DETERMINATION OF PARTICULATE MATTER FRACTIONS $PM_{2.5}$, PM_{10} AND CO_2 IN URBAN SCHOOLS IN IMPHAL, INDIA

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ABSTRACT

Measurements were carried out to determine the $PM_{2.5}$, PM_{10} and, CO_2 levels in schools located in the urban areas of Imphal, Manipur. The particulate matters ($PM_{2.5}$ and PM_{10}) were monitored gravimetrically with standardised particulate samplers, while the CO_2 in the air was measured by gas chromatography. Average $PM_{2.5}$ and PM_{10} concentration in the classrooms was 41.0 ± 9.0 $\mu g/m^3$ and 79.4 ± 20.2 $\mu g/m^3$, respectively, and it was comparatively higher than the outdoor concentration of 34.8 ± 8.0 $\mu g/m^3$ and 64.7 ± 18.9 $\mu g/m^3$, respectively. The average concentration of CO_2 in the indoor and outdoor air was 1250.6 ± 131.3 · 10^3 $\mu g/m^3$ and 885.7 ± 94.7 ·10^3 $\mu g/m^3$. The highest levels of $PM_{2.5}$ (58.3 $\mu g/m^3$), PM_{10} (112.5 $\mu g/m^3$) and CO_2 (1457.5 · 10^3 $\mu g/m^3$) were recorded indoors, in a school located at the heart of the city, whereas the lowest levels of $PM_{2.5}$ (25.0 $\mu g/m^3$), PM_{10} (45.8 $\mu g/m^3$) and CO_2 (1045.7 · 10^3 $\mu g/m^3$) were recorded in a school located away from the city centre. The levels of $PM_{2.5}$ and PM_{10} in the air were found to exceed the permissible limits prescribed by the National Ambient Air Quality Standards in more than half of the sampling. There was a strong positive correlation between indoor and outdoor pollutant concentrations.

Keywords: *air pollution, carbon dioxide, classroom, children, indoor air and outdoor air*

INTRODUCTION

Indoor air pollution occurring at workplaces has been recognised as one of the most critical environmental issues affecting human health and the World Health Organization (WHO) has now tightened the air quality guidelines [1, 2]. There is an increasing concern over the deterioration in ambient air quality in urban environments because of its associated potential health effects [3]. Poor indoor air quality (IAQ) causes a wide variety of adverse environmental impacts. Illnesses associated with indoor air pollutants in buildings are often referred to as the "sick building syndrome" [4 - 6]. Deterioration in the IAQ compromises work efficiency and job performance [7]. In a study, Wyon [8] attributed poor IAQ to the reduction of work performance in offices by 6 - 9 %. Schools are the first place for young children's social activity and the next important indoor environment after home. Children spend almost 25 - 30 % of their daily time inside classrooms [9]. Children are more prone to air pollution-related health hazards for various reasons due to their higher metabolic rates, growth and development of organs, breathing more air relative to their body size than adults [10 - 12]. Poor classroom air quality may cause short-term as well as long-term health problems for the students, staff and teachers. It decreases the student's learning capacity and comfort levels [13]. Particulate matters (PM) are tiny solid particles and liquid droplets suspended in the air. Atmospheric particles possess a range of morphological, chemical, physical, and thermodynamic properties. Classification of PM is generally carried out on the size range, and PM_{10} are inhalable particles with diameters of 10 μm and smaller, whereas $PM_{2.5}$ denotes fine particles with diameters of 2.5 μm and smaller [14]. The size of the particles determines how long they stay in the atmosphere [15]. The smaller the particles, the more potent they are, causing adverse human health problems [16, 17].

