# Chapter 4

# Comparison of PM Exposure: Within BHU Campus and On-Roads in Varanasi City

This chapter examines PM exposure inside the residential university and in Varanasi city, which is outside the university campus. The study also explains the rationale behind selecting Varanasi city as the study area.

## 4.1 Background

Both indoor and outdoor pollution can have adverse health effects on students. Thus, indoor and outdoor exposure studies are necessary for a complete assessment of exposure. Exposure to PM has serious effects on both the physical and mental health of students pursuing their studies at a university. Li et al. (2017) reported significantly higher stress and blood pressure among students. Each 10 μg $m^{-3}$ in $PM_{2.5}$ resulted in 2.61 and 0.86% increments in systolic and diastolic blood pressure. Exposure to PM has also been linked to increased levels of anxiety and depression (Azhdari et al., 2022; Kuo et al., 2018). Lung function is also severely affected by PM exposure (Raz-Maman et al., 2022).

There have been multiple exposure studies conducted indoors and outdoors on a university campus. Some studies considered the environment immediately outside the classrooms, laboratories and reading rooms as the outdoor environments (Table 4.1). Tiwari et al. (2015)

considered both locations inside and outside of a university as outdoor locations. They selected four and two locations in the city and campus locations, respectively. However, students, faculty, and staff traveling from the university campus to the city are also exposed to on-road particulate pollution on the way to their destination. Consequently, the studies that considered only a few outside locations lacked sufficient spatial coverage, especially along the traversed route. The primary goal of the study was to explore PM exposure inside and outside of a university campus during winter while incorporating the exposure in the journey as well. The objectives of the study are

1. to contrast PM exposure inside and outside of a campus during winter,
2. to find the effect of the day and hour of the day on PM exposure,
3. to find the relationships between inside and outside PM concentrations, and
4. to estimate the inhaled dose

Table 4.1 Summary of studies on PM exposure in various outdoor environments of university campuses.

| **Study** | **Location** | **Outdoor Environment** | **$PM_{2.5}$ (µg $m^{-3}$)** | **$PM_{10}$ (µg $m^{-3}$)** |
|---|---|---|---|---|
| This Study | Varanasi, India | City site | 166 | 294 |
| Sahu and Gurjar, 2020 | Roorkee, India | Outside classrooms | 16.7 – 110.5 | 110.4 – 174.6 |
| Osimobi and Nwankwo, 2018 | Choba, Nigeria | Car parking | 13.63 – 67.25 | 27.63 – 142.75 |
| Li et al., 2017 | Shenyang, China | Outside classrooms | 72.6 | – |
| Tiwari et al., 2015 | Varanasi, India | City site | 134.13 | 218.32 |
| | | Outside classrooms | 72.75 | 95.46 |

## 4.2 Methodology

### 4.2.1 Study Area and Routes

The Banaras Hindu University (BHU) campus, located in Varanasi city (82 km$^2$) in northern India (25.2677°N, 82.9891°E), was selected as the study area (Fig. 4.1). The university campus is spread over 5.5 km$^2$. The institute has an enrollment of over 30,000 students and comprises of six institutes, including a hospital. The university campus serves as the internal environment for its community, while the city outside the campus acts as an external environment for the university members, respectively. Thus, the study considered the portion of a trip inside the university (1.84 km) and Varanasi city (15.54 km) as inside and outside campus study environments for the exposure study. The university campus generally has fewer traffic activities in comparison to the outside campus. The vehicular traffic inside the campus is primarily created by the university staff, followed by patients coming to the hospital for treatment and the trips generated by the nearly commercial land use. The motorized trips that enter the campus get distributed across the campus in various academic departments, hostels and playgrounds. The university community also uses motorized two-wheelers and four-wheelers, which contribute to the vehicular traffic within the campus. The traffic outside the campus is influenced by diverse land use patterns such as residential areas (RA), railway stations (RS), commercial areas (CA), religious centers (RC), schools and colleges, retail stores and on-street vendors. The university community spends a significant fraction of their time on various activities within the campus, where they are exposed to particulate pollutants. However, they may be exposed to higher PM concentrations when they go outside the university campus for any work or recreational activities. Commonly visited locations such as commercial areas, religious centers, shopping malls, and railway stations were considered as locations outside the campus. PM exposure while traveling to commercial area-1 (0.46 km), commercial area-2

(1.99 km), commercial area-3 (5.59 km), railway station-1 (5.35 km), railway station-2 (R1) (8.96 km), railway station-2 (R2) (6.58 km), religious center-1 (1.31 km), and religious center-2 (3.91 km) were measured in the exposure study.

