on the campus was found to be either close to or greater than the daily NAAQS limit ($PM_{2.5}$: 60 µg m^{-3} and PM_{10}: 100 µg m^{-3}), while both PM concentrations exceeded the proposed daily WHO air quality standards ($PM_{2.5}$: 15 µg m^{-3} and PM_{10}: 45 µg m^{-3}).

During the study period, the average PM_{10} and $PM_{2.5}$ concentrations inside the campus were observed to be 115.51 ± 42.19 µg m^{-3} and 53.97 ± 23.89 µg m^{-3} respectively. $PM_{2.5}$ accounted for over 47% of the PM_{10} concentration (74.18–26.32%). Hence, it indicated that coarse particles were the predominant contributors to PM_{10}. The average RH and AT were found to be 44.81 ± 5.3% and $30° \pm 4.5$°C respectively. In comparison to $PM_{2.5}$ (SD: 23.89), PM_{10} (SD: 42.19) showed greater variation. The larger variance in PM_{10} could be attributed to dust resuspension generated by intense vehicular flow at the intersection. Furthermore, the interaction between tyres and pavements may contribute to PM_{10} concentration[37,38]. Morning street cleaning on the university campus may also contribute to the resuspension of road dust[39]. Sweeping in the morning is anticipated to have little effect on PM levels during data collection in the afternoon.

Table 2. Descriptive statistics (n = 45)

	$PM_{2.5}$ (μg m^{-3})	PM_{10} (μg m^{-3})	Relative humidity (RH, %)	Atmospheric temperature (AT, °C)	% Share of $PM_{2.5}$ in PM_{10}
Mean	53.97	115.51	44.81	30.00	47.17
Standard deviation	23.89	42.19	5.30	4.50	13.14
Minimum	23.00	50.00	34.50	21.95	26.32
Maximum	135.00	228.00	59.25	38.10	74.18

Table 3. Monthly average PM concentration (in μg m^{-3}) and meteorological parameters inside the university campus

Month	$PM_{2.5}$ (μg m^{-3})	PM_{10} (μg m^{-3})	AT (°C)	RH (%)
February (n = 23)	60.65	108.28	26.9	47.5
March (n = 22)	46.98	123.07	33.2	42.0

Table 3 provides details of monthly exposure. $PM_{2.5}$ exposure was greater on the campus in February (60.65 μg m^{-3}), whereas PM_{10} exposure was higher in March (123.07 μg m^{-3}). Changes in the values of meteorological parameters (AT and RH) during February and March led to the difference in exposure levels. Previous studies have also shown that PM levels are influenced by meteorological and traffic conditions[31,40]. The higher RH in February could enhance the generation of fine PM and increase its concentration[41]. Higher levels of PM_{10} are expected during March. This is because higher temperatures in March may help resuspend dust particles, resulting in increased PM_{10} concentration[42].

Day-of-week exposure

The study was performed on weekdays (Monday–Saturday) and weekends (Sunday). The university and the Outpatient Department (OPD) of the hospital on campus are both open on Saturdays but closed on Sundays. Therefore, Saturdays are also considered as weekdays. As a result, weekends see less traffic than weekdays. Past studies reveal that a reduction in road traffic can significantly reduce PM concentration[43,44]. Due to reduced human activity on weekends, pollutant concentrations on the campus are predicted to be lower than on weekdays. Figure 2 depicts the average PM concentration on various days of the week. The solid and dotted horizontal lines represent the average $PM_{2.5}$ and PM_{10} exposure during the study period respectively. Expect Tuesday and Friday, $PM_{2.5}$ exposures were lower or nearly equal to the daily average on the campus, whereas the PM_{10} exposure on Tuesday, Wednesday and Friday was comparatively higher than the daily average. The study also observed a decreasing pattern of pollutant concentration from Tuesday to Thursday and then again from Friday to Sunday. The precise cause for this pattern requires further analysis. Figure 3 represents the temporal (weekdays and weekends) PM concentration on the BHU campus. The analysis found significantly lower PM levels during weekends. The average PM_{10} levels on weekdays and weekends were 122 and 82 μg m^{-3}, respectively whereas the $PM_{2.5}$ levels on weekdays and weekends were 56 and 43 μg m^{-3} respectively. On weekends, the university campus experienced lesser traffic flow, lowering pollution levels. This observation is corroborated by previous studies[45,46].

