Original Article

JHSMR Journal of Health Science and Medical Research

Particulate Matter 2.5 and Respiratory Symptoms in Urban and Suburban Schoolchildren in Ho Chi Minh City, Vietnam

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Received 30 August 2023 ● Revised 11 October 2023 ● Accepted 11 October 2023 ● Published online 8 January 2024

Abstract

Objective: To document the pattern of particulate matter 2.5 ($PM_{2.5}$) concentration in urban and suburban schools in Ho Chi Minh City (HCMC) and to estimate the prevalence of wheezing and rhinitis among schoolchildren according to sociodemographic characteristics and school-related conditions.

Material and Methods: A cross-sectional study was conducted in two suburban and two urban schools in HCMC. $PM_{2.5}$ concentrations were monitored hourly from August to December in 2022. Children aged 9-13 years (N=1,033) provided data on wheezing and rhinitis symptoms in the previous year. The daily levels of $PM_{2.5}$ were monitored in each school. Respiratory symptoms were compared between areas and across school-related conditions.

Results: Geometric means of the daily $PM_{2.5}$ concentration in the suburban and urban areas were 61.2 μg/m^3 and 31.0 μg/m^3, respectively (p-value<0.001). In both areas, $PM_{2.5}$ levels increased in the evening to high levels at night

This paper was from The 2nd Annual Health Research International Conference 2023 (AHR-iCON 2023, July 19-20, 2023).
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J Health Sci Med Res 2024;42(4):e20241024
doi: 10.31584/jhsmr.20241024
www.jhsmr.org

and early morning. The prevalence of respiratory symptoms did not differ significantly between the suburban and urban areas: wheezing 20.6% and 16.9%, and rhinitis 55.7% and 61.5%, respectively. However, school-related conditions in which the prevalence was increased were travelling to school by bus, spending more than 15 minutes/day on the road and attending extra classes outside normal school hours.

Conclusion: Despite the significantly higher $PM_{2.5}$ levels in suburban schools, the prevalence of wheezing and rhinitis did not reveal significant differences between areas. However, respiratory symptoms were more common among those travelling by bus, having been infected with Coronavirus Disease-19 (COVID-19), spending longer time on the road and attending classes outside normal school hours.

Keywords: $PM_{2.5}$, schoolchildren, rhinitis, Vietnam, wheezing

Introduction

Air pollution is becoming a problem in many urban areas around the world due to the adoption of urban development and modernization. Air pollutants including fine particulate matter with particle size <2.5μm (particulate matter 2.5, $PM_{2.5}$) are worsening and are having an impact on human health, especially that of children, who are known to be particularly vulnerable. $PM_{2.5}$ can enter the alveoli, irritating and damaging the lungs1 and posing a significant risk to children's respiratory health, with both short-term and long-term consequences[2,3], especially when the air quality exceeds the recommended guidelines4. Levels of air pollution, including $PM_{2.5}$, are high in Vietnam. The annual average concentration of $PM_{2.5}$ in Vietnam reported is 27.2 μg/m^3 in 20225, which is 5.4 times higher than the World Health Organization (WHO) annual average standard (5 μg/m^3)[4]. In Ho Chi Minh City (HCMC), the average annual concentration of $PM_{2.5}$, 21.2 μg/m^3 in 2022[5], is also 4 times greater than the WHO annual average standard.

Respiratory symptoms like wheezing, asthma, and rhinitis are significant public health concerns, particularly among children living in megacities. The prevalence of respiratory disorders among children such as wheezing and rhinitis has increased during the past few decades. Globally, according to the WHO, the number of patients having asthma is 300 million and having rhinitis 400 million[6,7]. The worldwide epidemic of asthma and allergic illness that has been observed in both children and adults is still continuing, especially in low to middle-income countries, although it has decreased in some high-income countries[8]. The standardized survey instruments developed by the International Study of Asthma and Allergies in Childhood (ISAAC) have been extensively used and validated in several contexts for epidemiological research globally. According to recent ISAAC studies, pediatric allergy diseases are increasing most dramatically in developing countries. The frequency of allergic illnesses varies significantly between Asian countries and areas. Since the ISAAC phase I survey in 1995, there has been an increase in the prevalence of allergy disorders in Thailand, with rhinitis rising from 37.9% to 50.6% and asthma increasing from 12.2% to 14.5%[9,10]. In Japan, between 1995 and 2000, allergic rhinoconjunctivitis climbed from 7.8% to 10.6% and asthma from 17.4% to 18.2%. In Guangzhou, Southern China, the prevalence of asthma and rhinitis among young people increased between 1994 and 2009 from 3.9% to 6.9%, and from 17.4% to 25.1%, respectively[11].