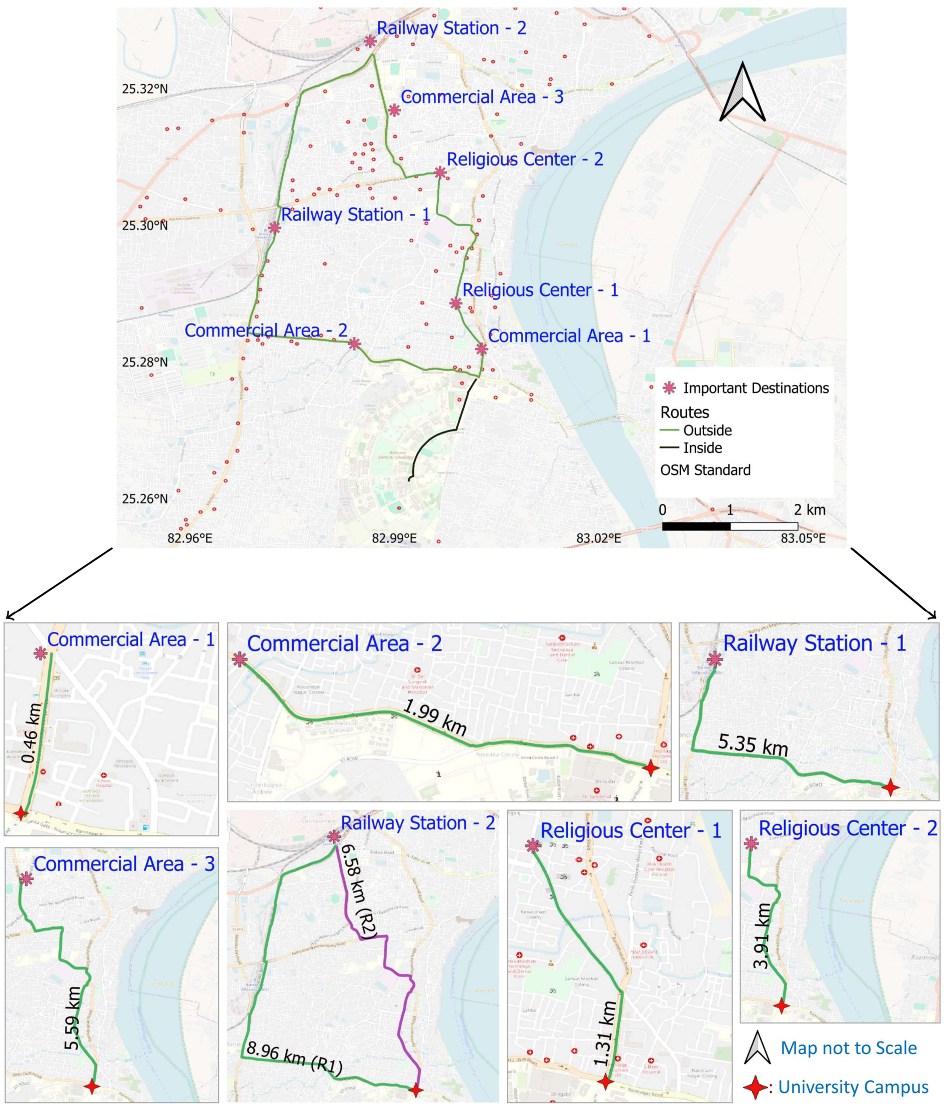



Fig. 4.1 Monitoring locations of air pollutants inside and outside the university campus.

### 4.2.2 Instrumentation and Data Collection

The instrumentation in the study is similar to the procedure mentioned in Chapter 3. However, only PM measurements and GPS locations were taken during the data collection. Both the PM and GPS data were collected at a frequency of 1-Hz. A motorcyclist carried the backpack setup and traversed the selected routes during fixed hours (8:00 – 11:00 am and 03:00 – 05:00 pm). The morning and evening rush hour were observed from 09:00 – 10:00 am and 16:00 – 17:00 pm, respectively. PM data were collected over two weeks in November 2020.

### 4.2.3 Exploratory Data Analysis and Data Visualization

Both inside and outside PM exposure was estimated using various techniques, such as spatial descriptive statistics, t-tests, differences in PM concentrations, ratio and percentage share of concentrations. The inside and outside exposure on various days of the week and hours of the day were visualized using box and whisker plots. Both $PM_{2.5}$ and $PM_{10}$ concentrations were mapped using the Quantum Geographic Information System (QGIS) for spatial visualization of PM levels. The linear relationship between inside and outside campus exposure was studied using scatter plots and linear regression.

### 4.2.4 Pollution Exposure Mapping

Pollution exposure mapping aids in visualizing the spatial distribution of pollutant concentrations. These maps can help be used for planning healthier routes. These maps also help analysts, urban planners and government bodies identify regions with higher exposure. Urban planners can provide abatement or policy measures to reduce pollutant concentrations in highly polluted areas. Fig. 4.2 depicts the steps taken to produce pollution exposure maps. Firstly, motorcycle trajectories synced with PM data were imported into the GIS database. Secondly, inside and outside study routes were drawn. Then, the routes were split into segments of 50 m and 25 m buffers were drawn around them. PM data within each segment were extracted. The mean PM exposure for the segment was calculated using a structural query language (SQL). For distinct visualization of pollutant levels, the $PM_{2.5}$ and $PM_{10}$ levels were divided into 5 bins of equal interval sizes of 36 and 90 µg $m^{-3}$, respectively. The exposure concentrations were categorized into their bins. The bins were color-coded from light brown to dark brown, where bins with higher pollutant values appeared darker.

### 4.2.5 Inhaled Dose Estimation

The United States Environment Protection Agency (USEPA) suggested the following four steps for health risk assessment: 1) hazard identification, 2) dose-response assessment, 3) exposure assessment, and 4) risk characterization (USEPA, 2022). The exposure assessment includes determining the health impact of the pollutant (diseases due to pollutant exposure), identifying the exposure range, and quantifying the exposure. The health impact of pollutants can be measured after exposure assessment (Khamraev et al., 2021). The inhaled dose can represent commuters' risk level in terms of pollutant concentration. The level of risk increases with higher inhaled doses. The inhalation dose can be estimated using exposure concentration (C in µg $m^{-3}$), minute ventilation (MV in $m^3$ $min^{-1}$), trip duration (T in minutes), and distance traveled (D in km). Eq.4.1 and Eq. 4.2 were used to estimate the inhaled dose per trip and inhaled dose per kilometer traveled, respectively.

$$\text{Inhaled dose per trip } (\mu\text{g}) = C \times MV \times T \tag{4.1}$$

$$\text{Inhaled dose per kilometer traveled } (\mu\text{g km}^{-1}) = \frac{C \times MV \times T}{D} \tag{4.2}$$

