Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2023 20(1): 232-238. **OPEN ACCESS**

Indoor and outdoor particulate matter ($PM_{2.5}$ and PM_{10}) concentrations in classrooms in Umm Al-Qura University, Makkah, Saudi Arabia

Mutasim Mohamed Khalafalla[1]* and Tariq Sultan Ul haq Pasha[2]

[1]Department of Environmental Health, College of Public Health, and Health Informatics, Umm Al-Qura University, **Saudi Arabia**
[2]Department of Occupational Health, College of Public Health, and Health Informatics, Umm Al-Qura University. **Saudi Arabia**

***Correspondence:** mmkali@uqu.edu.sa **Received: 14-02-2023, Revised: 26-03-2023, Accepted: 29-03-2023 e-Published: 31-03-2023**

Measurements were carried out to determine the indoor (I), and outdoor (O) mean concentrations of $PM_{2.5}$, PM_{10} and their I/O ratios in the presence and absence of students at twenty classrooms located in two different campuses namely Aziziya and Abidyah at Umm Al-Qura University, Makkah city, Saudi Arabia. The levels of both indoor and outdoor particulate matters were higher in classrooms at Aziziya campus than in Abidyah. Average indoor concentrations were comparatively higher than their corresponding outdoor concentrations at both campuses. In Aziziya campus in the presence of students the average levels of indoor of $PM_{2.5}$ ranged from 72 µg/m^3 to 178 µg/m^3 and outdoor ranged from 46 µg/m^3 to 94 µg/m^3. For the PM_{10} was ranged from 49 µg/m^3 to 150 µg/m^3 and outdoor ranged from 39 µg/m^3 to 84 µg/m^3. In Abidyah campus in the presence of students the average levels of indoor $PM_{2.5}$ ranged from 38 µg/m^3 to 58 µg/m^3 and outdoor ranged from 27 µg/m^3 to 50 µg/m^3. For PM_{10} was ranged from 27 µg/m^3 to 87 µg/m^3 and outdoor ranged from 22 µg/m^3 to 50 µg/m^3.The corresponding I/O (indoor/outdoor) ratios were ranged from 1.1 to 1.9 for $PM_{2.5}$, and 1.2 to 1.9 for PM_{10}, in Aziziya campus. In Abidyah campus the I/O ratios were ranged from 1.0 to 1.9 for $PM_{2.5}$ and from 1.2 to 1.7 for PM_{10}.The frequency percentages distribution of indoor and outdoor revealed that, 65% of the indoor and 45% of the outdoor PM_{10} concentrations exceeded both the maximum 24-h (50 µg/m^3) and the annual mean (50 µg/m^3) limits for PM_{10} set by WHO and EPA, respectively. Regarding $PM_{2.5}$, 10% (outdoor) of $PM_{2.5}$ concentrations at all classes in Umm Al university exceeded the maximum 24-h limits for $PM_{2.5}$ set by WHO. Moreover, 100% of $PM_{2.5}$ concentrations in indoor and outdoor of all classes in Umm Al Qura university exceeded the annual mean limits for $PM_{2.5}$ set by WHO. The results of this research can be useful in epidemiological research on students' exposure to PM and in the development and implementation of control actions for the protection of their health.

Keywords: Particulate matter, Classroom, Umm Al Qura University, Makkah.

INTRODUCTION

University's classrooms are places with a high level of activity and occupant load density of approximately four times that of office buildings (Katafygiotou & Serghides, 2014). Students spend most of their daytimes inside classrooms, which just come second after home concerning total time-spent in indoor environment. Therefore, they are more exposed to indoors contaminants which introduced from both indoor and outdoor sources (Chithra & Nagendra, 2018). Poor indoor classroom air quality is a critical problem worldwide, causes a wide variety of adverse environmental and health impacts. It causes both short-term and long-term health problems for students, staff, and teachers, such as sick building syndrome, a disease caused by indoor air pollutants in buildings. (Tran et al. 2020; WHO, 2021; Salleh, 2013). Furthermore, it decreases student's learning capacity and comfort levels (Chithra & Nagendra 2018).

