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Research Article

Assessment of Particulate Matter ($PM_{2.5}$) in Higher Education Facilities in the Public and Private Sectors in Karachi, Pakistan

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Abstract
Air pollution in educational institutions is an emerging issue since students spend a considerable amount of their time in classrooms where they are exposed to fine particulate matter ($PM_{2.5}$), which may have negative health and learning effects. In most urban and industrial areas, schools/universities are the direct sufferers of the pollution sources around them, and thus form a major area of concern as far as air quality evaluation is concerned. The purpose of this report is to assess $PM_{2.5}$ levels in higher educational institutes in Karachi, with the aim of highlighting the degree of exposure and its health consequences on students and the need to raise awareness among both students and among both students and relevant authorities. The experimental data on the concentrations of $PM_{2.5}$ were observed in two higher educational institutions (HEI) in Karachi. This is carried out by monitoring the air quality inside and outside of three different classrooms at different time intervals with a random number of students. The measured data were subsequently compared across the sites to determine the differences in the level of pollution and to determine the degree of exposure in comparison to international air quality guidelines. This study indicated that the quality of air in private institutes is much better than that in public sector institutes, but the overall air quality is not at the level as per WHO guidelines due to the general quality of air in the city. This study recommended that the elevated level of air pollution needs urgent attention from the government and other departments responsible for maintaining a sustainable environment in the city, as it is not only harmful to the residents of the city but also creates adverse effects on the students' health.

Keywords: Air Pollution, Aerial Particulate $PM_{2.5}$, Air Quality Index, Health

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1. INTRODUCTION

The world has experienced tremendous industrialization over the past ten years, along with an increase in the consumption of fossil fuels, which has led to higher emissions of carbon-containing particles and higher levels of air pollution. Air pollution is a growing global environmental problem that is responsible for causing 8.9 million deaths across the world, which accounts for 7.6% of mortality each year (Hassan et al., 2021). WHO reported that each year, nearly 4.2 and 3.2 million healthy people lose their lives because of poor outdoor and indoor air quality due to several causes (Anenberg et al., 2016). This alarming health situation is mainly caused by the presence of different pollutants, especially PM, which reduces the life expectancy of people and increases the mortality rate. A recent study also predicted that by the end of 2050, premature mortalities due to air pollution will be doubled, and hence it's important to take mitigation measures at the national scale to reduce the diseases and mortality burden associated with air pollution (Lelieveld et al., 2015).

The aerial particle having a size of $PM_{2.5}$ is of major concern as it is the main cause of disease related to the pulmonary system and the heart. The Third World countries and the countries on the edge of industrialization increase fossil fuel utilization in numerous ways to cater to the demand and to meet the industrial race of the world, thus ultimately raising the local level of air pollution (Banerjee & Linstead, 2001; Kaplan, 2015). Nowadays, the emigration of the population, from rural to urban areas, is also rising around the world, thus increasing urbanization, which further exerts pressure on the resources of the cities, and leads to environmental damage to the already overcrowded megacities. The population of megacities around the world has risen from 5% to 50% in the last two decades, and it is estimated that, by 2030, the megacities may have 2/3 of the world population (Cohen, 2006).

In rapidly growing megacities like Karachi, where residents and the government have a casual attitude toward the environment over time, the air quality has reached alarming levels of pollution, as evidenced by the steady rise in the number of people with lung ailments admitted to hospitals. The effect of particulate pollution on human health is twofold; firstly, while breathing, they are captivated in the lungs, causing them to malfunction, which may lead to hospitalization. Secondly, it can be converted into chronic respiratory disease over time and may lead to mortality. Furthermore, the consumption of fossil fuels inside the house for energy demand also raises the level of indoor air pollution. Thus, it can be imagined that air pollution increases the health hazards, and those who live continuously in such an environment may face severe health-related issues such as lung cancer, tuberculosis, cardiac arrest, and different respiratory diseases.

Around 3.4 to 3.7 million premature deaths are due to indoor air pollution (Giannadaki et al., 2016). Mostly, the urban population prefers to live in enclosed areas, and in order to minimize the indoor mortality rate, it is essential to have sufficient knowledge of the quality of air in that particular location. The quality of air at a particular location is measured by a standard scale called the Air Quality Index (AQI), relating to the range of pollutants and categories. Essentially, AQI tells the pollution level of the air at specific locations and helps to access the health hazards (Neidell, 2004).

