An Exposure Level of Fine Particulate Matter in Various Schools in Gaza Strip, Palestine

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Abstract- **In the first decade of the 21st century, previous studies showed good evidence that fine particulate matter pollution adversely affects the health of children and adults. Effects are wide ranging, and include reduced lung function, acute and chronic bronchitis, asthma attacks, and increase hospitalizations related to respiratory and cardiac. In Gaza strip the rates of previous disease increases during the last decade due to the increase in the concentration of fine particulate in the ambient air. The aims of this study were to (1) Monitor the indoors and outdoors mass concentrations of fine particulate matter ($PM_{2.5}$, $PM_{1.0}$) in 12 naturally ventilating schools (36 classroom) in United Nations Schools in Gaza Strip; (2) Assess the effect of outdoor pollutant concentrations on the indoor concentrations by using indoor/outdoor (I/O) ratios; and (3) Estimate the inhalation potential dose of fine particulate during student's activities. Fine particulate ($PM_{2.5}$, $PM_{1.0}$) were measured during winter season in 2012 for one and a half month. In each classroom and outdoor fine particulate ($PM_{2.5}$, $PM_{1.0}$) were measured during school hours from 07:00 am to 12:00 am. Meanwhile, data on student's activities during school hours were gathered. The results show that the indoor $PM_{2.5}$ and $PM_{1.0}$ were 197.4 and 34.6 µg/m^3 respectively and the outdoor $PM_{2.5}$ and $PM_{1.0}$ were 134.7 and 32.3 µg/m^3 respectively. Moreover, results show that the I/O ratios for most of school was close to unity but there was statistically significant difference in the mean value of I/O for both $PM_{2.5}$ and $PM_{1.0}$ among schematic building schools of 95% confidence interval (CI). The calculated mean value of potential dose and 95 percentile value shows that children inhaled a huge value of fine particulate matter during school day and the physical activities contribute to 50 percent of exposure.**

Keywords-$PM_{2.5}$; $PM_{1.0}$; Potential Dose; Physical Activities; Schools Children; Indoor Air Quality

I. INTRODUCTION

Several population based studies have established a strong correlation between exposures to fine particulate matter (PM) and increasing rates of mortality, morbidity, respiratory and cardiovascular problems especially among children [1-4]. As in [5] it was reported that the increased risk of cardiopulmonary and lung cancer mortality from 6% and 8%, respectively, was associated with the elevation of 10 µg/m^3 in fine particulate over the permissible value. Moreover, a short-term increase of 10 µg/m^3 of PM for several days is associated with more coughing, lower respiratory symptoms, an increase in hospital admissions due to respiratory problems [6]. These effects due to the facts that fine particulates have potentially long airborne retention time, have the ability to penetrate the human respiratory system and often contain acidic materials, metals and other contaminants [7].

Strong evidence is confirming that school buildings especially located near major roads have a high concentration level of particulate matter which exceeds the limits recommended by WHO and concluding that a large number of children may be regularly exposed to high levels of traffic-related emissions [8, 9]. Students spend a considerable part of their school hours breathing indoor air. The situation in children may be aggravated because they have larger lung surface area per kilogram of body weight compared to the adult and their nasal airways are less efficient in removing particulate matter. As a result, the deposition of particles in the lower respiratory tract may be greater among them [10]. Moreover, children spend a fraction of their school days doing physical activity, especially during physical education. The data shows that compared to sedentary activity the breathing rate of children aged 5-13 increases by nearly a factor of 2 during light physical activity and by about a factor of 5 during intense activity [11, 12]. Therefore, exercise under increased ambient particle conditions may elevate the risk of lung and vascular damage due to the increasing of total particle deposition in proportion to minute ventilation [10, 13-18].

In today's world, education has become a crucial component of the child's social development. Worldwide, the length of the education expectancy of children in Arab countries over the age of five increased from 8.2 years in 1990 to 10 years in 2008 [19]. Previous studies indicate that school children aged between 5 and 12 years spend 5 to 10 hours per day at school [20]. In Gaza Strip, Palestinian territories, where 1.7 million of the Palestinian people live and work, 52.4% of them are less than 15 years old and 453237 of those children are enrolled in the educational system. The average length of the school year ranges from 210 to 220 days [21] and the duration of a school day is 5 hours due to shortages of classrooms [22]. The prevalence of cancer and respiratory diseases increased in Gaza strip during the last five years where Trachea-Bronchus and lung cancer occupied the first cause of death from cancer with 21.35% and 13.4% in 2009 and 2008, respectively [23]. The death rates from Pneumonia, asthma and other respiratory disease have increased as shown in Table 1. In children population the admission rate for pneumonia, acute bronchiolitis and asthma to the hospital were 23.1 %, 9.7% and 3.6%, respectively as shown in Figure 1 [23].