Umm Al-Qura University (UQU) located in Makkah, which has a typical hot and dry desert climate with frequent dust storms. Makkah's annual mean temperature is 31.42 °C, with maximum temperatures exceeding 55 °C during the summer months (Almazroui M, 2012). Due to these extreme weather conditions, classrooms buildings are often tightly constructed, sealed to reduce natural air infiltration and exfiltration. This strongly may aggravate the levels of indoor toxic contaminants inside classrooms and persist for a long time.

Among classroom contaminants inhalable particulate matters (PM) are the major contributor with the greatest negative impact on human health. PM is described as minute solid granules or liquid droplets suspended in the air and derived from both natural and human activities in terms of their potential health impact. According to their diameter, they are categorized as PM_{10}, $PM_{2.5}$, and

ultrafine particles. PM_{10} particles have an aerodynamic diameter (AD) ranging from 2.5 to 10 µm. PM_{10} particles are emitted by street and agricultural dust, tire wear, building and demolition work, and mining activities. (Simkhovich et al. 2008). In comparison to PM_{10}, the main contributors of $PM_{2.5}$ are primarily from traffic and industry, which includes the combustion of fuel from power plants and oil refineries, as well as automobile brake emissions.

Numerous epidemiological studies have found that exposure to PM pollutants can have a negative impact on human health, while higher levels result in greater harm (Sanchez et al. 2020). Furthermore, there is a strong link between PM and coronavirus illness 2019 (COVID-19) infection (Amoatey et al. 2020; Setti et al. 2020). Indoor air particulate matter concentrations in classrooms may be even more serious than in other institutional buildings due to high level of student's activities and population density. As a result, the purpose of this research is to measure the indoor air quality in classrooms, with a focus on the concentration of indoor and outdoor pollutants of PM_{10}, $PM_{2.5}$ in the presence and absence of students.

MATERIALS AND METHODS

Sampling Sites and Classrooms Description

This study was carried out in Umm Al-Qura University (UQU), located in Holy Makkah, which is one of the most populated areas in Saudi Arabia. It has a population of more than 8.5 million people, according to the general authority for statistics of the Kingdom of Saudi Arabia, with a 1.8% growth rate (CDSI, 2020). Furthermore, every year, millions of Muslims from all over the world travel to Makkah to perform Hajj and Umrah. Because of its hot, arid climate, the average annual temperature in Makkah is 31.42 °C, with maximum temperatures exceeding 55 °C during the year's hottest months. Its weather is dry with very little rain each year. The city is rapidly expanding with fewer or no trees, except for date palms, and a constant influx of worldwide and national visitors. However, regarding vehicular traffic, Makkah's central region is busier than its outskirts. In this study, indoor and outdoor particulate matter (PM_{10}, $PM_{2.5}$) measurements were carried out in twenty classrooms in two different campuses of UQU, ten classrooms in the Aziziya campus located in the central region of Makkah and ten in the Abidyah campus located in the outskirts (Figure 1). Table 1 displays the location and information concerning the classroom building characteristics, area, and the number of students per cubic meter (M^3).