Relationship between PM exposure and meteorological parameters

Meteorological parameters (RH, AT, WS and WD) from the city's weather station were used for finding out linear correlations with the pollutants. $PM_{2.5}$ concentration was positively correlated with RH having a correlation coefficient of 0.65, whereas it was negatively correlated with temperature (0.47; Figure 4). Sulaiman *et al.*[47] found that outdoor PM_{10} concentrations were correlated with wind speed (0.5324) and humidity (0.5299). Other studies also reported that both meteorological and traffic parameters influence PM_{10} levels[31,40]. However, the present study found no strong correlation between PM_{10} and meteorological parameters. To depict the relationships among $PM_{2.5}$, PM_{10} and meteorological parameters, linear equations were developed (eqs (3) and (4)). Some of the meteorological variables (WS and WD) were statistically insignificant. So, the insignificant parameters were not considered in the subsequent iteration of regression models. Figure 5 shows the linear relationship between PM and meteorological parameters (RH and AT). The multilinear regression between $PM_{2.5}$, PM_{10} and RH, as well as $PM_{2.5}$, PM_{10} and AT showed a strong relationship with a coefficient of determination (R^2) of 0.833 and 0.772 respectively.

$$PM_{2.5} = -104.215 + 0.364PM_{10} + 2.592RH, \quad (3)$$

$$PM_{2.5} = +87.245 + 0.423PM_{10} - 2.736AT. \quad (4)$$

Spatial pattern of PM exposure

The BHU campus, which includes office complexes, academic buildings, playgrounds and dormitories, is divided into well-planned zones. A spatial observatory analysis was performed to determine the parts of the campus which are highly exposed. The concentration of $PM_{2.5}$ and PM_{10} at the campus intersections was observed to follow an exposure

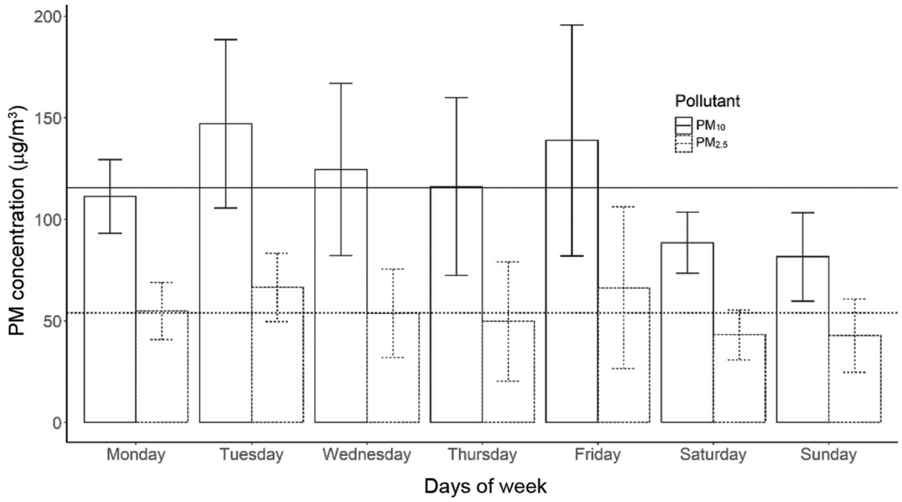

Figure 2. Day-of-week particulate matter (PM) exposure inside BHU campus, Varanasi, Uttar Pradesh, India. The solid and dotted horizontal lines are the average value of PM_{10} and $PM_{2.5}$ respectively.

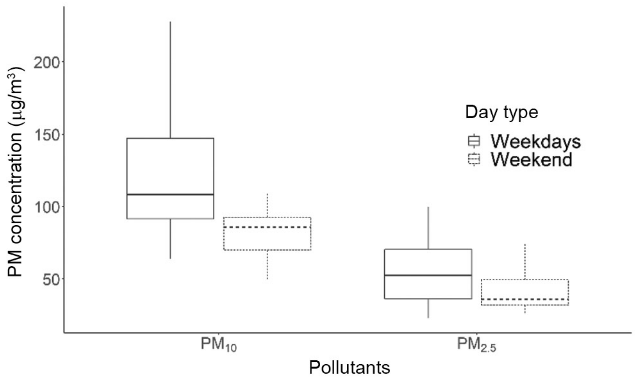

Figure 3. Weekday versus weekend PM exposure inside the BHU campus, Varanasi.

