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Characterizing Fine Particulate Air Pollution at Two Urban Elementary Schools: A Pilot Study of Arrival and Departure Environments

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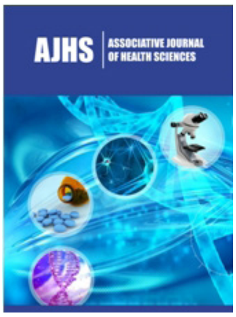

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Abstract

The purpose of this pilot study was to characterize arrival and departure environments based on fine particulate matter ($PM_{2.5}$) air pollution concentrations at two elementary schools. Ambient $PM_{2.5}$ was measured at the school front door, arrival/departure areas, street adjacent to the school, and in accompanying play fields (background). The overall average ratio of $PM_{2.5}$ to background at School-A (1.64) was less than at School-B (1.69) ($t(35721)=2.52$, $p=0.01$). $PM_{2.5}$ to background ratios were higher in the morning (1.80) than afternoon (1.43) ($t(36434)=21.13$, $p<0.001$). This study found a "plume" of $PM_{2.5}$ centered in the arrival/departure location at both schools. For morning $PM_{2.5}$ measures, arrival/departure locations were the highest at both schools, followed by front door, whereas, in the afternoon, street measures were the highest. Solutions include encouraging idle-free zones, carpooling and encouraging active travel along low-traffic routes.

Keywords: Particulate pollution; Fine particulate matter; School health; Children's environmental health; Commuting exposure

Abbreviations: $PM_{2.5}$ -Fine particulate matter

Introduction

Elementary school-age children are uniquely vulnerable to fine particulate air pollution ($PM_{2.5}$). Children inhale significantly higher doses of air pollution than do their adult counterparts due to higher respiration rates, increased mouth breathing, physical activity levels, and more time spent outdoors [1,2]. Children living in areas with chronically elevated $PM_{2.5}$ are more likely to suffer respiratory deficits including decreased lung function [3,4]. Furthermore, increased exposure to particulate matter is associated with lower respiratory, asthma-related symptoms in schoolchildren, particularly for sulfate particles below the 2.5µm cut-point [5]. Studies show there is great variability between indoor (school and home) and ambient $PM_{2.5}$ levels [6,7]; however, due to differences in pollution constituents, ambient $PM_{2.5}$ appears to be more hazardous than indoor $PM_{2.5}$ [8,9]. Schoolchildren between ages 5-10 spend approximately 22% of their time outdoors or in a vehicle [10]. Thus, understanding daily microenvironment and activity-dependent $PM_{2.5}$ exposures that occur outside of home or school may be useful to inform future intervention measures to protect schoolchildren.

To date, there is little published data on schoolchildren's air pollution exposures before and after school, when they are more likely to spend time outdoors. Pollution levels are often higher when children are commuting to school due to diurnal boundary layer patterns and higher traffic volume [11-13]. Once at school, school bus and vehicle exhaust associated with school arrivals and departures expose children to air pollution as they enter and leave the school [14-16]. Furthermore, depending on weather conditions, some children may spend several minutes outside near arrival/departure zones before and after school waiting for rides or visiting with other students while in this pollution microenvironment. Utah currently has the highest birth rate among all U.S. states [17]. The most densely populated communities in the State are located in Northern Utah, which has a mountainous geography and high traffic volumes along the Interstate-15 corridor. These factors contribute to seasonally high $PM_{2.5}$ levels in the region. However, to our knowledge there are no studies reporting microenvironment exposures around schools in the Intermountain West. The purpose of this study, therefore, was to characterize $PM_{2.5}$ levels around two elementary schools in Utah County, Utah.

Methods

Provo is the third largest municipality in Utah, with a population of 116,199 [18,19]. The population density in Provo is 1076.67 people/km^2 (2788.56 people/mi^2) [19,20]. Air pollution samples were collected at two Provo elementary schools. We choose these schools because they represent the highest and lowest socio-economic schools in the school district. School names have been masked, being referred to as School-A and School-B. Overall, Provo City, had a median household income of $39,688, 44.3% owner-occupied homes, and 42.5% hold bachelor's degree (or greater). For School-A, the median household income was $78,281, 81.1% owner-occupied homes, and 57.8% hold bachelor's degree (or greater); and School-B had a $37,347 median household income, 41.3% owner-occupied homes, and 19.8% hold bachelor's degree (or greater) [21-24].