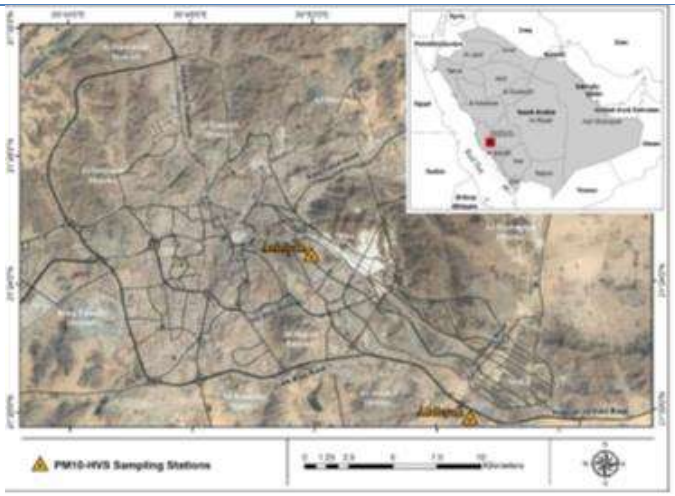

Figure 1: Location map of the PM $_{2.5}$ and PM_{10} sampling sites at Aziziya and Abidyah campuses in Umm Al-Qura University

The samples were collected during classroom activities (students' occupation). Furthermore, to know the contribution of students' occupation to PM_{10} and $PM_{2.5}$ concentrations, particulate matter measurements were carried out in the absence and presence of students. In classrooms, the sampling position was opposite the blackboard, roughly 1 meter above the floor level, the extent at which students would usually inhale, and away from the door, to avoid disturbances caused by air currents.

Particulate Matter Measurement

The Dusttrak II Aersosol Monitor (Model 8530) was used to measure particulate matter of various sizes. With this equipment, two different particle sizes were measured in the air, $PM_{2.5}$, PM_{10}, (Respirable) by employing impactors of the appropriate size. In place of the inlet cap, the impactor assembly is connected to the instrument. At the default factory settlings, air was taken at a rate of 3L/min. To ensure accuracy, the device was calibrated by running a Zero Cal run before each use in classrooms at two campuses.

Data analysis

The data was assumed to be not normally distributed. Therefore, descriptive statistics were limited to minimum, maximum and mean. Descriptive statistics were calculated for all the data and then separately by location and by student attendance.

RESULTS

The general characteristics of the classrooms at both Abidyah and Aziziya campuses of Umm A-Qura University are described in table 1. Classrooms at both campuses have similar characteristics except for class volume which

are bigger in Abidyah campus

.

Table 1: The General Characteristics of Classrooms at Al-Abidyah and Al-Aziziya Campuses in Umm Al-Qura University

classes	Location	Floor level	Size/ $m3$	Students/ $m3$	Air-condition	View from the classroom	Floor material	Type of board	Ceiling material
A	Al abdiayh	First	216	0.23	Yes, local	Patio	Mazico	Pen	Cork
B	Al abdiayh	First	216	0.16	Yes, local	Patio	Mazico	Pen	Cork
C	Al abdiayh	First	216	0.18	Yes, local	Patio	Mazico	Pen	Cork
D	Al abdiayh	First	216	0.18	Yes, local	Patio	Mazico	Pen	Cork
E	Al abdiayh	First	216	0.18	Yes, local	Patio	Mazico	Pen	Cork
F	Al abdiayh	First	216	0.27	Yes, local	Patio	Mazico	Pen	Cork
G	Al abdiayh	First	216	0.20	Yes, local	Patio	Mazico	Pen	Cork
H	Al abdiayh	First	216	0.19	Yes, local	Patio	Mazico	Pen	Cork
J	Al abdiayh	First	216	0.17	Yes, local	Patio	Mazico	Pen	Cork
K	Al abdiayh	First	216	0.13	Yes, local	Patio	Mazico	Pen	Cork
A	Al Azizia	First	144	0.14	Yes, local	Patio	Ceramic	Pen	Cork
B	Al Azizia	First	144	0.17	Yes, local	Patio	Ceramic	Pen	Cork
C	Al Azizia	First	144	0.13	Yes, local	Patio	Ceramic	Pen	Cork
D	Al Azizia	First	144	013	Yes, local	Patio	Ceramic	Pen	Cork
E	Al Azizia	First	144	0.15	Yes, local	Patio	Ceramic	Pen	Cork
F	Al Azizia	First	144	0.17	Yes, local	Patio	Ceramic	Pen	Cork
G	Al Azizia	First	144	0.07	Yes, local	Patio	Ceramic	Pen	Cork
H	Al Azizia	First	144	0.11	Yes, local	Patio	Ceramic	Pen	Cork
J	Al Azizia	First	144	0.09	Yes, local	Patio	Ceramic	Pen	Cork
K	Al Azizia	First	144	0.07	Yes, local	Patio	Ceramic	Pen	Cork

