ASSESSMENT OF INDOOR PARTICULATE MATTER AND ASSOCIATED HEALTH RISKS BEFORE AND AFTER VENTILATION IMPROVEMENT IN LABORATORIES OF A UNIVERSITY

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ABSTRACT

Laboratory activities related to indoor air pollution are an important health concern in educational institutions and in most cases in developing countries, where the ventilation system is inadequate. This study compares the levels of particulate matter ($PM_{2.5}$ and PM_{10}) and associated health risk values both prior to and following upgrades of the ventilation systems in the Civil Engineering Laboratories at Khulna University of Engineering & Technology (KUET) in Bangladesh. Two monitoring campaigns were carried out: the baseline on October 2, 2024, and the follow-up on September 9, 2025, using an Aeroqual Series 500 monitoring equipment at breathing zone height. The baseline test showed high variability of particulate matter concentration in the laboratories, and the maximum concentration of both $PM_{2.5}$ (151.64 ± 23.35 µg m^{-3}) and PM_{10} (377.12 ± 64.63 µg m^{-3}) was found in the Transportation Laboratory, significantly above World Health Organization (WHO) and USEPA global standards. The Engineering Material Laboratory also recorded moderately high values of $PM_{2.5}$ (35.67 ± 1.93 µg m^{-3}) and PM_{10} (98.56 ± 9.92 µg m^{-3}), mainly because of the use of cement and aggregates. Compared to these, the Environmental and Geotechnical Engineering Laboratories showed relatively lower concentrations of $PM_{2.5}$ ($32.15 \pm 0.86 - 32.31 \pm 1.82$ µg/m³) and PM_{10} ($58.95 \pm 3.40 - 65.72 \pm 4.25$ µg/m³), but also above the recommended international standards. After the installation of the mechanical ventilation and local exhaust systems, the concentrations of $PM_{2.5}$ and PM_{10} showed a considerable reduction, ranging from 0.0097 ± 0.0011 to 0.0112 ± 0.0016 µg/m³. Since most of the values declined ($p < 0.05$), the Wilcoxon signed-rank test indicated statistical significance. Health Risk Assessment (HRA) using the USEPA framework indicated that the $PM_{2.5}$ baseline HQ exceeded unity in all Laboratories for students and technicians, suggesting potential non-carcinogenic risks. However, the $PM_{2.5}$ ELCR was generally within the USEPA acceptable limit (10^{-6}–10^{-4}) for students and slightly higher for technicians. Following improvement in ventilation, HQ and ELCR values dropped to levels below threshold limits for all categories of exposure, with technicians presenting slightly higher risks under longer exposure durations. Overall, particulate exposure, along with the associated health hazards, has been significantly reduced as a consequence of effective ventilation and exhaust interventions. Thus, the application of engineering controls coupled with regular air-quality monitoring becomes an essential concern in academic laboratory settings.

***Keywords:** Indoor Air Quality, Particulate Matter, Health Risk Assessment, Ventilation*

1. INTRODUCTION

Indoor air quality (IAQ) has become a crucial public health and workplace safety concern, especially in crowded institutional environments where activities generating pollutants are frequent (Anderson & Thundiyil, 2012). Particulate matter (PM), particularly fine particles ($PM_{2.5}$) and inhalable coarse particles (PM_{10}), is seen as one of the most hazardous indoor air contaminants, as it can penetrate deep into the respiratory system and cause a wide range of harmful health effects (Thi et al., 2020). Over 4.2 million people prematurely die each year due to $PM_{2.5}$ exposure, mainly from stroke, heart disease, chronic obstructive pulmonary disease, and cancer, according to the World Health Organization (WHO)(WHO, 2021; Akther et al., 2019; Wang et al., 2020). Inhalation and even short-term exposure to particulate emissions may act as a causative element leading to respiratory symptoms, and chronic exposure is directly connected to health-related ailments, as stated by (Kebe et al., 2025; Yang et al., 2022).

