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INDOOR AIR POLLUTANTS CONCENTRATIONS INFLUENCED BY DUST STORM EVENT IN SELECTED SCHOOLS IN GAZA STRIP

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Abstract

Dust storm episode is a common transboundary phenomenon affecting the Eastern Mediterranean region, with significant impact on air quality. Quantitative information on the influence of Dust storm episodes in the indoor environment is still lacking. Real-time PM10, PM2.5, levels were measured in outdoor and indoor air before and during dust storm event in 2012. Relationships between indoor and outdoor pollutants concentrations were examined and discussed. The analysis revealed a significant contribution of dust storm event to the indoor PM levels. The average mass concentration of indoor PM2.5 was increased by a factor of 3 during the dust storm period (215.19±(93.73)$\mu g/m^3$) as compared to non- dust storm period (67.44±(32.46)$\mu g/m^3$) and exceeded the values set WHO guideline (25$\mu g/m^3$). The results show a high contribution of dust storm episode in PM2.5 concentrations in PM10 (PM2.5/PM10) where the average indoor and outdoor ratios during dust event were 0.28 and 0.40, respectively. The I/O ratio values were found to be influenced by outdoor sources for all pollutants during the non-dust and dust periods. The results serve to improve our understanding of dust episode, which may have implications for a development of approaches to control outdoor originated indoor PM and improve indoor quality.

Keywords: Dust storm episode; Indoor air quality; Outdoor air quality; Schools

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1. Introduction

Dust events are defined as natural events with substantial particulate matter (PM) concentrations, primarily resulting from low vegetation cover and strong surface winds which usually occurring in arid, semi-arid, or desert areas (Kurosaki and Mikami, 2003; Wang et al., 2005). Dust storm produce the large-scale of mineral dusts every year (Moulin et al., 1997). It is hypothesized that half of this amount is deposited near the sources. The other half can be suspended in the atmosphere, undergoing long-range transport which strongly affecting PM concentrations (Zhang, 2000; He et al., 2001), Several of studies have shown that the dust storm can affect the atmospheric visibility (Hashim et al., 1997; Xu et al., 2014), climate change (Satheesh and Moorthy, 2005), water budget (Sundarambal et al., 2010) and outdoor activities especially in school and airport closures (Nichol, 1998) and increased amount of economic losses suffered by countries in the region (Kurosaki and Mikami, 2003) .

In addition to the abovementioned impacts, several studies have also shown that dust storm can have a marked effect on human health, particularly during dust episode such as asthma, eye-associated illnesses, cardiovascular mortality (Kwon et al., 2002). Meng and Lu (2007) associated dust events with total respiratory hospitalization, upper respiratory tract infection, pneumonia, hypertension, and cardiovascular hospitalization. Epidemiological studies in dust storm have shown associations between aerosols and adverse health outcomes including increasing the number of emergency room visits (Emmanuel, 2000; Othman et al., 2014), acute childhood asthma (Chew et al., 1995), difficulty breathing time (Sillanpää et al., 2005), child mortality (Jayachandran, 2009). Moreover, Chen et al. (2004) indicated that dust storms increase the risk of respiratory disease in Taipei, Taiwan, with a 7.66% increase in total deaths one day after the event, and a 4.92% increase two days after a dust storm, as well as a 2.59% increase in circulatory diseases two days after such a storm. Furthermore, Chang et al. (2006) found that dust storm events increased the frequency of clinic visits for allergic rhinitis two days after an event in Taipei, Taiwan.

The Eastern Mediterranean region is a semi-enclosed area surrounded by the Mediterranean Sea and the Arabian and Saharan Deserts. It has been estimated that 70 million tons of the Saharan dust transported every year and third of this amount are deposited in eastern Mediterranean area (Zereini and Wiseman, 2010). Therefore, Dayan et al. (1991) estimated that 60%–80% of the coarse particulate fraction of the aerosols in the area is from Saharan dust outbreaks transported in the lower free troposphere. According to Krasnov et al. (2013) the dust storm of February 2012 showed a daily concentration of 680µg/m^3, but the maximum hourly PM concentration reached more than 5000µg/m^3 which is the most extreme PM_{10} value was recorded in the region.

