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Study on Indoor Air Quality Status of Fine Particulate Matter: A Case Study

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Abstract
The increasing levels in developing countries and the apparent scale of its impactson human health highlights the importance of particulate matter as an environmental health risk. The human health effects of outdoor PM are well-established and are used to set health-based standards for outdoor of ambient air. Particulate Matter is also found in all indoor environments. Indoor PM levels have the potential to exceed outdoor PM levels.In developed countries, people spend about 90% of their time indoors; hence the study of indoor air quality is as important as for the outdoors. PM2.5 was measured inside DTU Library during winter and summer, on differentfloors for the altitude and seasonal variations. PM concentrations were measured using EPAM 5000 Haz-Dust. The result of the study showed that the PM concentrations were directly proportional to average footfall and inversely proportional to altitude. The indoor average concentrations during winter and summer was the maximum for ground (365µg/m³, 144µg/m³) followed by first (250µg/m³, 127µg/m³) and second (210µg/m³, 117µg/m³) floors respectively. The seasonal comparison showed that the concentration was higher in winter than in summer.

1. Introduction

Indoor air quality is the air quality within and around buildings and structures, as it affects the health and comfort of the building occupants (Introduction to indoor air pollution, USEPA). Understanding and controlling common indoor pollutant is necessary for the reduction of health risks. Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the area. High temperature and humidity levels can also increase concentrations of some pollutants. Major sources of indoor air pollution include: Fuel-burning combustion appliances, tobacco products, deterioration of insulation material, carpet and furniture, central air conditioning systems, excess moisture and majorly outdoor pollution. Components of indoor air pollution include asbestos, biological pollutants, carbon monoxide, lead, nitrogen dioxide, radon, indoor particulate matter, smoke and VOCs.

Many health effects show up shortly after the exposure to a pollutant. These eye irritation, nose and throat problem, headaches, dizziness, and fatigue. Immediate effects are generally short term effects and are treatable. The level of reaction to the exposure of indoor air pollution depends on the individual sensitivity, age and preexisting medical conditions for the person under consideration. Long term effects include respiratory diseases, heart diseases and cancer, which may be fetal.

Risk analysis to the community caused by exposure to airborne pollutants should ideally include measurements of concentration levels of the pollutants in the microenvironments, where people spend their time. Due to the multiplicity of different microenvironments, it is usually, however, not possible to conduct measurements in all of them (Morawska et al; 2001). Considering the human exposure to airborne pollutants specifically fine fractions, of particular importance due to its higher probability of penetration into the deeper parts of the respiratory tract (Brick et al; 1997) and also contain higher levels of trace elements and toxin (Ando et al; 1996 and Kiss et al; 1998).

A large number of studies have been published, some based on reanalysis of the older results and some on new data sets, have greatly improved the ability to establish the health effects from particulate air pollution (Smith et al; 2002 and Kulkarni MM; 2006). Importantly, these studies have emphasized on the importance of small size fraction, which showed no apparent thresholds at lower concentration. A better characterization of the health relevant particle fraction will have major implication for air quality policy since it will determine which source should be controlled (Hoek et al; 2008).

Particulate matter (PM2.5) is the most ubiquitous air pollutant having many health effects. Fuel combustion processes and energy production are the primary sources of the outdoor PM2.5, while cooking, smoking and cleaning activities contribute primarily to the indoor PM2.5 levels (Massey et al; 2009). Traffic-related fine particles are recognized as an important contributor to outdoor PM2.5 concentrations. The concentration of airborne particles inside a house is governed by the generation of particles within the house, the concentration of particles outside the house, the rate of air exchange and the depositional characteristics of the particles. Most houses in the developing world are naturally ventilated, allowing particles from out-of-doors to readily penetrate the house through given spaces and cracks in the structure.

Reports (USEPA, 1987; NIOSH, 1998) suggest that the highest levels of atmospheric pollutants found not outdoors, but rather inside the buildings we live and work in. Indoor air pollution may be responsible for many human diseases such as eye, nose and throat irritation, headaches, nausea, heart diseases, chronic lung diseases and cancer (WHO 1999). There is growing concern about indoor air quality and this has consequently led to many studies on air quality in offices, hospitals, schools and libraries (NIOSH 1998, Godish 1989).

In libraries, pollutants are caused by the deterioration and handling of books, skin exfoliation, human breathing, photocopying, using chemical substances to clean furniture and floors, among other aspects (Christinelli et al; 2011).Bio-aerosols, containing bacteria, fungi and their excrements are expected to be found in libraries. Moreover, the fact that people are constantly moving helps keep the dust, particularly the larger sized particles, in the air for more time. Most houses in the developing world are naturally ventilated, allowing particles from out-of-doors to readily penetrate the house through given spaces and cracks in the structure.

2. Objective

The main objectives of this study are:

- To compare the air quality in DTU librarywith the outside air quality by measuring the average concentration of PM2.5.
- To study the trend of temporal variations of fine particulate matter concentration.
- To establish the relationship between PM2.5 concentration with altitude and average footfall.
- To compare and analyse the monitored concentration of PM2.5 during winter and summer season (seasonal variation).

3. Methodology

3.1 Monitoring Location

The study was conducted in DTU Library, which is situated in the geographical center in the DTU campus located in Bawana, Delhi. The library is fully air-conditioned having 3 floors (ground floor,1st floor and 2nd floor).DTU has about 8000 enrolled students. Approximately 1000 people circulate in the library per day from Monday to Saturday. The library is closed on Sunday. It has approximately 150,000 printed volumes. All floors have tables and chairs where students read their individual books. The campus is surrounded by residential colonies on one side, Yamuna link canal and Agricultural land on the other side. The instrument was placed at 0.3 metre from the walls and on the desks which were around 1 metreabove the ground, which is the actual breathing height for most of the students sitting in the library.

3.2 Instrument: EPAM 5000 Haz-Dust Sampler

The EPAM-5000 uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m^3 of airborne dust particles This principle utilizes an infrared light source positioned at a 90-degree angle from a photo detector. As the airborne particles enter the infrared beam, they scatter the light. The amount of light received by the photo detector is directly proportional to the aerosol concentration. A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability. Interchangeable size-selective impactors allow PM10, PM2.5, and PM1.0 monitoring; TSP measuring does not require an impactor. Download and store sampling data on a PC for analysis and reporting using included DustComm Pro Software. The instrument is a real time concentration detecting device which records the data itself and eliminates the need of laboratory analyses. The portable HAZ-DUST EPAM-5000 particulate monitor is ideal for ambient, environmental, and indoor air quality investigations.

3.3 Sampling of PM 2.5

Time varying concentrations of PM2.5 were measured and collected using EPAM 5000.The EPAM 5000 is a highly sensitive and accurate portable monitor for ambient and environmental monitoring. Interchangeable size-selective sampling heads for PM10, PM2.5, PM1.0 and TSP enables specific particle fractions to be targeted.The samples were collected on each floor with a sampling frequency of 10 seconds, with air flow rate of 4 L/minute for one hour intervals. They were taken between the working time 9a.m. to 10 p.m. Real timeconcentrations levels were recorded into the device itself in the internal memory. The data were then further downloaded from the instrument using the DustComm software and graphical analysis was done. A total of twelve samples was taken in four days, of which, one was non-working (Saturday) and other were working days. They were taken for one hour on different floors. Total 360 readings were recorded in one sample.

4. Observations

Data was recorded for four days on each of the three floors in the library of DTU during winter season(December) and summer season (May); data were plotted showing the relationship of concentration of PM2.5 with respect to time. 1st day of sampling during the winter session was a busy day, due to exams. So concentration was higher as compared to other days. Although the permissible limit for PM2.5 in indoor locations set by WHO is 25µg/m^3 and according to USEPA, it is 65µg/m^3.

4.1 During Winters

Ground Floor Sampling:

Sampling was done in four sessions on the ground floor. The fact, that the concentration of PM2.5 is higher at low height, is proved by numerous studies (Kyung Hwa Jung et al; 2011). Adding to this, the study was done during examination period so the circulation of students in library was high and maximum on the ground floor. Concentration of particulate matter was ranging from 400µg/m^3 to 460µg/m^3 on exam day, which is 16 to 18 times higher than the limit set by the World Health organization. But the concentration levels decreased gradually as the footfall decreased during the following days.Figure 1(a), 1(b), 1(c) and 1(d) represents the sampling on ground floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

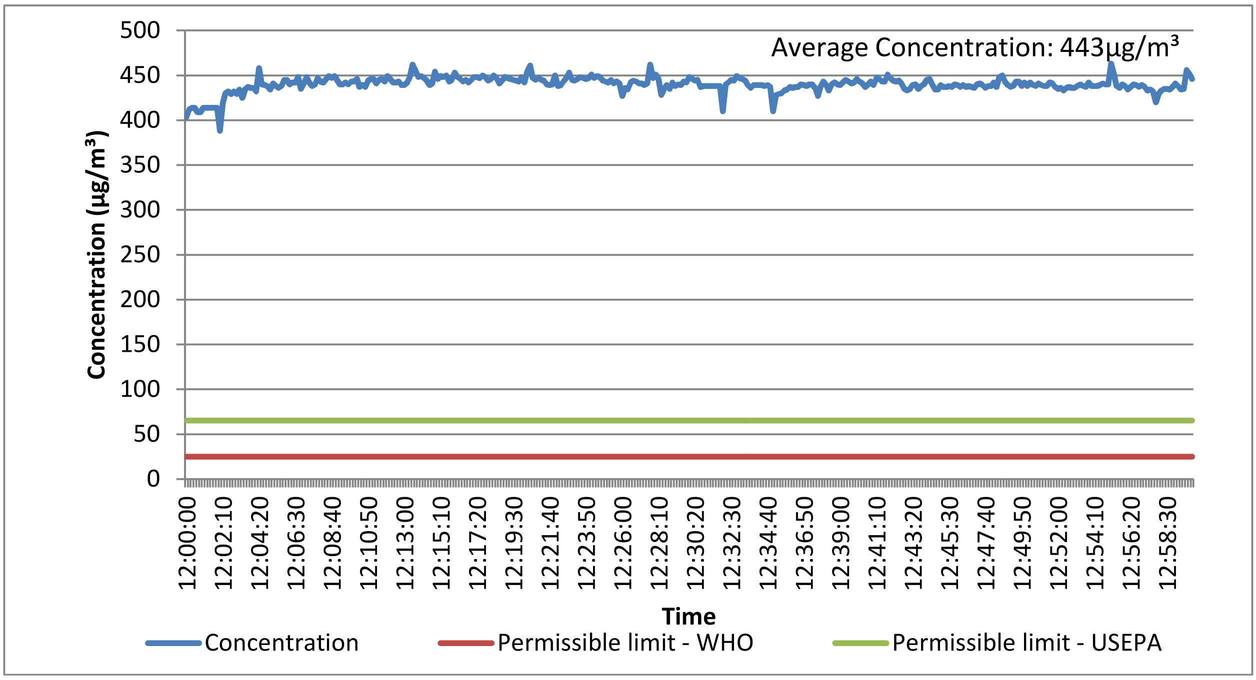

Figure 1(a)-Temporal Variation of PM2.5 at Ground floor (day 1)