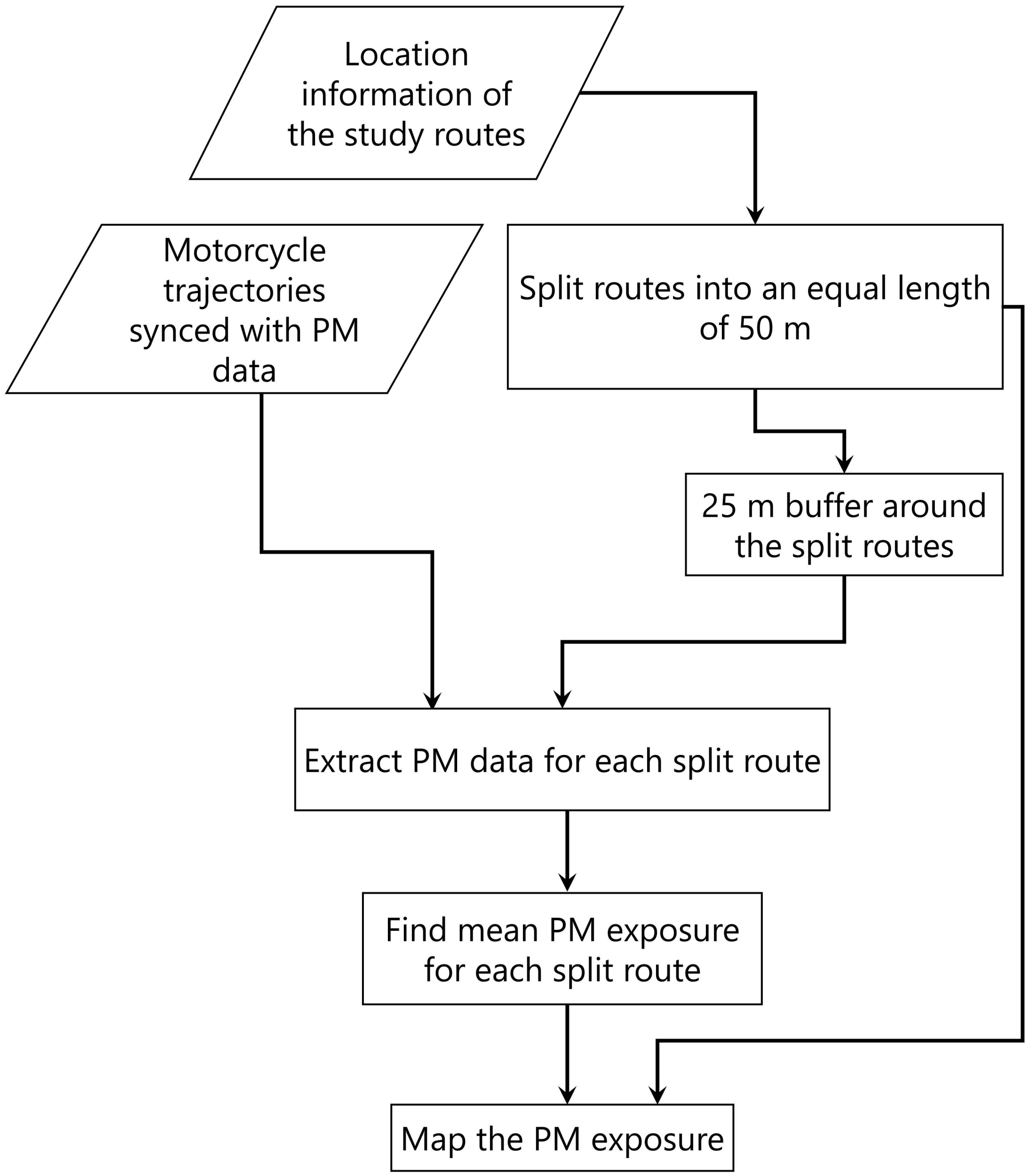



Fig. 4.2 Process of mapping on-road pollution exposure.

Several researchers have recently used these equations to estimate motorcycle riders' inhaled dose (Huy et al., 2022; Manojkumar et al., 2021; Ramos et al., 2016). The average MV rate for a motorcyclist in India can be assumed to be 0.01 $m^3$ $min^{-1}$ (Goel et al., 2015; Manojkumar et al., 2021).

## 4.3 Results and Discussion

### 4.3.1 Summary Statistics

Daily PM exposure inside and outside of the university campus is summarized in Table 4.2. The values exceeded the daily NAAQS limit ($PM_{2.5}$: 60 µg $m^{-3}$ and $PM_{10}$: 100 µg $m^{-3}$) both inside and outside the campus. The average "outside" $PM_{2.5}$ and $PM_{10}$ concentrations (166 ± 88 and 294 ± 154 µg $m^{-3}$) were found to be higher than "inside" campus exposure (147 ± 73 and 234 ± 118 µg $m^{-3}$), respectively. The exposure during trips to various commonly visited locations outside the campus was found to be different. Comparably higher and lower PM exposures were observed for trips to railway stations and religious centers. The trips to railway stations had average $PM_{2.5}$ and $PM_{10}$ exposure of 173 – 173 and 310 – 314 µg $m^{-3}$, respectively. In contrast, the trips to religious centers had $PM_{2.5}$ and $PM_{10}$ exposure of 118 – 145 and 196 – 250 µg $m^{-3}$, respectively. The exposure pattern during trips followed the order: railway stations > commercial areas > religious centers, except for commercial area-1. The trips to railway stations are comparably higher, followed by commercial areas and religious centers, which might be the reason for this pattern of PM exposure. The lowest PM exposure was observed at commercial area-1 compared to all outside locations. The reason behind this anomaly in the pattern might be lower traffic volume compared to other locations during the study period. Due to its proximity to the university campus, commercial area-1 saw a higher percentage of non-motorized trips, such as cycling and walking, which may explain the lower PM concentrations observed in the trips. A similar study conducted by Sahu and Gurjar (2020) during winter found comparatively lower inside $PM_{10}$ (17.1 – 146.5 µg $m^{-3}$) compared to outdoor $PM_{10}$ (110.4 – 174.6 µg $m^{-3}$). However, the study found a little higher inside $PM_{2.5}$ (16.7 – 110.5 µg $m^{-3}$) compared to outside $PM_{2.5}$ (57.1 – 82.7 µg $m^{-3}$). The primary reasons for the anomaly in the pattern could be attributed to the physical attributes of indoor monitoring locations (lecture halls, a reading hall, an office, and laboratories) in the study. The study found higher PM at three monitoring points at lecture halls compared to outside PM concentrations, which was caused due to differences in ventilation and occupancy rates. The windows and doors were closed during winter to get a warmer environment, which restricted the dilution process and increased the accumulation of particulate concentrations. The other reason for the difference in PM concentration in the study, including the current study, can be attributed to the difference in traffic volume. The higher traffic volume outside the campus increases the PM levels (Dons et al., 2013). Again, the presence of a sufficient number of trees is likely to reduce students' exposure to PM inside the campus (Chen et al., 2019). Comparatively higher variations for $PM_{10}$ were observed in the outside portion of trips (SD: 154) than in the inside trips (SD: 118). The higher variation in outside environments might be a result of resuspension dust due to heavy traffic movement outside the campus. Apart from this, the interaction of tires and pavement may also contribute to $PM_{10}$ concentrations (Lee and H., 2013; Panko et al., 2019). Street sweeping in the morning can also be another reason for the resuspension of road dust both inside and outside the university campus (Sinha and Dammani, 2018). Sweeping in the morning is likely to have a negligible effect on PM concentration during data collection, which was done in the afternoon.