Carbon dioxide (CO_2) is a colourless, odourless, universal compound in the air. CO_2 is not harmful as an air pollutant at the natural background concentrations. Exhaled respiration air is usually the largest source of CO_2 in classrooms resulting in the built-up of indoor concentrations. Carbon dioxide concentration in the indoor environments acts as a measure of ventilation efficiency, revealing whether the exchange of outside air is sufficient to dilute and flush indoor contaminants [18]. Indoor CO_2 concentrations above 1000 ppm indicate poor ventilation. Many researchers reported CO_2 concentrations in the classroom exceeding the 1000 ppm mark [19, 20]. Indoor pollutants may come from in-situ sources from activities such as smoking, cooking, heaters, building materials, and furnishings, or it may come from ex-situ sources outside the room. Air pollution intensity may vary considerably depending on the type and location of the building, ventilation, energy sources, season and most importantly, human lifestyle. Numerous studies have established relationship between indoor and outdoor air quality [21 - 23]. In the urban sprawling of Imphal, vehicular emission, fugitive road dust, vehicle-induced air turbulences re-entrained roadside dust considerably contribute to air pollution. However, so far, no studies have been carried out on the IAQ in the educational institutes in the state and this study is the first of its kind in Manipur. The current study attempts to determine the status of IAQ in the classroom with respect to PM_{10}, $PM_{2.5}$ and CO_2 in five schools in Imphal city of Manipur, India. The scientific findings of the study would be of interest to academics, health workers, architects, education policymakers in framing strategies to improve the conditions of the classrooms in the schools.

EXPERIMENTAL

Description of schools

This study was carried out in five urban schools in Imphal (24.721 at 24.883 N latitude and 93.887 E and 93.982 E longitude) in north-eastern India. Particulates and gaseous pollutants were measured during the monsoon season of 2019. The schools selected for the current study were: S-1: Johnstone Higher Secondary School; S-2: Lamlong Higher Secondary School; S-3: Ananda Singh Higher Secondary Academy; S-4: Churachand Higher Secondary School; and S-5: Ibotonsana Girls Higher Secondary School (Figure 1). The classrooms relied on natural light and ventilation through windows, doors, and other wall openings. All the indoor measurements were carried out in the classroom on the ground floor.

Monitoring of $PM_{2.5}$ and PM_{10}

The particulate ($PM_{2.5}$ and PM_{10}) measurements were conducted for four months (June to September 2019). Air sampling was conducted during schooling hours (8 am to 4 pm) for three consecutive days, covering a total of 24 hours (8 h x 3 days) on a monthly basis. Measurements were carried out simultaneously for the indoor and outdoor environment.