The air quality of educational facilities is of utmost importance because these areas have a very high density of students, and they spend most of their daytime in the classrooms. Although classrooms don't have the kind of pollution sources that other indoor environments may have, such as cooking and smoking, one can still measure particulate matter like $PM_{2.5}$ and PM_{10} (Hollowell & Miksch, 1981). In classrooms, the number of students at any given time influences the level of pollutants, such that a large number of students present in a small classroom will lead to the generation of particulate matter (Fromme et al., 2007). It is reported that the level of $PM_{2.5}$ in the classroom increases significantly in the presence of students (Braniš et al., 2005).

2. MATERIAL AND METHOD

2.1. Experimentation Site

The measurement of particulate $PM_{2.5}$ is carried out in government (Department of Physics, University of Karachi; UoK) and private (Department of Computer Science, Sir Syed University of Engineering and Technology; SSUET) universities located in Karachi. The indoor and outdoor measurements were carried out simultaneously in both universities in 3 different classrooms, with a random number of students and dimensions as given in Tables 1 and 2.

Table 1. Site 01, Department of Physics, University of Karachi, Karachi, Pakistan

Public Sector University	Area (Sq. ft.)	Student Capacity
Class Room # 01	24 x 30	30
Class Room # 02	24 x 30	50
Class Room # 03	32 x 24	65

Table 2. Site 02, Department of Computer Science, Sir Syed University of Engineering and Technology, Karachi, Pakistan

Private Sector University	Area (Sq. ft)	Student Capacity
Class Room # 01	25 x 25	30
Class Room # 02	25 x 25	50
Class Room # 03	35 x 25	65

2.2. Experimentation Equipment

The particulate concentration was measured with a $PM_{2.5}$ Air Quality Monitor (TES-5321) having a $PM_{2.5}$ range of 0-500 µg/m³, 1-99% humidity, and -20 to 60°C temperature range. The instrument also provides color-coded AQI as per the following color indication (Table 3).

Table 3. Color Code for the AQI (TES 5321)

Color	AQI	$PM_{2.5}$ (µg/m³)
Green	Good (0-50)	0 - 12
Yellow	Moderate (51-100)	12.1 - 35.4
Aqua	Unhealthy for Sensitive Groups (101-150)	35.5 - 55.4
Red	Unhealthy (151-200)	55.5 - 150.4
Purple	Very Unhealthy (201-300)	150.5 - 250.4
Blue	Hazardous (301-500)	250.5 - 500

3. RESULTS AND DISCUSSION

Table 4-6 shows the indoor measurement of$PM_{2.5}$ in 3 different classes of SSUET, while Tables 7, 8, and 9 provide the data of $PM_{2.5}$ in UoK. From Table 4-6, it is clear that the average indoor concentration of $PM_{2.5}$ in SSUET is 47.30 (µg/m³), 42.46 (µg/m³), and 58.36 (µg/m³) for classrooms 1, 2, and 3, respectively.

Table 4. $PM_{2.5}$ Concentration in the 1st Classroom of SSUET

S. No.	Time (Sec)	$PM_{2.5}$ (µg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (µg/m³)	H.I
1	16:00	50	5	16	16:30	47	5
2	16:02	48	5	17	16:32	47	5
3	16:04	48	5	18	16:34	46	4
4	16:06	48	5	19	16:36	46	4
5	16:08	49	5	20	16:38	47	5
6	16:10	49	5	21	16:40	47	5
7	16:12	47	5	22	16:42	45	4
8	16:14	48	5	23	16:44	47	5
9	16:16	48	5	24	16:46	46	4
10	16:18	48	5	25	16:48	48	5
11	16:20	47	5	26	16:50	47	5
12	16:22	47	5	27	16:52	46	4
13	16:24	48	5	28	16:54	48	5
14	16:26	46	4	29	16:56	48	5
15	16:28	46	4	30	16:58	47	4

Table 5. $PM_{2.5}$ Concentration in the 2nd Classroom of SSUET

S. No.	Time (Sec)	$PM_{2.5}$ (µg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (µg/m³)	H.I
1	12:20	42	4	16	12:50	43	4
2	12:22	48	5	17	12:52	41	4
3	12:24	46	4	18	12:54	42	4
4	12:26	46	4	19	12:56	40	4
5	12:28	46	4	20	12:58	42	4
6	12:30	46	4	21	13:00	42	4
7	12:32	44	4	22	13:02	42	4
8	12:34	43	4	23	13:04	41	4
9	12:36	42	4	24	13:06	42	4
10	12:38	43	4	25	13:08	41	4
11	12:40	43	4	26	13:10	39	4
12	12:42	44	4	27	13:12	40	4
13	12:44	42	4	28	13:14	40	4
14	12:46	44	4	29	13:16	39	4
15	12:48	41	4	30	13:18	40	4