Academic laboratories, particularly in engineering facilities, are distinctive indoor microenvironments that involve activities such as material handling, mechanical grinding, preparing concrete and asphalt, chemical reactions, and thermal processing, which have been identified as substantial PM emission sources (Ilacqua et al., 2023). Several studies performed in university laboratories and workshop environments reported that indoor $PM_{2.5}$ concentrations are 2-10 times higher than outdoor levels due to multiple indoor sources and low ventilation rates (Mbazima, 2022). Some specific activities in civil engineering laboratories, such as aggregate sieving, handling of cement, heating of asphalt, and compaction of soil, generate large amounts of both fine and coarse particles. Laboratories with natural or insufficient mechanical ventilation are risky to students and technicians exposed for extended periods (Bayram et al., 2024).

Indoor air pollution within educational institutions has also been emerging prominently within low- and middle-income countries (LMICs) such as Bangladesh, where the development of related ventilation systems and monitoring activities has been rudimentary (Mahmood et al., 2019). Various studies within Bangladesh have also shown the importance of the issue, demonstrating the presence of a considerable level of PM within schools, universities, and offices, beyond the recommended WHO standards, because of poor air circulation, occupancy density, and the lack of appropriate control of pollution (Begum et al., 2013). However, regardless of the extensive use of civil engineering laboratories within the public universities of Bangladesh, empirical studies related to the level of PM and related health risks are found to be extremely limited.

Ventilation systems, whether natural, mechanical, or hybrid, are the main determinant of indoor PM levels. Many studies have found that increasing ventilation rates, adding powered mechanical venting, or implementing a local extract system tends to reduce particle levels in occupational spaces(Chua et al., 2017). In line with that, powered mechanical systems and local extract venting systems have been recommended by the WHO IAQ guidelines and the U.S. EPA manual for essential control in high-emission spaces (Forum & Agency, 2005; WHO, 2021). Still, the success of these strategies may be conditionally specific to the building type and characteristics, pollutant source, and management practices followed. Thus, field studies of the success of these strategies are essential for informing the management of IAQ within educational institutions in LMICs.

Aside from the quantification of the concentration of PM, it is also important to assess the related health implications for the users of the laboratory. Health risk assessment (HRA), using the health and ecological assessment of hazardous materials model proposed by the U.S. Environmental Protection Agency (USEPA), is a way to estimate the risk of both the carcinogenic and the non-carcinogenic effects of pollutant exposure (Khamal et al., 2019; Umar et al., 2025). One of the reasons why $PM_{2.5}$ is a matter of concern is because of its small aerodynamic diameter, allowing it to penetrate the alveolar region of the lungs and carry toxic metals and organic compounds that are capable of generating harmful substances(Kelly et al., 2020; Sarasamma & Narayanan, 2014). Based on the above research gaps, the current study aims to: (i) measure the concentration of $PM_{2.5}$ and PM_{10} in four civil engineering laboratories of Khulna University of engineering & technology (KUET), (ii) assess the efficacy of ventilation improvement intervention using pre- and post-comparison and (iii) calculate the level of both non-carcinogenic and carcinogenic risks using the HRA approach of the USEPA model. This study offers the first comprehensive evaluation of laboratory-based PM exposure within the Bangladeshi civil engineering context and informs ways of enhancing IAQ management practices to protect the health of personnel within laboratories. The work is anticipated to inform the development of policies that improve the safety of laboratories within engineering institutions across both the Bangladeshi and broader LMIC contexts.

2. METHODOLOGY

2.1 Study Area

This study was conducted in the laboratories of the civil engineering department of KUET (Figure 1), which is located in the southwestern part of Bangladesh (22.9009° N, 89.5021° E). The department building is centrally located within the university campus and houses a number of laboratories that are utilized for teaching and research purposes. In the present study, four laboratories were selected based on their high usage and different experimental activities that generate particulate matter in the air. These laboratories include the Geotechnical Engineering Laboratory (Geotech Lab), Environmental Engineering Laboratory (Environment Lab), Engineering Materials Laboratory (EM Lab), and the Transportation Engineering Laboratory (Transport Lab), out of which the Environment Lab is situated on the third floor of the civil engineering building, and the remaining are situated on the ground floor.