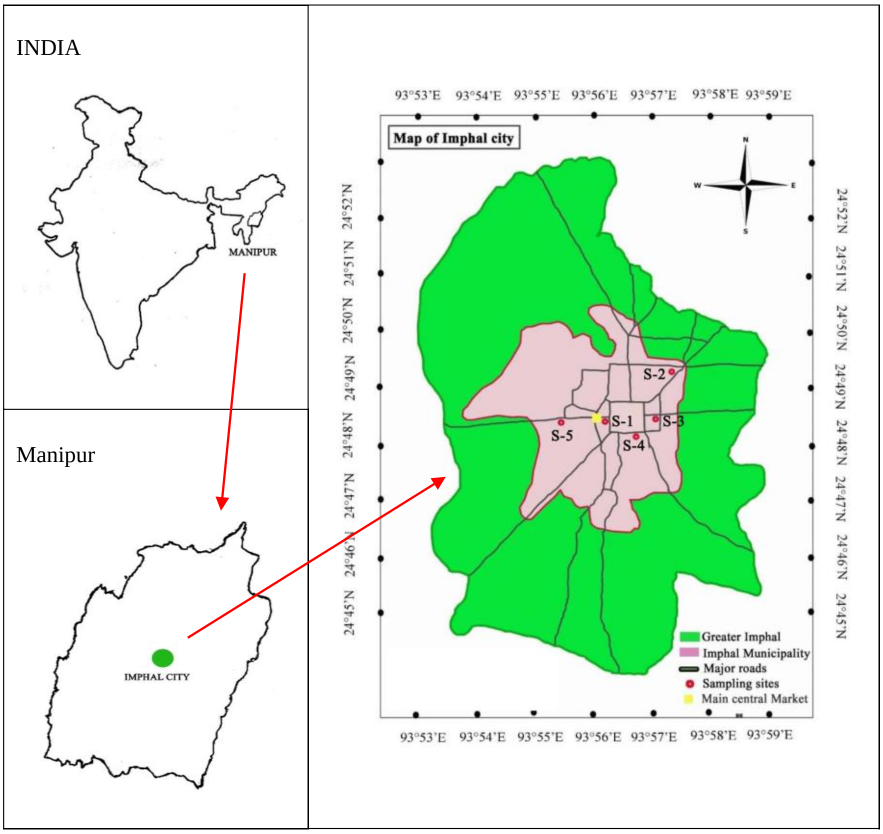


Figure 1. Geographical representation of studied sampling sites (schools)

Fine particulate sampler (Envirotech APM 550) standardised as per USEPA norms was used for the assessment. In the indoor measurements, the sampler was kept on the rear portion of the classroom to avoid inconvenience to the occupants, maintaining proper distances from the door, windows, and wall. The outdoor samplings were carried out in an open space free from trees and other structures. The particulate matter determination was carried out following the standard gravimetric method [24]. The height of the sampler air inlet was maintained 1.5 m above the ground (student breathing level in the classroom). The air drawn was passed through a Teflon membrane filter, measuring 47 mm in diameter with 2 µm pore size at a constant flow rate of 1 m^3 per hour (16.67 L/m) to collect either the airborne PM_{10} or $PM_{2.5}$. All the filters were conditioned (desiccated) for 24 h to remove the moisture before weighing. The weight of each filter was evaluated three times by a high-precision analytical digital balance (Aczet, Micro Balance CM 2, readability: 0.001 mg) to obtain an accurate reading.

Analysis of CO_2

Gaseous samples (CO_2) were collected using a 15 mL airtight syringe fixed with a three-way stopcock. Air samples (10 mL) were drawn separately for the indoor and outdoor air, 1 m above the ground. The gas samples were collected between 9.30 and 11.30 h on all the days of particulate sampling. Analysis of gas sample (CO_2) was carried out in a gas chromatograph (Trace 1110; Thermo scientific) fitted with Flame Ionization Detector (FID), a Porapak Q column, and a methanizer attached to it. The column, FID detector, methanizer and injector were maintained at 200, 240, 350 and 70 °C, respectively. The carrier gas was N_2 with a flow rate of 15 mL/min. Hydrogen gas was the fuel gas and zero air, the supporting gas having flow rates of 20 and 300 mL/min, respectively. Each injected sample before reaching the detector passed through the methanizer, where the samples were subjected to catalytic reduction by H_2 over the Ni-catalyst at 280 °C. The retention time of CO_2 was 3.6 min. The concentration of gas in a sample was determined by calculating it from the standard curve obtained by injecting standard gas. The primary standards used were 204 ppmV CO_2 in N_2, procured from Chemtron Science Laboratories Pvt. Ltd., Banglore, India.