Table 4.2 Average (SD) PM exposure for trips from the campus to key locations.

| Environment | Key Locations | $PM_{2.5}$ (in µg $m^{-3}$) | $PM_{10}$ (in µg $m^{-3}$) |
|---|---|---|---|
| Inside | University Campus | 147 (73) | 234 (118) |
| Outside | Commercial Area-1 | 106 (53) | 161 (90) |
| | Commercial Area-2 | 166 (86) | 296 (137) |
| | Commercial Area-3 | 152 (74) | 264 (125) |
| | Religious Center-1 | 118 (61) | 196 (103) |
| | Religious Center-2 | 144 (72) | 249 (122) |
| | Railway Station-1 | 172 (94) | 313 (166) |
| | Railway Station-2 (R1) | 172 (94) | 309 (163) |
| | Railway Station-2 (R2) | 155 (76) | 267 (127) |
| Outside (all average) | Trip to all Locations | 166 (88) | 294 (154) |

### 4.3.2 Difference in PM Exposure

Table 4.3 provides information about the difference in PM exposure between the outside and inside the campus. The difference between the average concentration of outside and inside environments was calculated on each day and then the average of all the differences was computed. A higher difference in exposure was found for $PM_{10}$. The mean difference in exposure for $PM_{2.5}$ and $PM_{10}$ was found to be 18 and 57 µg $m^{-3}$, respectively. Past studies have found that 70 – 82% of outdoor $PM_{2.5}$ concentrations infiltrated into indoor environments (Krasnov et al., 2015; Pekey et al., 2010). A t-test was performed on hourly PM exposure concentration to analyze the significance of the difference between inside and outside campus. The higher t-value (p-value less than 0.05) rejects the null hypothesis and shows that there is a significant difference between the set of two groups. The difference in $PM_{10}$ between inside and outside exposure measurements was significant (p-value = 0.002). For $PM_{2.5}$, the difference was not significant (p-value = 0.079).

Table 4.4 presents the ratio of outside (average of all outside portion of trips) and inside concentrations for $PM_{2.5}$ and $PM_{10}$. It also shows the percentage share of fine particles for

Table 4.3 Comparison of PM exposure (μg $m^{-3}$) between trip portions outside and inside the campus.

| **Pollutant** | **Sample Size** | **Mean (SD)** | **Median** | **Min** | **Max** |
|---|---|---|---|---|---|
| $PM_{2.5}$ | 12 | 18 (35) | 10 | -43 | 72 |
| $PM_{10}$ | 12 | 57 (37) | 44 | 19 | 155 |

*Abbreviations:* SD, standard deviation.

both inside and outside environments. The average ratio for $PM_{10}$ and $PM_{2.5}$ was found to be 1.3 and 1.2, respectively. The $PM_{10}$ exposure outside was found to be 1.1 – 1.8 times that of exposure inside, where the ratio for $PM_{2.5}$ ranged from 0.8 – 1.6. The lower range ratio for $PM_{2.5}$ was found to be less than 1, which meant the PM level was lower in some of the outside portions of trips than inside the campus. The ratio between outside portion of trips to important destinations and inside trips is plotted in Fig. 4.3. Both $PM_{2.5}$ and $PM_{10}$ ratios between outside and inside trips for commercial areas (except commercial area-1) and railway stations were found to be higher than 1. The $PM_{2.5}$ and $PM_{10}$ ratios for the religious center-2 were found to be slightly lower and higher than 1. However, the $PM_{2.5}$ and $PM_{10}$ ratios for the commercial area-1 and religious center-1 were found to be significantly lower than 1, which might be the reason for getting lower average PM ratios ($PM_{2.5}$: 0.8) for all outside portions of trips. The study found outside-to-inside PM exposure ratios greater than 1 during various outside campus trips. This implies that PM exposure is generally higher outside the university campus compared to travel within the campus.

Both exhaust and non-exhaust emissions contribute to PM concentrations. The contribution to $PM_{2.5}$ can be attributed to exhaust emissions, while the contribution to $PM_{10}$ can be attributed to non-exhaust emissions (Harrison et al., 1997). The percentage of $PM_{2.5}$ share in $PM_{10}$ was 65% and 59% for inside and outside the university campus (Table 4.4). Thus, it may be concluded that exhaust emissions are primarily responsible for particulate pollution. However, a thorough source apportionment study must be performed

Table 4.4 Ratio and percentage share of aggregate concentrations for trip portions inside and outside the campus.

| **Parameters** | **$PM_{10}$ (outside)/ $PM_{10}$ (inside)** | **$PM_{2.5}$ (outside)/ $PM_{2.5}$ (inside)** | **% Share of $PM_{2.5}$ (inside) in $PM_{10}$ (inside)** | **% Share of $PM_{2.5}$ (outside) in $PM_{10}$ (outside)** |
|---|---|---|---|---|
| **Average** | 1.3 | 1.2 | 65 | 59 |
| **Maximum** | 1.8 | 1.6 | 91 | 82 |
| **Minimum** | 1.1 | 0.8 | 43 | 43 |

to find the source of particulate pollution. Also, the percentage of $PM_{2.5}$ share in $PM_{10}$ inside the campus was comparatively higher than the outside, which implies that a higher percentage of exhaust emissions were observed inside the campus environment.This can be attributed to the resuspension of vehicular dust, which has a higher percentage of coarse particles. Thus, the lower vehicle movements compared to outside campus resulted in a higher percentage of fine particles in $PM_{10}$.

### 4.3.3 Effect of Day Type on PM Exposure

Fig. 4.4 represents the spatial and temporal (weekdays and weekends) concentrations of PM at both places. The University and the Outpatients Department (OPD) of the hospital are both open on Saturdays and closed on Sundays. The offices, schools and other establishments outside the campus are also open on Saturdays. Therefore, Saturdays are also treated as other weekdays. The analysis found a comparatively lower PM level at weekends. The median $PM_{2.5}$ levels inside and outside the campus on weekdays were found to be 135 and 155 μg $m^{-3}$, respectively, while the $PM_{2.5}$ levels on weekends were found to be 149 and 141 μg $m^{-3}$, respectively. The $PM_{2.5}$ inside the campus (149 μg $m^{-3}$) is slightly higher than outside the campus (141 μg $m^{-3}$) during weekends. This may be due to increased vehicle activity on weekends, as more tourists visit the campus for a temple. The median $PM_{10}$ levels inside and outside the campus on weekdays were found to be 238 and