TABLE 1 DEATH RATE FROM PNEUMONIA AND OTHER DISEASES BY YEARS PER 100,000 FROM THE POPULATION IN GAZA STRIP

Disease	Death rate/100,000 of population	
	2005	2009
Pneumonia and asthma disease	11.1	14.8
Heart disease	56.5	67.5

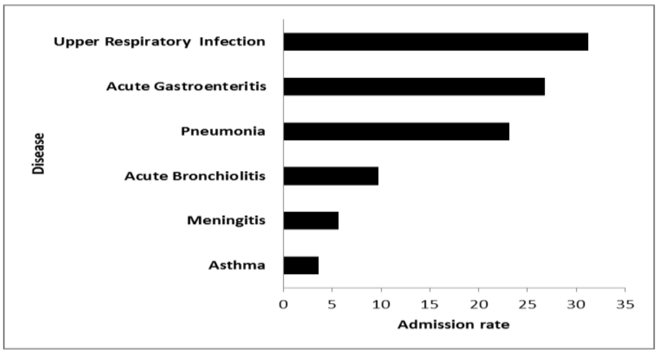


Fig. 1 Reasons for hospital admissions of children at Al-Nasser and El-Dorra hospitals

Air pollution is considered as one of the main factors contributing to the increase of the previous diseases in Gaza strip. However, there is lack of studies that establish a baseline for air quality in this over populated area. Therefore, this study aims to: (a) monitor the indoors and outdoors mass concentrations of fine particulate matter ($PM_{2.5}$, $PM_{1.0}$) in Gaza strip areas; (b) assess the effect of outdoor pollutant concentrations on the indoor concentrations by using Indoor/Outdoor (I/O) ratios; and (c) estimate the inhalation potential dose of fine particulate during student's activities.

II. METHODOLOGY

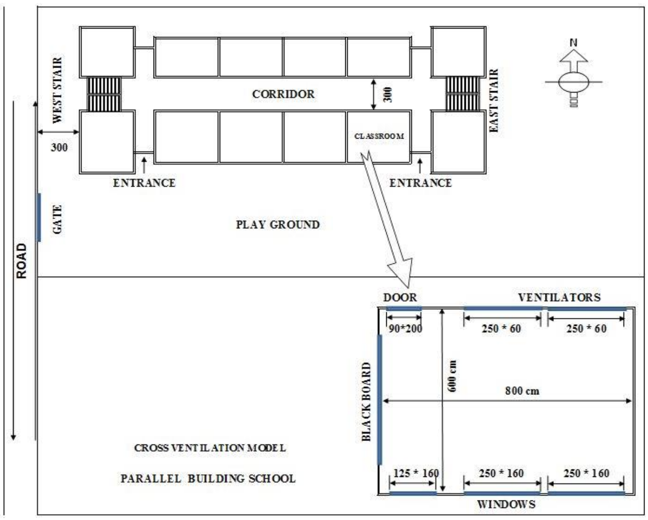
A. Site Description

Sampling was done at Gaza strip in twelve naturally ventilated school buildings with three storeys and work in a double session. The sampling was held in winter season (December 25, 2011-March 15, 2012) from 7:00 in the morning to 12:00 noon during complete school hours (5 hours). Selection of schools were based on the location of the schools in different microenvironments (overpopulated camps, cities), ventilation types and male or female schools so as to get a general view of the exposure of particulate matter in the area. Details of each school are presented in Table 2 and Figure 2 (a, b).