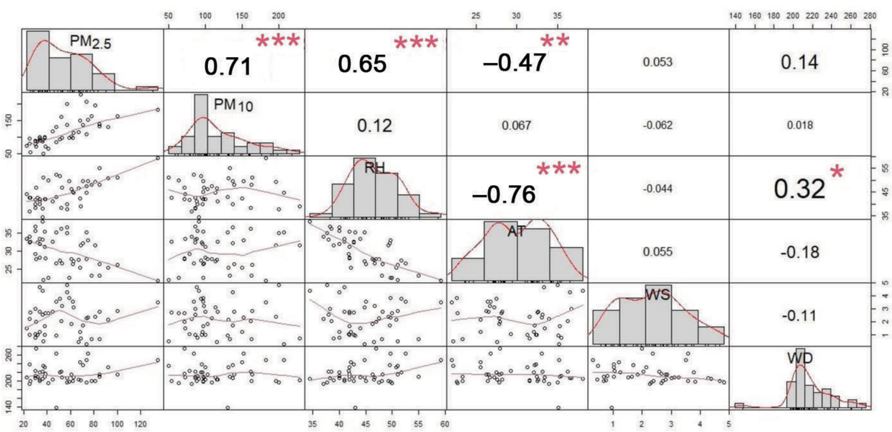

Figure 4. Dependencies among PM concentration and meteorological parameters. Asterisks indicate the significance levels of the correlations with P values of 0, 0.001 and 0.05 for ***, ** and * respectively.

pattern in terms of route number (Figure 6). The $PM_{2.5}$ concentration ranged from 50.8 to 61 and 44 to 50.8 μg m^{-3} for route 1 (except one location) and route 2 respectively, whereas the PM_{10} exposure ranged from 110 to 153 and 81 to 110 μg m^{-3} for route 1 (except one location) and route 2 respectively. In conclusion, route 1 is exposed more

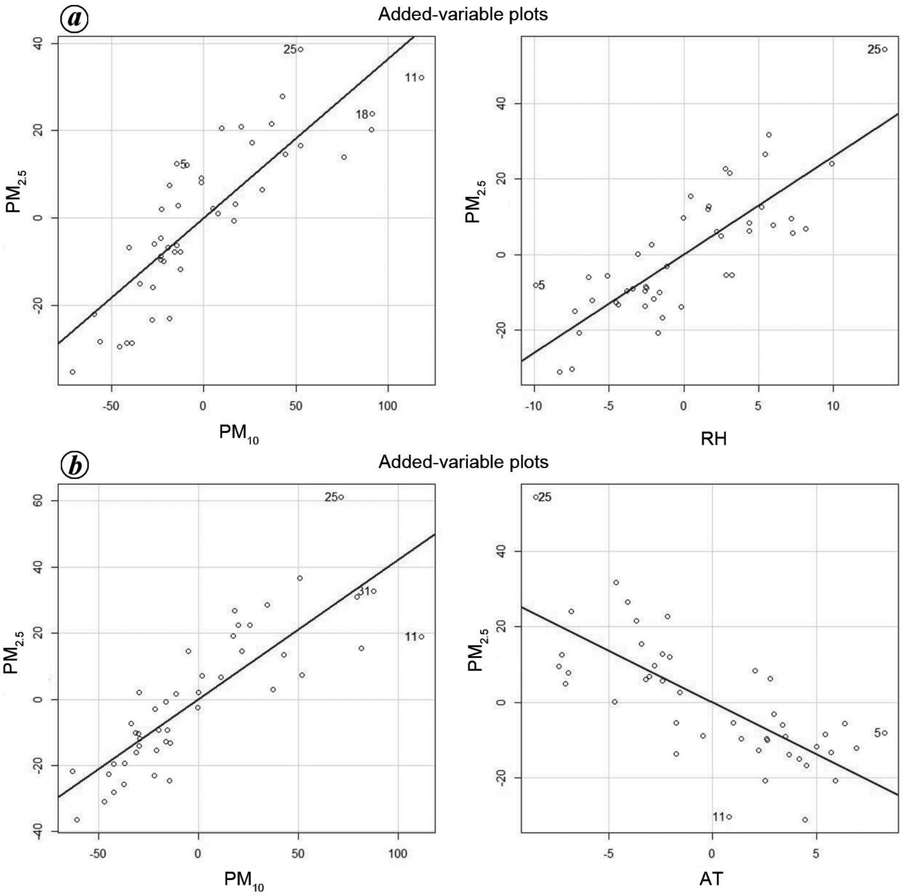

Figure 5. Multilinear regression between (***a***) $PM_{2.5}$, PM_{10} and relative humidity (RH) and (***b***) $PM_{2.5}$, PM_{10} and atmospheric temperature (AT). Note: $PM_{2.5}$ and PM_{10} are in μg m^{-3}, RH in % and AT in °C.