Table 6. $PM_{2.5}$ Concentration in the 3rd Classroom of SSUET

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	16:00	67	7	16	16:30	57	6
2	16:02	67	7	17	16:32	61	6
3	16:04	62	6	18	16:34	58	6
4	16:06	57	6	19	16:36	57	6
5	16:08	57	6	20	16:38	62	6
6	16:10	55	5	21	16:40	58	6
7	16:12	58	6	22	16:42	55	5
8	16:14	64	6	23	16:44	55	5
9	16:16	56	6	24	16:46	59	6
10	16:18	55	5	25	16:48	58	6
11	16:20	58	6	26	16:50	59	6
12	16:22	64	6	27	16:52	55	6
13	16:24	60	6	28	16:54	53	5
14	16:26	56	6	29	16:56	56	6
15	16:28	57	6	30	16:58	55	5

Similarly, the data from Tables 7 to 9 give the average indoor concentration of $PM_{2.5}$ in UoK were 49.53 (μg/m³), 49.66 (μg/m³), and 57.20 (μg/m³) for classrooms 1, 2, and 3, respectively.

Table 7. $PM_{2.5}$ Concentration in the 1st Classroom of UoK

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	12:00	51	5	16	12:30	52	5
2	12:02	50	5	17	12:32	48	5
3	12:04	49	5	18	12:34	49	5
4	12:06	50	5	19	12:36	50	5
5	12:08	49	5	20	12:38	49	5
6	12:10	50	5	21	12:40	49	5
7	12:12	50	5	22	12:42	48	5
8	12:14	52	5	23	12:44	48	5
9	12:16	51	5	24	12:46	48	5
10	12:18	52	5	25	12:48	47	5
11	12:20	51	5	26	12:50	48	5
12	12:22	54	5	27	12:52	48	5
13	12:24	52	5	28	12:54	47	5
14	12:26	52	5	29	12:56	47	5
15	12:28	50	5	30	12:58	45	4

Table 8. $PM_{2.5}$ Concentration in the 2nd Classroom of UoK

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	10:10	52	5	16	10:40	47	5
2	10:12	54	5	17	10:42	47	5
3	10:14	54	5	18	10:44	47	5
4	10:16	53	5	19	10:46	48	5
5	10:18	52	5	20	10:48	47	5
6	10:20	51	5	21	10:50	48	5
7	10:22	52	5	22	10:52	49	5
8	10:24	50	5	23	10:54	50	5
9	10:26	49	5	24	10:56	48	5
10	10:28	50	5	25	10:58	48	5
11	10:30	50	5	26	11:00	50	5
12	10:32	48	5	27	11:02	50	5
13	10:34	51	5	28	11:04	51	5
14	10:36	48	5	29	11:06	50	5
15	10:38	47	5	30	11:08	49	5

Table 9. $PM_{2.5}$ Concentration in the 3rd Classroom of UoK

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	14:20	60	6	16	14:50	57	6
2	14:22	56	6	17	14:52	57	6
3	14:24	55	6	18	14:54	57	6
4	14:26	56	6	19	14:56	59	6
5	14:28	56	5	20	14:58	58	6
6	14:30	59	6	21	15:00	57	6
7	14:32	57	6	22	15:02	57	6
8	14:34	59	6	23	15:04	56	6
9	14:36	61	6	24	15:06	61	6
10	14:38	57	6	25	15:08	55	5
11	14:40	59	6	26	15:10	55	5
12	14:42	59	6	27	15:12	56	6
13	14:44	58	6	28	15:14	54	5
14	14:46	57	6	29	15:16	55	5
15	14:48	59	6	30	15:18	54	5

Tables 10 and 11 show the outdoor measurements of $PM_{2.5}$ in SSUET and UoK. The average outdoor concentration of $PM_{2.5}$ in SSUET and UoK was 63.73 (μg/m³) and 66.66 (μg/m³), respectively. Moreover, Figures 1 and 2 show the comparison of indoor and outdoor levels of $PM_{2.5}$ in both stations.