b

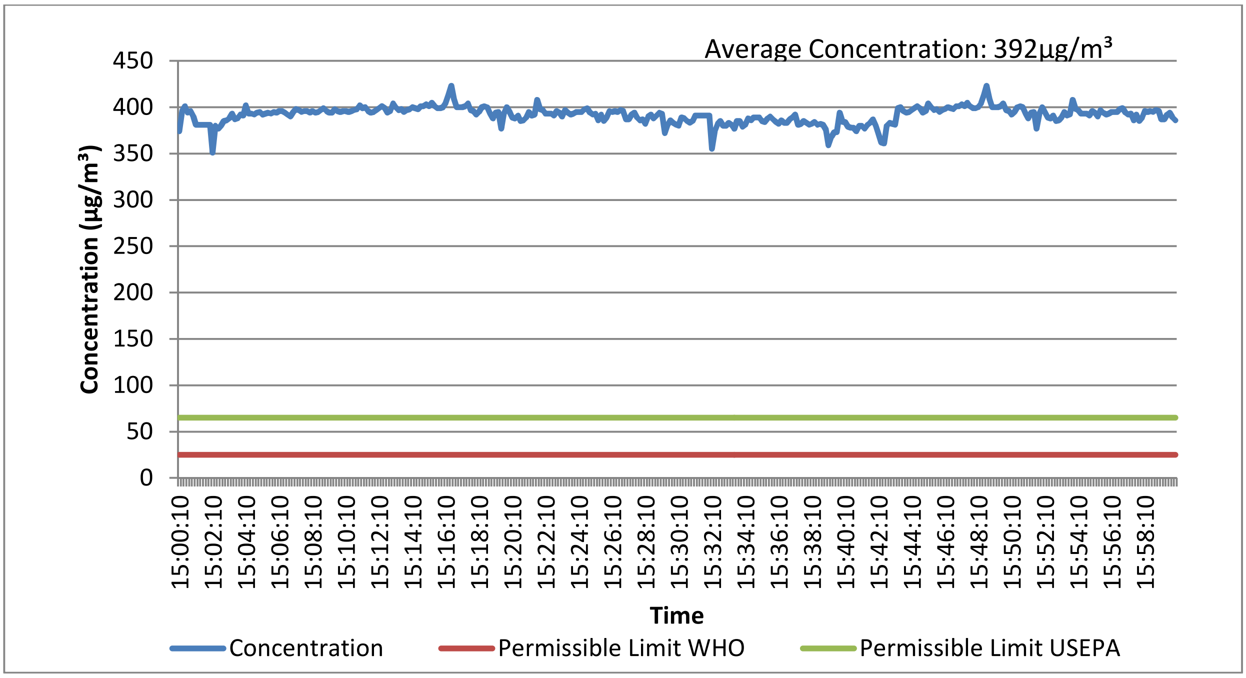

Figure 1(b) Temporal variation of PM2.5 on Ground floor (day 2)

c

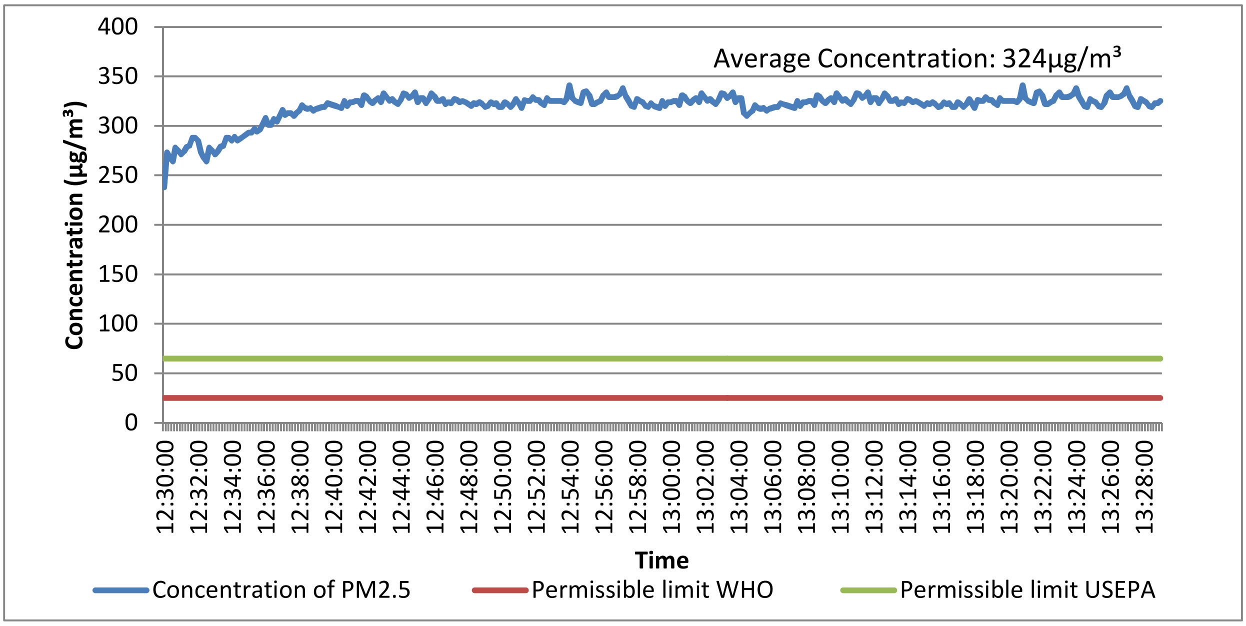

Figure 1(c) Temporal variation of PM2.5 on Ground floor (day 3)

d

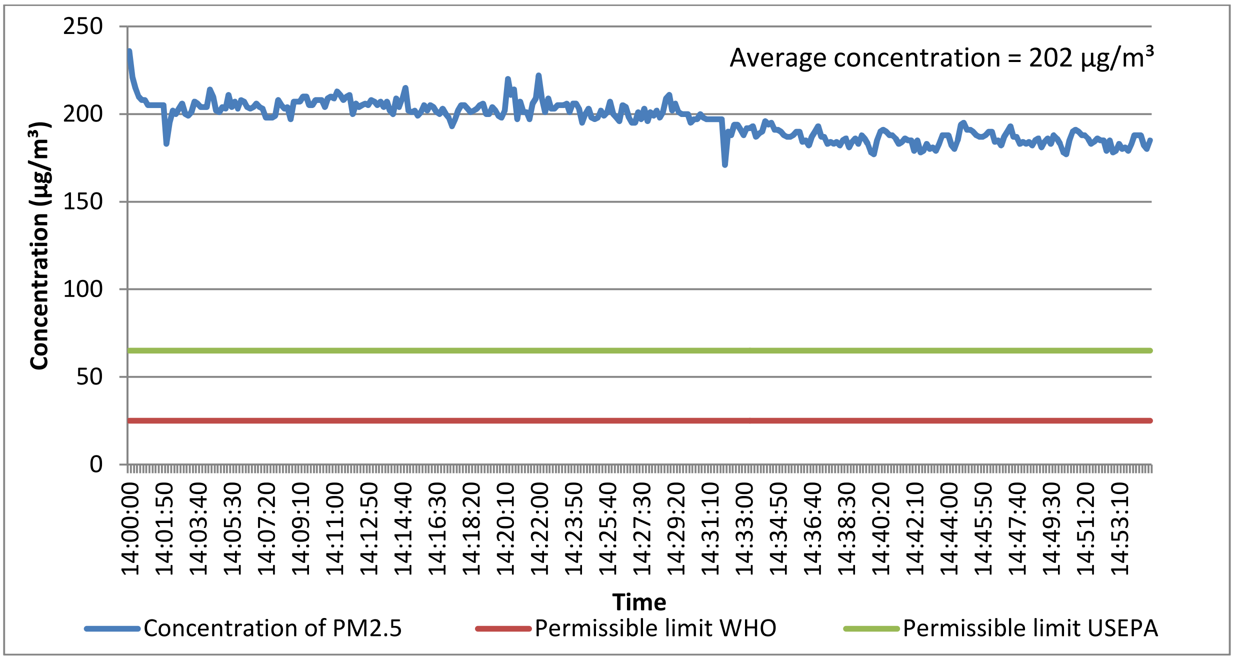

Figure 1(d) Temporal variation of PM2.5 on Ground floor (day 4)

First Floor Sampling

Four samples were taken on the first floor. As Exams were going on, the circulation of students in library was high, but on this floor it was less as compared to ground floor. Concentration of particulate matter was ranging from 300µg/m^3 to 349µg/m^{3}on exam day, but decreased gradually in the later days.Figure 2(a), 2(b), 2(c) and 2(d) represents the sampling on first floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

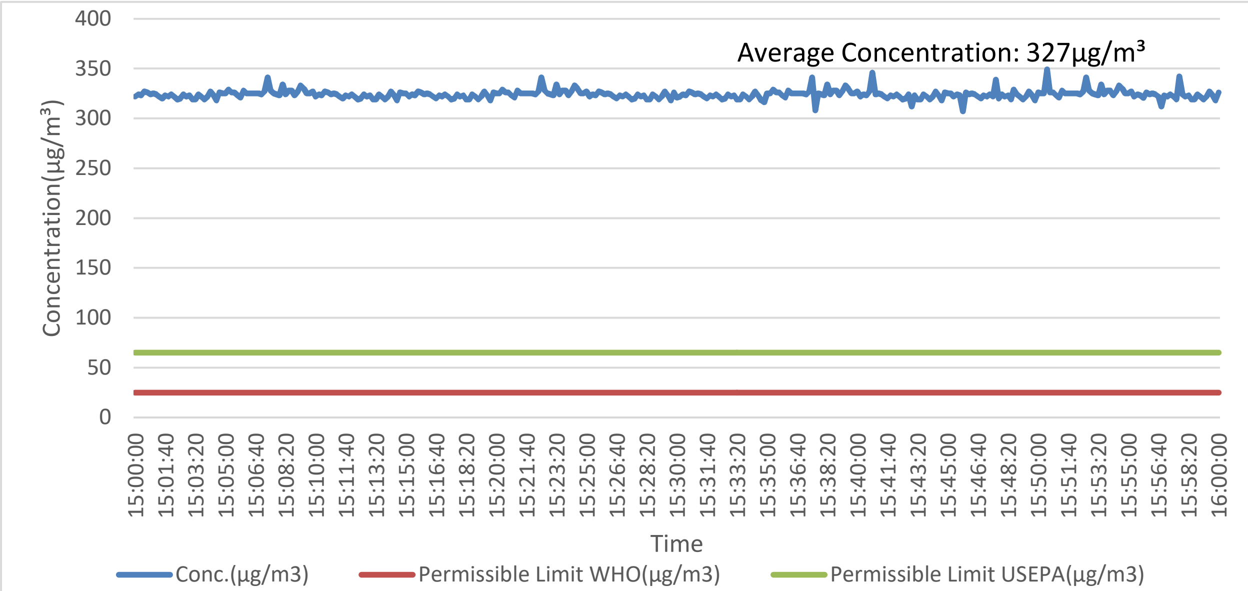

Figure 2(a) Temporal variation of PM2.5 on First floor (day 1)