RESULTS AND DISCUSSION

The concentrations of $PM_{2.5}$, PM_{10} and CO_2 in the schools observed during the four-month study period are presented in Table 1. The indoor $PM_{2.5}$ and PM_{10} ranged from 25.0 µg/m^3 to 58.3 µg/m^3 and 45.8 µg/m^3 to 112.53 µg/m^3 with an average value of 41.0 ± 9.0 µg/m^3 and 79.4 ± 20.2 µg/m^3, respectively. The outdoor $PM_{2.5}$ and PM_{10} ranged from 25.0 µg/m^3 to 50.0 µg/m^3 and 37.5 µg/m^3 to 95.8 µg/m^3 with the average values of 34.8 ± 8.0 µg/m^3 and 64.7 ± 18.9 µg/m^3, respectively. The indoor concentrations of CO_2 ranged between 1045.7 · 10^3 µg/m^3 and 1457.5 · 10^3 µg/m^3 with an average value of 1250.6 ± 131.3 · 10^3 µg/m^3, while the outdoor values ranged between 717.7 · 10^3 µg/m^3 and 1084.8 · 10^3 µg/m^3 with an average value of 885.7 ± 94.7 · 10^3 µg/m^3, respectively. Fomme et al. [25] found that the median of $PM_{2.5}$ and PM_{10} in 75 classrooms ranged from 4.6 µg/m^3 to 34.8 µg/m^3 ($PM_{2.5}$) and 18.3 µg/m^3 to 178 µg/m^3 (PM_{10}) during summer, whereas the CO_2 concentration ranged from 400 ppm to 2000 ppm. The concentrations of CO_2 reported by the above author were comparatively higher than indoor CO_2 (586.5 ppm to 817.5 ppm) concentration obtained in the current study. Halek et al. [26] reported an average indoor (classroom) $PM_{2.5}$ and PM_{10} concentrations of 42 µg/m^3 and 274 µg/m^3, respectively. The concentration of PM_{10} in their study was found to be substantially higher than the levels 79.4 ± 20.2 µg/m^3 obtained in this study, whereas the $PM_{2.5}$ concentration was very close to the current research 41.0 ± 9.0 µg/m^3. Marina et al. [27] found that the average concentrations of $PM_{2.5}$, PM_{10} and CO_2 in the classroom were 43.58 µg/m^3, 70.63 µg/m^3 and 575 ppm. The three parameters in their study were found to be very close to the levels (41.0 µg/m^3, 79.4 µg/m^3, and 701.4 ppm) obtained in this study, whereas lower concentrations of the parameters than the ones obtained in the current study were also reported by Yang et al. [28] for schools in Malaysia - they observed the overall average concentrations of $PM_{2.5,}$ $PM_{10,}$ and CO_2 in the classrooms to be 18 µg/m^3, 31 µg/m^3, and 903.6 µg/m^3 during summer.

Table 1. Concentrations of $PM_{2.5,}$ PM_{10} and CO_2 in the schools

	Indoor			Outdoor		
	$PM_{2.5}$ (µg/m^3) X ± SD min-med-max	PM_{10} (µg/m^3) X ± SD min-med-max	CO_2 (·10^3 µg/m^3) X ± SD min-med-max	$PM_{2.5}$ (µg/m^3) X ± SD min-med-max	PM_{10} (µg/m^3) X ± SD min-med-max	CO_2 (·10^3 µg/m^3) X ± SD min-med-max
S-1	52.1 ± 5.4 45.8–52.1–58.3	104.2 ± 9.0 91.7–106.3–112.5	1425.2 ± 24.8 1400.4–1421.4-1457.5	41.7 ± 3.4 37.5–41.7–45.8	84.0 ± 18.2 56.9–91.7–95.8	1018.5 ± 83.8 897.1–1046.0–1084.8
S-2	39.6 ± 9.9 29.2–39.6–50.0	85.4 ± 7.2 79.2–83.3–95.8	1126.1 ± 95.1 1045.7–1099.7–1259.3	33.3 ± 9.6 25.0–33.3–41.7	65.6 ± 17.1 50.0–62.5–87.5	805.1 ± 83.8 717.7–796.5–909.6
S-3	39.6 ± 5.4 33.3–39.6–45.8	64.6 ± 8.7 54.2–64.6–75.0	1323.9 ± 95.7 1183.4–1361.9–1388.2	35.4 ± 11.0 25.0–33.3–50.0	53.1 ± 7.1 45.8–52.1–62.5	852.2 ± 73.4 756.0–8688.6–915.6
S-4	33.3 ± 7.6 25.0–33.3–41.7	53.1 ± 7.1 45.8–52.1–62.5	1128.5 ± 38.0 1079.1–1134.1–1166.7	29.2 ± 4.8 25.0–29.2–33.3	45.8 ± 5.9 37.5–47.9–50.0	845.1 ± 20.0 817.3–851.2–860.6
S-5	40.6 ± 7.1 33.3–39.6–50.0	89.6 ± 9.9 75.0–93.8–95.8	1249.1 ± 23.1 1226.1–1247.0–1276.4	34.4 ± 7.1 25.0–35.4–41.7	75.0 ± 16.0 54.2–79.2–87.5	907.9 ± 21.8 885.6–905.6–934.9
Average of all schools	41.0 ± 9.0 25.0–41.7–58.3	79.4 ± 20.2 45.8–81.3–112.5	1250.6 ± 131.1 1045.7–1246.9–1457.5	34.8 ± 8.0 25.0–35.4–50.0	64.7 ± 18.9 37.5–55.6–95.8	885.7 ± 94.7 717.7–890.8–1084.8