Table 10. Outdoor Concentration of $PM_{2.5}$ in SSUET

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	11:20	57	6	16	11:50	70	7
2	11:22	61	6	17	11:51	73	8
3	11:24	61	6	18	11:53	76	8
4	11:26	50	6	19	11:56	70	7
5	11:28	57	6	20	11:58	74	8
6	11:30	58	6	21	12:00	70	7
7	11:32	56	6	22	12:02	67	7
8	11:34	58	6	23	12:04	67	7
9	11:36	57	6	24	12:06	67	7
10	11:38	57	6	25	12:08	66	7
11	11:40	56	6	26	12:10	65	7
12	11:42	63	6	27	12:12	63	6
13	11:44	65	7	28	12:14	61	6
14	11:46	71	7	29	12:16	62	6
15	11:48	72	7	30	12:18	62	6

Table 11. Outdoor Concentration of $PM_{2.5}$ in UoK

S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I	S. No.	Time (Sec)	$PM_{2.5}$ (μg/m³)	H.I
1	10:30	104	9	16	11:00	58	6
2	10:32	95	9	17	11:02	54	5
3	10:34	87	9	18	11:04	60	6
4	10:36	80	8	19	11:06	59	6
5	10:38	72	7	20	11:08	60	6
6	10:40	69	7	21	11:10	61	6
7	10:42	65	7	22	11:12	58	6
8	10:44	67	7	23	11:14	63	6
9	10:46	65	7	24	11:16	61	6
10	10:48	70	7	25	11:18	60	6
11	10:50	61	6	26	11:20	78	8
12	10:52	60	6	27	11:22	68	7
13	10:54	58	6	28	11:24	67	7
14	10:56	60	6	29	11:26	62	6
15	10:58	60	6	30	11:28	58	6