b

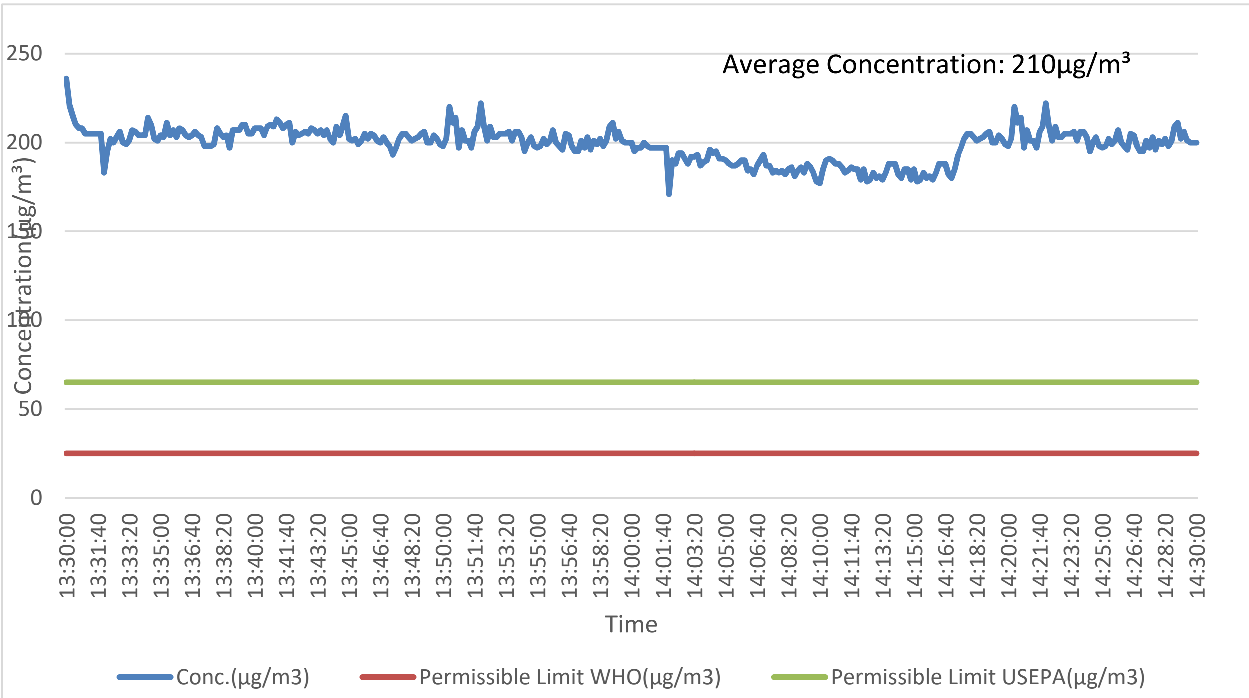

Figure 2(b) Temporal variation of PM2.5 on first floor (day 2)

c

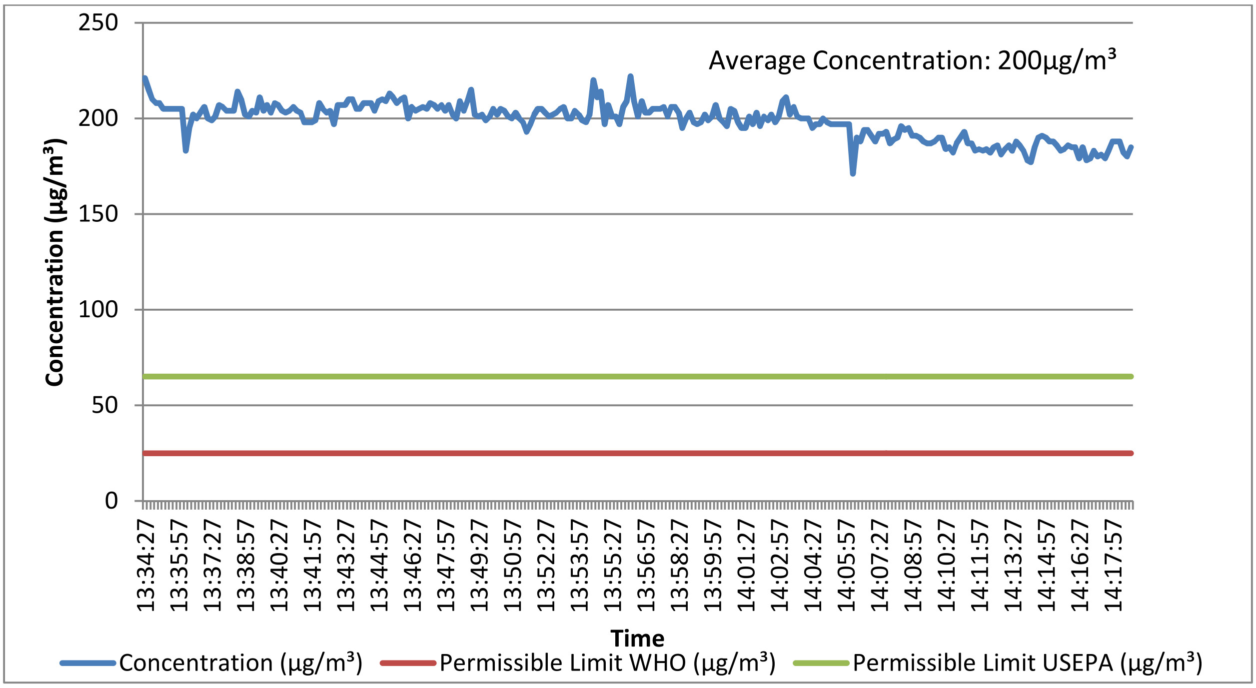

Figure 2(c) Temporal variation of PM2.5 on first floor (day 3)

d

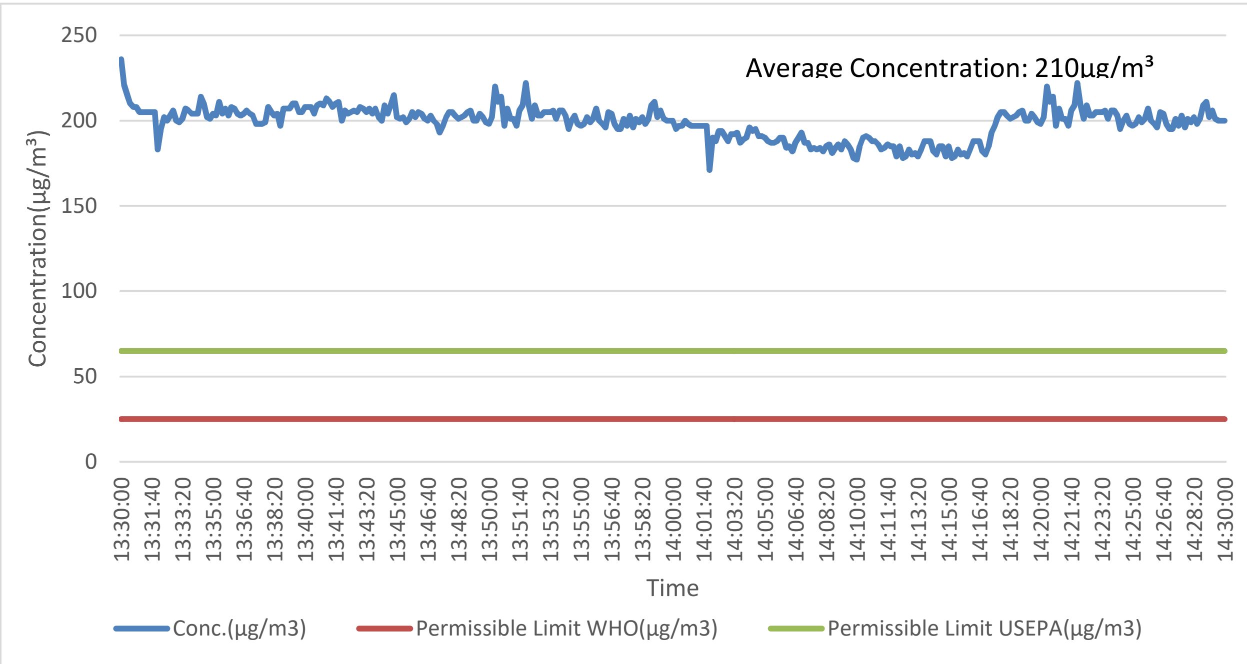

Figure 2(d) Temporal variation of PM2.5 on first floor (day 4)

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Second Floor Sampling

Four sets of samples were collected on Second floor. Even as the circulation of students was high in the library, due to exams, but on this floor concentration of PM 2.5 was least. Concentration of particulate matter was ranging from 350µg/m^3 to 420µg/m^3 on exam day and lower on other days.Figure 3(a), 3(b), 3(c) and 3(d) represents the sampling on second floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

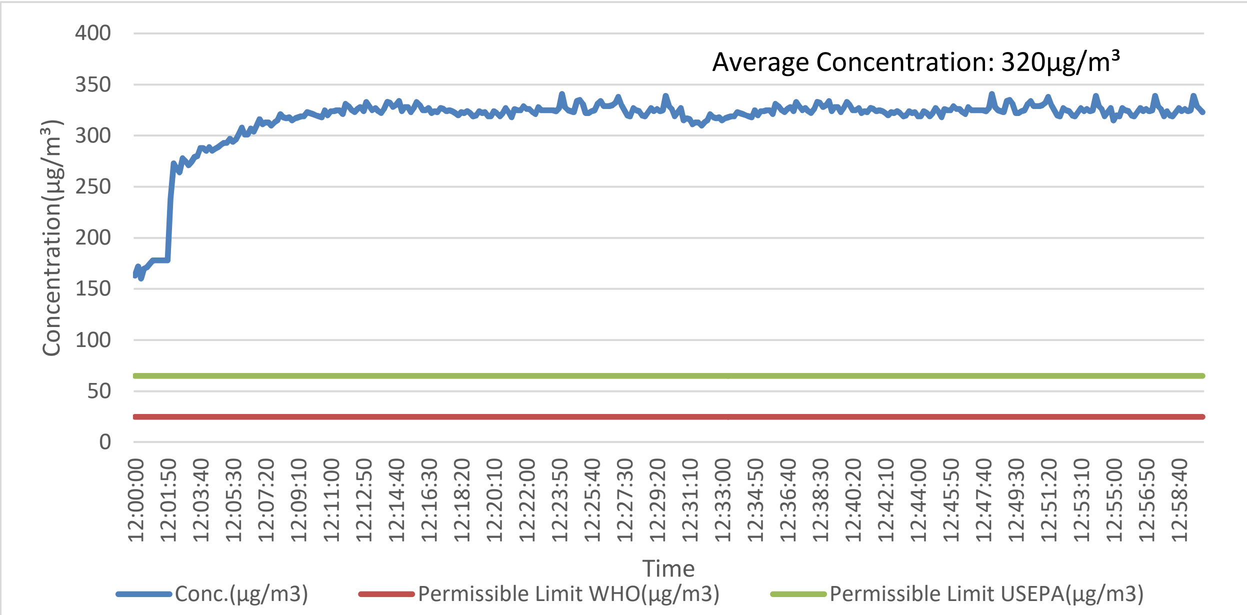

Figure 3(a) Temporal variation of PM2.5 on second floor (day 1)

b

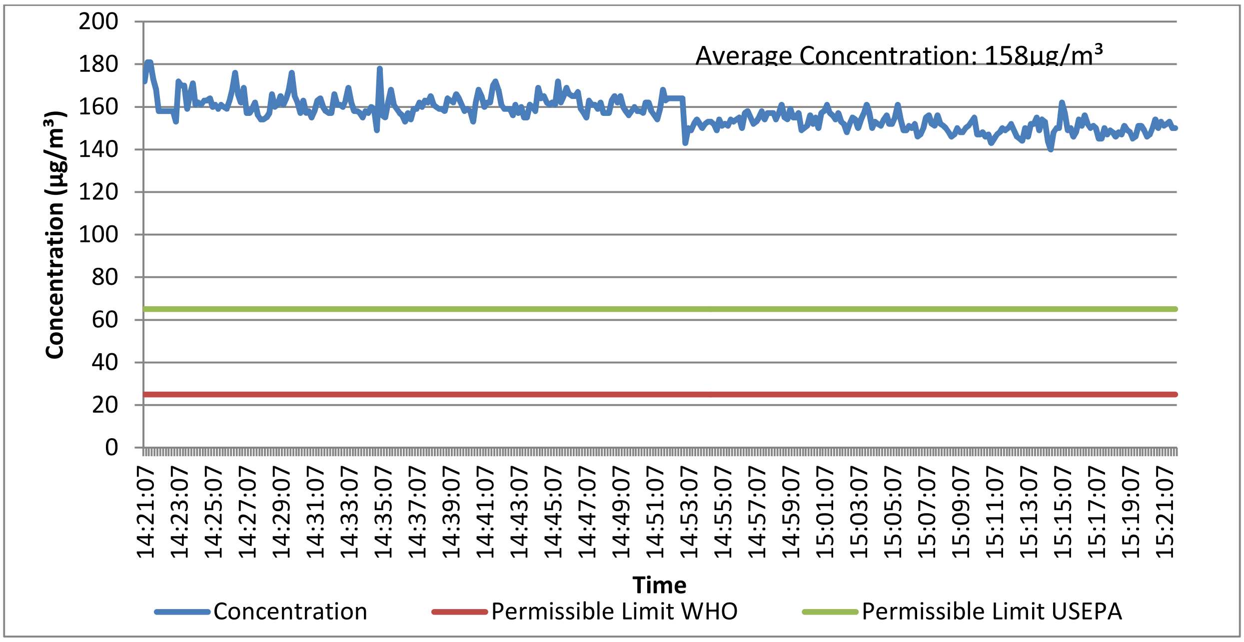

Figure 3(b) Temporal variation of PM2.5 on second floor (day 2)