A major gap in our understanding of dust storm is their impact on indoor environments, particularly school environments where students spend seven or more hours a day inside school buildings. Several studies showed that indoor environmental quality at schools is more serious than in other categories of buildings due to inadequate ventilation, insufficiently and infrequently cleaning of indoor surfaces, a higher occupant density per classroom volume and constant resuspension of particles from room surfaces due to the activity of students (Janssen et al., 1999; Pegas et al., 2010; Elbayoumi et al., 2013; Hassanvand et al., 2014).

This paper explores the impact of outdoor pollutants on IAQ through analyses of real-time data collected in and around school buildings during a dust episode and non-dust periods with the aim to identify the factors affecting indoor pollutants levels. The results of this study aim to provide a better understanding the influence of dust storm phenomenon in indoor air quality in Gaza and to help in developing approaches to control outdoor originated indoor pollutants in the dust episodes.

2. Method

This study was conducted in schools situated in Gaza strip at Palestinian territories. Gaza strip is a semi-arid coastal land of roughly 360 km^2 of arable land along the eastern Mediterranean Sea Figure 1. The climate is characterized by mild and humid winter (December–March), which is dominated by rainfall. The summer months (June–September) are characterized by high humidity and lack of wet precipitation. The spring season (March–June) is characterized by unsettled winter type weather for the first month, associated with North African cyclones, while the rest of this period is very similar to that in summer. Fall season (September–December) is characterized by an abrupt summer type weather in the first month, while the rest of this period is characterized by the unsettled weather of winter (Koçak et al., 2010; PMD, 2012).