The indoor (I), outdoor (O) mean concentrations of particulate matter and their I/O ratios in the presence and absence of students at ten classrooms in each campus are shown in table 2 and table 3. It could be concluded from these tables that in Abidyah campus in the presence of students the average levels of indoor of $PM_{2.5}$ ranged from 38 µg/m^3 to 58 µg/m^3 and outdoor ranged from 27 µg/m^3 to 50 µg/m^3. For the average levels of indoor of PM_{10} are ranged from 27 µg/m^3 to 87 µg/m^3 and outdoor ranged from 22 µg/m^3 to 50 µg/m^3. In the absence of students only indoor $PM_{2.5}$ and PM_{10} levels were measured and ranged from 28 µg/m^3 to 59 µg/m^3 and from 30 µg/m^{3}to 60 µg/m^3 for $PM_{2.5}$ and PM_{10} respectively. For Aziziya campus in the presence of students the average levels of indoor of $PM_{2.5}$ ranged from 72 µg/m^3 to 178 µg/m^3 and outdoor ranged from 46 µg/m^3 to 94 µg/m^3. For the average levels of indoor of PM_{10} are ranged from 49 µg/m^3 to 150 µg/m^3 and outdoor ranged from 39 µg/m^3 to 84 µg/m^3. Similarly in the absence of students only indoor $PM_{2.5}$ and PM_{10} levels were measured and ranged from 60 µg/m^3 to 150 µg/m^3 and from 58 µg/m^{3}to 159 µg/m^3 for $PM_{2.5}$ and PM_{10} respectively.

In Abdiyah campus the I/O concentrations ratios for $PM_{2.5}$ were ranged from 1.0 to 1.9 where highest ratio was found in class B and lowest one in class J. For PM_{10}, it ranged from 1.2 to 1.7 where highest ratio was found in class C and D and lowest one in class J and K.

In Aziziya campus for $PM_{2.5}$ the I/O concentrations ratios were ranged from 1.1 to 1.9 where highest ratio was recorded in class C, F, G and H and the lowest ratio measured in class K. For PM_{10}, it ranged from 1.2 to 1.9 with highest ratio measured in class E and the lowest one in class C.

Tables 4 and 5 summarize descriptive statistics for indoor and outdoor particulate matter levels at Umm Al-Qura University's twenty classrooms at both campuses.

Based on the data from all classrooms at both campuses, The indoor $PM_{2.5}$ and PM_{10} concentrations were higher than corresponding levels outdoors. The levels of both indoor and outdoor particulate matters were higher in Aziziya campus than in Abidyah. The indoor mass concentrations of particulate in classes at Abidyah ranged from 41 µg/m^3 to 58 µg/m^3 with a mean of 47.3 µg/m^3) and from 27 µg/m^3 to 87 µg/m^3 (with a mean of 57.2 µg/m^3) for $PM_{2.5}$ and PM_{10} respectively. Outdoor levels are ranged from 27 µg/m^3 to 50 µg/m^3 with a mean of 32.4 µg/m^3) and from 22 µg/m^3 to 50 µg/m^3 (with a mean of 38.3 µg/m^3) for PM2.5 and PM_{10} respectively.

At Aziziya campus the indoor mass concentrations of PM ranged from 72 µg/m^3 to 178 µg/m^3 with a mean of 113.9 µg/m^3) and from 49 µg/m^3 to 150 µg/m^3 (with a mean of 101.7 µg/m^3) for $PM_{2.5}$ and PM_{10} respectively. Outdoor levels are ranged from 46 µg/m^3 to 94 µg/m^3 (with a mean of 69.6 µg/m^3) and from 39 µg/m^3 to 84 µg/m^3 (with a mean of 61.9 µg/m^3) for $PM_{2.5}$ and PM_{10}

respectively.