c

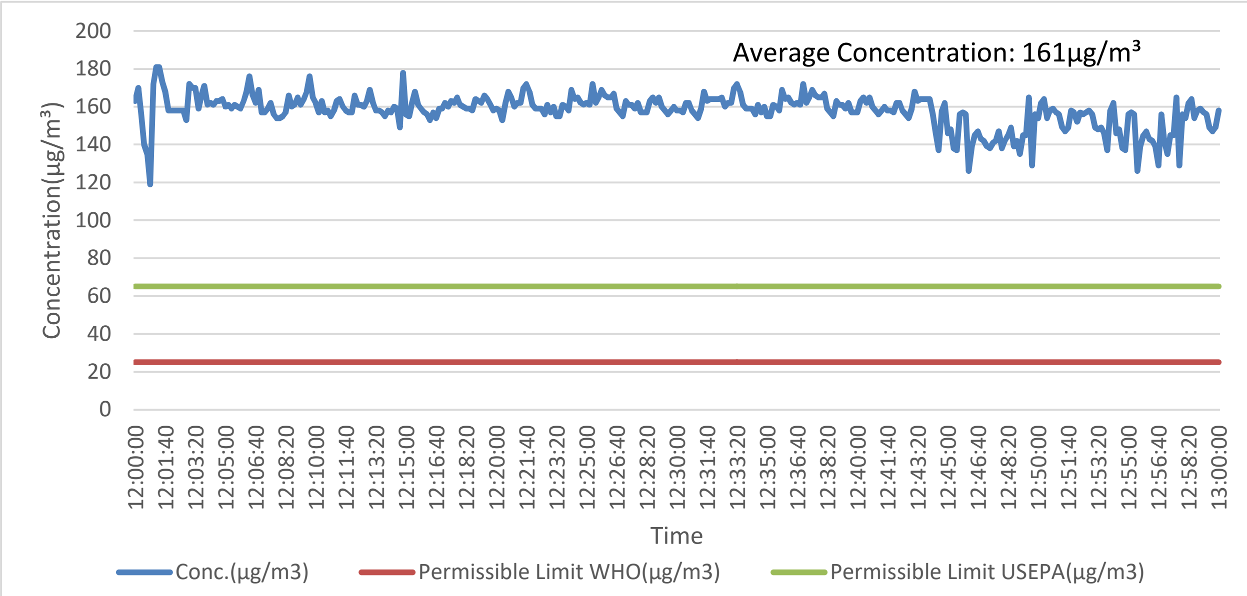

Figure 3(c) Temporal variation of PM2.5 on second floor (day 3)

d

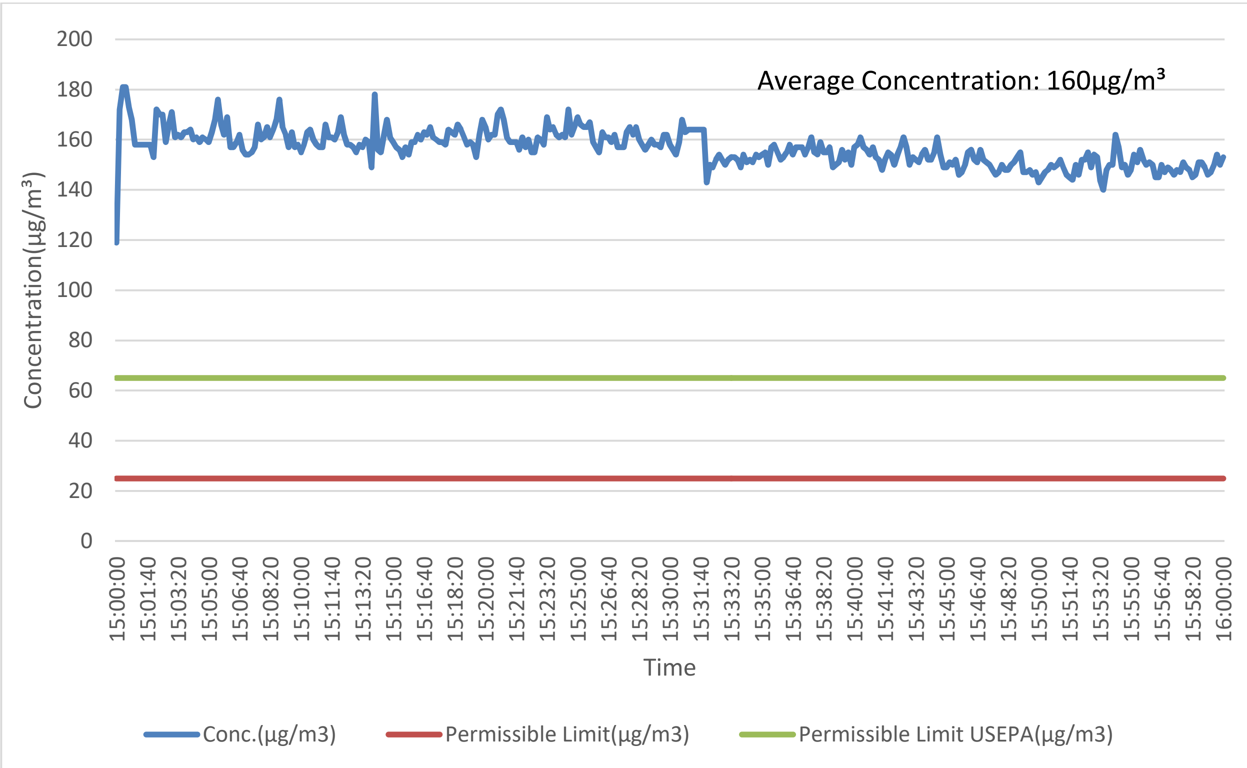

Figure 3(d) Temporal variation of PM2.5 on second floor (day 4)

4.2 During Summers

Ground Floor Sampling

Sampling was done in four sessions on the ground floor. The fact, that the concentration of PM2.5 is higher at low height, is proved by numerous studies (Kyung Hwa Jung et al; 2011). Adding to this, the study was done during examination period so the circulation of students in the library was high and maximum on the ground floor. Concentration of particulate matter was ranging from 130µg/m^3 to 180µg/m^3 on exam day, which is 5 to 7 times higher than the limit set by the World Health organization. But the concentration levels decreased gradually as the footfall decreased during the following days.Figure 4(a), 4(b), 4(c) and 4(d) represents the sampling on the ground floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