Schoolchildren spend much of their time in the school and classroom during the typical week. It is of particular importance to understand the air quality at school, where they can be exposed to harmful pollutants, especially in schools located near high pollution sources such as heavy traffic. There are few studies that evaluate the air quality at schools in HCMC or the patterns of respiratory symptoms in schoolchildren. The aim of this study was to provide current baseline data on the air quality at school as measured by $PM_{2.5}$ concentration in urban and suburban HCMC as well as document the period prevalence of wheezing and rhinitis in the population of schoolchildren, and its variation across sociodemographic and school-related conditions.

Material and Methods

$PM_{2.5}$ sampling

$PM_{2.5}$ mean concentration over the previous hour was recorded every hour at 2 urban schools (1 primary school (10.75404°N, 106.62076°E) and 1 junior high school (10.75679°N, 106.62087°E) in the Binh Tan district) and 2 suburban schools (1 primary school (10.78771°N, 106.51701°E) and 1 junior high school (10.76598°N, 106.5607°E) in the Binh Chanh district) in HCMC (Supplement Figure 1) from 1st August to 31st December 2022. The period of recording $PM_{2.5}$ concentrations was the latter part of the rainy season (August, September, October), which was recorded in HCMC as having an average temperature of 27.9 °C, an average relative humidity of 83.4%, average rainfall of 175.7 mm and average of 28.2 rainy days per month, and continuing to the start of the dry season (December) with an average temperature of 27.2 °C, an average relative humidity of 74.9%, an average rainfall of 32.0 mm, and an average of 14.0 rainy days[12,13]. November is somewhat transitional between the two seasons with an average temperature of 27.7 °C, an average relative humidity of 80%, an average rainfall of 111.0 mm, and an average of 21.7 rainy days[12,13] (Supplement Table 1). Particulate concentrations were measured using the PAM Air monitors located 3.4 to 4.4 m above ground level at an outside location in each school, near the entrance gate which is within a distance from the nearest main road of about 20 m (suburban schools) and about 40 m (urban schools). This location was not obstructed by trees or roofs to ensure direct contact with the surrounding air and had a continuous power supply for the device. The PAM Air monitor (JSC Consulting & Integrating Technology, Vietnam) is a dedicated air quality meter that can withstand a variety of weather conditions as well as having ease of maintenance, and uses light scattering technology to measure the concentration of $PM_{2.5}$ within a range of 0-999 μg/m^3. It uses the light scattering method and was evaluated by calibration methods adapted from the US EPA 2021. Eight performance aspects were examined: linearity of response, precision of measurement, bias and error, low and mid concentration drift, accuracy at high concentration, and relative humidity and temperature influences. PAM Air has been assessed and found to be in conformance with the requirements set forth by the International Organization for Standardization (ISO) 9001:2015.

Survey on the respiratory symptoms in schoolchildren

A cross-sectional survey was undertaken among children aged 9-13 years in the two selected schools in Binh Chanh (a suburban district) and the two selected schools in Binh Tan (an urban district) in HCMC in October 2022. In each school, seven classes (35-36 students each) of fourth and fifth grades in the primary schools and sixth and seventh grades in the junior high schools were randomly chosen to achieve the required sample size of 1,000 (approximately 250 per school). All students of these classes were initially invited, and their parents/primary caregivers were contacted to request permission for their children to participate in the study. Only students whose parents agreed to participate in the project were finally included.

The questionnaire was based on standard questions from the ISAAC questionnaire, which had been back translated from English to Vietnamese and published in 2022 with test-retest reliability of 66.0% to 99.0%[14]. The Vietnamese version was used. Information for the study was gathered in two different ways: one was self-administered by junior high school students in the classroom. Researchers explained the study's aims and methodology to participants before they answered the questionnaire. For the primary school students, questionnaires were enclosed in an envelope and sent home with the students so that their parents or guardians could complete them at home and return them to the schools for collection by the researchers.

Respiratory symptoms covered in this study were wheezing and having rhinitis in the previous 12 months. Wheezing was assessed using the question "Have you/your child had wheezing or whistling in the chest in the past 12 months?" and rhinitis was assessed by the question "In the past 12 months have you (has your child) had a problem with sneezing, or a runny, or blocked nose when you/your child did not have a cold or the flu?". This definition has been similarly used and is widely accepted to assess the prevalence of respiratory symptoms in children in previous studies with sensitivity ranging from 53.5% to 75.0% and specificity ranging from 62.4% to 91.3%[15–17]. Associated respiratory symptoms such as ≥4 wheeze attacks in the last 12 months, sleep disturbances due to wheezing in the last 12 months, speech limitation due to wheezing in the last 12 months, rhinitis symptoms accompanied by itchy-watery eyes in the last 12 months, and rhinitis symptoms interfering with daily activities were also asked about. Sociodemographic characteristics were recorded for each child, including sex, date of birth, weight, height, household's economic level, underlying medical condition, infection with COVID-19 in the previous year, and presence and type of allergy (food, pollen, fur). School-related conditions were also recorded, including details of transport mode to and from school, the official school time, the total time on the road in the typical day, and whether the child attended extra classes out of normal school hours.