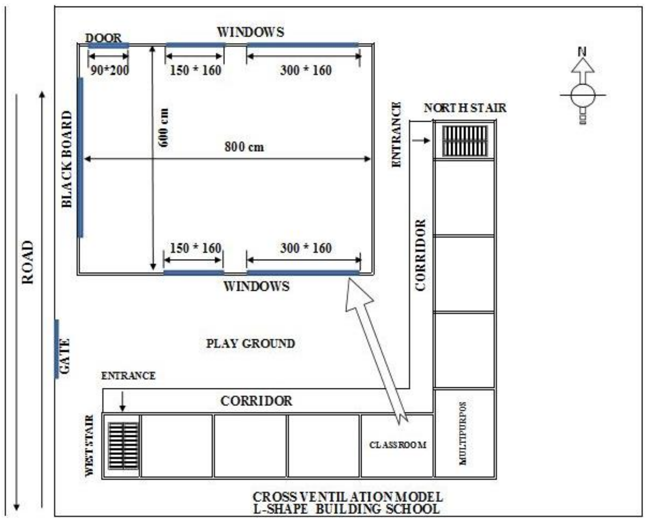
B. Room's Selection

In each selected school, three representative classrooms were selected for three sampling days. The initial inspection of wind direction was made in every school to identify the windward side of the building and one classroom was selected from each floor.

C. Selection of Monitoring Instruments



(a)



(b)

Fig. 2 Diagrams for cross ventilated schools (a) parallel schematic (b) L-shape schematic

The mass concentration of particles ($PM_{2.5}$ and $PM_{1.0}$) has been monitored using handheld optical particle counter (HAL-HPC300). The monitor performs particulate size measurements by using laser light scattering. Air with multiple particle sizes passes through a flat laser beam produced by an ultra-low maintenance laser diode. A three channel pulse height analyser for size classification detects the scattering signals. These counts from each precisely sized pulse channel are converted to mass using a well–established equation and the data is then formatted for US-EPA categories of fine particulate. The particle counter was factory calibrated, prior to the sampling campaign and the calibration was repeated every week using Zero-Count Filter [24].

TABLE 1 CHARACTERISTICS OF MONITORING SCHOOLS

School name	**Code**	**Number of students**	**Distance from main road (m)**	**Classroom Cleaning activity**	**Location area**
Nusirate Prep Boys A	MCB	733	43	Daily in the morning	Over populated camp
Nusirate Prep Boys D	MOB	712	65	Daily in the morning	Over populated camp
Elburaj Prep Girls B	MCG	903	50	Daily in the morning and between school hours	Over populated camp
Dier Elbalah Prep Girls	MOG	1024	50	Daily in the morning and between school hours	Small town
Bany Suhiela Prep Boys	SOG	1132	40	Daily in the morning	Urban area
Bany Suhiela Prep Girls B	SOB	1448	55	Daily in the morning	Urban area
Ahmad Abed Elaziz Prep Boys B	SCB	729	50	Daily in the morning	Urban area
Rafah Prep Girls B	SCG	578	55	Daily in the morning and between school hours	Over populated camp
Elzaytoon Prep Girls B	NOG	883	58	Daily in the morning and between school hours	Urban area
New Gaza Prep Boys A	NCB	1066	30	Daily in the morning and between school hours	Urban area
Beach Prep Girls B	NCG	1183	50	Daily in the morning and between school hours	Over populated camp
Salah Eldien Prep Boys	NOB	623	43	Daily in the morning and between school hours	Urban area

D. Sampling Method

Sampling was conducted both inside and outside 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 [25]. For outdoor sampling, the samplers were placed at the front side of the building. The lack of multiple samplers caused the indoor and outdoor measurements to be taken alternately after every 15 minutes within a 45-minute class hour [26].

E. Inhalation Parameters

US-EPA [27] conducted a large sample size study to ascertain inhalation rates for children and adults depending on a revised approach used by different studies in which an individual's inhalation rate was derived from oxygen consumption rate. The calculation of oxygen consumption rate depends on several factors such as age, body-weight, metabolic equivalents, Human Activity Database and food consumption. Short-term mean and 95th percentile data in m^3/minute are provided in Table 3 for males and females combined for children for whom activity patterns are known. These values represent averages of the activity level data which short-term inhalation rate data were available [27].