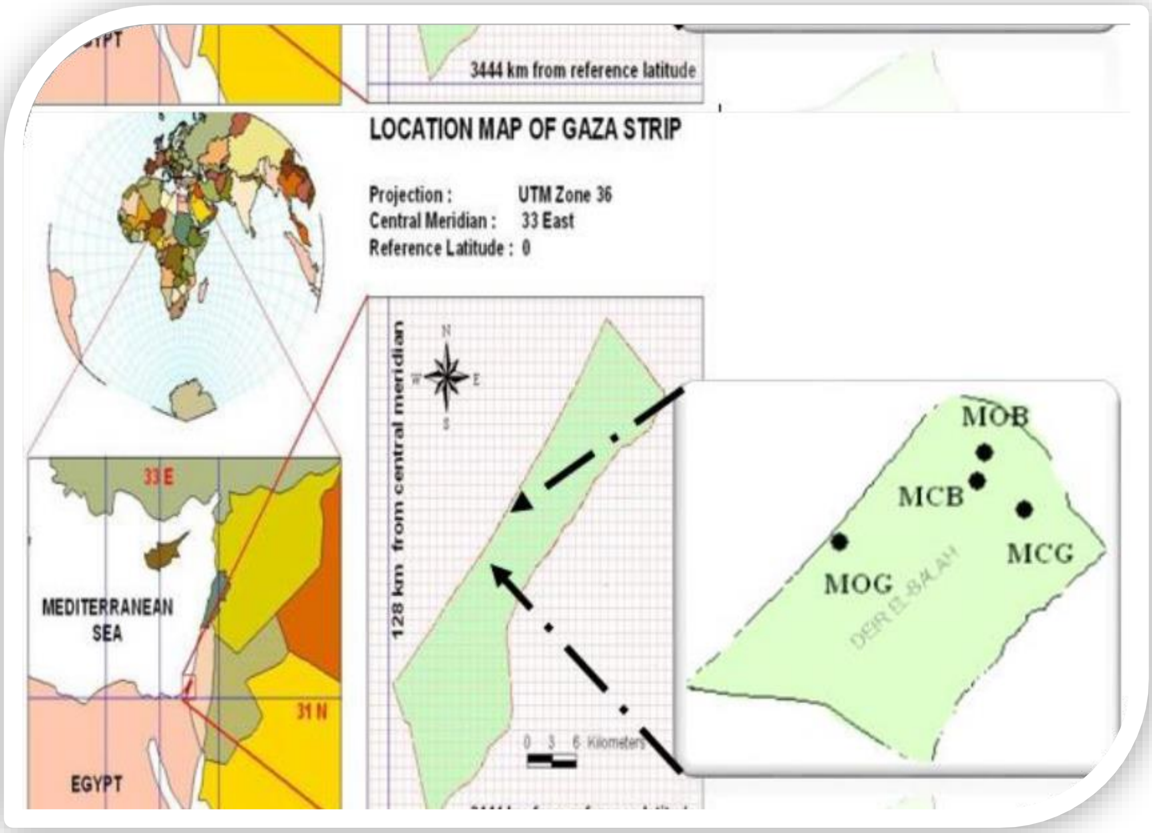

Figure 1: Site map of Gaza Strip showing sampling sites in Middle Governorate

2.1 School selection and sampling

The sampling site for monitoring of PM10, PM2.5 and meteorological parameters was chosen in in four naturally ventilated and overcrowded schools buildings with three storey's and work in double shift in middle governorate in Gaza strip. Table 1 and Figure 1 present b the details of each school. The sampling was held in fall season (background) and winter season (dust storm) during complete schools hours (five hours).The monitoring was carried out for three days. Sampling was conducted both inside and outside of the selected classrooms during the studying activities. The sampler was placed inside the classroom opposite the blackboard at least 1 m from the wall and at least 1.5 m height from the floor (WHO, 2011). For outdoor sampling, the sampler was placed at the front side of the building usually near the playground area.

Table 1: Characteristics of monitoring schools in study area

School name	chool code	Number of students	Distance from the main road (m)	Location area	Building schematic
Nusirate Prep Boys A	MCB	733	43	Refugee camp	Parallel shape
Nusirate Prep Boys D	MOB	712	65	Refugee camp	L-shape
Elburaj Prep Girls B	MCG	903	50	Refugee camp	Parallel shape
ah Prep Girls B	MOG	1024	50	Refugee camp	L-shape

2.2 Indoor and outdoor particles relationship (I/O)

I/O ratio represents the relationship between indoor and outdoor particle concentrations, which is very easy to understand and widely used. Chen and Zhao (2011) and Chen *et al.* (2012) defined I/O as follows:

In all classrooms, when windows are closed during winter and most of spring season, the season change in indoor PM concentration per change in outdoor PM concentration, I/O ratio can be approximated using

$$\text{I/O ratio} = \left(\frac{in}{C_{in\,(windows-closed)}} \right) = \frac{P\lambda_{infilt}}{\lambda_{infilt} + k_{sr.infilt}} \qquad (1)$$

Where Cin and $Cout$ are the indoor and outdoor particle concentration, respectively. *P* is the particle penetration factor, $\lambda infilt$ is the average infiltration rate, and k *is* the surface removal rate constant when windows are closed.

In all classrooms, the season change in indoor PM concentration per change in outdoor PM concentration, when windows are opened during fall season, I/O ratio can be approximated using Where Cin and $Cout$ are the indoor and outdoor particle concentration, respectively. $\lambda iwin\_open$ is the air change rate, and *k* is the surface removal rate constant when windows are opened.

Average infiltration rates ($\lambda infilt$). The infiltration rate is the rate at which a given building's air is replaced with outdoor air when its windows are closed. The infiltration rate is assumed to be 1ACH for house or office with closed windows, 2.4 ACH for half open windows and 6.4 ACH for half open windows (Gehring et al., 2015)

Penetration factor (P). Penetration factor has been estimated from linear regression of indoor concentrations against outdoor concentrations for respective particle sizes which representing as slope in the regression equation (Chen and Zhao, 2011).

Air change ratio (λwin-open). The outdoor air flow rate have been estimated using CO_2 concentration and occupancy data in ASHRAE formulation with an assumption that indoor CO_2 concentration is surrogate index of IAQ in terms of ventilation rates indoors (Scheff et al., 2000; Goyal and Khare, 2009). More complete results obtained from building ventilation rate (VR) method in the monitoring schools have been published elsewhere (Elbayoumi et al., 2014).

Surface removal rate constant (k). Air surface loss term is characterized by the rate of loss of material either by reaction or deposition inside a building (D*A/V), which is the product of the reaction rate constant or deposition velocity (D) and area (A) to volume (V) ratio (A/V) of the building. In case of particulates, D is interpreted as their deposition velocity (Goyal and Khare, 2009). Fernandez et al. (2015) have measured deposition velocity of $PM_{2.5}$ as 0.0012 m/min and for PM10 as 0.06 m/min. since the A/V differ among microenvironments , the *(k)* values have been estimated for PM2.5 as 0.0236 hr^{-1} for a typical classroom with ceiling height of 300 cm and 1.18hr^{-1} for PM10.