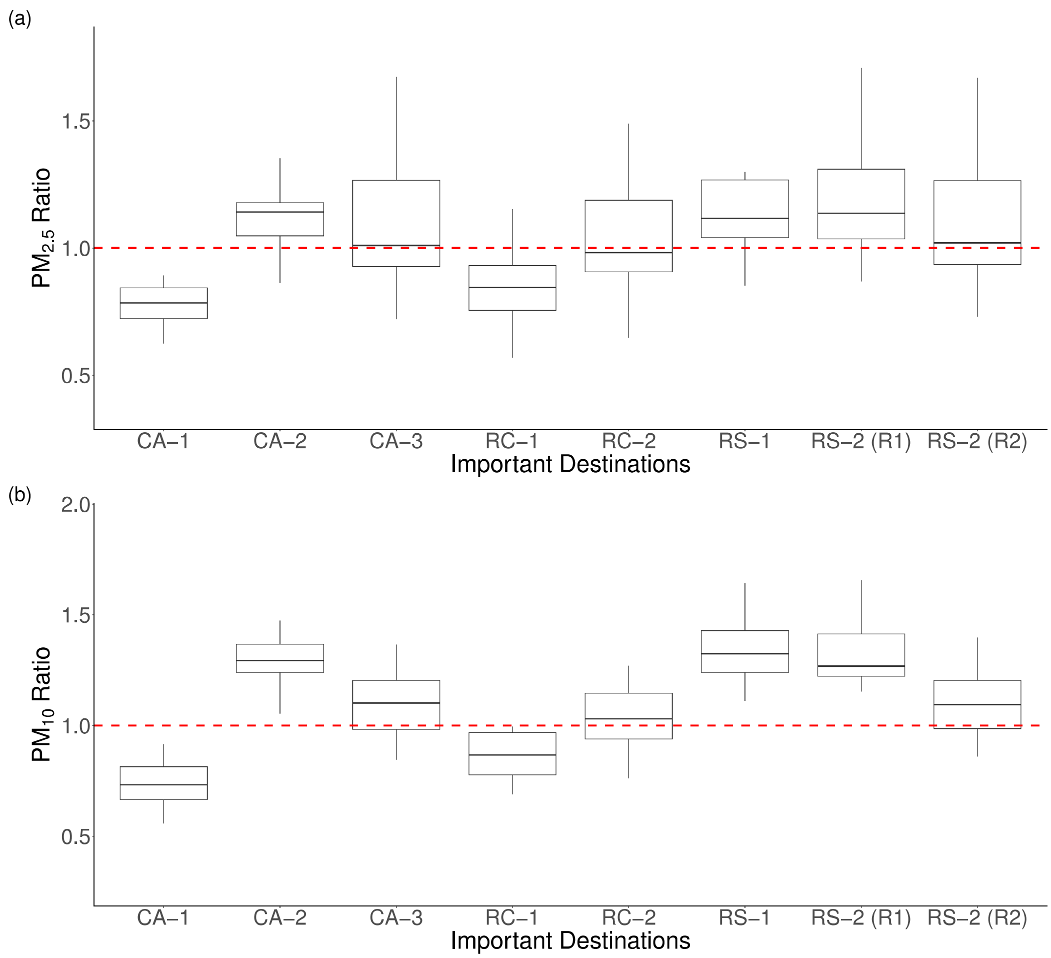



Fig. 4.3 Ratio of PM exposure outside to inside campus.

278 µg m$^{-3}$, respectively, whereas the pollutant concentrations on weekends were 201 and 231 µg m$^{-3}$, respectively. This study observed lower traffic flow on weekends both inside and outside the campus due to holidays, resulting in reduced human activities on weekends. Therefore, the study observed lower pollutant levels on weekends in both environments. The observation is corroborated by previous studies (Lonati et al., 2006; Song et al., 2020). Reducing road traffic can significantly lower PM concentrations (Gopalaswami, 2016; Yuval and Broday, 2008). Fig. 4.5 shows the effect of the day type on different trips to prominent places outside the campus. Both average $PM_{2.5}$ and $PM_{10}$ exposure on weekdays were found to be comparatively higher than on weekends. If possible, it is better to travel outside of the campus during weekends.

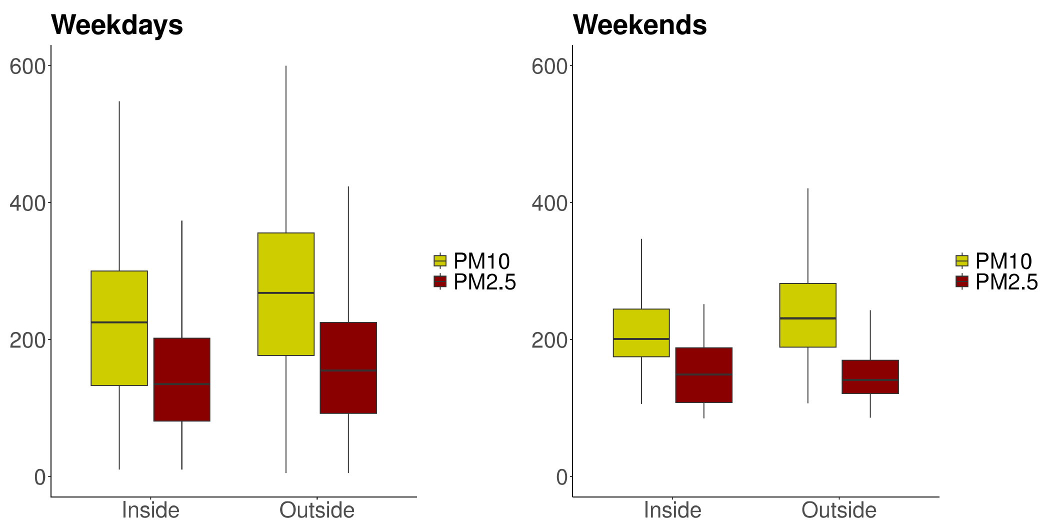



Fig. 4.4 Comparison of inside and outside PM (µg m$^{-3}$) exposure during weekdays and weekends.

### 4.3.4 Effect of Hour of the Day on PM Exposure

As shown in Fig. 4.6, the peak PM exposures were observed during non-rush hours (08:00 – 09:00), while comparatively lower exposures were observed during rush hours during 09:00 – 10:00 and 16:00 – 17:00. This trend is generally observed in the winter