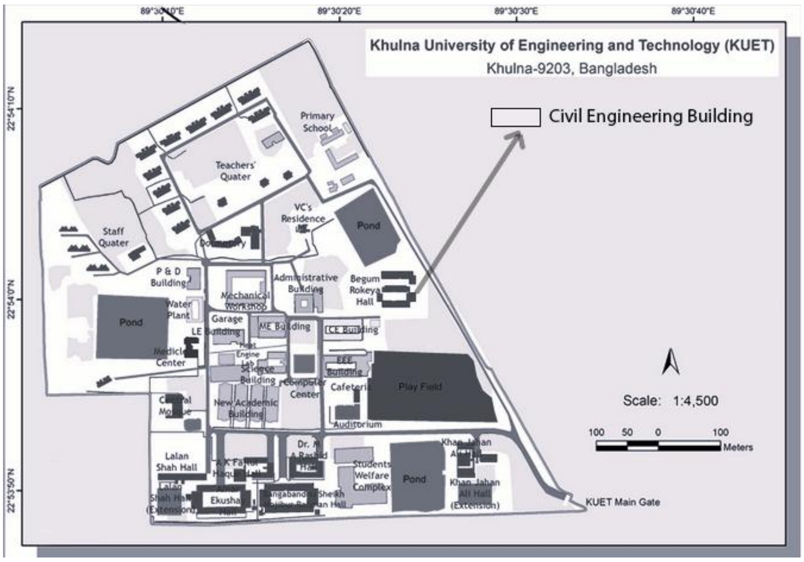


Figure 1: Civil Engineering Department at KUET

2.2 Measurement of PM

The concentration of $PM_{2.5}$ and PM_{10} was measured using a portable monitoring equipment (Aeroqual Series 500), fitted with pre-calibrated particulate matter sensors (Figure 2). The measurement of the concentration of PM was done through two campaigns: the baseline campaign, which was conducted on 2 October 2024, under natural ventilation before any kind of improvement, and the other is post-improvement campaign performed after the installation of mechanical ventilation systems, exhaust fans, and some air conditioners on 9 September 2025. The equipment was placed at breathing height 1.2-1.5 m above the floor level, simulating normal conditions of exposure to the population. The time of each measurement period lasted for one hour during normal laboratory operations. The data was recorded every 30 seconds. All concentration values were measured in micrograms per cubic meter ($\mu g \cdot m^{-3}$).

Figure 2: Aeroqual Series 500 monitoring equipment

2.3 Statistical Analysis of PM

Statistical analysis was used to analyse the distributions of baseline PM and changes in PM concentration following ventilation improvements. To determine the normality of $PM_{2.5}$ and PM_{10} datasets for each laboratory, the Shapiro–Wilk test was applied. Since the distributions of the data were not normal, the non-parametric Wilcoxon signed-rank test was used for the comparison of the baseline and post-intervention PM concentration data. All statistical procedures were conducted using Microsoft Excel and the Python program, with the significance level at $p < 0.05$.

2.4 Human Health Risk Assessment (HRA)

The HRA was used to examine possible harmful effects of inhalation exposure to $PM_{2.5}$ and PM_{10} within the laboratories. The procedure followed the U.S. Environmental Protection Agency (USEPA) methodology (USEPA 2010, 2014), considering both carcinogenic and non-carcinogenic risks for two groups: undergraduate students and technicians. The Lifetime Average Daily Dose (LADD) in $\mu g \cdot kg^{-1} \cdot day^{-1}$ was calculated using equation (1) to quantify the inhalation exposure for both exposure groups.

$$LADD = \frac{C\ x\ IR\ x\ ET\ x\ EF\ x\ ED}{BW\ x\ AT} \quad (1)$$

Where C is the concentration of PM, IR is the inhalation rate ($m^3 \cdot h^{-1}$), ET is exposure time ($h \cdot day^{-1}$), EF is exposure frequency ($days \cdot year^{-1}$), ED is exposure duration (years), BW is body weight (kg), and AT is averaging time (days). Hazard Quotient (HQ) is used to evaluate non-carcinogenic risk. Equation (2) was used to calculate HQ.

$$HQ = \frac{LADD}{Rfd} \quad (2)$$

where Rfd ($\mu g \cdot kg^{-1} \cdot day^{-1}$) is the reference dose, derived from the WHO reference concentration (RfC) guideline values using equation (3).

