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Scientific paper

INDOOR PM_1, $PM_{2.5}$, PM_{10} AND OUTDOOR $PM_{2.5}$ CONCENTRATIONS IN PRIMARY SCHOOLS IN SARI, IRAN

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This study was carried out to determine the distribution of particles in classrooms in primary schools located in the centre of the city of Sari, Iran and identify the relationship between indoor classroom particle levels and outdoor $PM_{2.5}$ concentrations. Outdoor $PM_{2.5}$ and indoor PM_1, $PM_{2.5}$, and PM_{10} were monitored using a real-time Micro Dust Pro monitor and a GRIMM monitor, respectively. Both monitors were calibrated by gravimetric method using filters. The Kolmogorov-Smirnov test showed that all indoor and outdoor data fitted normal distribution. Mean indoor PM_1, $PM_{2.5}$, PM_{10} and outdoor $PM_{2.5}$ concentrations for all of the classrooms were 17.6 μg m^{-3}, 46.6 μg m^{-3}, 400.9 μg m^{-3}, and 36.9 μg m^{-3}, respectively. The highest levels of indoor and outdoor $PM_{2.5}$ concentrations were measured at the Shahed Boys School (69.1 μg m^{-3} and 115.8 μg m^{-3}, respectively). The Kazemi school had the lowest levels of indoor and outdoor $PM_{2.5}$ (29.1 μg m^{-3} and 15.5 μg m^{-3}, respectively). In schools located near both main and small roads, the association between indoor fine particle ($PM_{2.5}$ and PM_1) and outdoor $PM_{2.5}$ levels was stronger than that between indoor PM_{10} and outdoor $PM_{2.5}$ levels. Mean indoor $PM_{2.5}$ and PM_{10} and outdoor $PM_{2.5}$ were higher than the standards for $PM_{2.5}$ and PM_{10}, and there was a good correlation between indoor and outdoor fine particle concentrations.

KEY WORDS: *indoor particle concentrations, outdoor particle concentrations*

Recent epidemiological studies have documented an association between changes in ambient particulate matter (PM) concentrations and changes in daily mortality and morbidity (1-3). Furthermore, air quality at schools seems to be a major determinant of health outcomes (4). Most of these studies have emphasised the importance of particulate matter with aerodynamic diameter of less than 10 μm (PM_{10}) and, recently, 2.5 μm ($PM_{2.5}$), measured at fixed monitoring sites. It seems that traffic-related particles are more toxic than others. Peters et al. (5) have reported that the risk of exposure to black carbon (BC) as a surrogate of traffic particles is higher than to other ambient particulates (5). Schwarz et al. (6) have also reported a stronger association of BC than of $PM_{2.5}$ with changes in heart rate. In a multi-city study, Dominci et al. (7) have shown that the association between PM_{10} concentrations and increased risk of death generally remains unchanged after control for other air pollutants.

People spend considerable time indoors: at home, school, work or in vehicles (8-10). School children, the elderly, and other groups of people more susceptible to the effects of poor air quality spend even more time indoors (11). Several studies have reported high concentrations of PM in classrooms (12-17). Major studies about personal exposure to particles (18, 19) have found poor correlation between personal exposure to fine particulate matter and outdoor air particle concentrations, but they have also reported good correlation between personal exposure and indoor air particle concentrations.

The aim of this study was to address this issue by determining the distribution of PM_1, $PM_{2.5}$, and PM_{10} in the classrooms of primary schools located in the centre of the city of Sari and by identifying the relationship between indoor and outdoor $PM_{2.5}$ concentrations.

Sari is the capital of the Iranian province of Mazandaran, located some 30 km to the south of the Caspian Sea and stretching from the northern slopes of the Elburz Mountains to across the Tajan River. It has a population of 270,000 people residing in the town and about as many residing in the suburbs. Our earlier reports have shown that personal exposure to PM_{10} among taxi and bus drivers and to $PM_{2.5}$ in shops in the city centre area are higher than the standards recommended by the US Environmental Protection Agency (EPA) (20-22).

MATERIALS AND METHODS

Our indoor and outdoor monitoring involved primary schools located in the centre of Sari with four major roads of varying traffic density. In Enghlab Street (south) it is about 1,500 vehicles per hour, in 18-Day Street (east) 2,220, in Jomhori Street (west) 1,260, and in Modarres Street (south) 1,250. Khosravi School is located in Enghlab Street; Shahed Boy and Shahed Girl Schools are located on Modarres Street; Kazemi School, Ghaemi School, and Ameneh School are located on three smaller roads less than 100 m away from Jomhori Street. School buildings are about 10 to 40 years old. Classrooms - all accommodating between 27 and 32 pupils - have a similar design, and their area varies from 24 m^2 to 34.2 m^2. Floors are stone. No mechanical ventilation or air conditionings were in use during the monitoring period. However, all classrooms were heated by radiators in the cold months.