Statistical analysis

The hourly $PM_{2.5}$ values were analyzed in the following manner for each school and/or area (suburban and urban). 1. The distribution of the $PM_{2.5}$ throughout each day was examined and, because of the relatively symmetrical distribution with the day, the arithmetic mean was calculated. 2. The distribution of these daily means across days and school areas was examined and, because of the right skew, the values were logarithm-transformed

Table 1 Summary of the distribution of $PM_{2.5}$ concentration over 5 months of observation by school location

Parameter	$PM_{2.5}$ G.M. (G.S.D.) (μg/m^3)		
	Suburban	**Urban**	**p-value***
August to December: by time of day			
Overall 24-hour mean	61.2 (1.6)	31.0 (1.7)	<0.001
Overall mean between 07.00 h and 17.00 h (school time)	38.1 (1.6)	30.2 (1.4)	<0.001
Overall mean between 17.00 h and 21.00 h (evening)	55.4 (1.2)	32.2 (1.1)	<0.001
Overall mean between 21.00 h and 07.00 h (night time)	97.5 (1.2)	40.6 (1.1)	<0.001
By Season			
Overall 24-hour mean in rainy season (August–October)	52.7 (1.5)	27.7 (1.6)	<0.001
Overall 24-hour mean in transitional month (November)	69.9 (1.5)	38.2 (1.9)	<0.001
Overall 24-hour mean in dry season (December)	84.3 (1.7)	35.6 (1.8)	<0.001

*p-values from mixed-effects linear models, G.M.=geometric means, G.S.D.=geometric standard deviations, $PM_{2.5}$=particulate matter 2.5

and their means and standard deviation exponentiated to yield geometric means (G.M.) and geometric standard deviations (G.S.D.). 3. The overall G.M. and G.S.D. for the whole 5-month period, and for the three rainy season months (August-October), the intermediate month (November) and the early dry season month (December) were summarized for each school and each area. Similar summaries were made for the $PM_{2.5}$ concentration during the day-time (recordings from 07.00 h to 17.00 h) and the evening (recordings from 17.00 h to 21.00 h) to distinguish $PM_{2.5}$ levels during the normal school day from those in the evening, when children may be attending extra classes. 4. Time-series plots of the daily G.M. were constructed for the entire 5-month period. 5. The distribution of hourly $PM_{2.5}$ levels throughout the 24-hour period in each season was examined graphically.

Comparisons between suburban and urban areas of the logarithm-transforms of the daily means, the school-day means and the evening means were made using mixed effects linear regression models, in which date was considered to be the random element and area to have fixed effects.

Schoolchildren's characteristics and school-related conditions were displayed as numbers and percentages for each area. Differences in the occurrence of respiratory symptoms in the previous 12 months across sociodemographic characteristics and school-related conditions were explored using tabulation and chi-square or Fisher's exact test as appropriate.

In all statistical comparisons, a p-value<0.05 was considered to indicate statistical significance. All statistical analyses were performed using Stata version 14.2 (StataCorp, College Station, TX, USA).

Ethical considerations

The study was approved by the Institutional Ethics Committees of Prince of Songkla University, Hat Yai, Thailand (REC. 65-376-18-9), and the Board of Ethics in Biomedical Research at the University of Medicine and Pharmacy in Ho Chi Minh City (726/HDDD-DHYD). Children participated voluntarily and received approval from the school and their parents before they were included in the study. During the data collection period, participants had the right to decline to respond to any question they did not wish to answer. This research ensured that the personal information of the interviewees was completely confidential.

Results

Temporal and spatial pattern of $PM_{2.5}$ concentration

Table 1 summarizes the ambient fine particulate levels in urban schools and suburban schools using the geometric mean and geometric standard deviation of the daily means over the 5-month data collection period (August–December 2022). These $PM_{2.5}$ levels were significantly higher in the suburban (61.2 [1.6] µg/m^3) than in the urban areas (31.0 [1.7] µg/m^3) (p-value<0.001). Similar discrepancies were also seen when school-time means, evening-time means, and night-time means were compared across areas (Table 1).