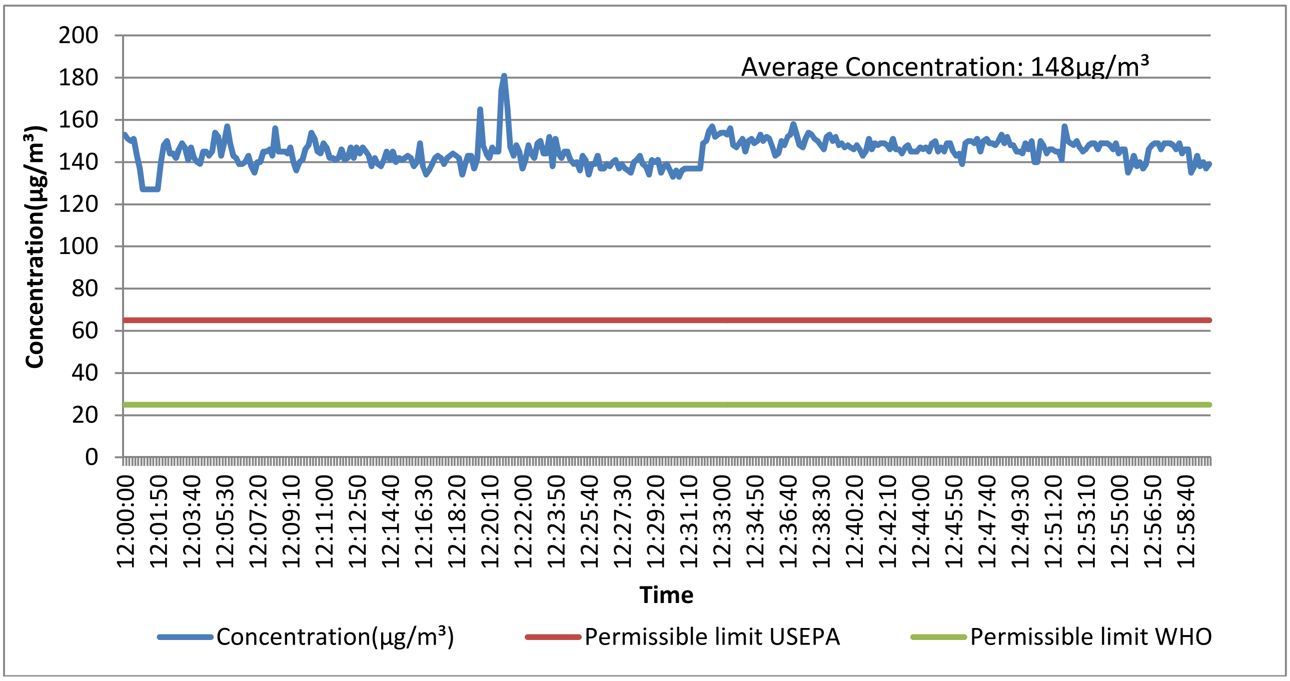

Figure 4(a)-Temporal Variation of PM2.5 at Ground floor

b

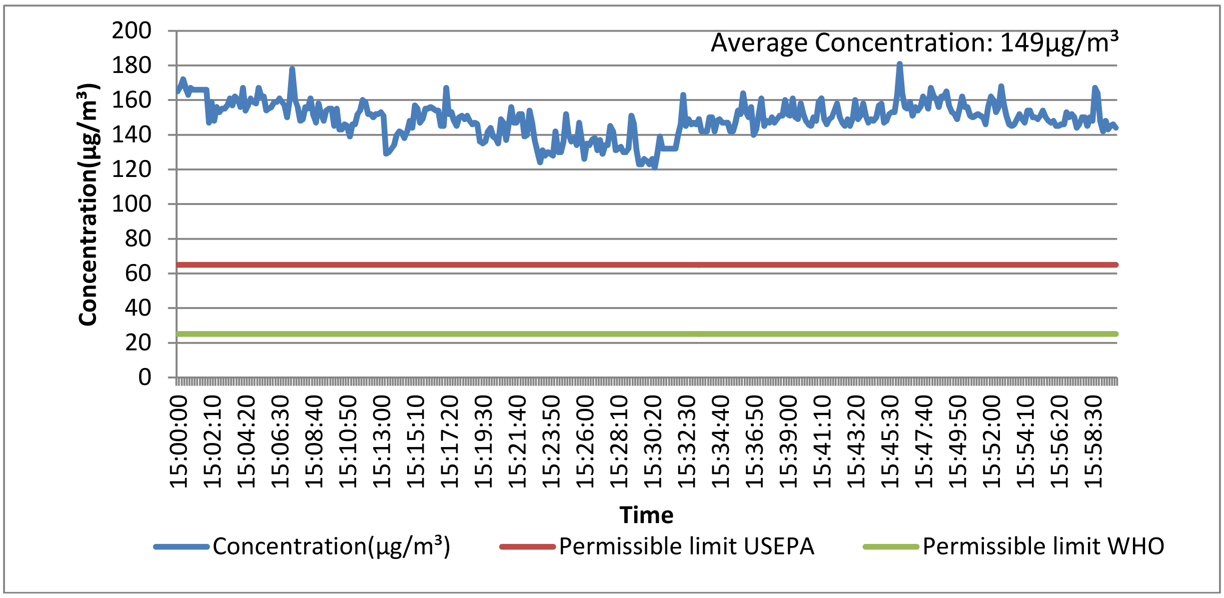

Figure 4(b) Temporal variation of PM2.5 on Ground floor

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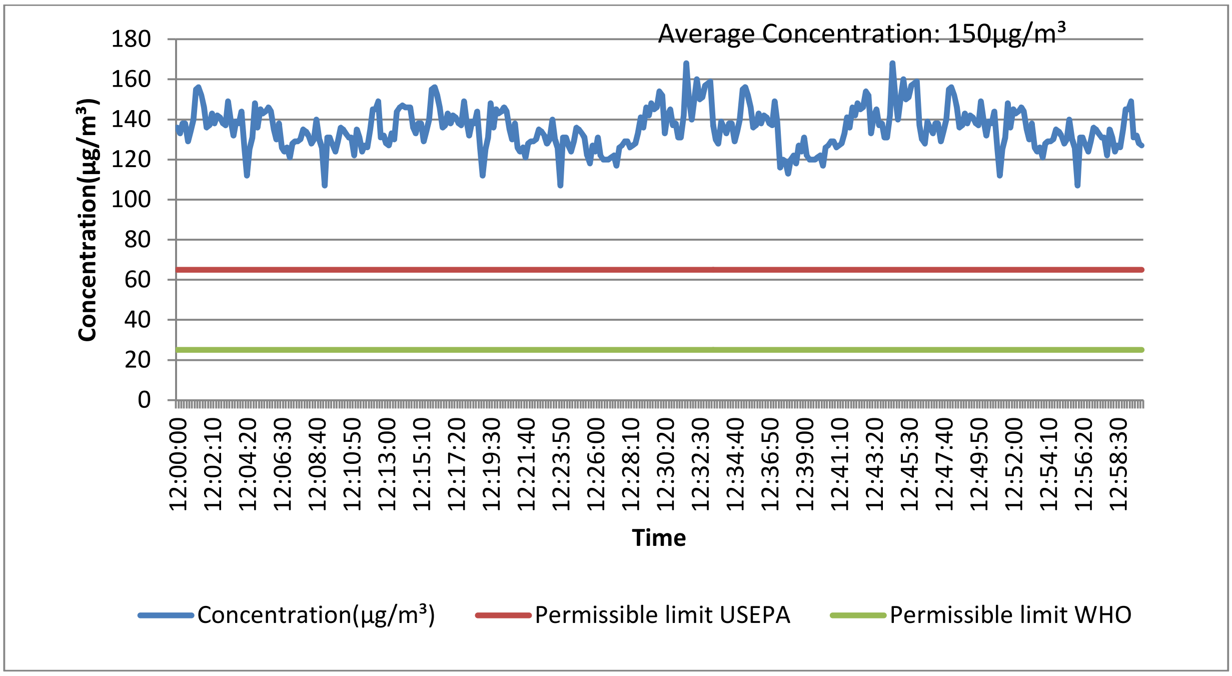

Figure 4(c) Temporal variation of PM2.5 on Ground floor

d

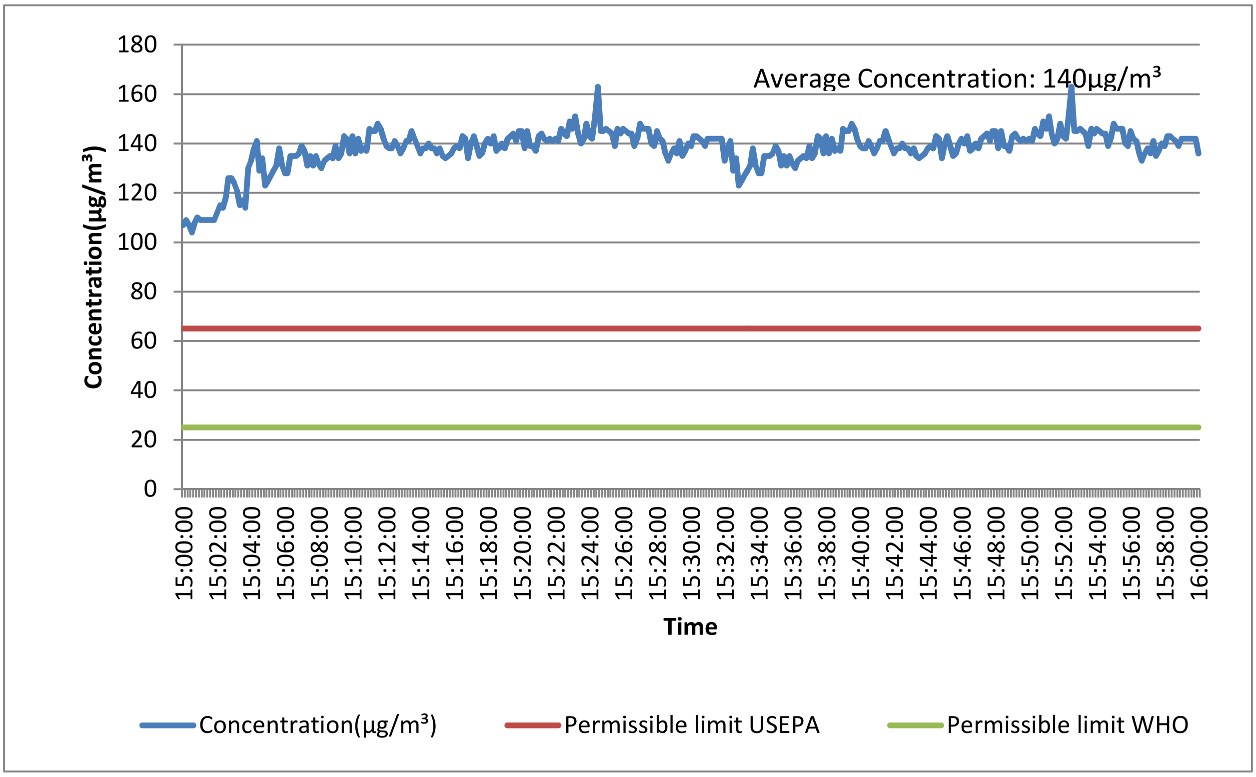

Figure 4(d) Temporal variation of PM2.5 on Ground floor

First Floor Sampling

Four samples were taken on the first floor. As Exams were going on, the circulation of students in library was high, but on this floor it was less as compared to ground floor. Concentration of particulate matter was ranging from 110µg/m^3 to 150µg/m^{3}on exam day, but decreased gradually in the later days.Figure 5(a), 5(b), 5(c) and 5(d) represents the sampling on first floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