TABLE 3 RECOMMENDED SHORT-TERM EXPOSURE VALUES FOR INHALATION FOR 11-16 YEARS OLD

Activity Level	**Mean (m^3/minute)**	**95^{th} Percentile (m^3/minute)**
Sleep or Nap	4.5×10^{-3}	6.3×10^{-3}
Sedentary/Passive	5.4×10^{-3}	7.5×10^{-3}
Light Intensity	1.3×10^{-2}	1.7×10^{-2}
Moderate Intensity	2.5×10^{-2}	3.4×10^{-2}
High Intensity	4.9×10^{-2}	7.0×10^{-2}

F. Calculating Potential Dose for Intake Processes.

Children exposure was calculated by using the general equation of potential dose (D_{pot}) for intake processes [12, 28, 29]. This simple equation depends on the integration of the chemical intake rate (concentration of the particulate matter (C)), inhalation rate (IR) over time (t). The quantity t_1 - t_2, represents the period of time over which exposure is being examined as presented in the following equation.

$$D_{pot} = \int_{t_1}^{t_2} C(t) \times IR(t)\, dt \qquad (1)$$

By integrating Equation 1 over time we have Equation 2

$$D_{pot} = \sum_i C_I \times IR_i \times ED_i \quad (2)$$

where ED_i is the exposure duration for various events (I). If C and IR are nearly constant (which is a good approximation if the contact time is very short), Equation 2 becomes

$$D_{pot} = \bar{C} \times I\bar{R} \times ED \quad (3)$$

where C bar and IR bar are the average values for these parameters. By using Equation 3 the potential dose was estimated for every school day by using three microenvironments that were visited by students during the school day for fraction of times as in Table 4 and by using inhalation rate from Table 3 and measuring the indoor and outdoor of $PM_{2.5}$ and $PM_{1.0}$.

TABLE 4 DURATION OF VARIOUS ACTIVITIES DURING THE SCHOOLS DAY

Activities	**Duration (minutes)**
Reading and writing, seated(indoor)	225
Walking at playground during the break	20
Moderate physical activities in the morning	10
Heavy physical activities during the physical Education class	45

III. RESULT AND DISSCUTION

A. Indoor and Outdoor Pollutant Concentrations

Descriptive statistics for the indoor and outdoor aerosol concentrations are given in Table 5. The concentration of $PM_{1.0}$ ranged from 25.5 μg/m^3 to 66.3 μg/m^3 and 16.2 μg/m^3 to 54.1 μg/m^3 for indoor and outdoor, respectively. Moreover, the concentration of $PM_{2.5}$ ranged from 71.6 μg/m^3 to 569.6 μg/m^3 and 23.3 μg/m^3 to 464.9 μg/m^3 for indoor and outdoor, respectively. Figure 3 shows the spatial distribution with values of the respective indoor and outdoor $PM_{2.5}$ and $PM_{1.0}$. The indoor and outdoor averages of $PM_{2.5}$ concentrations for most schools were higher than the recommended WHO 24-h limit for $PM_{2.5}$ (25 μg/m^3) on 100 % of the days measured. The average concentration value for outdoor environment was 134.7 μg/m^3. This suggested that outdoor air being introduced into the classrooms through doors, windows and infiltration was a major contributor to the suspended particulate matter.

TABLE 5 DETAILED STATISTICS OF FINE PARTICULATE MATTER CONCENTRATION DURING WINTER SEASON

	Indoor $PM_{1.0}$	**Outdoor $PM_{1.0}$**	**Indoor $PM_{2.5}$**	**Outdoor $PM_{2.5}$**
Minimum (μg/m^3)	11.84	5.69	71.6	23.27
Maximum (μg/m^3)	154.53	111	569.67	464.87
Mean (μg/m^3)	34.65	32.37	197.9	134.73
Std. Deviation	19.59	13.89	84.80	57.42
Skewness	2.91	1.6	1.57	1.71
Kurtosis	11.45	1.48	2.82	6.24

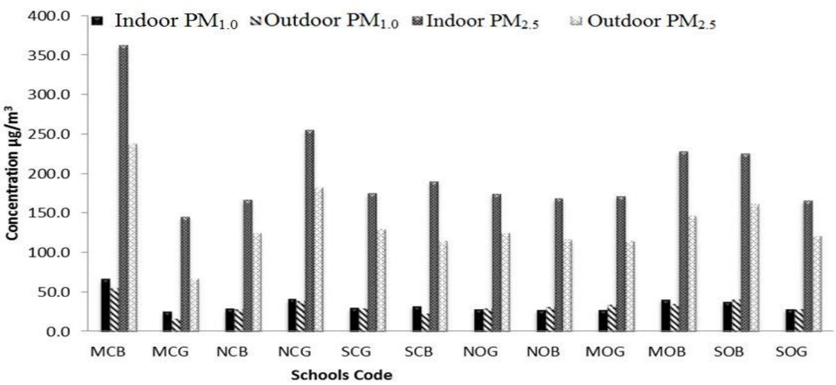


Fig. 3 Daily 5-hours average of indoor and outdoor $PM_{2.5}$ and $PM_{1.0}$ concentrations during winter period