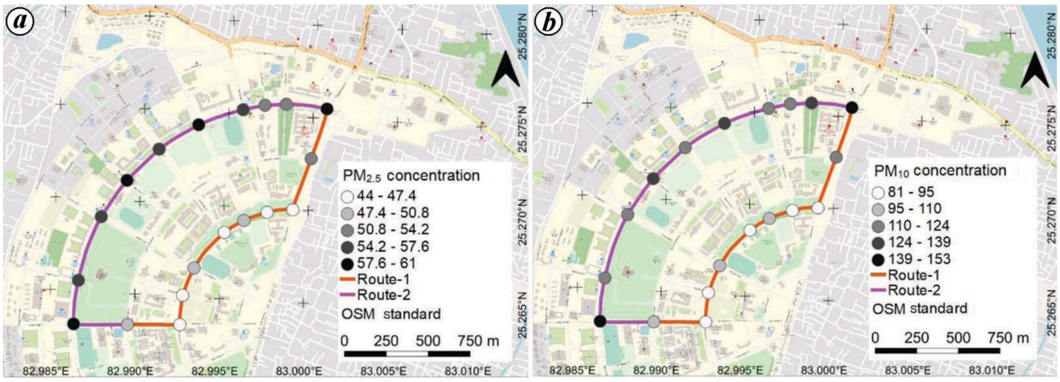

Figure 6. (***a***) $PM_{2.5}$ and (***b***) PM_{10} exposure at different locations in the university campus.

to both $PM_{2.5}$ and PM_{10}. The higher concentration at intersections present in route 1 (in comparison to route 2) could be attributed to the larger traffic volume and speed breakers at each intersection. Thus, students living in the hostels on the campus are highly exposed to PM due to dormitories close to route 2, whereas during class hours, they are comparably less exposed to pollutants as the academic buildings are close to route 1.

Conclusion

PM exposure studies for house residents and school pupils have been undertaken in residential and educational settings around the world respectively. Few studies concentrate on college students on university campuses. In this study, PM measurement on a university campus was carried out. The study analysed the exposure of college students to particulate pollution on the BHU residential campus to determine the status of the university campus in terms of PM exposure. Based on the analysis performed in this study, the following conclusions were drawn.

The average PM_{10} and $PM_{2.5}$ concentrations inside the campus were 115.51 and 53.97 $\mu g\ m^{-3}$ respectively. PM exposures were significantly higher on weekdays due to higher vehicular movement in comparison to weekends. $PM_{2.5}$ concentration on both weekdays (56 $\mu g\ m^{-3}$) and weekends (43 $\mu g\ m^{-3}$) was below the NAAQS daily safety limits (60 $\mu g\ m^{-3}$), where PM_{10} concentration on weekdays (122 $\mu g\ m^{-3}$) was found to be violating the safety standards (100 $\mu g\ m^{-3}$).

The average $PM_{2.5}$ concentration was higher in February (RH 47.5%), whereas the average PM_{10} concentration was marginally higher in March (RH 42%). This is mainly because of meteorological factors. $PM_{2.5}$ had a strong positive correlation (0.65) with RH and a negative correlation (0.47) with AT, whereas PM_{10} was less affected by RH (correlation: 0.12) and AT (correlation: 0.067).

The exposure levels in the campus at various intersections were determined by the route parameters. Higher traffic volume and the presence of speed breakers on route 2 led to higher PM concentration in its surrounding areas.

Fine particles less than 2.5 μm ($PM_{2.5}$) can pass through the lung layers and be carried in the blood throughout the body. PM_{10} is a significant concern because it affects the upper respiratory tract, producing allergic rhinitis, sleep disorders, breathing problems, middle ear and sinus problems, and persistent cough. $PM_{2.5}$ exposure inside the campus was within NAAQS limits during peak hours, while PM_{10} exceeded the limits. Thus, the students are more prone to health hazards due to PM_{10} than $PM_{2.5}$.

Competing interests: The authors declare that there is no conflict of interest.

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