Ambient $PM_{2.5}$ was measured with stationary TSI SidePak AM510 personal exposure monitors (TSI, Inc., Shoreview, MN, USA) placed near the schools' front doors, arrival/departure areas, street adjacent to the schools, and in accompanying play fields (as background measure). The inlet for the SidePak stationary monitor was located roughly 0.9m (3ft.) off the ground on a stand. Data collection occurred from April 16th-April 26th, 2018. Monitoring was conducted for 15 minutes prior to school commencing (8:35-8:50am for School-A, 8:25-8:40am for School-B) and 15 minutes after school release (3:30-3:45pm for School-A, 3:20-3:35pm for School-B). Prior to sampling each day, the instruments' internal clocks were set to the lab computer date/time. We also cleaned and greased the impaction plates, calibrated pump flow rates to 1.7L/min with a Defender 510 volumetric flow calibrator (Mesa Labs, Butler, NJ, USA), zeroed the 670nm laser using an in-line HEPA filter, and charged the batteries. Following data collection, we recorded post-calibration pump flow rates. Pre- and post-calibrations were within ±5% of 1.7L/min. SidePak AM510 instruments were calibrated by the manufacturer to ISO 12103-1 A1 test dust (Arizona road dust) prior to using them in this study.

Data were cleaned by matching all stationary by date and second. The detection limit of the SidePak recorded by TSI is 0.001mg/m^3 with a zero stability of ±0.001mg/m^3 over 24 hours. In order to account for this known limit, readings below 0.001mg/m^3 were recoded as 0.0007mg/m^3, which is the detection limit divided by the square root of two. This allowed us to use readings where the SidePak read 0mg/m^3 due to the monitor's inability to detect particle counts that low (the particle count is never truly zero) and proceed with analysis at those time points. We then calculated the ratio of each commuting type to the background levels recorded at each second. The ratios were averaged and reported along with standard errors for overall particulate exposures by school, time of day, and monitor location. Statistical differences between groups were calculated using t-tests and ANOVA within R (v 3.5.0) [25].

Results

The overall average ratio of $PM_{2.5}$ to background at School-A (1.64) was less than at School-B (1.69) ($t(35721)=2.52$, $p=0.01$). Mean concentrations ranged from 1.48µg/m^3 to 9.53µg/m^3 (overall mean concentration 5.56µg/m^3). All monitor locations were statistically different than the background monitor measures. The number of data points (seconds), means, medians, variances and standard errors of the ratios of $PM_{2.5}$ by school, time of day, and monitor type are shown in Table 1. $PM_{2.5}$ to background ratios were higher in the morning (1.80) than afternoon (1.43) ($t(36434)=21.13$, $p<0.001$). Time of day concentrations were different within schools, with morning monitoring having greater mean aerosol ratios [School-B-morning (2.90), afternoon (1.38), $t(24337)=32.48$, $p<0.001$; School-A-morning (4.91), afternoon (1.83), $t(17379)= 30.42$, $p<0.001$]. The overall average $PM_{2.5}$ ratio was highest for morning arrival areas at School-B (2.29) and lowest for afternoon front door at School-A (1.07).

Table 1: Descriptive statistics for school zone/background $PM_{2.5}$ ratios by campus location. [1]SidePak AM510 personal exposure monitors (TSI, Inc., Shoreview, MN, USA) were set to record measurements every second.

School	Time of Day	Location	Data Points (N)[1]	Mean Aerosol Ratio to Background	Med. Aerosol Ratio to Background	Variance	StdErr	25% Quartile	75% Quartile
School-A	Morning	Arrival/Departure	3762	2.29	1	8.43	0.05	1	2.86
		Street	3777	1.18	1	3.42	0.03	0.8	1
		Front Door	3777	1.82	1	7.43	0.04	1	1.43
	Afternoon	Arrival/Departure	2060	1.12	1	0.05	0.01	0.75	1.33
		Street	2057	1.71	1.6	0.73	0.02	1.2	2
		Front Door	2060	1.46	1.33	0.64	0.02	1	1.67

School-B	Morning	Arrival/Departure	4660	2.26	1.5	6.74	0.04	1	2.5
		Street	4603	1.39	1	3.79	0.03	0.5	1.5
		Front Door	4371	1.85	1.25	4.04	0.03	0.78	2
	Afternoon	Arrival/Departure	2342	1.34	1	1.2	0.02	0.75	1.5
		Street	2364	1.9	1.67	1.29	0.02	1.25	2.25
		Front Door	2398	1.07	0.8	0.88	0.02	0.57	1.25