Table 2: Indoor and outdoor particulate matter ($PM_{2.5}$ and PM_{10}) mean concentrations and their ratios at different classes in presence and absence of students in Al-Abidyah campus

Presence of student	Class	A	B	C	D	E	F	G	H	J	K
. $PM_{2.5}$	Indoor	55	58	41	41	43	57	38	46	49	45
	Outdoor	37	32	29	26	30	37	28	28	50	27
	I/O ratio	1.5	1.9	1.4	1.6	1.4	1.5	1.4	1.6	1.0	1.7
PM_{10}	Indoor	87	53	61	71	63	49	66	44	51	27
	Outdoor	50	46	35	42	42	31	43	28	44	22
	I/O ratio	1.6	1.3	1.7	1.7	1.5	1.6	1.5	1.6	1.2	1.2
Absence of student											
$PM_{2.5}$	Indoor	51	51	28	29	30	55	59	44	58	39
PM_{10}	Indoor	36	37	30	31	31	41	60	50	59	42

Table 3: Indoor and outdoor particulate matter ($PM_{2.5}$ and PM_{10}) mean concentrations and their ratios at different classes in presence and absence of students in Aziziya campus

Presence of student	Class	A	B	C	D	E	F	G	H	J	K
. $PM_{2.5}$	Indoor	170	95	115	102	121	88	118	178	80	72
	Outdoor	94	62	59	83	81	46	61	91	56	63
	I/O ratio	1.8	1.5	1.9	1.2	1.5	1.9	1.9	1.9	1.4	1.1
PM_{10}	Indoor	150	102	49	110	97	102	92	130	120	65
	Outdoor	84	61	39	70	51	57	55	84	67	51
	I/O ratio	1.8	1.7	1.2	1.6	1.9	1.8	1.7	1.5	1.8	1.3
Absence of student											
$PM_{2.5}$	Indoor	150	107	105	103	73	60	67	68	72	60
PM_{10}	Indoor	159	110	92	94	72	74	58	79	67	89

Table 4: A statistical summary of indoor/outdoor mass concentrations of particulate matter in classrooms of Umm Al-Qura University at Abidyah campus.

		$PM_{2.5}$			PM_{10}	
	Indoor	**Outdoor**	**I/O**	**Indoor**	**Outdoor**	**I/O**
Minimum	41	27	1.1	27	22	1.2
Maximum	58	50	1.9	87	50	1.7
Mean	47.3	32.4	1.6	57.2	38.3	1.5
S.D.	7.2	7.3	0.24	16.4	16.37	0.2

Table 5: A statistical summary of indoor/outdoor mass concentrations of particulate matter in classrooms of Umm Al-Qura University at Aziziya campus

		$PM_{2.5}$			PM_{10}	
	Indoor	**Outdoor**	**I/O**	**Indoor**	**Outdoor**	**I/O**
Minimum	72	46	1.1	49	39	1.2
Maximum	178	94	1.9	150	84	1.9
Mean	113.9	69.6	1.6	101.7	61.9	1.6
S.D.	35.6	16.3	0.3	29.4	14.5	0.2

Descriptive statistics for the average I/O ratios for at

Abidyah campus were ranged from 1.0 to 1.9 (with mean of 1.6) and from 1.2 to 1.7 (with mean of 1.5) for $PM_{2.5}$ and PM_{10} respectively. For Aziziya campus the average I/O ratios were ranged from 1.1 to 1.9 (with mean of 1.6) and from 1.2 to 1.9 (with mean of 1.6) for $PM_{2.5}$ and PM_{10}. respectively.