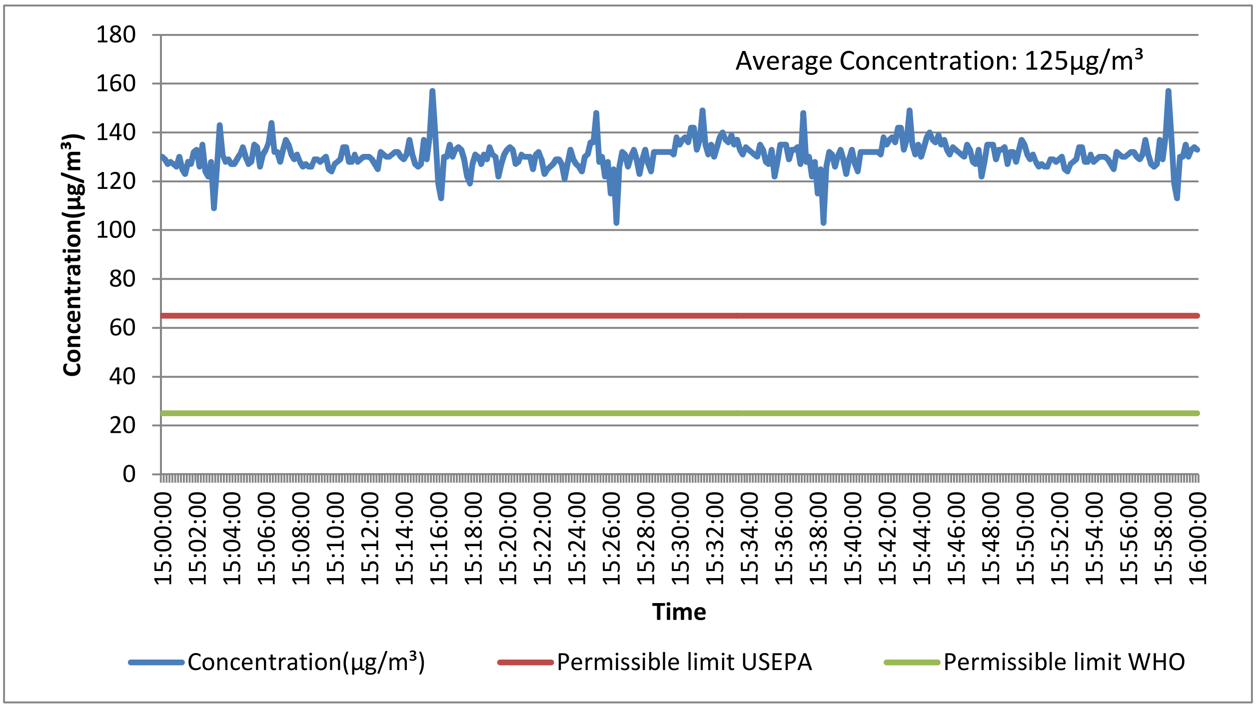

Figure 5(a) Temporal variation of PM2.5 on First floor

b

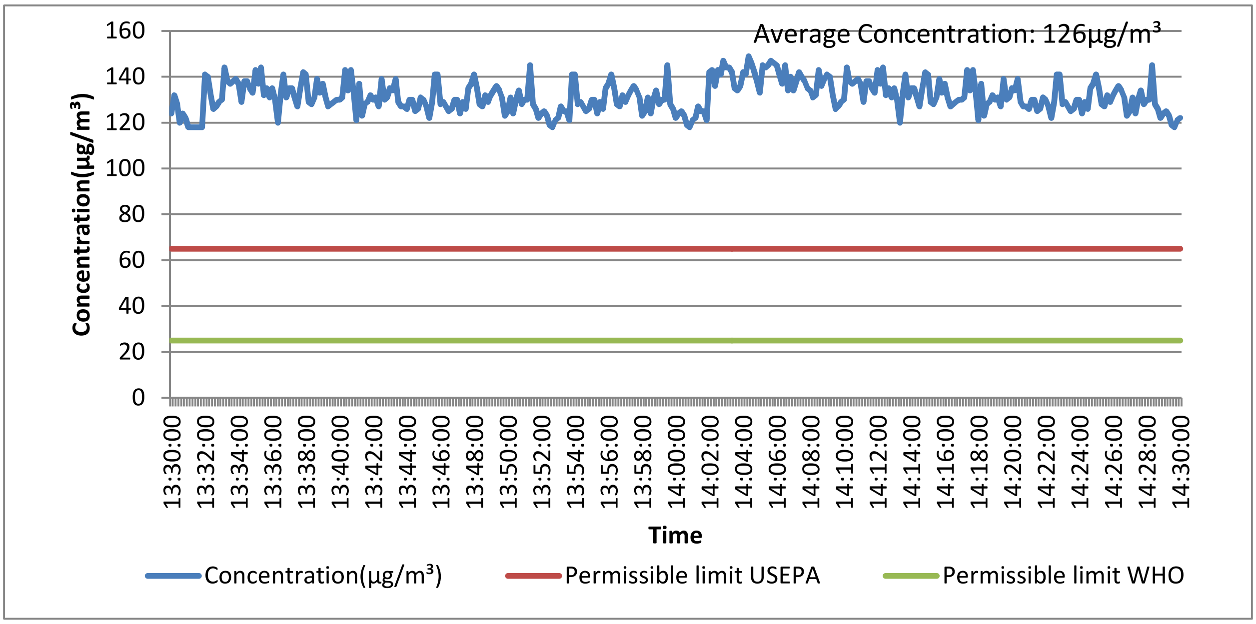

Figure 5(b) Temporal variation of PM2.5 on first floor

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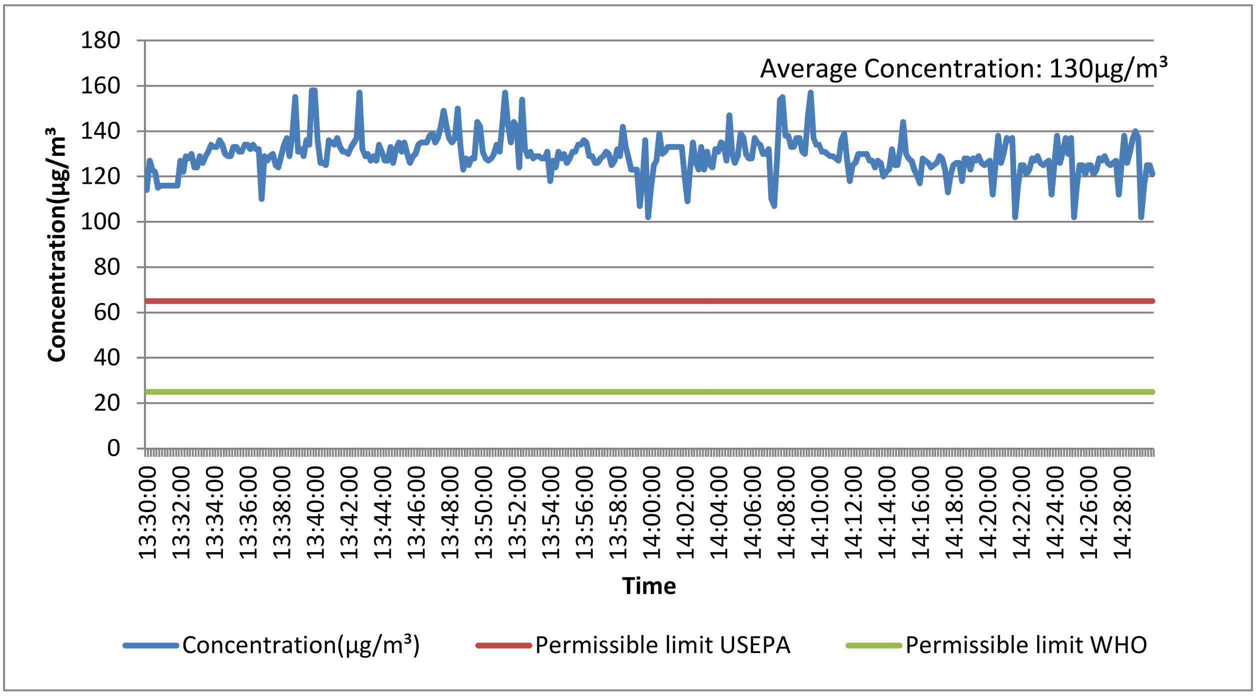

Figure 5(c) Temporal variation of PM2.5 on first floor

d

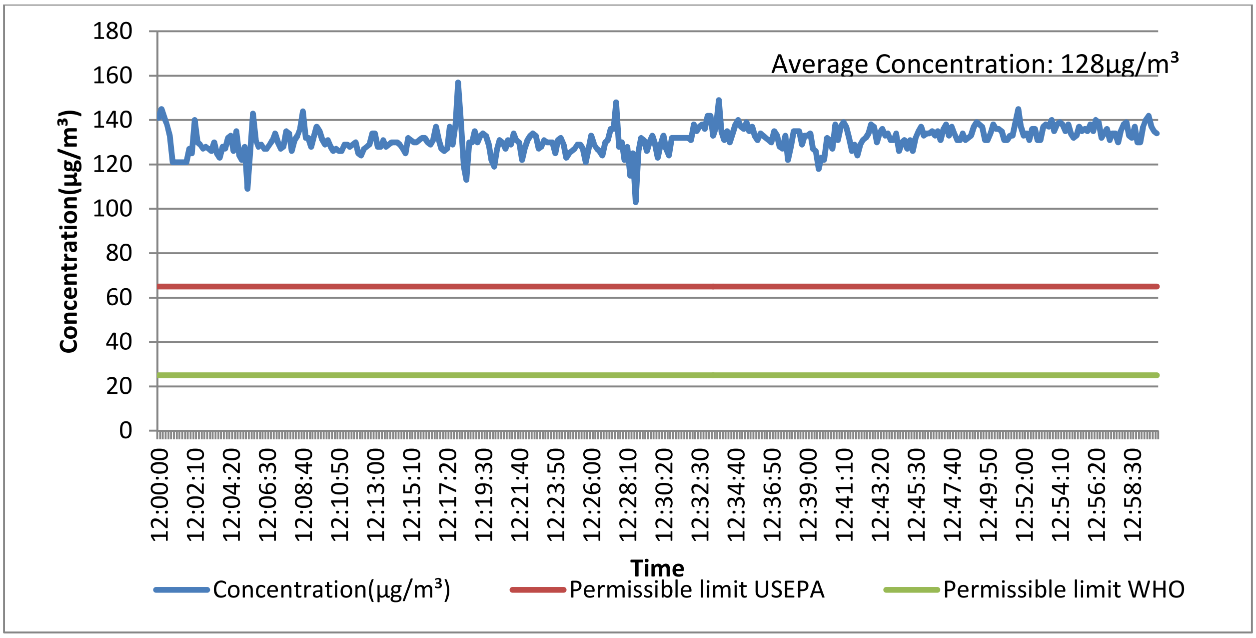

Figure 5(d) Temporal variation of PM2.5 on first floor

Second Floor Sampling

Four set of samples were collected on Second floor. Even as the circulation of students was high in the library, due to exams, but on this floor concentration of PM 2.5 was least. Concentration of particulate matter was

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ranging from 100µg/m^3 to 130µg/m^3 on exam day and lower on other days.Figure 6(a), 6(b), 6(c) and 6(d) represents the sampling on second floor on day 1, 2, 3 and 4 respectively at an interval of 60 minutes.