Mean ratio between schools, time of day, and monitor location are shown in Figure 1 (a generic aerial figure is being used to preserve school anonymity). Overall arrival/departure ratios were nearly significant between schools [School-B (1.95), School-A (1.87), t(11999)=1.87, p=0.06]. They were significantly different in the afternoon [School-B (1.34), School-A (1.11), t(3956.9)=8.37, p<0.001] but not the morning. Overall front door ratios were significantly different between schools [School-B (1.57), School-A (1.69), t(10949)=-3.20, p=0.001] even though only afternoon times were significantly different between schools [School-B (1.07), School-A (1.46), t(4455.5)=-14.93, p<0.001]. Street ratios were greater for School-B [School-B (1.56), School-A (1.37), t(12691)=6.51, p<0.001]. Results were consistent between morning [School-B (1.39), School-A (1.18), t(8203.3)=4.84, p<0.001] and afternoon times [School-B (1.90), School-A (1.71), t(4330.7)=6.41, p<0.001].

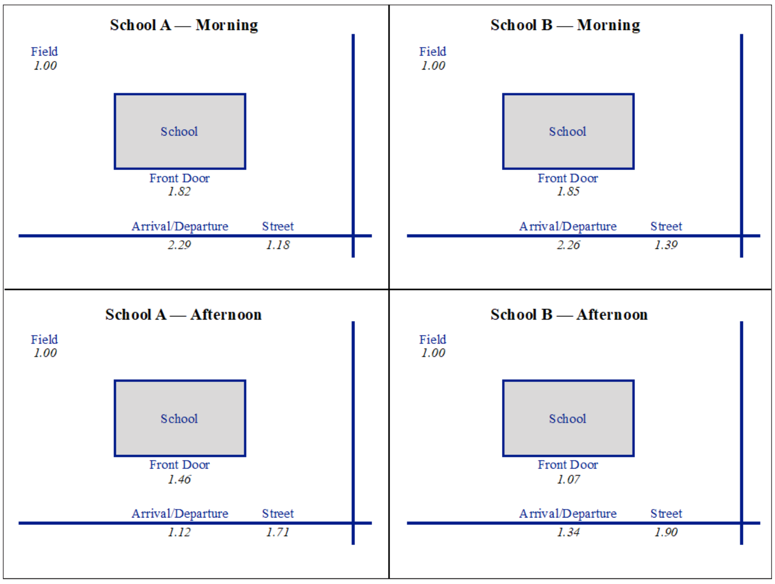

Figure 1: School $PM_{2.5}$ concentration ratio to background level (Field) and monitor locations by time of day. The figure demonstrates the "plume" effect near the arrival/departure area of the school.

Discussion

Overall, this study found significant air pollution concentration differences between school arrival/departure sites, and that all monitor locations were higher than background. Morning arrival/departure locations posed the greatest risk for student exposure, followed by morning front door location, and afternoon street. These findings add to prior work characterizing the variability, and corresponding risk, in exposure between environments, both in terms of micro-environments and systematic environmental differences [6,7,12]. School-B had higher overall mean $PM_{2.5}$ to background ratios than School-A. We offer two possible explanations. First, School-B is located nearer to the urban city center and is more proximal an Interstate freeway compared to school-A. Second, our anecdotal observations suggest that School-A had many more students being driven to school, often in non-carpooling vehicles, whereas School-B tended to have more walking students. Though traffic volume for this area was unavailable, we suspect it to have an important influence on $PM_{2.5}$ near School-B.

Prior work done in Cincinnati, Ohio describes high particulate matter due to busses [14,15]. Our study sites had few diesel busses that travel near them, but these findings confirm that schools tend to have a "plume" near the front door and arrival/departure areas linked to vehicular traffic. Future work should expand upon this pilot study by examining multiple schools in diverse neighborhoods. Though our study, as a pilot, is limited in scope, higher $PM_{2.5}$ concentrations were observed at School-B, which is of significantly lower neighborhood-level socio-economic status compared with School-A. An additional expansion could include the students' commuting environment, including exposure students experience while walking to school [12,26,27].

Conclusion

Our recommendations are to encourage drop-offs/pick-ups further away from the front door of the school as well as for schools to encourage carpooling (i.e., taking more than one child to school from the neighborhood) and not waiting with an idling engine in the "pick up line." Anti-idling campaigns may help reduce the air pollution plume around schools. Ryan PH et al. [28] showed this type of campaign was effective in reducing air pollution levels around one school with high bus traffic [28]. Public health practitioners should holistically consider the school environment when promoting health and safety. This consideration includes adult behaviors that affect school children such as idling or driving a child to school.

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Conflict of Interest

The authors have no financial interest in this project or conflicts of interest to declare.

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