$$RfD = \frac{RfC\ x\ IR}{BW} \quad (3)$$

An HQ ≤ 1 suggests that there are no risks of non-carcinogenic effects, while HQ >1 could imply a possible harmful effect (Abdullah et al., 2025; Deng et al., 2019; Saju et al., 2023).The carcinogenic risk caused by $PM_{2.5}$ was estimated through the Excess Lifetime Cancer Risk (ELCR), which is given by Equation (4).

$$ELCR = LADD \times SF \quad (4)$$

where SF is the slope factor (kg·day·µg⁻¹), derived from inhalation unit risk (IUR) using Equation (5)

$$SF=\frac{IUR}{BW\ X\ IR} \tag{5}$$

PM_{10} is not considered for carcinogenic evaluation as there is no IUR, and a slope factor is available in the USEPA's IRIS and WHO databases. The ELCR $<10^{-6}$ represents negligible cancer risk, while the level of 10^{-6} to 10^{-4} represents acceptable or tolerable risk, and ELCR $>10^{-4}$ represents unacceptable cancer risk (USEPA 2011, 2014; Khamal et al., 2019). The exposure factors used for the students and the technician are presented in Table 1, adopted from the USEPA Exposure Factors Handbook 2011, and other related literature.

Table 1**:** Exposure parameters for estimation of non-carcinogenic and carcinogenic risks via inhalation of particulate matter.

Parameter	value	unit	References
C- Concentration of PM	**	$\mu g \cdot m^{-3}$	This Study
EF - Exposure frequency	S= 180, T= 250	days/year	KUET academic calendar
ED -Exposure duration	S =3, T =25	years	This Study
AT-Averaging time (NC)	ED x 365	days	(USEPA, 2011)
AT-Averaging time (C)	70 x 365	days	(USEPA, 2011)
IR - Inhalation rate	S =0.83, T=1.25	$m^3 \cdot h^{-1}$	(USEPA, 2011)
BW-Average body weight	70	kg	(USEPA, 2011)
ET – Exposure time	S =4, T= 8	h/day	This Study
IUR- Inhalation unit risk ($PM_{2.5}$ only)	0.008	$(\mu g \cdot m^{-3})^{-1}$	(Mbazima, 2022)
RfC-Reference Concentration	$PM_{2.5}$=15 PM_{10} = 45	$\mu g \cdot m^{-3}$	(WHO, 2021)