3. Results and Discussion

3.1 Characteristics of indoor and outdoor pollutants levels

The PM (PM2.5-10, and PM2.5), and meteorological variables (RH, temperature, and wind speed (WS) recorded in the classrooms at selected schools are presented in Table 2. The average concentrations of indoor PM2.5-10 and PM2.5 during the study period were 475.93±218.27μg/m^3 and 141.32±101.89μg/m^3, respectively. Meanwhile, outdoor concentration for PM2.5-10 and PM2.5 were 193.21±117.20μg/m^3 and 88.14±73.68μg/m^3, respectively. On comparing the averages of PM2.5-10 and PM2.5 concentrations with 24 hours guidelines of WHO (50μg/m^3 and 25μg/m^3 for PM2.5-10 and PM2.5 respectively), the results for indoor and outdoor concentrations of PM2.5-10 showed that all the schools (100%) exceeded the standards. Meanwhile, the indoor and outdoor concentration of PM2.5 showed some variation. During fall and winter 100% of schools exceeded the standards.

The higher concentration may be attributed to several factors. On one the hand, most of the school have unpaved playgrounds and this may increase the outdoor and indoor concentration by the elevation of both PM2.5-10 and PM2.5 due to student activity. On the other hand, the geographic location of Gaza strip between Sinai and Negev deserts and in the front of Mediterranean sea makes the aerosol concentrations directed by several important phenomena's such as long range aerosol transportation (Matvev *et al.*, 2002), seasonal dust storms (Dayan *et al.*, 1991; Koçak *et al.*, 2010; Zereini and Wiseman, 2010), sea salt aerosol formation (Krom *et al.*, 2004), the elevation of road and unpaved playgrounds and streets dust due to the low rainfall rates and several anthropogenic resources (Zereini and Wiseman, 2010).

Table 2: Summary of the results for outdoor and indoor measurements during the dust free event (background) and dust event

Parameter	Background	Dust storm
PM2.5-10(in) (μg/m^3)	417.58±(164.46)	534.28±(249.02)
PM2.5-10(out) (μg/m^3)	124.96±(53.13)	261.46±(124.09)
PM2.5(in)(μg/m^3)	67.44±(32.46)	215.19±(93.73)
PM2.5(out)(μg/m^3)	33.61±(14.50)	142.67±(68.51)
RH(in)	62.58±(4.28)	66.35±(8.22)
RH(out)	58.99±(3.95)	67.02±(11.32)
Temp (in) (◦c)	27.43±(1.06)	14.48±(1.61)
Temp (out)(◦c)	28.33±(1.32)	14.00±(2.40)
WS (m/s)	3.40±(1.58)	3.27±(2.18)

A comparison with other studies that conducted worldwide shows that the indoor average concentrations of PM2.5-10 and PM2.5 recorded in this study were far higher compared with results obtained from other studies such as: Razali et al. (2015) in Malaysia; Almeida et al. (2011) in Portugal; Habil et al. (2013) and Mathew et al. (2014) in India.

Figure 2 demonstrates the daily five-hour average pattern (school hours) of indoor and outdoor PM10 and PM2.5 for the three seasons. The pattern of PM10 and PM2.5 shows a clear seasonal influence. Indeed, higher concentrations for PM10 and PM2.5 can be observed during winter due to sand storm. Moreover, the daily fluctuation pattern for PM10 is much higher than daily pattern for PM2.5.

This is due to the shorter residence times of PM10 (minutes to hours) leaving PM2.5 suspended in the air for long time (days to weeks) (Wilson and Suh, 1997; Arkouli et al., 2010). However, these concentrations increased (background event) and indoor PM2.5-10 and PM2.5 concentrations were greater than outdoor concentrations which reflect the presence of children inside the classrooms. This was in good agreement with the previous results studies conducted by Diapouli et al. (2007), and Ismail et al. (2010) which reported that the indoor PM levels were higher than outdoor which due to student's activities including writing on the blackboard using chalks, erasing chalks using duster and cleaning habits.