S-1: Johnstone Higher Secondary School; S-2: Lamlong Higher Secondary School; S-3: Ananda Singh Higher Secondary Academy; S-4: Churachand Higher Secondary School; S-5: Ibotonsana Girls Higher Secondary School; X ± SD - Mean ± Standard deviation; min-med-max - minimum-median-maximum.

Among the five schools, the S-1 (Johnstone Hr. Sec. School) was found to be most polluted with the three pollutants. The concentration of particulates in the school was 52.1 ± 5.4 μg/m^3 for indoor $PM_{2.5}$, 104.2 ± 9.0 μg/m^3 for indoor PM_{10}, 41.7 ± 3.4 μg/m^3 for outdoor $PM_{2.5}$ and 84.0 ± 18.2 μg/m^3 for outdoor PM_{10}. Similarly, the highest concentration of CO_2 (1425.2 ± 24.8 · 10^3 μg/m^3) for indoor and (1018.5 ± 83.8 · 10^3 μg/m^3) for outdoor was recorded in the school. Such results were well expected as the S-1 is located at the heart of the city, surrounded by heavy traffic streets, highways, and commercial centres. The lowest levels of particulates were recorded in S-4 (Churachand Hr. Sec. School). The school is located away from the heart of the city and has comparatively lesser air polluting sources in the vicinity of the campus. The average concentration of particulates in the S-4 was 33.3 ± 7.6 μg/m^3 for indoor $PM_{2.5}$, 53.1 ± 7.1 μg/m^3 for indoor PM_{10}, 29.2 ± 4.8 μg/m^3 for outdoor $PM_{2.5}$ and 45.8 ± 5.9 μg/m^3 for outdoor PM_{10}. However, the lowest average concentration of CO_2 in the air was recorded in S-2 (Lamlong Hr. Sec. School), with an indoor and outdoor concentration of (1126.1 ± 95.1) · 10^3 μg/m^3, and (805.1 ± 83.8) · 10^3 μg/m^3, respectively. The prime sources of air pollutants in Imphal city comes from vehicular emissions. Other sources include commercial activities, construction and repair works, poorly maintained road, etc. The vehicular population in the state has increased considerably in the last couple of decades. Annually about 8000 to 9000 vehicles are added, and the vehicle population is expected to reach up to 400000 - 500000 until 2030 [29].