S= Students, T= Technicians, C=carcinogenic, NC= Non carcinogenic

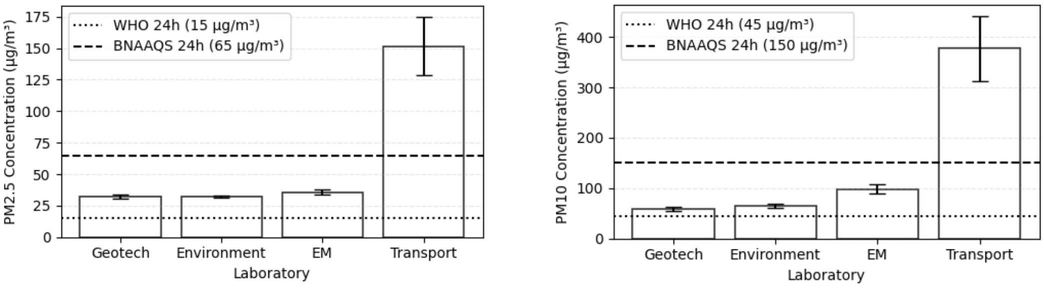
3. RESULTS AND DISCUSSION

3.1 Baseline PM Concentrations

The baseline measurement indicated significant variability in the concentrations of PM among the laboratories because of different activity types and their efficiencies of ventilation. As depicted in Table 2 and Figure 3, the Transport Lab had the highest mean $PM_{2.5}$ and PM_{10} concentrations of 151.6 ± 23.35 $\mu g \cdot m^{-3}$ and 377.1 ± 64.63 $\mu g \cdot m^{-3}$, respectively. This was caused by frequent heating of bitumen and preparation of asphalt samples that generated visible fumes and coarse dust. A moderate level of $PM_{2.5}$ and PM_{10} with mean concentrations of 35.67 ± 1.93 $\mu g \cdot m^{-3}$ and 98.56 ± 9.92 $\mu g \cdot m^{-3}$ are shown in the EM lab due to frequent handling of cement and aggregates. Relatively, the Environment and Geotech Labs recorded lower $PM_{2.5}$ concentrations of 32.15 ± 0.86, 32.31 ± 1.82 $\mu g \cdot m^{-3}$, and PM_{10} concentrations of 65.72 ± 4.25, 58.95 ± 3.40 $\mu g \cdot m^{-3}$, consistent with less dust-generating activities and better natural ventilation. Results of the measured baseline values exceeded the daily average threshold limit for safe exposure in all laboratories compared to the WHO (2021) guideline limits (15 $\mu g \cdot m^{-3}$ for $PM_{2.5}$ and 45 $\mu g \cdot m^{-3}$ for PM_{10}) and Bangladesh's national ambient air quality standard (BNAAQS) (65 $\mu g \cdot m^{-3}$ for $PM_{2.5}$ and 150 $\mu g \cdot m^{-3}$ for PM_{10}) (Saju et al., 2023). The results underlying the necessity of effective ventilation control are consistent with the reported trends in similar academic settings (Sarasamma & Narayanan, 2014; Zhao et al., 2020).

Lab	Pollutant	Minimum	Mean	Maximum	Median	SD
Geotech	PM$_{2.5}$	30	32.31	36	32	1.82
	PM$_{10}$	51	58.95	63	60	3.40
Environment	PM$_{2.5}$	31	32.15	33	33	0.86
	PM$_{10}$	53	65.72	69	67	4.25
EM	PM$_{2.5}$	32	35.67	40	35.5	1.93
	PM$_{10}$	82	98.56	114	96.5	9.92
Transport	PM$_{2.5}$	106	151.64	181	155	23.35
	PM$_{10}$	247	377.12	463	386	64.63

Table 2: Descriptive statistics of baseline PM concentrations (µg·m^{-3})



(a) (b)

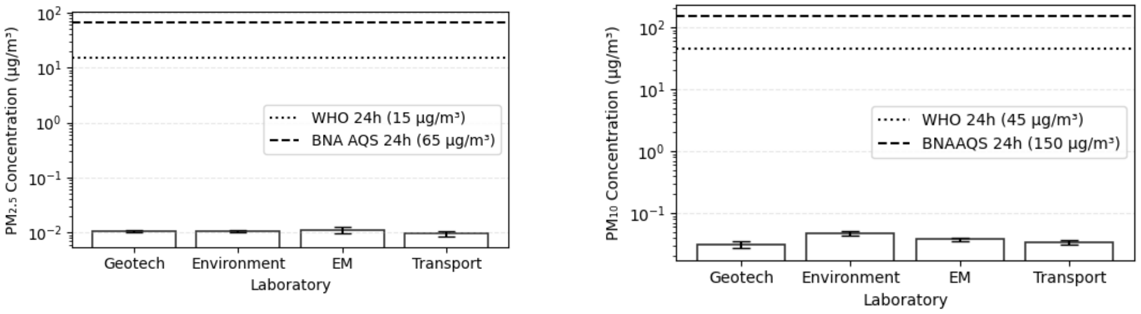
Figure 3: Baseline PM concentration across laboratories with WHO and BNAAQS limits for (a) PM$_{2.5}$,(b) PM$_{10}$

3.2 Post Improvement PM Concentrations

Following the installation of mechanical ventilation and exhaust systems, PM$_{2.5}$ and PM$_{10}$ concentrations were significantly reduced in all laboratories, as shown in Table 3 and Figure 4. On average, the concentration of PM$_{2.5}$ came down to 0.0097± 0.0011-0.0112 ± 0.0016 µg.m^{-3} while PM$_{10}$ was reduced to 0.031 ± 0.0041-0.047 ±0.0033 µg.m^{-3}, reflecting more than 95% reduction. The highest improvement was recorded in the Transport Lab, whose elevated levels were brought down to less than 0.05 µg.m^{-3}. This reflects the efficiency of improved airflow, ensuring efficient dispersion of aerosols and reducing concentration close to the source. Mechanical ventilation is very efficient as a PM control measure in the laboratory.