Over 26 days of a school year (spanning from November 2011 to June 2012), we monitored PM_1, $PM_{2.5}$, and PM_{10} concentrations indoors and $PM_{2.5}$ concentrations outdoors. Both indoor and outdoor monitoring started and ended with the classes (from 8:00 a.m. to around 12:30 p.m.). Average indoor monitoring time was 4.39 h (range 2.95 h to 4.7 h), depending on the duration of a particular class. The indoor dust monitor was placed in the centre of the classroom, about 80 cm above the floor, and the outdoor monitor in the school yard at least one metre away from any obstacle and one metre above ground.

For indoor measurements we used a GRIMM real-time aerosol spectrometer and dust monitor (Model 1.108, Grimm Aerosol Technik GmbH, Ainring, Germany). PM_1, $PM_{2.5}$ and PM_{10} concentrations were recorded at one-minute intervals. This dust aerosol spectrometer has been designed for continuous particle count and for calculating particle mass based on particle density. It has an integrated gravimetric filter that collects all particles after optical measurement for further analysis. Data can be displayed as particle concentration and as mass concentration. Sample air is sucked through a measuring cell and a gravimetric filter by an internal flow-control pump. The filter serves as a dust collector and as gravimetric control of optical measurements.

For outdoor measurements we used a MicroDust Pro real-time monitor (Casella, Bedford, UK). This instrument is calibrated to a known reference dust standard. Different dust types cause a different response from this instrument due to variation in particle size, refractive indices, particle density, and colour. In order to correct for this, it is necessary to calibrate the response of the instrument. This involves the collection of a gravimetric (filtered) sample of the dust after it has passed through the probe optics. To measure $PM_{2.5}$ concentrations, a size-selective sampling cyclone was used in combination with a particle size adaptor and a small polyurethane foam (PUF) filter that was designed for $PM_{2.5}$ size fraction monitoring. A small personal sampling pump was used to provide continuous air flow through the gravimetric adaptor and photo detector. For gravimetric calibration, particles were then collected on a 37 mm, 2.0 μm Teflon filter (SKC Inc., Dorset, UK), which was placed in the cassette behind air sample stream. To obtain mean $PM_{2.5}$ concentrations we divided particle mass (in μg), obtained by weighing the filter, with the volume of sampled air drawn through the instrument (in m^3). For calibration we compared mean $PM_{2.5}$ concentration with the average $PM_{2.5}$ concentration obtained from direct reading from the MicroDust Pro instrument.

The results for each location had to be corrected with a gravimetric factor – the so-called C-factor. To determine the C-factor and to compare the displayed data, the GRIMM dust monitor and the MicroDust Pro monitor were run side by side in six classrooms for five hours, one day a month over the study period.

The GRIMM monitor was run on the particle concentration mode to measure particles between 0.3 μm and 20 μm, and the MicroDust monitor was run to measure $PM_{2.5}$. Filters were desiccated for 24 h and weighed with a microbalance (resolution 1 μg) three times before and after sampling. Total dust weight on filters was divided with the calculated total volume of air sucked by pumps to determine mean gravimetric concentrations of particles. Running both instruments side by side provided information on actual average gravimetric concentrations, which were then divided by mean particle concentrations downloaded from respective instruments to obtain gravimetric calibration factors. Finally, all real-time data were multiplied by calibration factors obtained for either instrument to obtain actual particle concentrations. In total, we collected data for 7,115 one-minute indoor and outdoor particle concentration readings. Mean correction factors of 1.03 and 1.14 were applied for the GRIMM and the MicroDust Pro monitor data, respectively. One-minute data were used for statistical analysis.

Statistical analysis

The statistic package SPSS v.17 for windows was used for running the Kolmogorov- Smirnov test (K-S test) to assess the normality of the frequency distributions of PM_1, $PM_{2.5}$, and PM_{10} concentrations. This statistic package also was used for running descriptive statistics and univariate regression model to assess the association between outdoor $PM_{2.5}$ concentrations and indoor classroom PM_{10}, $PM_{2.5}$, and PM_1. The Microsoft Office EXCEL 2007 software was used to make a graph for demonstration of daily mean indoor PM_{10} and $PM_{2.5}$ concentrations.