B. Indoor/Outdoor Ratios (I/O)

I/O ratio is an indicator for the strength of indoor sources, which could highly vary depending on the indoor source and outdoor concentration levels. Pollutants can migrate from outdoors to indoors and indoor air sources could exacerbate indoor air pollution. Generally, during the campaign, the mean I/O ratios for $PM_{1.0}$ were found to be close to unity at most schools which ranged from 0.83 to 1.16. However for SCB and MCB schools the $PM_{1.0}$ I/O ratio ranged from 1.4 to 1.7. The higher value of the $PM_{1.0}$ I/O ratio in comparison to the other schools is related to the increased infiltration of fine outdoor particles due to their smaller size.

Meanwhile, the I/O ratio for $PM_{2.5}$ in all monitoring schools is more than unity as shown in Figure 4 which indicates that the concentration of $PM_{2.5}$ is higher indoors than outdoors. In natural ventilated buildings (NVBs) the I/O may be influenced by different factors. Building ventilation rate is primarily affected by the frequent opening and closing of windows and doors at different times. Thus, manual forms of ventilation affect the mobility of indoors PM from the polluted outdoor environment. The ventilation rate increases when all windows and ventilators are open in the classrooms, thereby reducing the indoor PM concentration due to increased mixing and dilution [30, 31]. Moreover, the penetration factors are higher for NVBs than for mechanically-ventilated buildings because it has windows, doors ventilators, cracks and leaks in the building envelope [32-34]. Furthermore, different parameters may directly influence and increase I/O such as differences in building envelope tightness and seasonal effects; pollutant differential penetration efficiency; building air exchange rates; and building design [35-36]. Moreover, human presence, occupancy rates and occupant activities such as walking and using chalk are other important factors in generation or re-suspension of deposited particles and determining indoor/outdoor pollution ratios [37]. High I/O ratios, in all schools suggest that building envelope may not prevent the infiltration of particles indoor. As shown in Table 6 t-test results show that the difference in the mean value of I/O among L-shape and parallel building schools for both $PM_{1.0}$ and $PM_{2.5}$ is found to be statistically significant of 95% confidence interval (CI) for $PM_{1.0}$. This difference may be due to the difference in ventilation rate between both models. The ventilation rate for L-shape shape is better than the parallel shape [38].

TABLE 6 T-TEST OF THE DIFFERENCE BETWEEN BUILDING SHAPE IN I/O RATIO

	$PM_{1.0}$	$PM_{2.5}$
t value	2.5	0.77
P value	**0.029***	0.471

**p is significant at the 0.05 level (2-tailed).*

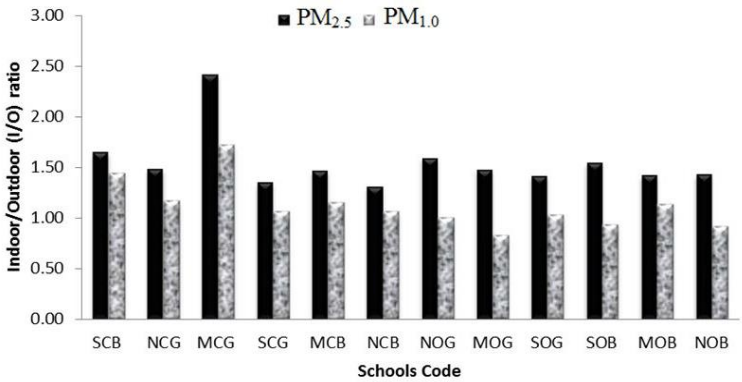


Fig. 4 Daily 5-hour average I/O ratio of PM for winter period

C. *Indoor–Outdoor PM Correlations*

The indoor–outdoor correlations for PM ($PM_{1.0}$ and $PM_{2.5}$) were carried out to view the dependency of indoor particles on their corresponding outdoor ones at all schools as shown in Table 7. Most of the schools showed a very strong correlation between indoor–outdoor levels. Indoor–outdoor correlations ranged from 0.50 to 0.80 for $PM_{2.5}$ and from 0.51 to 0.82 for $PM_{1.0}$. Such a strong correlation indicates possibly similar sources of origin for both indoor and outdoor levels. However, MCB school result showed poor correlations for $PM_{2.5}$ which is indicating that different indoor sources existed compared to the outdoor air pollutants.