Lab	Pollutant	Minimum	Mean	Maximum	Median	SD
Geotech	PM$_{2.5}$	0.010	0.0105	0.011	0.0105	0.0005
	PM$_{10}$	0.023	0.031	0.036	0.033	0.0041
Environment	PM$_{2.5}$	0.010	0.0106	0.011	0.011	0.00048
	PM$_{10}$	0.041	0.047	0.051	0.048	0.0033
EM	PM$_{2.5}$	0.010	0.0112	0.015	0.0105	0.0016
	PM$_{10}$	0.034	0.038	0.042	0.0385	0.0022
Transport	PM$_{2.5}$	0.008	0.0097	0.011	0.01	0.0011
	PM$_{10}$	0.029	0.034	0.038	0.0345	0.0025

Table 3: Descriptive statistics of post- improvement PM concentrations (µg·m^{-3})



(a)

(b)

Figure 4: PM concentrations after post improvement across laboratories with WHO and BNAAQS limits for (a) $PM_{2.5,}$ (b) PM_{10}

3.3 Statistical Comparison Between Two Campaigns

The ventilation improvement effectiveness was statistically assessed by the Wilcoxon signed-rank test, as both $PM_{2.5}$ and PM_{10} values were non-normally distributed. The experiment compared the paired concentrations of $PM_{2.5}$ and PM_{10} in the same laboratories at baseline and following the improvement. The test outcome (Table 4) revealed significant reductions (p-value < 0.05) of both particulate air pollutants in all laboratories, except for the Environment Laboratory, where $PM_{2.5}$ concentration demonstrated a reducing trend without significant statistics (p-value = 0.0625). The Transport Laboratory recorded the maximum reduction (p-value < 0.001), due to the prevention of particulate emissions from bitumen heating and other high-temperature processes. The paired comparison plot (Figure 5) shows the trend in $PM_{2.5}$ and PM_{10} concentrations, and it is evident that there was a downward trend in concentrations for both $PM_{2.5}$ and PM_{10} between the two campaigns. In all labs, there were steady reductions, and this indicates that mechanical ventilation and exhaust systems reduced particulate concentration inside.

Table 4: Wilcoxon signed-rank test results for $PM_{2.5}$ and PM_{10}.

Lab	Pollutant	p-value
Geotech	$PM_{2.5}$	0.03125
	PM_{10}	0.007812
Environment	$PM_{2.5}$	0.0625
	PM_{10}	0.000977
EM	$PM_{2.5}$	0.001953
	PM_{10}	3.10E-05
Transport	$PM_{2.5}$	0.000977
	PM_{10}	0.000488

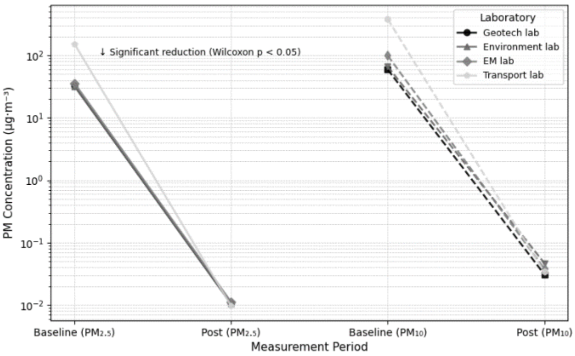


Figure 5: Paired comparison of baseline and post-intervention PM concentrations

3.4 Health Risk Assessment

The Human Health Risk Assessment (HRA) showed a significant reduction in both non-carcinogenic and carcinogenic risks after the improvement of ventilation. In the baseline phase, HQ values of $PM_{2.5}$ were greater than one $(HQ>1)$ in the Transport and EM Labs for both types of population, suggesting non-carcinogenic health risks due to inhalation exposure. Additional consideration should be given to HQ, which was significantly higher in the case of technicians compared to students, as they are frequently exposed to this air pollutant for longer periods and are also working for a longer period of time. HQ values for PM_{10} were less than one in all other labs, suggesting less non-carcinogenic health risk. After the ventilation measures, HQ values for all laboratories for both PM fractions decreased dramatically to the range of 10^{-3} to 10^{-4}, well below the acceptable risk level (Table 5), proving that the optimized ventilation system significantly reduced non-carcinogenic health hazards.