The frequency percentages distribution of indoor and outdoor PM_{10} and $PM_{2.5}$ concentration at all classes in Umm Al Qura University were shown in Figure2 and Figure 3 respectively.

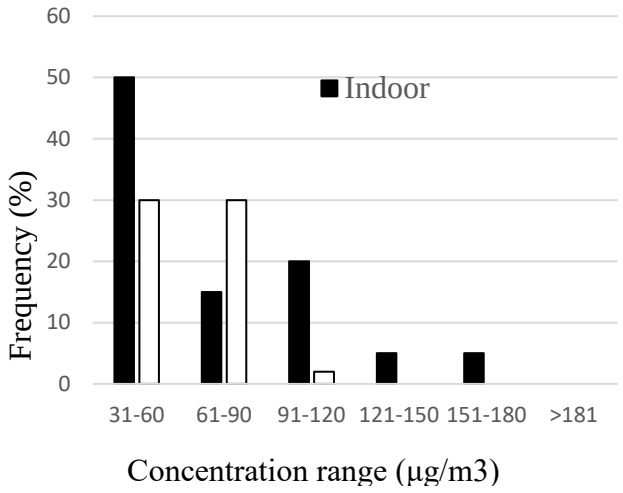

Figure 2: Frequency percentages distribution of indoor and outdoor $PM_{2.5}$ concentration at all classes in Umm Al-Qura University.

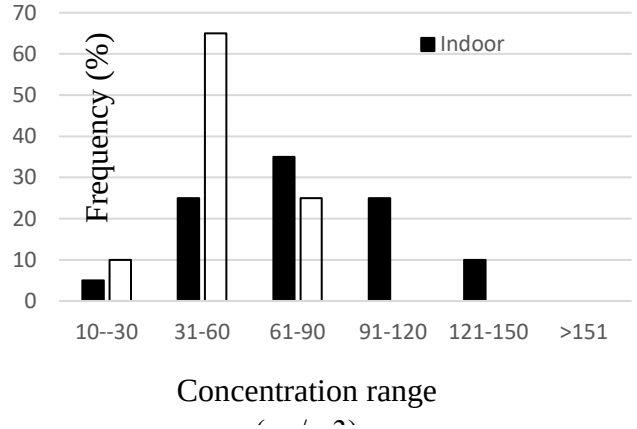

Figure 3: Frequency percentages distribution of indoor and outdoor PM_{10} concentration at all classes in Umm Al-Qura University.

The result revealed that, 65% of the indoor and 45% of the outdoor PM_{10} concentrations surpassed both the maximum 24-h (50 µg/m^3) and the annual mean (50 µg/m^3) limits for PM_{10} set by WHO and EPA, respectively. Moreover, 6.67% and 3.33% of the indoor and outdoor PM_{10} levels at all classes in Umm Al Qura University exceeded the annual mean (80 µg/m3) limits for PM_{10} set by Presidency of Meteorology and Environment (PME) of Saudi Arabia. Regarding $PM_{2.5}$ 85% (indoor) and 10% (outdoor) of $PM_{2.5}$ concentrations at all classes in Umm Al-Qura University surpassed the maximum 24-h limits for $PM_{2.5}$ set by WHO. Moreover, 100% of $PM_{2.5}$ levels in indoor and outdoor of all classes at Umm Al Qura University exceeded the annual mean limits for $PM_{2.5}$ set by WHO.

DISCUSSION

In this study indoor and outdoor measurements of particulate matters ($PM_{2.5}$ and PM_{10}) were carried out in twenty classrooms at two different campuses of Umm Al-Qura University namely Aziziya and Abdiyah. In this study the PM evaluation was based on two parameters which are the campus geographic locations and the presence or absence of students in the classroom during data collection.