RESULTS AND DISCUSSION

The Kolmogorov-Smirnov (K-S) test shows that all indoor particle concentration data fit normal distribution (Figures 1-3). The indoor classroom $PM_{2.5}$ concentrations show distributions that are bi-modal, suggesting that there may be outliers within the indoor classroom $PM_{2.5}$ data. Resuspension of fine particles as a result of student activities may explain transient high indoor classroom particle concentrations. Mean indoor PM_1, $PM_{2.5}$, PM_{10}, and outdoor $PM_{2.5}$ concentrations were 17.6 μg m^{-3}, 46.6 μg m^{-3}, 400.9 μg m^{-3}, and 36.9 μg m^{-3} respectively. Figure 4 shows daily mean indoor classroom $PM_{2.5}$ and PM_{10} levels. On some days, mean $PM_{2.5}$ and PM_{10} exceeded the respective US EPA standards of 35 μg m^{-3} and 150 μg m^{-3} (23). High concentrations of PM_{10} could be due to resuspension of chalk dust, skin flaks, and insect dander that can increase the particle concentration when the students are active. In Tehran, Halek et al. (17) reported mean indoor classroom PM_1, $PM_{2.5}$, and PM_{10} of 19 μg m^{-3}, 42 μg m^{-3}, and 274 μg m^{-3}, respectively. Mean $PM_{2.5}$ and PM_{10} concentrations were lower than in our study (46.6 μg m^{-3} and 400.9 μg m^{-3}, respectively), whereas mean indoor PM_1 concentration and mean outdoor $PM_{2.5}$ in our study were similar with those reported by in Tehran (17.6 μg m^{-3} and 36.9 μg m^{-3} vs. 19 μg m^{-3} and 38 μg m^{-3}, respectively). In Munich, Germany,