a

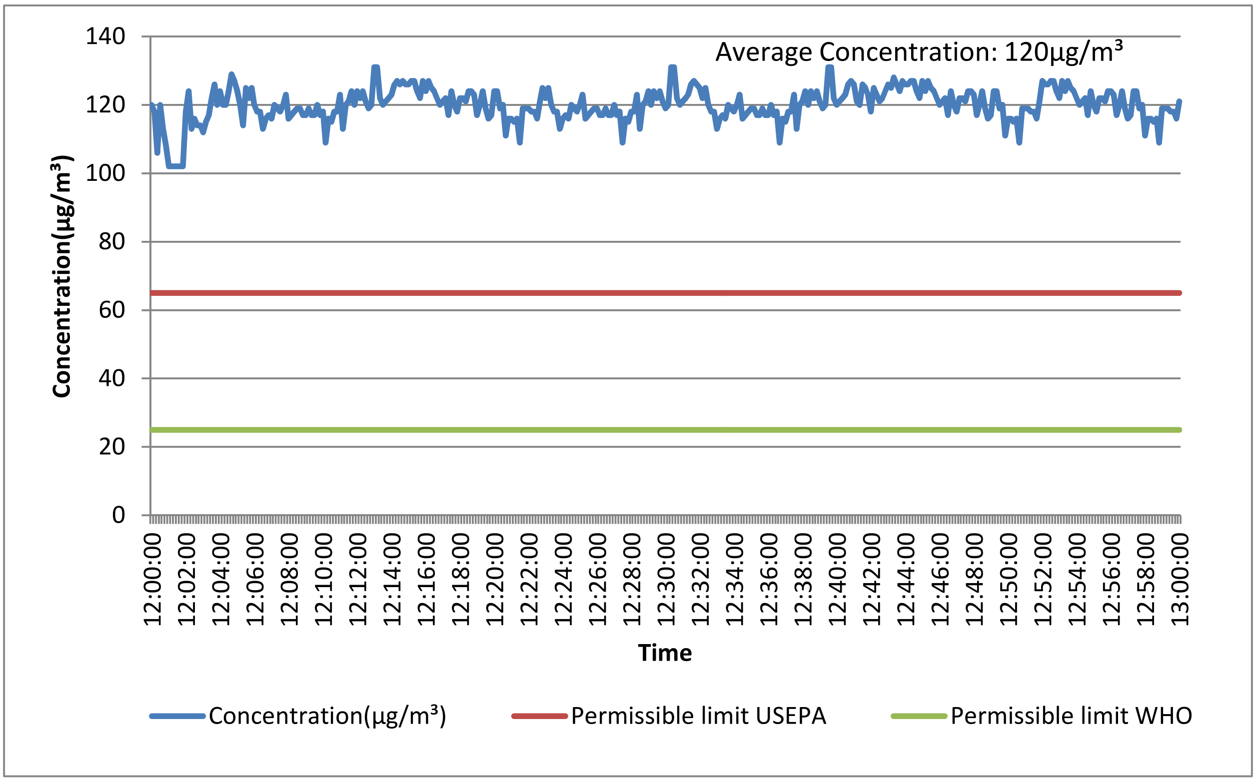

Figure 6(a) Temporal variation of PM2.5 on second floor

b

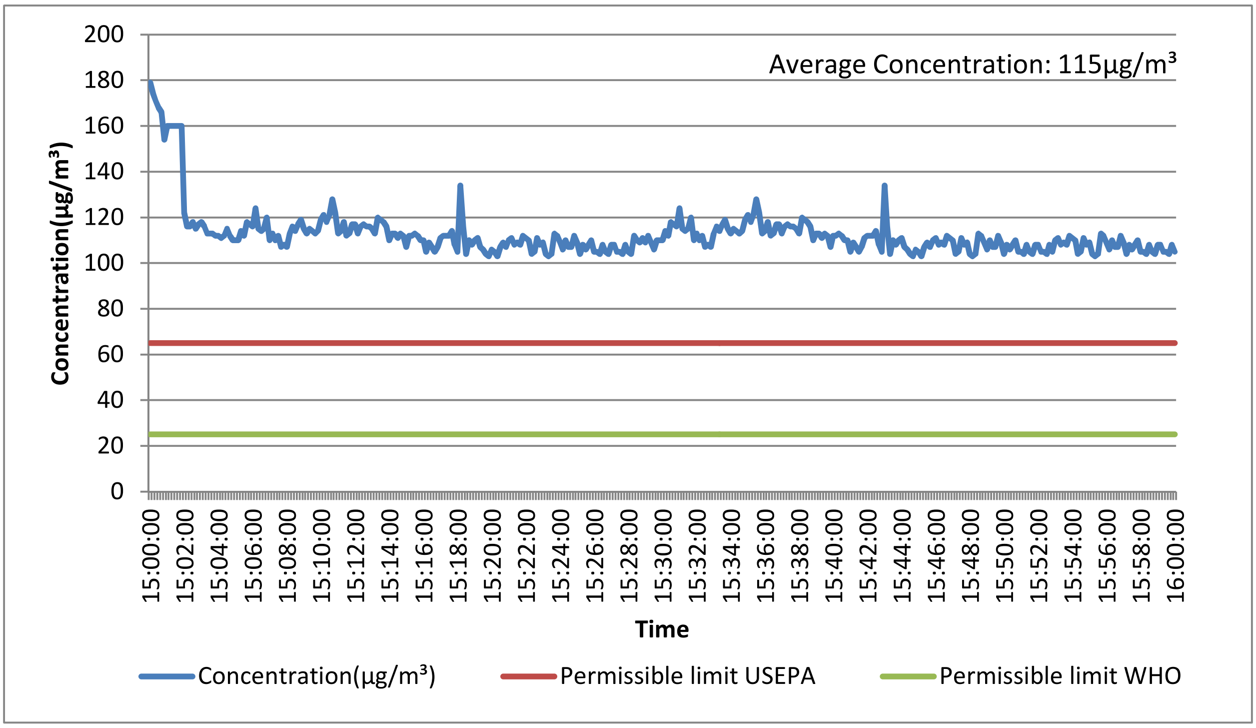

Figure 6(b) Temporal variation of PM2.5 on second floor

c

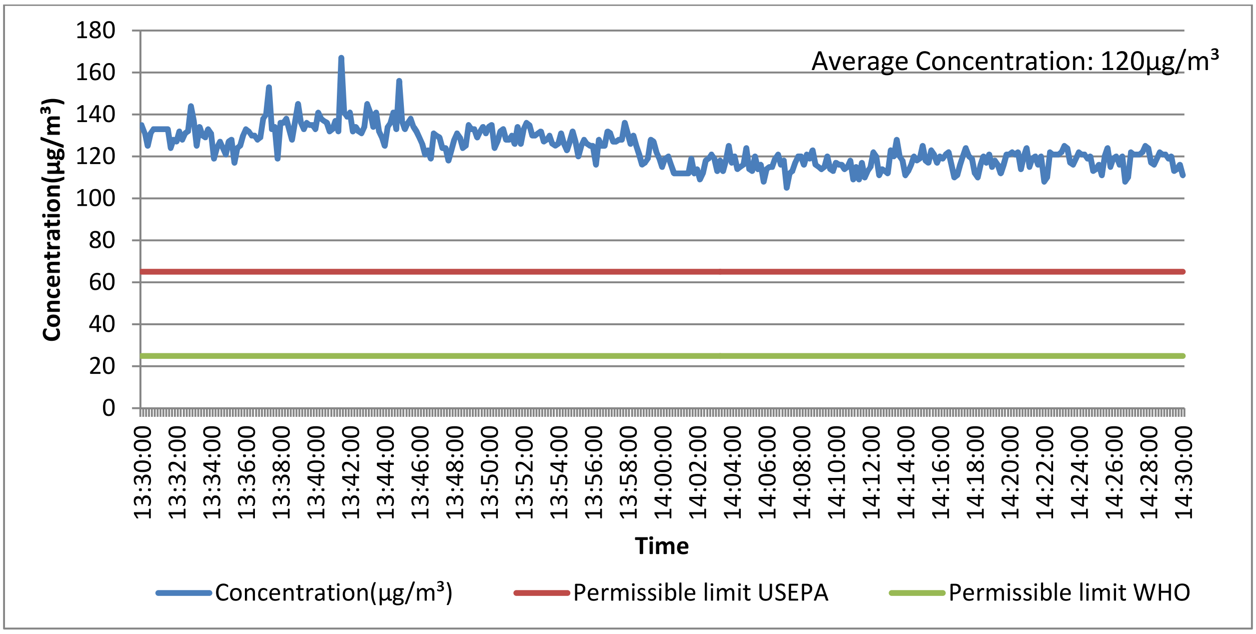

Figure 6(c) Temporal variation of PM2.5 on second floor

d

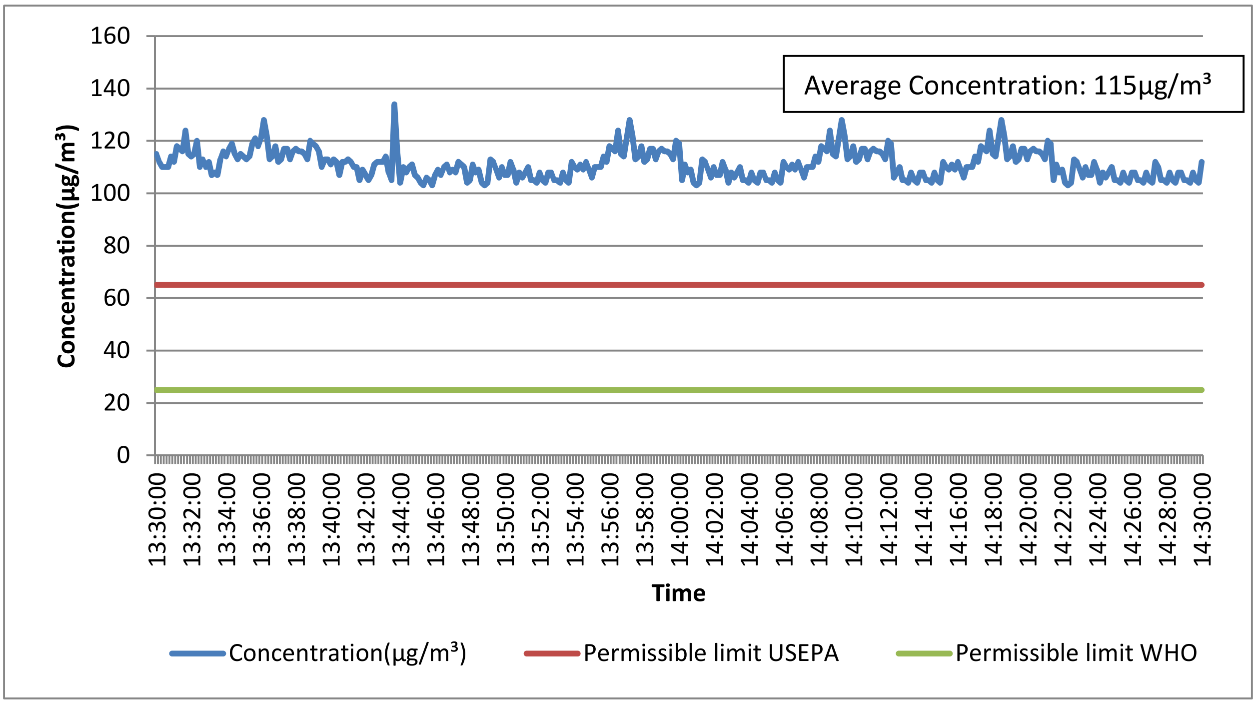

Figure 6(d) Temporal variation of PM2.5 on second floor

Comparison between average concentrations of different floors

Average of concentrations of $PM_{2.5}$ for different floors was calculated and analyzed. It was found that when the height increases concentration of $PM_{2.5}$ keeps on decreasing. This result of our study was in agreement with other studies done in many residential buildings in New York (Kyung Hwa Jung et al;2011). As in Figure 7 a, the concentrations on ground floor were the highest followed by first and second floor respectively.

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a

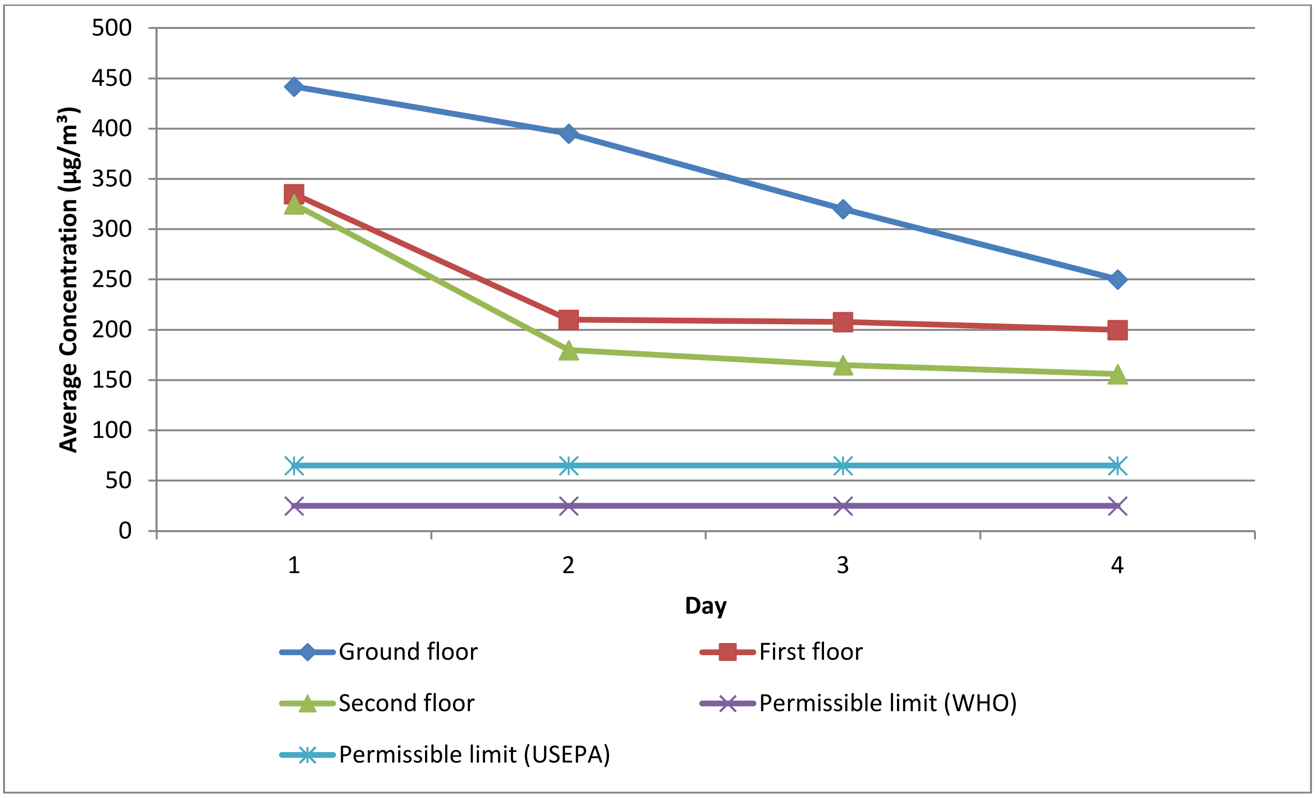

Figure 7(a) Comparison of average concentration for different floors during Winter