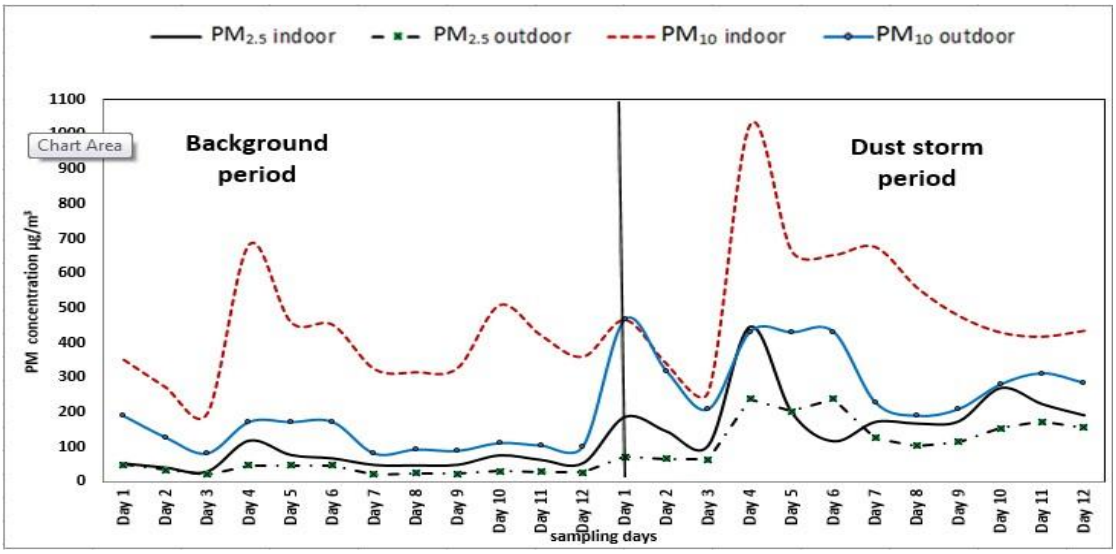

Figure 2: Average daily concentrations of indoor and outdoor PM_{10} and $PM_{2.5}$ during three monitoring periods.

3.2 Variation characteristic of PM mass concentrations Indoor and outdoor $PM_{2.5}/PM_{10}$ fractions:

The average mass concentration of indoor PM2.5 and outdoor PM2.5 increased by a factor of 3 and 4, respectively during the dust period as compared to that during the non-dust period. Furthermore, the average mass concentration of outdoor PM2.5-10 increased by a factor of 2 during the dust period as compared to that during the non- dust period. Moreover, the PM2.5/PM2.5-10 ratios obtained for the non-dust period and dust period were ranged from 0.16-0.40 and 0.26 to 0.55 for indoor and outdoor, respectively. This suggests that the contributions of PM2.5 to PM2.5-10 are not similar in the two period and indicates that in all monitoring schools coarse particles (>2.5 μm) originated from road dust soil re-suspension and abrasion processes are the dominating fraction in PM. Furthermore, the higher outdoor PM2.5/ PM2.5-10 ratio in winter was predominantly as a consequence of higher particulate emission from combustion sources and dust storm than in fall. Similar results have been reported from studies that were conducted in Middle East as shown in Table 3 which have shown ratios of PM2.5 to PM2.5-10 varying and depending on the type and distance from the source.

Table 3: Comparative concentrations of $PM_{2.5}$/ $PM_{2.5\text{-}10}$ ratio in Middle East

Country	Site	Season	$PM_{2.5}$/ $PM_{2.5\text{-}10}$	Reference
Saudi Arabia	Jeddah	Summer	0.33	(Khodeir *et al.*, 2012)
Lebanon	Beirut	Annual	0.37	(Saliba *et al.*, 2010)
Egypt	Cairo	Summer	0.43	(Abu-Allaban *et al.*, 2007)
Palestine	Gaza	Fall/ Winter	0.34	This study

3.3 Indoor/outdoor ratios (I/O)

The I/O ratio can provide a general impression on the relationship between indoor and outdoor concentration, nevertheless, it varies due to many influencing factors such as indoor source , outdoor concentration, air exchange rate, penetration factor and deposition rate (Chen and Zhao, 2011). Average I/O ratio values for 6-h periods are shown in Fig. 3. The average daily I/O ratio during background period for PM2.5-10 and PM2.5 ranged from 3.1 to 4.0 and 1.9 to 2.2, respectively. Furthermore, the mean I/O ratios during dust storm period for PM2.5-10 and PM2.5 ranged from 1.0 to 2.1 and 1.4 to 2.4, respectively. Indeed, several studies revealed that particulate matter concentrations can exceed outdoor air concentrations (Zock et al., 2002; Diette et al., 2007; USEPA, 2012).