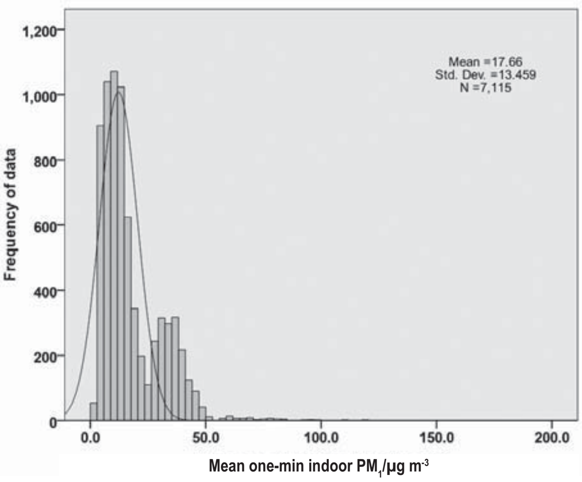

Figure 1 *Distribution of indoor classroom PM_1 concentrations*

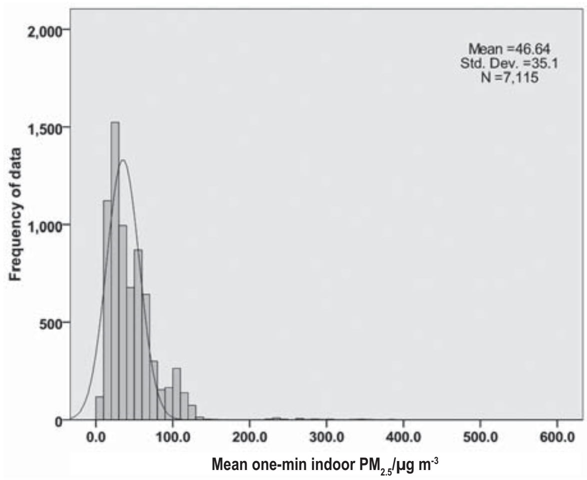

Figure 2 *Distribution of indoor classroom $PM_{2.5}$ concentrations*

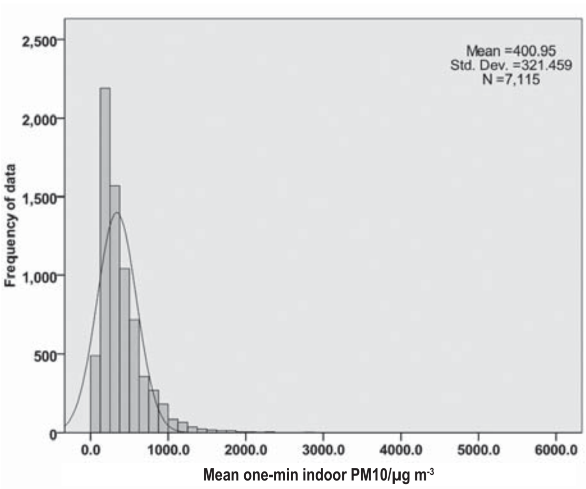

Figure 3 *Distribution of indoor classroom PM_{10} concentrations*

Fromme et al. (15) reported lower indoor and outdoor median $PM_{2.5}$ and PM_{10} than we have, but our findings are lower than those reported for Athens and Istanbul (25, 26).

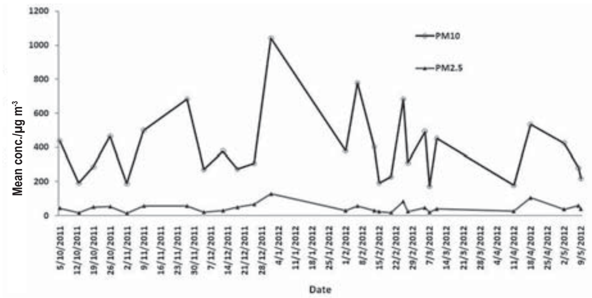

Figure 4 *Mean indoor classroom $PM_{2.5}$ and PM_{10} concentrations*

Table 1 shows the descriptive statistics for indoor PM_{10}, $PM_{2.5}$, PM_{10} and outdoor $PM_{2.5}$ in monitored schools. Khosravi school showed the highest mean PM_{10} concentration and Ameneh School the lowest. The highest indoor and outdoor $PM_{2.5}$ concentration was recorded in Shahed Boy School (69.1 μg m^{-3} and 115.8 μg m^{-3}, respectively). Kazemi School, in turn, showed the lowest indoor and outdoor $PM_{2.5}$ (29.1 μg m^{-3} and 15.5 μg m^{-3}, respectively). Despite

Table 1 *Outdoor $PM_{2.5}$ and indoor classroom PM_{10}, $PM_{2.5}$, and PM_1 concentrations by school*

Location	School	*N*	Mean	SD	Min	Max
Indoor PM_{10}	Khosravi	1284	568.2	353.2	44.7	2911.1
	Kazemi	1233	286.9	129.9	55.2	898.6
	Ghaemi	1064	381.0	275.8	23.9	2036.4
	Ameneh	1355	265.8	157.6	62.9	994.5
	Shahed boys	1078	428.2	261.3	68.9	1752.5
	Shahed girls	1101	492.5	503.6	54.6	5858.5
Indoor $PM_{2.5}$	Khosravi	1284	49.8	22.6	10.4	136.9
	Kazemi	1233	29.1	16.8	6.5	156.8
	Ghaemi	1064	38.2	20.9	6.2	182.7
	Ameneh	1355	38.3	16.3	6.2	87.9
	Shahed boys	1078	69.1	36.5	9	141.1
	Shahed girls	1101	59.0	62.0	6.7	504.7
Indoor PM_1	Khosravi	1284	12.1	4.2	3.7	28.9
	Kazemi	1233	14.1	14.5	2.8	140.1
	Ghaemi	1064	14.9	12.0	3.9	151.3
	Ameneh	1355	21.0	10.5	2.4	50
	Shahed boys	1078	28.9	15.2	3.1	51.7
	Shahed girls	1101	15.6	14.6	2.6	99.6
Outdoor $PM_{2.5}$	Khosravi	1284	22.1	23.1	0	196.1
	Kazemi	1233	15.5	18.4	0	201.8
	Ghaemi	1064	26.2	48.1	0	963.7
	Ameneh	1355	25.9	28.3	0	138.8
	Shahed boys	1078	115.8	146.9	1.2	498.2
	Shahed girls	1101	24.938	25.3	0	88.1

Table 2 *Relationship between outdoor $PM_{2.5}$ and indoor classroom PM_{10}, $PM_{2.5}$, and PM_1 levels in schools located close to main or small roads.*

PM	School location	Indoor PM_{10}		Indoor $PM_{2.5}$		Indoor PM_1	
		R	Sig	R	Sig.	R	Sig.
Outdoor $PM_{2.5}$	Main roads	0.09	0.00	0.35	0.00	0.51	0.00
	Small roads	0.08	0.00	0.30	0.00	0.62	0.00

the highest average PM_{10}, Khosravi School also had the lowest mean PM_1 concentration (12.1 µg m^{-3}).