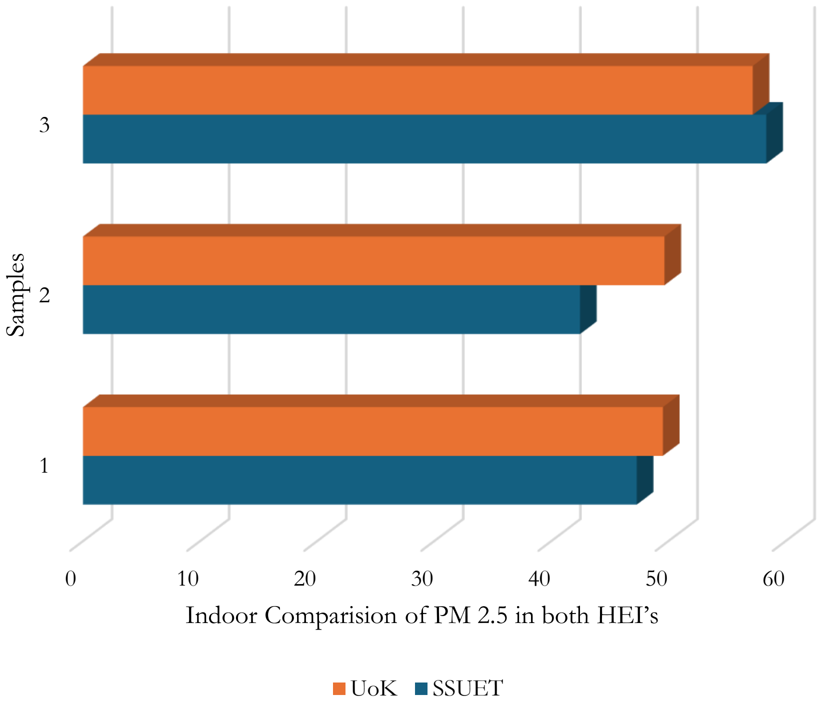

Figure 1. Indoor Comparison of $PM_{2.5}$ in SSUET and UoK

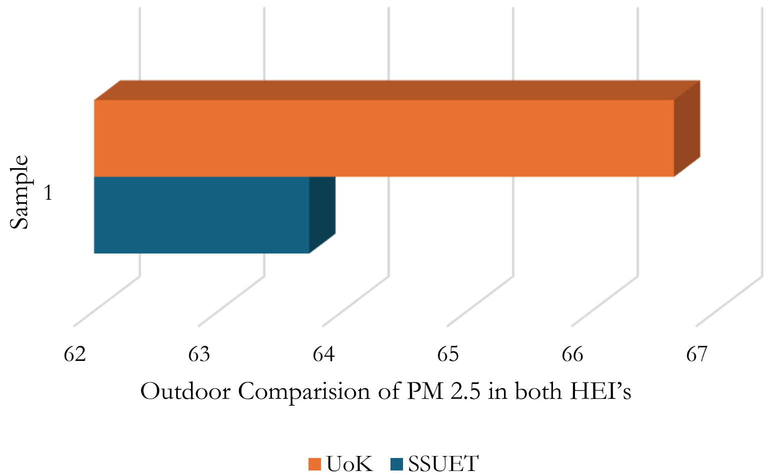

Figure 2. Outdoor Comparison of $PM_{2.5}$ in SSUET and UoK

The concentration of $PM_{2.5}$ in Classrooms 1 and 2 is comparatively lower than in Classroom 3 in both Universities (Figure 1), while the outdoor concentration of $PM_{2.5}$ is almost identical in both universities (Figure 2). It is clear that the concentration of $PM_{2.5}$ in different classrooms (indoor measurement) is slightly greater in UoK when compared with SSUET. The possible reason might include the number of students in a single class at UoK is greater than SSUET. Generally, it was evident that the indoor concentration of $PM_{2.5}$ was higher in those classrooms where the number of students was higher, i.e., $PM_{2.5}$ increases with the increase in students, exceeding the acceptable limit of the WHO. The classrooms in SSUET have Air conditioning cooling systems, thus the indoor AQI of these classes is affected only due to student density.

Observed that the highest average is seen in the 3rd classroom of SSUET; this is due to the fact that the dimension of this classroom is smaller than the others, and also has the highest density of students, thus yielding a high concentration of $PM_{2.5}$. Moreover, the outdoor air quality of both universities is almost identical, which is due to the similar atmosphere, surrounding environment, and locality of the universities. Different studies have also been conducted in various regions of Pakistan to highlight how the population is exposed to poor air quality, and the possible health implications are also being assessed (Mehmood et al., 2020; Qadeer et al., 2020; Rehman et al., 2020). However, comparative analysis of air pollution-related disease burden is not widely studied in mega megacities of Pakistan. Therefore, it is crucial to evaluate how the air quality in the cities affects human health so that appropriate mitigation measures can be implemented to enhance public health.

The air quality in South Asian countries has also been deteriorating, and it was reported that the highest annual exposure of $PM_{2.5}$ in 2019 was observed in Pakistan, India, Bangladesh, and Nepal, respectively (Anjum et al., 2021). Furthermore, it is observed that the levels of $PM_{2.5}$ in urban educational institutions in different countries with lower-middle income are quite unpleasant, as in Karachi's education institutions. For instance, in Dhaka, the capital of Bangladesh, a research study explored the effects of particulate matter (PM) and toxic gases on the health of schoolchildren. Indoor/outdoor air quality in 10 schools from April to November 2018 is reported in this study from monitoring $PM_{2.5}$, PM_{10}, $PM_{1.0}$, NO^2, TVOCs, and CO_2, as well as lung function (peak expiratory flow, PEF) of 250 students aged 9-12 years. Findings indicated that the mean $PM_{2.5}$ and PM_{10} concentrations were more than two times higher than the WHO recommendations, with schools on busy roads and populated neighborhoods recording the highest levels. The $PM_{2.5}$ and PM_{10} Hazard Quotients (HQs) were all above 1, which is an unacceptable health risk. The lung functioning of children was negatively correlated with the PM concentrations, which indicates a poor respiratory capacity (Roy et al., 2023).

The population of Pakistan has also been exposed to poor air quality because of the negligence of proper air monitoring and control of air pollution at the source. A study reported that the air quality of Karachi is being affected by industrial activities and vehicular emissions, which led to exceeding pollutant concentrations as compared to the WHO guidelines (Khan et al., 2017). Thus, it is crucial for policymakers to develop a comprehensive urban air quality management strategy that includes the installation of real-time air quality monitoring stations in and around educational institutions, particularly in high-density urban areas. Policies should prioritize the enforcement of emission standards for vehicles and industries, promote the use of clean fuels, and mandate regular environmental audits of institutional buildings. Additionally, investment in green infrastructure, such as planting vegetation around campuses and improving indoor ventilation systems, can mitigate exposure to $PM_{2.5}$. Educational institutions should also be encouraged to incorporate indoor air quality management into their campus planning and maintenance protocols to protect the health and cognitive performance of students and faculty. Besides these, socioeconomic disparity could also be a factor, with under-resourced schools or institutions that serve socioeconomically disadvantaged communities more likely to be situated in polluted areas, in older infrastructure, and have limitations to implementing effective air-quality management. Such conditions may lead to relatively increased $PM_{2.5}$ exposures compared to the exposures in better-resourced institutions (Mathiarasan & Hüls, 2021; Mullen et al., 2020).