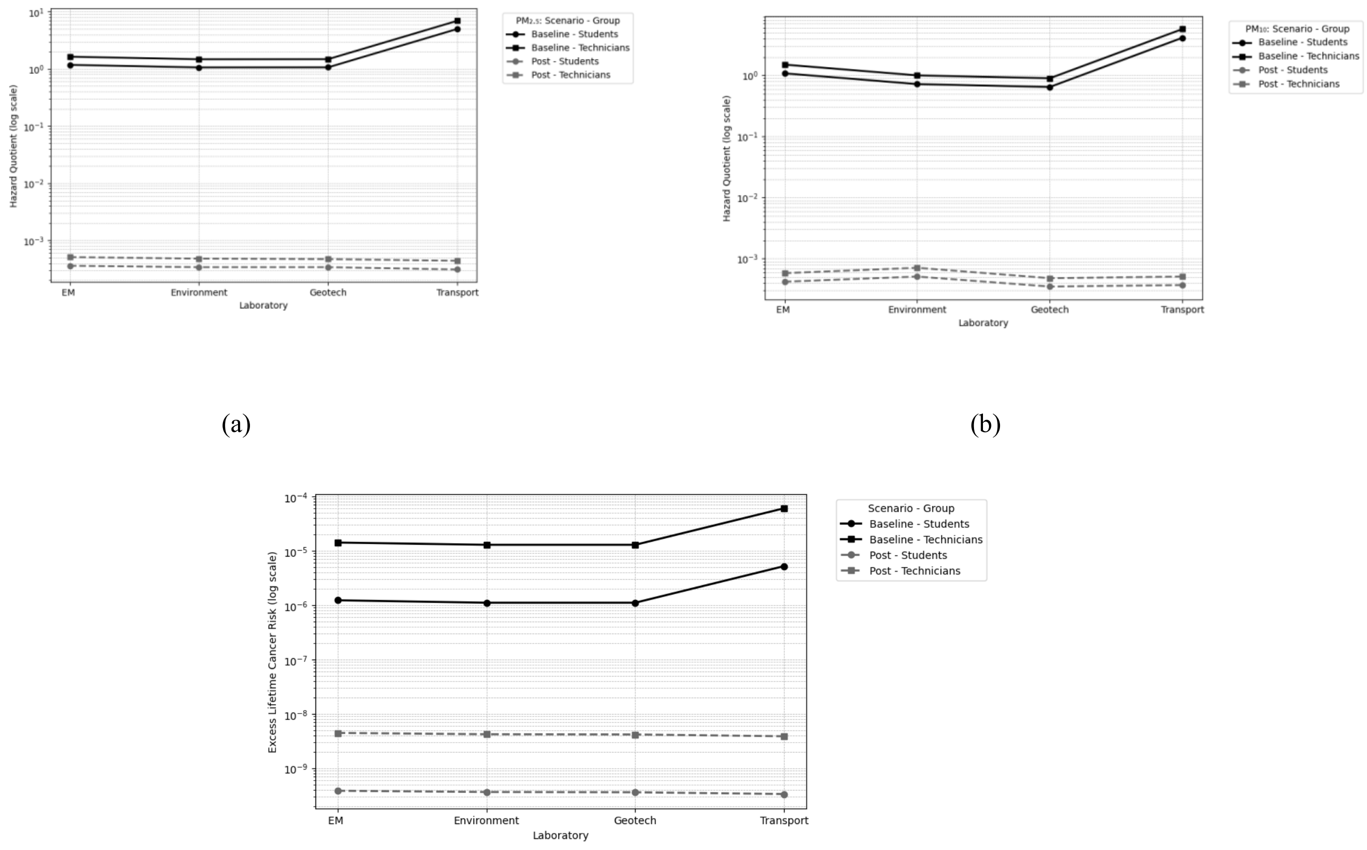
The carcinogenic risk, carried out only for $PM_{2.5}$, indicated that ELCR exceeded the moderate risk level of 10^{-6} to 10^{-4}, and the technicians' exposure level reached up to 6.06×10^{-5} (Table 6). However, after the ventilation improvement, ELCR decreased by four to five orders of magnitude to the range of 10^{-9} to 10^{-10}, which indicates no significant carcinogenic risk. The order of reduction achieved by HQ and ELCR is shown in Figure 6 (a-c), and it is evident that all environments show a substantial reduction in both HQ and ELCR, confirming the success achieved by the proposed ventilation improvement technique in eliminating non-carcinogenic and carcinogenic risks posed by $PM_{2.5}$ in all lab environments.