We established a significant correlation between indoor classroom PM_1, $PM_{2.5}$, and PM_{10} concentrations and outdoor $PM_{2.5}$ concentrations for both schools located near main and small roads. However, Shahed boys school, which located on a main road, showed the highest mean indoor and outdoor $PM_{2.5}$ levels and Kazemi school located on a small road had a lowest mean indoor and outdoor $PM_{2.5}$. Mean indoor PM_{10} and $PM_{2.5}$ concentrations in schools located on the main roads were significantly higher than in schools on small roads (486.3 µg m^{-3} and 49.2 µg m^{-3} vs. 320.7 µg m^{-3} and 44.3 µg m^{-3}, respectively). However, mean indoor PM_1 concentration was higher in schools on small roads than in schools on the main roads (21.0 µg m^{-3} vs. 14.0 µg m^{-3} respectively). One possible explanation is that PM_1 and $PM_{2.5}$, which were mainly emitted from combustion sources, can distribute in the ambient easily and might be an effective factor for indoor particle concentrations. Similar studies concluded that proximity to traffic is a major determinant of the level of student exposure (12, 27).

The association between indoor fine particle concentrations ($PM_{2.5}$ and PM_1) and outdoor $PM_{2.5}$ levels was stronger than between indoor PM_{10} concentrations and outdoor $PM_{2.5}$ levels (Table 2). This is most likely because outdoor air enters classrooms through doors and windows, which are generally left open because of a moderate climate in Sari. On the other hand, the reason for the weak correlation between coarse PM_{10} indoor particles and outdoor $PM_{2.5}$ concentrations is that coarse particles are mainly produced by indoor student activities. In contrast to our study, in which indoor $PM_{2.5}$ was higher than outdoor $PM_{2.5}$, Buonanno et al. (24) reported higher concentrations of outdoor than indoor particles of up to 3 µm in Cassino, Italy (24).

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Sažetak

KONCENTRACIJE LEBDEĆIH ČESTICA PM_1, $PM_{2.5}$, PM_{10} U ZATVORENOM PROSTORU TE KONCENTRACIJE $PM_{2,5}$ ČESTICA U OTVORENOM PROSTORU OSNOVNIH ŠKOLA U GRADU SARIJU U IRANU

Svrha je ovog istraživanja bila utvrditi raspodjelu lebdećih čestica u osnovnim školama u središtu iranskoga grada Sarija te vidjeti jesu li razine lebdećih čestica mjerenih u dvorištima škola i u učionicama međusobno povezane. Vani su mjerene $PM_{2,5}$ čestice pomoću stalnog Micro Dust Pro monitora, a unutra PM_1, $PM_{2,5}$ i PM_{10} čestice pomoću GRIMM monitora. Oba su instrumenta kalibrirana gravimetrijskom metodom pomoću filtara. Kolmogorov-Smirnovljev test pokazao je normalnu raspodjelu vanjskih mjerenja. Srednje razine unutrašnjih čestica PM_1, $PM_{2,5}$, PM_{10}, odnosno vanjskih $PM_{2,5}$ čestica, za sve su škole iznosile 17,6 $\mu g\ m^{-3}$, 46,6 $\mu g\ m^{-3}$, 400,9 $\mu g\ m^{-3}$, odnosno 36,9 $\mu g\ m^{-3}$. Najviše razine unutrašnjih i vanjskih $PM_{2,5}$ čestica zabilježene u školi Shahed za dječake (69,1 $\mu g\ m^{-3}$ i 115,8 $\mu g\ m^{-3}$), a najniže u školi Kazemi (29,1 $\mu g\ m^{-3}$ i 15,5 $\mu g\ m^{-3}$). Bez obzira na to jesu li škole bile smještene na glavnim ili sporednim ulicama, povezanost između razina unutrašnjih sitnih čestica ($PM_{2,5}$ i PM_1) i razina $PM_{2,5}$ vanjskih čestica bila je snažnija nego između razina PM_{10} čestica izmjerenih unutra i $PM_{2,5}$ čestica izmjerenih vani. Srednje razine $PM_{2,5}$ i PM_{10} čestica u učionicama te $PM_{2,5}$ čestica u dvorištima škola bile su više od standarda, a razine sitnih čestica u zatvorenom i na otvorenom dobro su kolerirale.

KLJUČNE RIJEČI: *unutrašnje čestice, vanjske čestice*

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