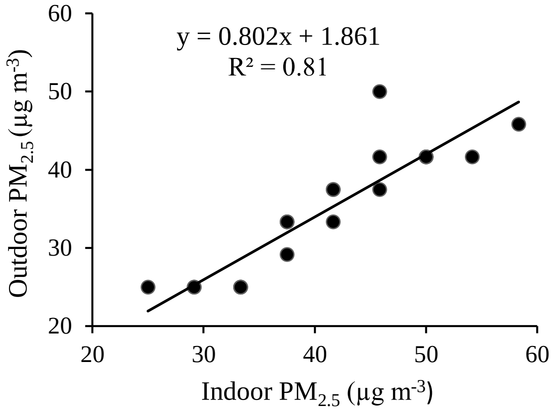
As per the National Ambient Air Quality Standards (NAAQS) [30], Central Pollution Control Board (CPCB), New Delhi, the permissible concentration of $PM_{2.5}$ and PM_{10} in the ambient air is 40 μg/m^3 (annual average) and 60 μg/m^3 (annual average), respectively. Similarly, the prescribed standards by the WHO [31] for the two particulates are 10 μg/m^3 and 20 μg/m^3 in annual average. The number of sampling events that exceeded the NAAQS recommended permissible limits in the current study for $PM_{2.5}$ was 55 % (indoor sampling) and 35 % (outdoor sampling), whereas for PM_{10} it exceeded 80 % and 45 % in the indoor and outdoor samplings. However, it is noteworthy to mention that the result obtained in the current study falls short of giving a complete comparative analysis with the annual average standards mentioned above due to the limitation in the period of measurement covering the monsoon season. It was observed that the concentration of CO_2 exceeded the recommended standards (700 ppm for indoor air) prescribed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. /American National Standards Institute [32] in 50 % of the sampling incidents. High indoor CO_2 concentrations may indicate inadequate ventilation per occupant and elevated indoor pollutant concentrations, leading to sick building symptoms [33]. In general, the highest CO_2 levels (> 600 ppm) were observed during break time classrooms while the outdoor levels were relatively stable, ranging from 440 to 650 ppm [34]. The data obtained revealed that the concentrations of the three pollutants increased in a similar pattern. Overall, there was a positive correlation ($r = 0.66$, at $p < 0.001$) between the concentration of particulates ($PM_{2.5}$ and PM_{10}) in the schools. Likewise, a positive correlation was also established between the gaseous (CO_2) pollutant and particulates, $PM_{2.5}$ ($r = 0.63$, at $p < 0.001$), and PM_{10} ($r = 0.57$, at $p < 0.001$).

Indoor and outdoor relationship

The relationship between indoor and outdoor concentrations level for the three parameters ($PM_{2.5}$, PM_{10}, and CO_2) was investigated using Pearson bivariate analysis (Figures 2a, 2b and 2c). A significant positive correlation was observed for $PM_{2.5}$ ($r = 0.89$, at $p < 0.001$), PM_{10} ($r = 0.89$, at $p < 0.001$), and CO_2 ($r = 0.81$, at $p < 0.001$), indicating the influence of outdoor sources on the indoor pollution levels. Usually, a significant correlation indicates a regular exchange of air between the indoor and the outdoor environments. In the schools, the air in the classrooms was replenished with ambient air through natural ventilation without being filtered or conditioned. Opening doors and windows facilitate the movement of outdoor pollutants into the indoor and vice-versa. The build-up of air pollutants in the indoor environment may be contributed both by indoor and outdoor polluting sources. The gaseous pollutants and small fractions of particulate matter can penetrate from outdoor to indoor environments [35, 36]. The indoor to outdoor (I/O) ratios of the three parameters, $PM_{2.5}$, PM_{10}, and CO_2 were 1.19 ± 0.11, 1.25 ± 0.18, and 1.41 ± 0.09, respectively.

The I/O ratio is often used as an indicator of the source strength of indoor pollutants and the values vary depending on the indoor and outdoor concentration levels. The ratios observed in this study were greater than one for all the three parameters throughout the sampling, except in a single incident at the S-3 during August 2019, where the outdoor concentration of $PM_{2.5}$ was recorded slightly higher than the indoor concentration.