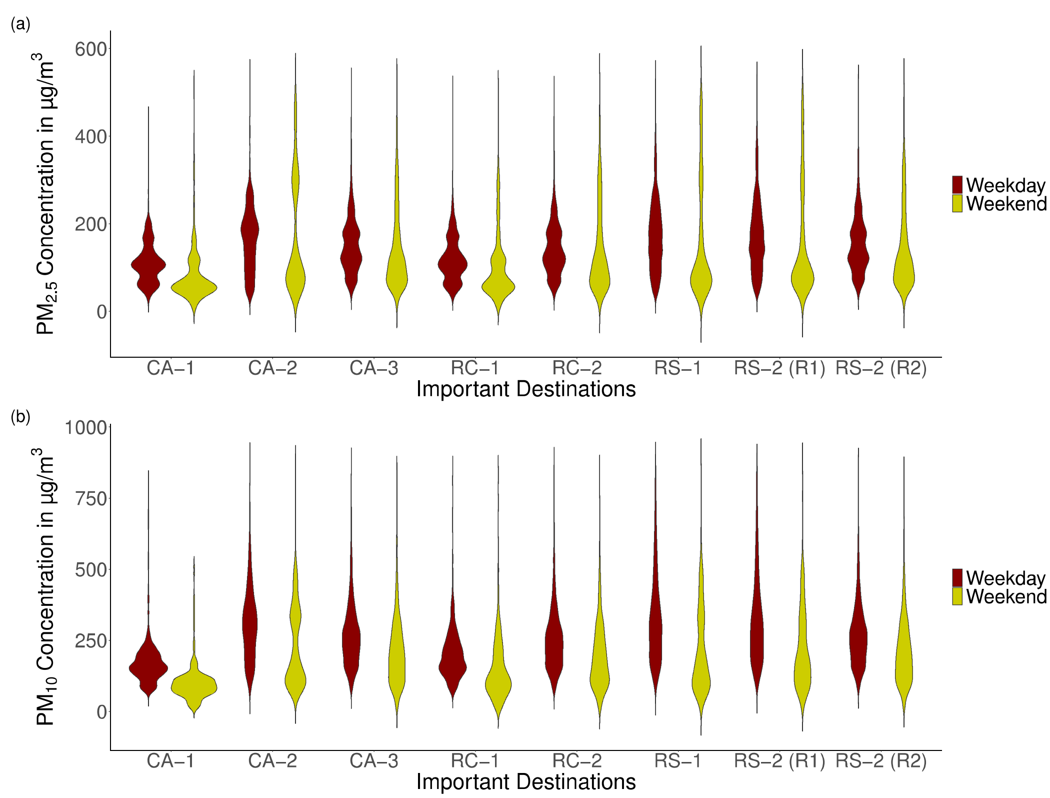



Fig. 4.5 Comparison of the effect of day of the week on trips to outside university locations.

season (Behera et al., 2023). The main cause behind this could be attributed to lower dispersion and dilution in winter (Kgabi and Mokgwetsi, 2009). Due to low wind speed and temperature, the dust particles take longer duration to get diluted and dispersed in the air. Thus, the particulates from the exhaust and non-exhaust emissions accumulated and higher PM concentrations were observed during non-rush hours. However, this trend was not observed during other non-rush hours (10:00 – 11:00 and 15:00 – 16:00). However, Behera et al. (2023) observed that the PM concentration in winter started increasing from the morning rush hour (09:00 – 10:00) and resulted in higher value during the mid-day non-rush hour (12:00 – 13:00).

### 4.3.5 Exposure Maps

Both $PM_{2.5}$ and $PM_{10}$ exposure concentrations were mapped (Fig. 4.7). Areas with multiple hotspots can be visualized on the map. Most segments outside the campus had $PM_{10}$ and $PM_{2.5}$, ranging between 331 – 602 and 173 – 281 µg $m^{-3}$, respectively. Meanwhile, the maximum number of segments outside the campus having $PM_{10}$ and $PM_{2.5}$ ranged between 241 – 331 and 137 – 173 µg $m^{-3}$, respectively. Therefore, it can be concluded that exposure levels were comparatively lower inside the campus compared to outside. Thus, the students, faculties and other employees are exposed to lower levels of pollutants and live in healthier environments. However, the environments, both inside and outside the campus, are not safe as the daily NAAQS limit is exceeded at all locations. Immediate attention should be given to counter the higher pollution levels. The public administration and urban planners should frame certain policy measures for lowering pollution levels.

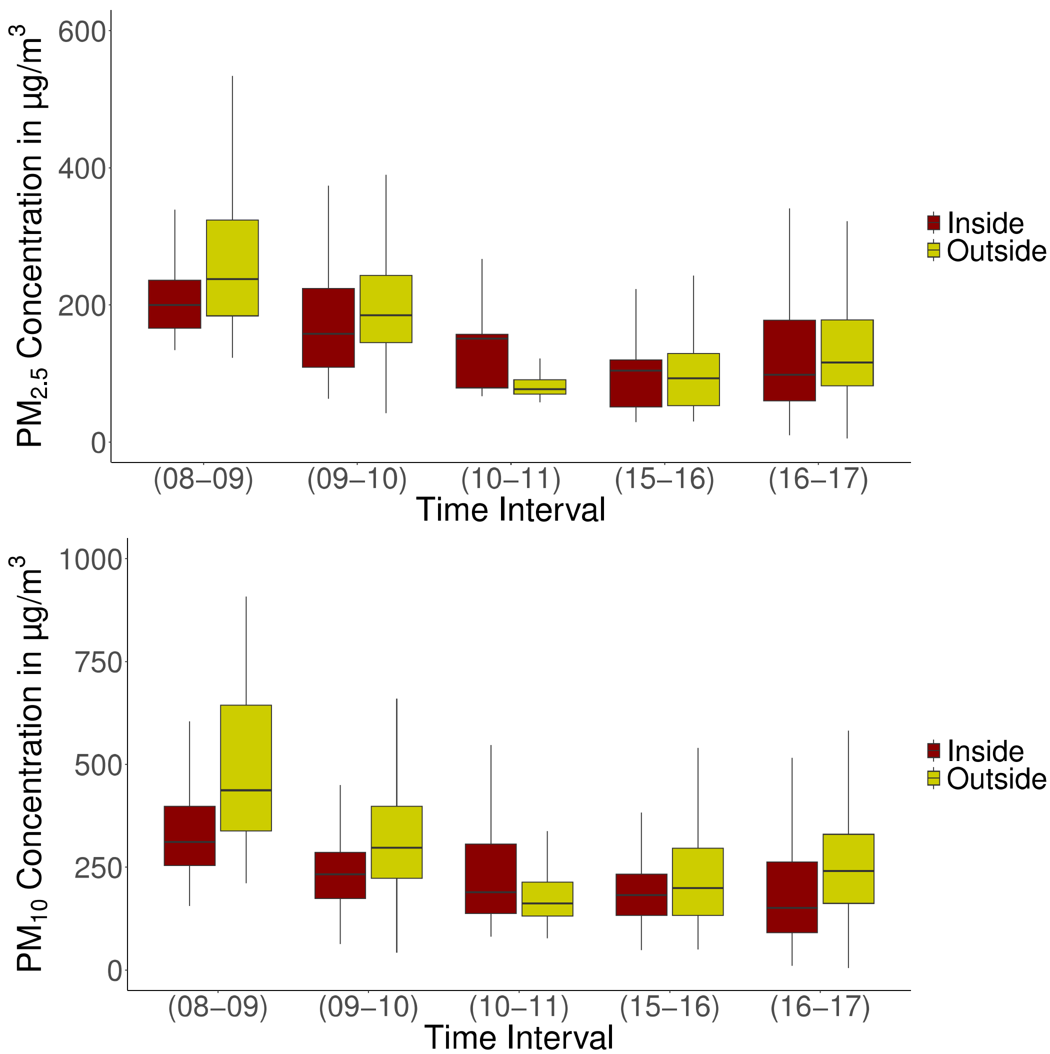
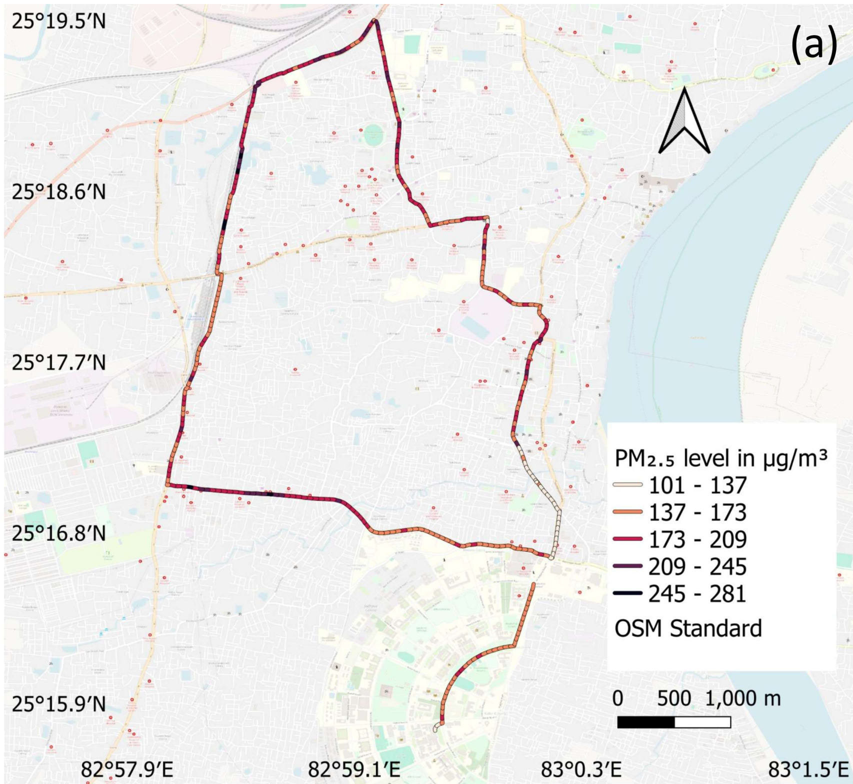