As expected, our results showed that the concentration levels of indoor and outdoor particulate matters (PM), were higher at Aziziya campus which located in a densely populated residential area near Al-Haram (the Holy Grand Mosque in Makkah) and continuously remains busy in terms of road traffic with frequent traffic congestion and visitors all year round compared to PM levels obtained in Abidyah nonresidential area far from Al-Haram with low road traffic located in the outskirts of Makkah city. Therefore, higher PM in Aziziya could be caused by higher road dust suspension and pollutant emissions, particularly from diesel car exhaust, brake pads, and wheels. Moreover, high traffic density increases PM emissions and re-suspension of street dust from sources such as construction and daily business operations around the classrooms (Alshetty, & Nagendra, 2022). In agree with our result, study on five elementary schools in Istanbul, Turkey, showed PM levels increased with the increase of traffic intensity (Ekmekcioglu & Keskin, 2007).

The indoor levels of both PM_{10} and $PM_{2.5}$ in this study were higher than the corresponding levels outdoors of all classes at both campuses except for $PM_{2.5}$ at classes J in Abidyah where relatively same concentrations were recorded. The high indoor PM levels may be attributed to outdoor air intrusion and particle re-suspension and generation caused by the presence of students in the classrooms. Moreover, due to the hot and dry desert climate of Makkah city which accompanied with frequent dust storms, classrooms buildings are often tightly constructed, sealed to reduce natural air infiltration and exfiltration. This strongly may aggravate the levels of indoor toxic contaminants inside classrooms and its

persistency for a long time.

Metabolic activities of building users such as respiration, perspiration, running and playing could also make contribution to the sources of air pollutants in the classroom. Similar results were reported by Rivas et al. (2021) who declared that indoor mean PM levels were greater than outdoor levels.

In this study, the findings revealed that human activities are a significant contributor to high indoor levels and I/O ratios of PM. It was found that both $PM_{2.5}$ and PM_{10} concentrations were higher in both campuses in the presence of students than in their absence. In support of our results, study carried in primary schools in Kuala Terengganu, Malaysia reported higher indoor PM concentrations in the presence of students and attributed that to resuspension and particle generation resulting from the presence of students in classrooms (Sofiana & Ismail, 2012). Furthermore, this result agrees with higher indoor PM reported in Portuguese (Custódio et al. 2014) and UK homes (BéruBé et al. 2004) compared to outdoor levels. The greater indoor PM levels than outdoor, it could be because of housekeeping activities such as sweeping and cleaning routines, erasing with a duster, painting, and opening windows and doors (Diapouli et al. 2007).

Furthermore, occupancy, through resuspension of earlier deposited particles and newly generated particle, greatly influences the indoor concentration of airborne particles, especially in the coarse fraction (Almeida et al. 2011; Blondeau, 2005).

CONCLUSION

This work examines indoor and outdoor concentration levels of $PM_{2.5}$ and PM_{10} at twenty classrooms located in Aziziya and Abidyah campuses of Umm Al-Qura University, Makkah, Saudi Arabia. The findings indicated that certain control measures, such as installation of ventilation, reducing windows areas might have to be taken in account to control PM concentrations in classrooms. The recorded concentrations of PM_{10} and $PM_{2.5}$, pointed to the existence of significant indoor pollutants. The long-term health impact of these effects is uncertain. The findings of this study can be applied to epidemiological studies on student exposure to PM, as well as the development and implementation of corrective measures to protect their health. More studies are needed to replicate the reported findings in other contexts while categorizing the source/composition of PM as well as other hazardous air pollutants such as nitric oxides, ozone, and volatile organic compounds (VOCs). Seasonal and temporal variations in particle volume fraction in classrooms must be considered.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEDGEMENT

The authors would like to thank Institute of Scientific Research and Revival of Islamic Heritage at Umm Al-Qura University (Project # 43409065) for the financial support.

AUTHOR CONTRIBUTIONS

Both MMK and TSP monitored classrooms in two sites of Umm Al Qura University with the help of Dusttrak II Aersosol Monitor. MMK collected the data and TSP analyzed the data. MMK and TSP reviewed the manuscript and both authors read and approved the final version.

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