Rovelli et al. [37] assessed $PM_{2.5}$ and PM_{10} levels in seven schools and found that the average indoor $PM_{2.5}$ concentrations were lower than average outdoor $PM_{2.5}$ concentrations. Wichmann et al. [38] concluded that the median of indoor $PM_{2.5}$ concentration was lower than outdoor levels. The result indicated the presence of potential indoor pollution sources. In general, the classrooms concentrations are highly variable, with episodes of high concentrations in short durations. Such short duration episodes may occur due to student activities at the beginning and end of the school day or break times [25]. The use of chalk and dusters on the blackboard and lack of diluting air in the indoor sources could explain at least some contribution to the higher indoor PM concentrations observed during the study. Outdoor concentration may influence the indoor air quality, particularly during traffic congestion in the adjacent roads. In naturally ventilated classrooms, the particulates may arise from outdoor infiltration and indoor activities [39]. Comparatively higher values of the I/O ratio indicate the critical factors of occupancy and student activities resulting in resuspension of the coarser particles inside the classroom [40, 41].



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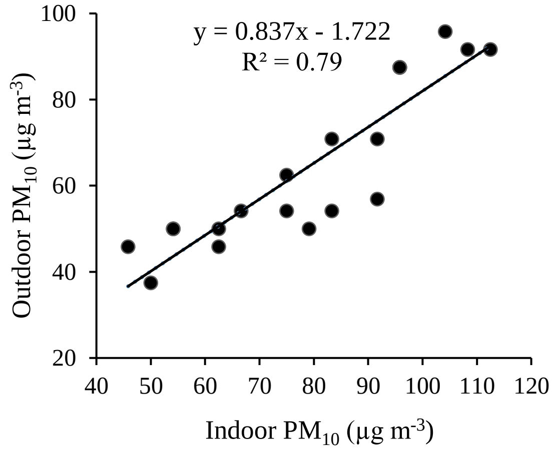

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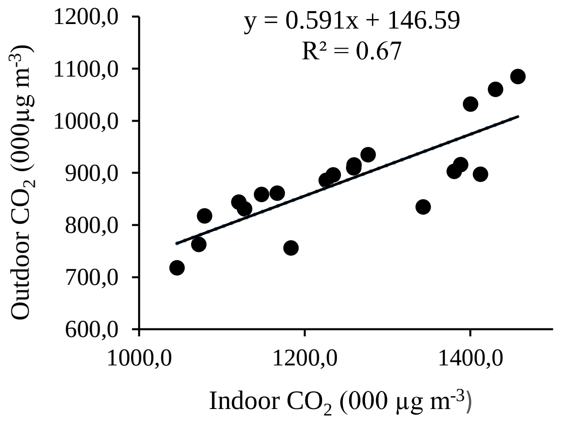

c)

Figure 2. a) relationship between the concentrations of $PM_{2.5}$ in indoor and outdoor air, b) relationship between the concentrations of PM_{10} in indoor and outdoor air,
c) relationship between the concentrations of CO_2 in the indoor and outdoor air

CONCLUSION

The current study examined the gaseous (CO_2) levels and particulates ($PM_{2.5}$ and PM_{10},) pollution in five urban schools in Imphal, India. The school located at the heart of the city was comparatively more polluted than those schools located far away from the primary urban centre. The concentration of $PM_{2.5}$ and PM_{10} were found to exceed the annual permissible limits given by the National Ambient Air Quality Standards (NAAQS) in many sampling incidents. In the classrooms, the $PM_{2.5}$ concentration was exceeded in 55 % of the sampling, whereas for the PM_{10} it exceeded in 80 % of the sampling. Similarly, the indoor concentrations of CO_2 were exceeded the prescribed standards in 50 % of the sampling. The concentrations of particulates and CO_2 were higher in the classrooms compared to the outside campus environment. There was a strong positive correlation between the air pollutant levels in the indoor and the outdoor environment, primarily due to natural ventilation. The indoor to the outdoor concentration ratio for all the three pollutants was greater than one. However, due to limitations of the study period, the data obtained in the current study falls short of establishing an accurate air quality profile of the schools. Further, long-term monitoring is needed to fully understand the precise scenario. Nonetheless, the study convincingly revealed the deteriorating state of indoor air quality in schools in the city of Imphal.

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