Fig. 4.6 Comparison of PM levels at different hours of the day.



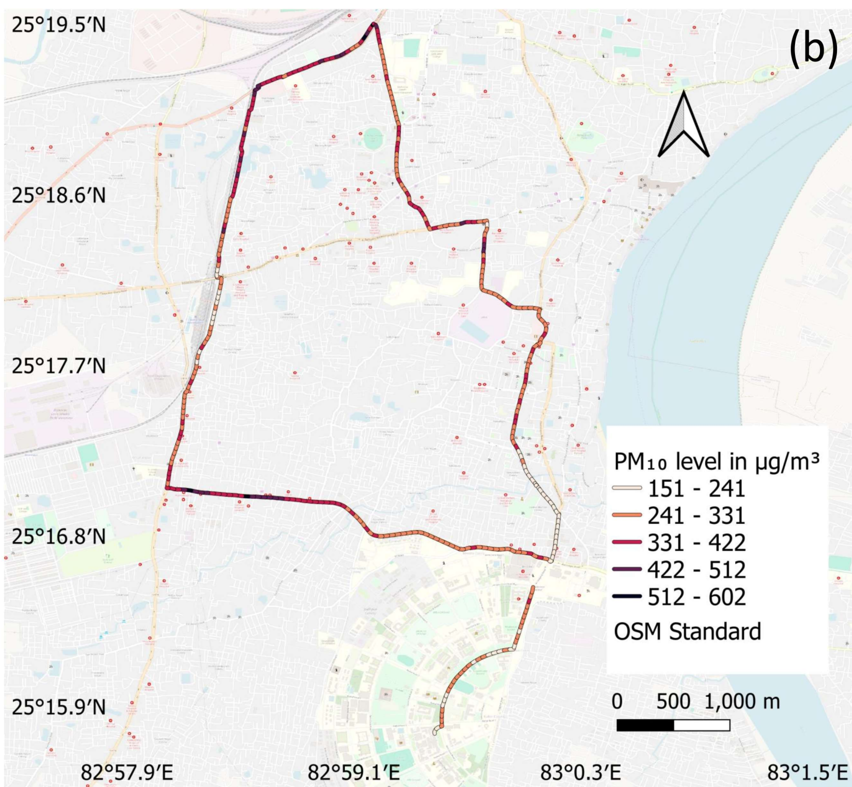




Fig. 4.7 Inside and outside $PM_{2.5}$ and $PM_{10}$ exposure maps of the university campus.

### 4.3.6 Relationships between Inside and Outside PM Exposures

The inside and outside PM concentrations were correlated. PM concentration in inside and outside environments showed a strong correlation for both $PM_{2.5}$ and $PM_{10}$. The outside $PM_{2.5}$ was positively correlated (r: 0.75) with inside $PM_{2.5}$, while the outside $PM_{10}$ concentration was positively correlated (r: 0.88) with inside $PM_{10}$. The higher correlation for $PM_{2.5}$ might be due to traffic volume inside and outside being correlated at peak hours. Liu et al. (2014) found an almost equal correlation between $PM_{2.5}$ (0.67) and $PM_{10}$ (0.72) in the indoor-outdoor exposure study. Fig. 4.8 shows the linear relationship between inside and outside environments for both $PM_{2.5}$ and $PM_{10}$ concentrations. The coefficient of determination (R2) values for $PM_{2.5}$ and $PM_{10}$ were found to be 0.56 and 0.78, respectively.