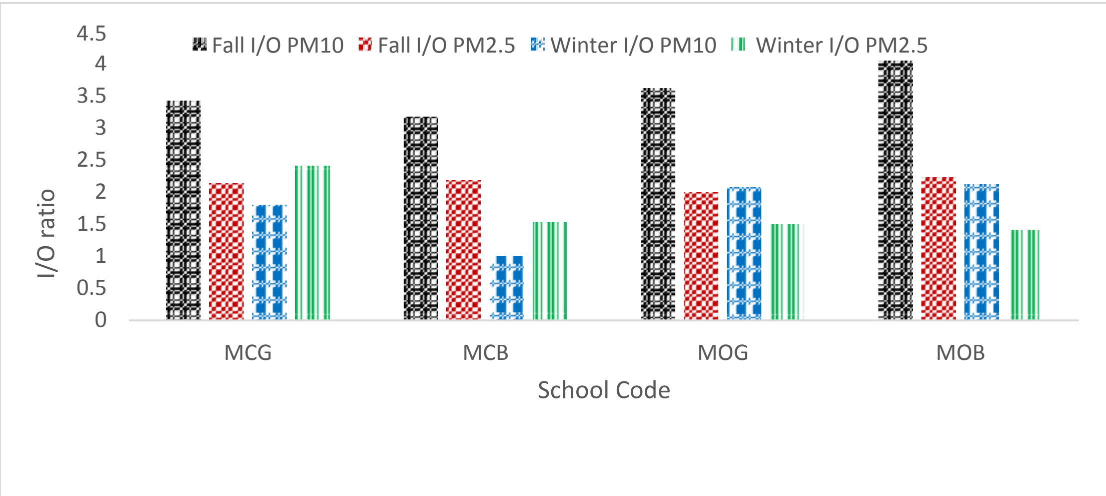

Figure 3: Indoor/Outdoor (I/O) ratio values from two different periods

The results show that the I/O ratios of PM2.5-10 are higher than that of PM2.5 during background period (fall season). The indoor sources may emit more coarse particles than fine particles, while outdoor coarse particle concentration is lower than fine particles, which may cause the lower I/O ratio of PM2.5 than that of PM2.5-10 (Chen and Zhao, 2011). Further, the deposition rate for PM2.5-10 should be larger than that of PM2.5, while penetration factor for PM10 should be smaller than that of PM2.5. The characteristics of penetration factor and deposition rate may cause the higher I/O ratio of PM2.5-10 than that of PM2.5 during the monitoring periods. During dust storm event (winter season), the I/O ratios of PM2.5-10 are lower than that of PM2.5 which in accordance with Thatcher and Layton (1995) and Wang et al. (Goodman et al., 2015) studies. According to Chen and Zhao (2011) the deposition rate for PM10 should be larger than that of PM2.5, while penetration factor for PM2.5-10 should be smaller than that of PM2.5. The characteristics of penetration factor and deposition rate may cause the higher I/O ratio of PM2.5 than that of PM2.5-10 during the aforementioned seasons.

4. Conclusions

This study analysed the impact of dust storm episode on the indoor classrooms environment in four different schools in Palestine that is subject to frequent dust storm events. The results showed that the indoor PM2.5 and PM 2.5-10 were affected mainly by the outdoor PM on both non-dust days and dust days. On dust days, the levels of hourly indoor PM2.5 and PM2.5-10 (215.19±93.73μg/m^3 and 534.28±249.02μg/m^3, respectively) significantly increased well beyond WHO guidelines (25μg/m^3). The average indoor and outdoor PM2.5/PM10 ratios in during background and dust storm ranged from 0.16-0.40 and 0.26 to 0.55, respectively. This indicates that fine particles (<2.5 μm) are the dominating fraction in particulate matter in the three monitoring periods. The I/O ratio values were found to be influenced by the influence of outdoor sources during the two periods. The results show that the I/O ratios of PM2.5-10 are higher than that of PM2.5 which due to higher indoor emission source of coarse particles than fine particles. This study thus demonstrates the impact of dust events on IAQ in school classrooms. It is evident that further study should be implemented in other schools during dust events for better protection of human health and life quality.

5. Acknowledgement

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