4. SUGGESTIONS/REMEDIES

A multimodal approach is necessary to improve Karachi's air quality index (AQI), with a focus on reducing $PM_{2.5}$ concentrations. It is important to adopt and strictly enforce emission control measures, particularly in the industrial sector, which includes factories and power plants. These rules should include strict monitoring systems and sanctions for non-compliance. To reduce reliance on fossil fuels, which are a substantial source of $PM_{2.5}$ emissions, it is necessary to support the transition to renewable energy sources, such as solar and wind power.

Improving and expanding the public transport network is a crucial step in lowering the number of vehicles on the road. Using electric or hybrid buses and railways can cut pollution dramatically. Along with encouraging the deployment of electric and hybrid vehicles, legislation governing vehicle emissions requirements and the promotion of cleaner fuels should be implemented.

Urban tree growth and the construction of green areas are crucial because they act as natural air filters that lower $PM_{2.5}$ concentrations. To reduce dust emissions, strong construction and demolition standards should be put in place. Effective waste management techniques are also crucial because they prevent open burning and the subsequent emission of particulates into the sky.

Increasing the number of air quality monitoring stations and providing the public with real-time data can enable locals to make educated choices about outdoor activities. Campaigns to educate the public about the health risks associated with poor air quality, as well as tips for reducing personal exposure, are crucial. To create new approaches for lowering $PM_{2.5}$ concentrations and improving the overall quality of the air, scientific investigation and technical innovation should be undertaken.

Given that problems with air quality usually cross-regional and international borders, worldwide collaboration is necessary. Therefore, it is crucial to include neighboring nations and areas in the reduction of transboundary air pollution. Additionally, by empowering locals to monitor and report air quality issues through citizen science projects, the community is encouraged to take responsibility for its actions.

For situations of extreme air pollution, a clear and effective emergency action strategy is essential. This strategy should include warnings and limitations to protect the public's health. Another important aspect is promoting green building methods, which place an emphasis on energy efficiency and lower emissions. To encourage the adoption of greener technologies and practices, the government should expand its incentives and subsidies to enterprises and individuals. It will take a long time to improve the air quality, and lowering $PM_{2.5}$ concentrations, in particular, will require cooperation from all facets of society. It is essential for the citizens of Karachi's welfare and health.

5. CONCLUSION

It is evident from the comparison that the indoor AQI of the 1st and 2nd classrooms of both HEIs falls in the range of "Unhealthy for Sensitive Groups," while classroom 3 of both HEIs falls in the "Unhealthy" range, as given in AQI table 3. Similarly, the outdoor AQI of both HEIs falls in the range of the "Unhealthy" group. Thus, from these results, it is concluded that the quality of air in both the HEI is not up to the standards as per the AQI. The possible causes may include a high density of students in the classes, the passageway of the road around the campuses, a construction site near the campuses, and, most importantly, these data are collected at the beginning of the winter season, so the AQI of the whole city is disturbed during these days due to smoke. Now, to improve the AQI, it is required to have government-level efforts to minimize the construction work around the campuses, or to reduce the smoke output from the industries, and from the burning of crops in the fields, as these two are the main contributors to bad AQI in the city, which ultimately affects the AQI in the HEIs. Besides the significant insights of our study, some limitations need to be mentioned. Notable constraints of this study are the narrow sampling period, the few institutions that were sampled, and the lack of specific identification of the sources of indoor pollution. Future studies can be expanded to monitor over a longer period of time and in different seasons, and a more detailed indoor source analysis should also be added, as well as more sophisticated statistical analysis to explain the variability and factors that influence it. Also, a study of possible health implications for students and staff exposed to $PM_{2.5}$ in educational institutions would enhance future research.

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Research Ethics. No ethics approval was required for this work.

Data Availability Statement. All data supporting this study are included in the paper.

Conflicts of Interest. The author declares no conflicts of interest.

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