TABLE 7 PEARSON CORRELATION COEFFICIENTS BETWEEN INDOORS $PM_{1.0}$ AND $PM_{2.5}$ CONCENTRATION AND OUTDOOR

Schools Codes	Indoor $PM_{2.5}$ vs. Outdoor $PM_{2.5}$	Indoor $PM_{1.0}$ vs Outdoor $PM_{1.0}$
SCB	0.76**	0.62**
NCG	0.83**	0.84**
MCG	0.76**	0.73**
SCG	0.69**	0.65**
MCB	0.35	0.52*
NCB	0.68**	0.66**
NOG	0.82**	0.67**
MOG	0.72**	0.78**
SOG	0.64**	0.63**
SOB	0.50*	0.79**
MOB	0.74**	0.51*
MOB	0.75**	0.82**

***Correlation is significant at the 0.01 level (2-tailed).*Correlation is significant at the 0.05 level (2-tailed).*

D. Potential Dose of $PM_{2.5}$ and $PM_{1.0}$

Schools provide a favourable learning environment and give the students the opportunity to practice physical activities which are associated with a range of beneficial health and fitness outcomes. However, there is increasing concern about the long-term effects of chronic exposure of healthy children to particulate matter and its effects on the respiratory system that result from this exposure [3]. Table 8 shows the estimated mean and 95th Percentile of potential dose for both $PM_{1.0}$ and $PM_{2.5}$ for one representative school day. The mean D_{pot} value for $PM_{1.0}$ for parallel shape building and L-shape building schools were 136.9 μg/m^3 and 132.6 μg/m^3, respectively. Moreover, the potential dose for $PM_{2.5}$ was 631.3 μg/m^3 and 616.3 μg/m^3 for parallel shape building and L-shape building schools, respectively.

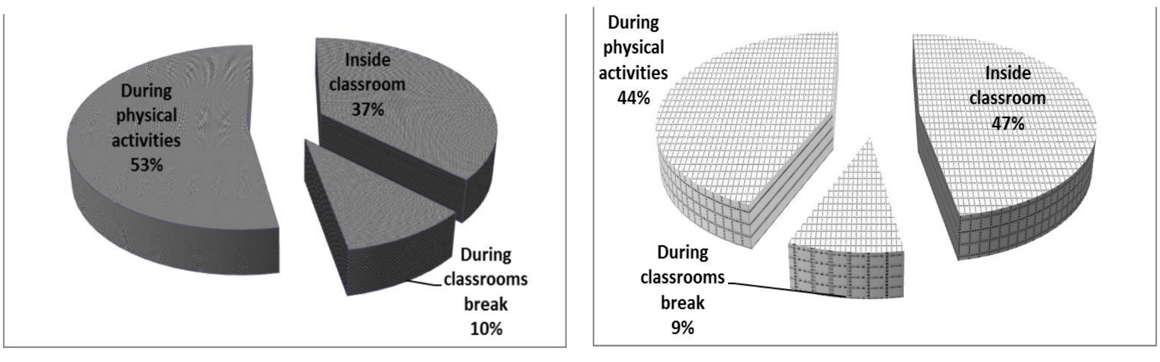
TABLE 8 THE ESTIMATION OF POTENTIAL DOSE DURING WINTER PERIOD FOR ONE REPRESENTATIVE SCHOOL DAY

$PM_{1.0}$ (μg/m^3)					**$PM_{2.5}$ (μg/m^3)**			
	Parallel		**L-shape**		**Parallel**		**L-shape**	
	Mean	**95th Percentile**	**Mean**	**95th Percentile**	**Mean**	**95th Percentile**	**Mean**	**95th Percentile**
Minimum	79.7	109.3	116.2	159.4	389.4	535.1	545.6	748.6
Maximum	239.6	324.7	161.5	219.3	843.5	1577.6	748.3	1023.0
Mean	136.9	187.0	132.6	181.1	631.3	941.4	616.3	843.8
Std. Deviation	56.7	76.3	19.5	25.7	171.6	369.6	93.1	125.1