b

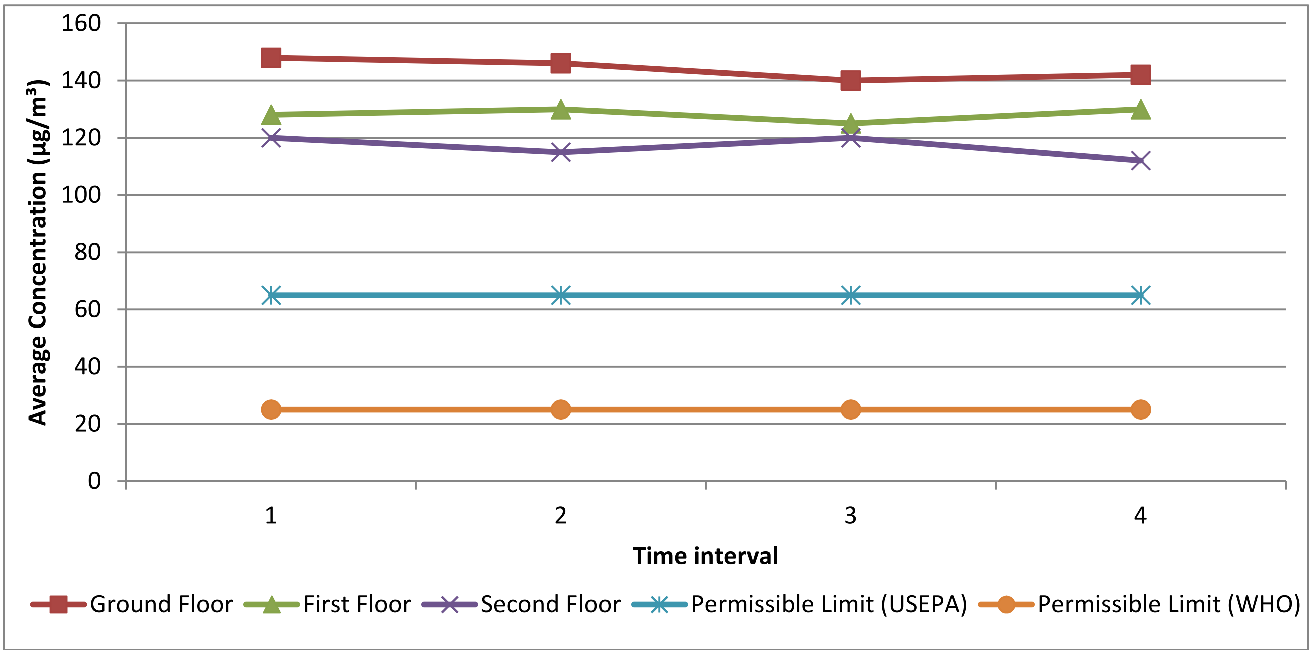

Figure 7(b) Average concentrations of Different floors on different days during Summer

Comparison between Crowded and Uncongested days

As the readings were taken on few days, which were during the examination period in the university which means large number of visitors and few days which saw minimal amount of visitors in the library. Given below is the comparison of average concentration of PM 2.5 between congested and uncongested days. During winter season, comparatively higher concentration of fine particulate matter was found at all the floors of the library during busy day (working days) than holiday (non-working days), whereas no more difference was observed in the concentration PM2.5 in summer season at all the floors of library during working and non-working days of the University (Figure 8a and 8b).

a

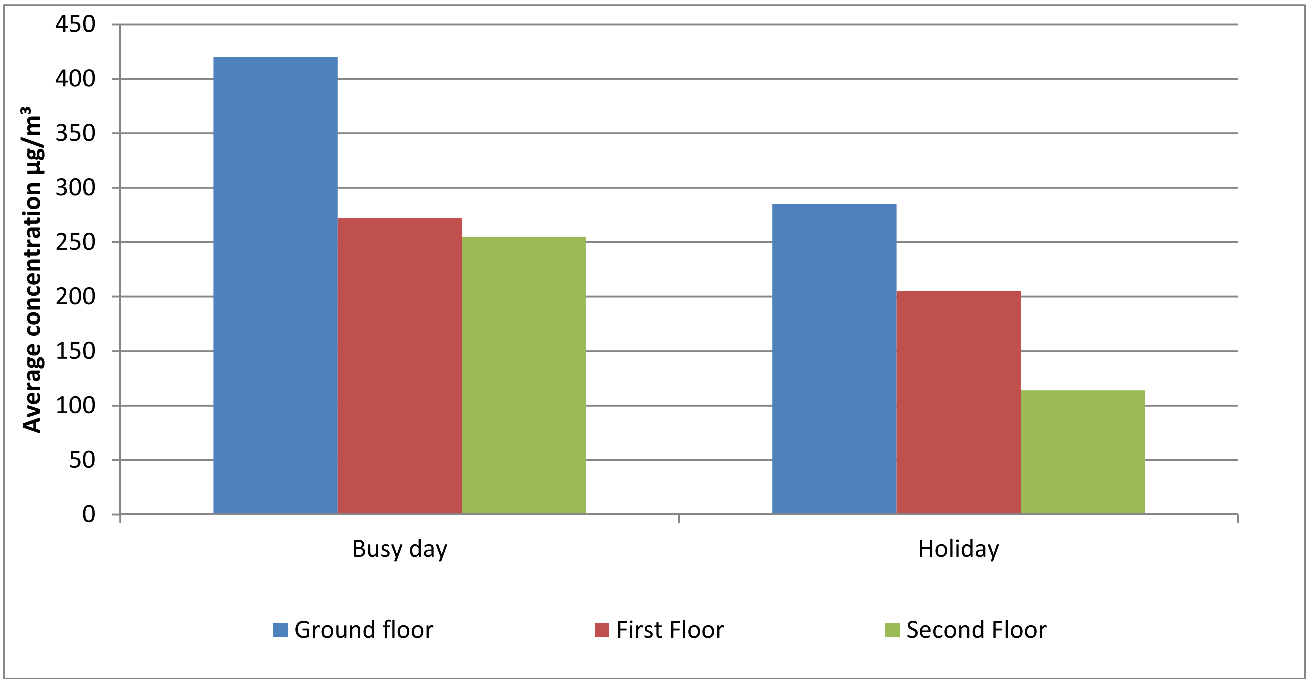

Figure 8(a) Difference between average concentration for working days and holidays during Winters

Figure 8(b) Difference between average concentration for working days and holidays during Summers

b

Seasonal Variation:Comparison between summers and winters

Average concentrations ofPM2.5for different weathers were taken and analyzed (Figure 9a). It was found that during winters, particulate matter concentration was relatively higher when compared tothat of summers and it may be due the reason that during winters there was no ventilation as all the windows were generally closed and also there was no use of fans or air conditioner so all the particles were trapped in the inner atmosphere which results in the higher concentration of PM2.5.Duringthe month of December, the particulate matter concentration was found to be between 400-450 µg/m³. The other reason for this high concentration was the smog present around the Delhi region in the months of November and December which was very harmful and cause many diseases. Whereas in the month of May, the concentration is found between 110-160 µg/m³ which is relatively lower when compared to December. This difference in the concentration of PM2.5 can be explained by some factors and the change in climatic conditions, with the help of rain, the suspended particles present in the air got settled down and have no further effect. This difference in the concentration of matter due to changes in climatic conditions is known as seasonal variation.

a

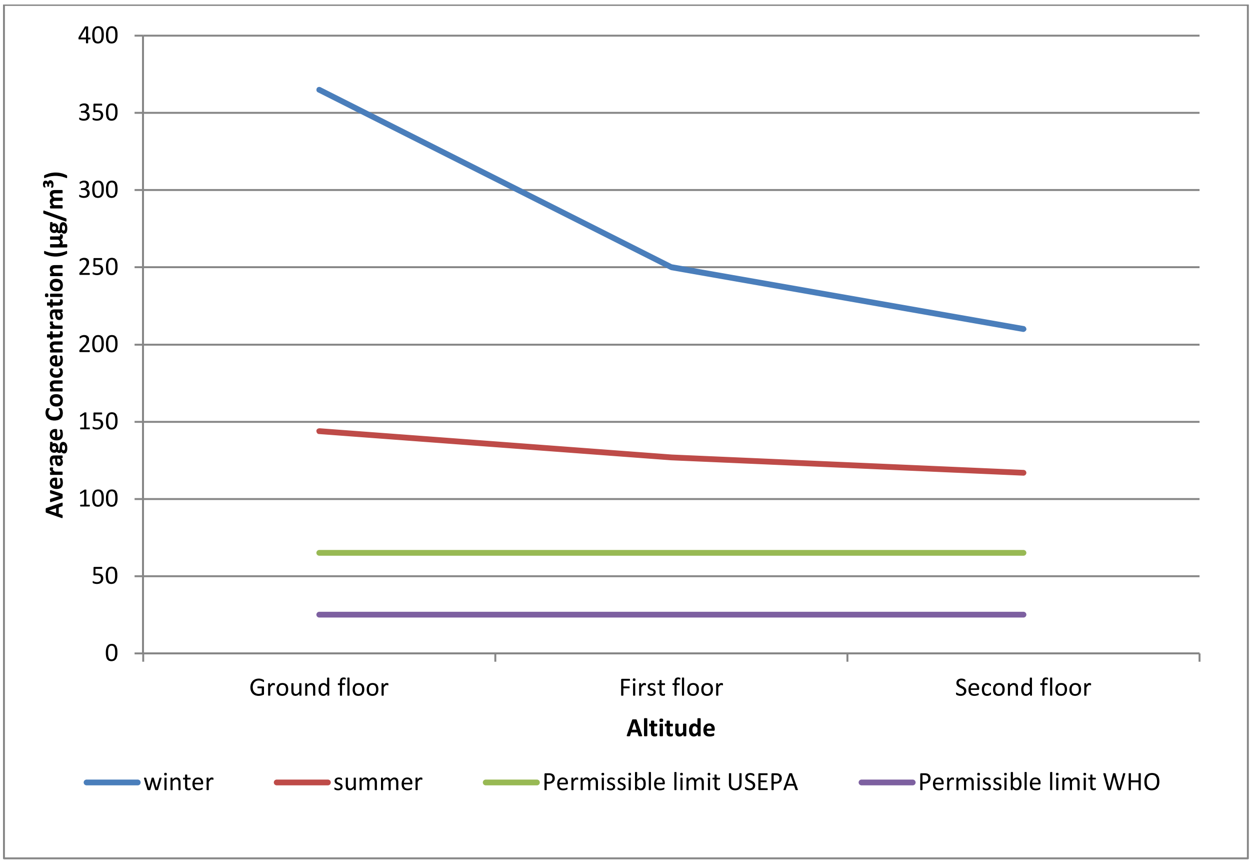

Figure 9(a) Seasonal Variation of average concentration of PM2.5

5. Conclusion

The average indoor level of PM2.5 was found to be around 380µg/m^3 on a busy day and around 210µg/m^3 on a normal day during winters whereas the average concentration of PM2.5 was found to be 144µg/m^{3}on crowded day and around 120µg/m^{3}in summer. The indoor level of PM2.5 was found to be alarmingly exceeding than that of the outdoor level (276µg/mg^3) during winters and 168µg/m^3 during summers. The concentration data of PM2.5 outside the library were taken from CPCB website. From the findings of the experiment, it is clear that the primary reason for the increase in the PM2.5 concentration is the outdoor pollution level. Other reasons being foot traffic or average footfall on the particular day and the ventilation system. Closed cabins inside the library had lesser level of PM2.5, than open halls, due to less transfer of air from outside. The concentration levels were observed to rise with the rise in footfall, i.e. at opening time the concentration was less and increased with the time. The observation period in winters observed inversion conditions and hence high particulate matter concentrations were recorded, in summer the observations were taken after heavy rain, which caused the particulate matter to settle down and hence lowered the recorded PM2.5 concentration.

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