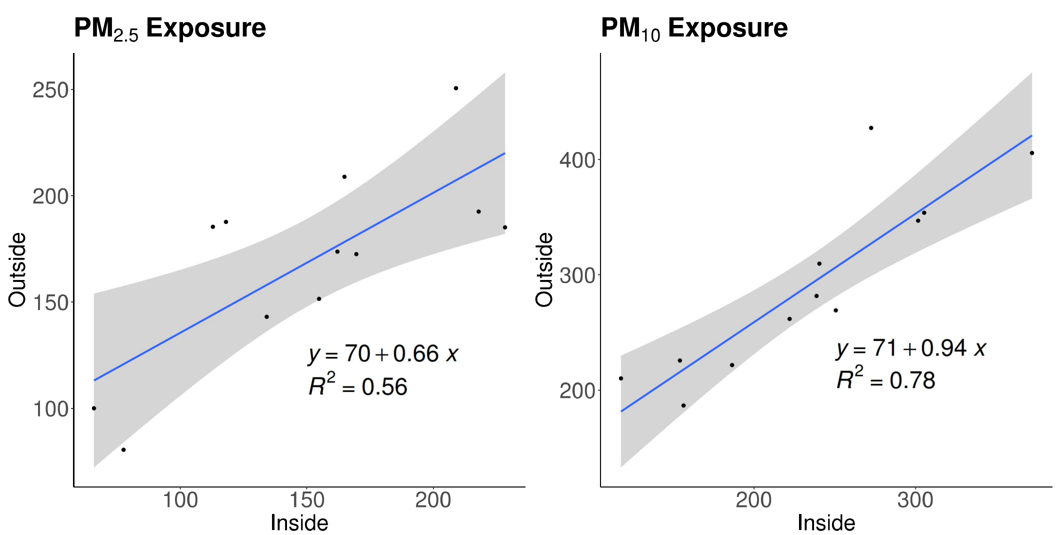



Fig. 4.8 Linear relationship between exposure to particulate matter inside and outside the campus.

### 4.3.7 Inhaled Doses

Table 4.5 presents a summary of the inhaled dose per km and per trip, both inside and trips to outside the university campus. The average weekday (weekends) inside and outside $PM_{2.5}$ doses per km were 4.5 (5.5) and 5.7 (2.5) µg, respectively. However, average weekday (weekends) inside and outside $PM_{2.5}$ doses per trip were 8.3 (10.2) and 45.1 (23.2) µg, respectively. The same trend was observed for $PM_{10}$ doses, both per km and per trip. Considering trips to prominent locations, weekend trips resulted in lower PM doses for both per trip and km compared to weekday trips. However, the weekend PM dose, both per trip and per km inside the campus, was found to be higher than on weekdays. The reason for the anomaly might be due to higher trips to commercial areas during weekends to outside campus. The inhaled dose estimation (see Eq. 4.1 and 4.2) is completely time-dependent. Hence, the time taken during trips on weekends was higher compared to weekdays, which resulted in higher PM doses during weekends.

Table 4.5 PM dose (µg) inhaled during Weekday (Weekend) trips to destinations outside the campus.

| **Location** | **PM Dose per km** | | **PM Dose per trip** | |
|---|---|---|---|---|
| | **$PM_{2.5}$** | **$PM_{10}$** | **$PM_{2.5}$** | **$PM_{10}$** |
| Inside | 4.5 (5.5) | 7.4 (7.9) | 8.3 (10.2) | 13.5 (14.5) |
| Commercial Area-1 | 4.2 (1.5) | 6.4 (2.9) | 1.9 (0.7) | 2.9 (1.4) |
| Commercial Area-2 | 6.2 (1.6) | 11.1 (3.1) | 12.4 (3.1) | 22.0 (6.1) |
| Commercial Area-3 | 5.7 (3.3) | 9.8 (6.9) | 31.6 (18.7) | 54.6 (38.3) |
| Religious Center-1 | 4.9 (2.6) | 8.0 (5.7) | 6.4 (3.4) | 10.4 (7.5) |
| Religious Center-2 | 5.3 (3.5) | 9.0 (6.7) | 20.5 (13.7) | 35.2 (26.2) |
| Railway Station-1 | 6.7 (2.0) | 12.2 (4.3) | 36.1 (10.5) | 65.1 (22.8) |
| Railway Station-2 (R1) | 6.6 (2.0) | 11.8 (4.3) | 59.2 (18.0) | 105.7 (38.8) |
| Railway Station-2 (R2) | 5.8 (3.3) | 9.9 (6.8) | 37.9 (21.8) | 65.0 (44.8) |
| **All Outside Average** | 5.7 (2.5) | 9.7 (5.1) | 25.7 (11.3) | 45.1 (23.2) |

The PM doses per trip were higher on all trips to outside locations compared to per km doses, except for the commercial area-1. The trip length (D: 0.46 km) to the commercial area-1 was less than 1 km. Thus, the PM doses per km were found to be higher for the trip to this location compared to doses per trip. The difference between inside and outside PM doses per trip was found to be highly significant compared to per km doses (see Table 4.6). The primary reason behind this was the travel duration (T) during each trip, which is affected by the trip length. The trip length varied depending on the destinations. Due to traffic conditions and travel time fluctuations, higher doses of PM were observed outside the university campus. Commuters do not always cover the whole trip. Thus, the inhaled doses per km can be a better approach than per-trip doses for comparing inhaled doses between two environments. Except for the location (inside and outside), these environments can be different transport modes, workplaces, playgrounds or hospitals.

Table 4.6 Difference in PM doses between trip portions inside and outside the university campus.

| **Dose Type** | **$PM_{2.5}$** | | | **$PM_{10}$** | | |
|---|---|---|---|---|---|---|
| | **95% CI** | **t-value** | **p-value** | **95% CI** | **t-value** | **p-value** |
| Per km | -3.36 to 0.88 | -1.21 | 0.24 | -7.22 to 1.09 | -1.53 | 0.14 |
| Per trip | -108.41 to -58.83 | -1.53 | < 0.001 | -203.50 to -95.87 | -6.11 | < 0.001 |

## 4.4 Summary

Mixed results were found in different indoor-outdoor studies around the world. Some studies found the indoor environment to be more polluted, whereas others found outdoor environments to be more polluted. A university campus may be treated as an indoor environment for the students. It is important to investigate how healthy the university campus is in terms of exposure to PM concentration and compare the exposure concentration inside the campus with respect to that outside the campus. Thus, the objective of this study was to explore PM concentration inside the university campus concerning the outside environment. The following conclusions are drawn:

1. The daily PM concentrations inside the campus were significantly less than the concentrations outside campus (difference in $PM_{2.5}$: 18 μg $m^{-3}$ and $PM_{10}$: 57 μg $m^{-3}$). The PM exposures were higher on weekdays, both inside and outside the campus, due to the higher vehicular movements in comparison to weekends.

2. The exposure levels of PM outside the campus were strongly correlated with inside PM concentration. Thus, the PM concentrations in the outside portion of trips can be estimated with the help of PM measurements inside the university campus.

3. Both $PM_{2.5}$ and $PM_{10}$ exposure inside and outside the campus exceeded the NAAQS ($PM_{2.5}$: 60 μg $m^{-3}$ and $PM_{10}$: 100 μg $m^{-3}$) daily limit. However, fine pollutants can penetrate the lungs more than coarse particles. $PM_{2.5}$ being a greater health hazard than $PM_{10}$, the University campus seems to be safer for students as compared to the outside environment.