Moreover, students during their school days have different activities such as reading, writing, walking and exercising as illustrated in Table 4. Therefore, the amount of air pollutants that students take into their lungs depends on many factors, including their activity level and resultant respiratory rate, their mode of breathing, and the concentration of fine particulate matter. Table 9 shows the estimated mean of potential dose for both $PM_{1.0}$ and $PM_{2.5}$ for several activities during one representative day. Students spent 225 minutes during the school day reading and writing (Light Intensity activity). Thus, by using Equation 3 from methodology part, the inhalation rate from Table 3 and the average concentration of $PM_{2.5}$ and $PM_{1.0}$ within class period (45 min) the D_{pot} are estimated. As shown in Table 9 and Figure 5 (a, b) the physical activities contributed to a high potential dose compared to other activities within 45 minutes of exposure which is due to increasing the respiratory rate and changing the mode of breathing from through the nose to through the mouth. The inhalation amount of particulate matter for both $PM_{1.0}$ and $PM_{2.5}$ during physical activities is five times greater than the amount that inhaled during sedentary activity. This finding was recognized by other studies such as [11, 12]. Moreover, during exercise, the inhaled air is taken in predominantly through mouth which has a limited filtration effect. According to [8, 39] higher levels of inhaled particle matter may be responsible for higher bacterial contamination in crowded places such as school area; Therefore, this may explain the serious health problems such as infections, allergies, and respiratory irritation that children suffered and increased the admission rate in the hospitals in Gaza strip during the last five years. As a result, the high concentrations of particulate matter in schools may contribute to increased short-term inhalation exposure of exercising children and enhanced adverse effects in sensitive students who are suffering from asthma.

TABLE 9 POTENTIAL DOSES FOR BOTH $PM_{1.0}$ AND $PM_{2.5}$ FOR SEVERAL ACTIVITIES DURING ONE REPRESENTATIVE DAY

Activity level	**Parallel schools**		**L-shape schools**	
	$PM_{1.0}$ (μg/m^3)	**$PM_{2.5}$** (μg/m^3)	**$PM_{1.0}$** (μg/m^3)	**$PM_{2.5}$** (μg/m^3)
Light intensity (reading and writing inside classroom)	54.6	315.2	46.4	276.0
Moderate Intensity (walking between classrooms break)	12.5	58.6	13.1	51.0
High intensity (Physical education exercise)	69.7	257.3	73.0	289.1
Total	136.8	631	132.5	616.1



(a) (b)

Fig. 5 Percentages of estimated potential dose of (a) PM2.5 and (b) PM1.0 that inhaled during different student's activities

IV. CONCLUSIONS

The results of this study show that students within the monitoring schools are exposed to high level of particulate matter 34.6 µg/m^3 and 197.9 µg/m^3 for $PM_{1.0}$ and $PM_{2.5,}$ respectively, which will affect their health negatively on the long run. Moreover, the results show that indoor $PM_{2.5}$ and $PM_{1.0}$ as well as outdoor concentrations are violating the permissible limits as prescribed by World Health Organization (WHO) and Environmental Protection Agency (US-EPA). For most of the schools the ratio of $PM_{1.0}$ is close to unity, indicating that the outdoor concentration is reasonably a good predictor of indoor $PM_{1.0}$ concentration. However, $PM_{2.5}$ I/O ratio is more than unity in winter which indicates that the concentration of $PM_{2.5}$ is higher indoors than outdoors due to the reduction in ventilation rate, increasing the penetration rate and students activities. The analysis shows that the estimated mean and 95th Percentile of the potential dose of the inhalation for both $PM_{2.5}$ and $PM_{1.0}$ for one representative school day are high, which explains the increasing admission rate of respiratory diseases in Gaza strip hospitals among the children during the last 5 years. Moreover, the data shows that physical activities contribute to five times greater than the sedentary activity in the amount that inhaled of $PM_{2.5}$ and $PM_{1.0}$. Therefore, to protect the children from high exposure of fine particulate matter during exercise, attention should be paid and new schools should be located away from major roads. Regular physical activity has positive influence on the health of students at all stages of their life. However, the elevated outdoor concentration of $PM_{2.5}$ identifies possible modifications in activity patterns to lessen health risk from air pollution. Furthermore, the playground area inside the schools should be paved and the courts must be covered with grass to decrease the proportion amount of suspension dust due to student movement during exercise.

V. ACKNOWLEDGMENT

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