Campaign	Pollutant	Geotech lab	Environment lab	EM lab	Transport lab
Baseline	$PM_{2.5}$ (S)	1.06232	1.05909	1.17299	4.98565
	$PM_{2.5}$ (T)	1.47545	1.47097	1.62915	6.92452
	PM_{10} (S)	0.64605	0.72024	1.08018	4.13279
	PM_{10} (T)	0.89729	1.00033	1.50025	5.73999
Post-Improvement	$PM_{2.5}$ (S)	0.00034	0.00034	0.00036	0.00031
	$PM_{2.5}$ (T)	0.00047	0.00048	0.00051	0.00044
	PM_{10} (S)	0.00035	0.00051	0.00042	0.00037
	PM_{10} (T)	0.00048	0.00071	0.00058	0.00051

Table 5: Hazard Quotient (HQ) for $PM_{2.5}$ and PM_{10} of two campaigns.

Table 6: Lifetime carcinogenic risk (ELCR) for two campaigns of $PM_{2.5}$

Campaign	Pollutant	Geotech lab	Environment lab	EM lab	Transport lab
Baseline	$PM_{2.5}$ (S)	1.1149E-06	1.1115E-06	1.2311E-06	5.2327E-06
	$PM_{2.5}$ (T)	1.2904E-05	1.2865E-05	1.4249E-05	6.0564E-05
Post-Improvement	$PM_{2.5}$ (S)	3.6231E-10	3.6576E-10	3.8646E-10	3.3565E-10
	$PM_{2.5}$ (T)	4.1934E-09	4.2334E-09	4.4730E-09	3.8848E-09



(a) (b)

(c)

Figure 6: Comparative variations for students and technicians between baseline and post-improvement conditions for (a) HQ of $PM_{2.5}$, (b) HQ of PM_{10}, (c) ELCR of $PM_{2.5}$

4. CONCLUSION

This study offers a detailed analysis of indoor air quality (IAQ) and health risks related to particulate matter ($PM_{2.5}$ and PM_{10}) inside the Civil Engineering laboratories at KUET, before and after ventilation modifications. The findings revealed notable differences in PM levels within the laboratories, with the highest concentrations observed in the Transportation and Engineering Materials Laboratory, where activities like bituminous heating and cement handling produce extensive particles. The levels exceeded WHO (2021) and USEPA standards, leading to elevated non-carcinogenic risks (HQ > 1 for $PM_{2.5}$) and moderate carcinogenic risks for technicians with prolonged exposure. After installing mechanical ventilation and local exhaust systems, $PM_{2.5}$ and PM_{10} levels decreased significantly across all laboratory environments. The Wilcoxon Signed-Rank Test confirmed a meaningful reduction in all sampled environments and pollutants, confirming the effectiveness of these measures. The subsequent Health Risk Assessment (HRA) results showed substantial decreases in HQ and ELCR levels, with all risks falling within acceptable or negligible ranges for students and technicians. Overall, the results highlight the vital role of engineering controls, particularly mechanical ventilation and local exhaust systems, in lowering exposure to particulate air pollutants in academic labs. Continuous indoor air quality monitoring, ventilation system upgrades, and activity-specific hazard management are essential to ensure a safe learning environment for students and staff in engineering education settings.

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Declaration of Use of AI

The authors declare that generative artificial intelligence (AI) tools were used only for limited supportive purposes during the preparation of this manuscript. AI-assisted search tools were utilized to identify recent, relevant literature, and AI-based language tools were employed for grammar refinement and sentence clarity improvement. No AI tools were used for generating original content, data analysis, methodological development, or interpretation of results. The concepts, analyses, and conclusions presented in the manuscript are the sole responsibility of the authors.

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