Figure 1 displays the time series of daily mean values of $PM_{2.5}$ from August to December. This period covers 3 months of the rainy season (August, September and October), one transitional month (November), and 1 month at the start of the dry season (December). Elevated levels of $PM_{2.5}$ were seen in the transitional and dry months. The patterns are similar in suburban and urban areas, but levels are higher in the suburban areas. There is noticeable variability in the daily means in both areas, but no major frequencies could be identified. Over the 5 months of data collection $PM_{2.5}$ concentration daily mean exceeded 15 µg/m^3 on more than 87.0% of days in urban and more than 97.0% of days in suburban schools.

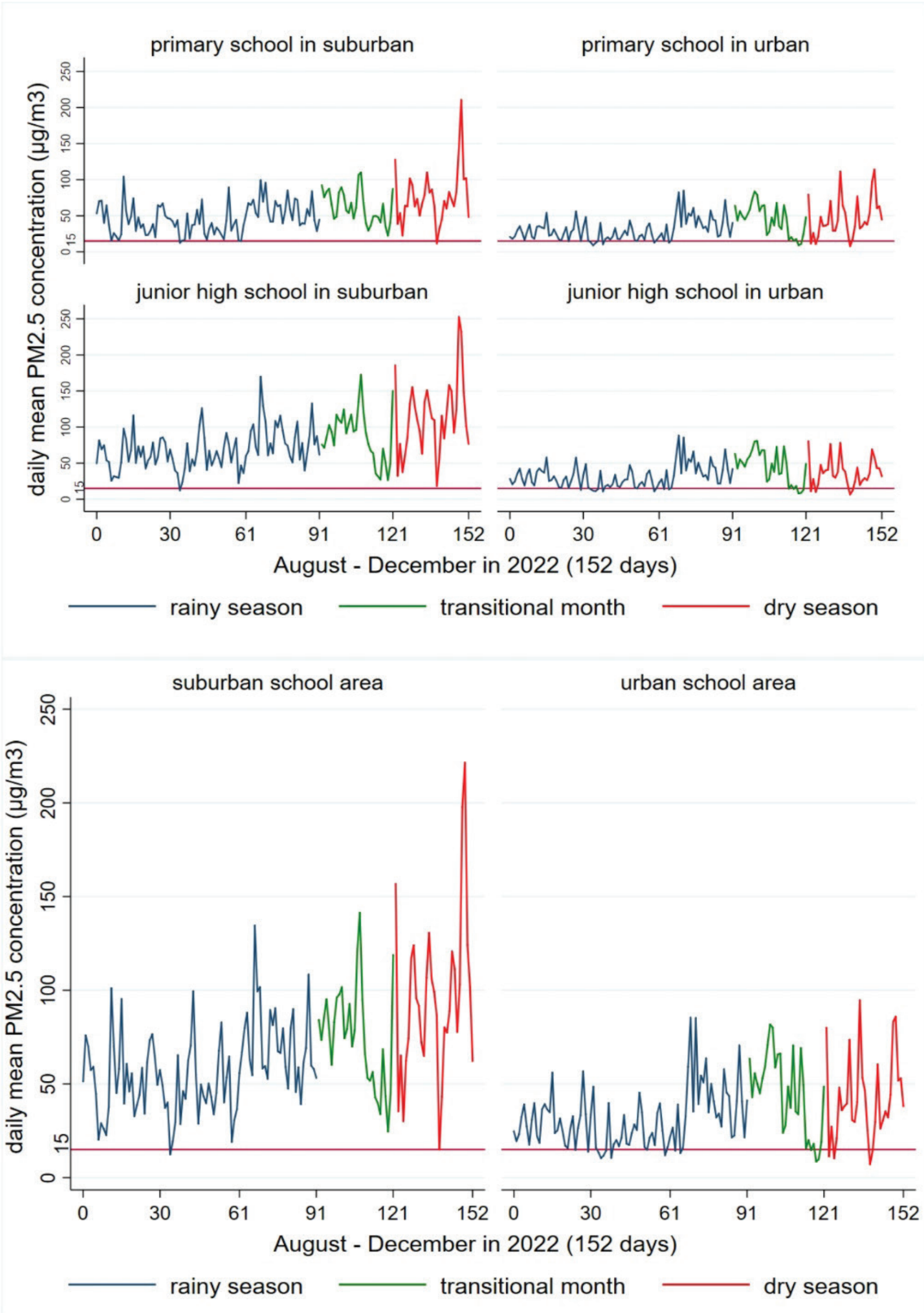

Figure 1 Distribution of daily $PM_{2.5}$ concentration (µg/m^3) over 5 months observation by school location

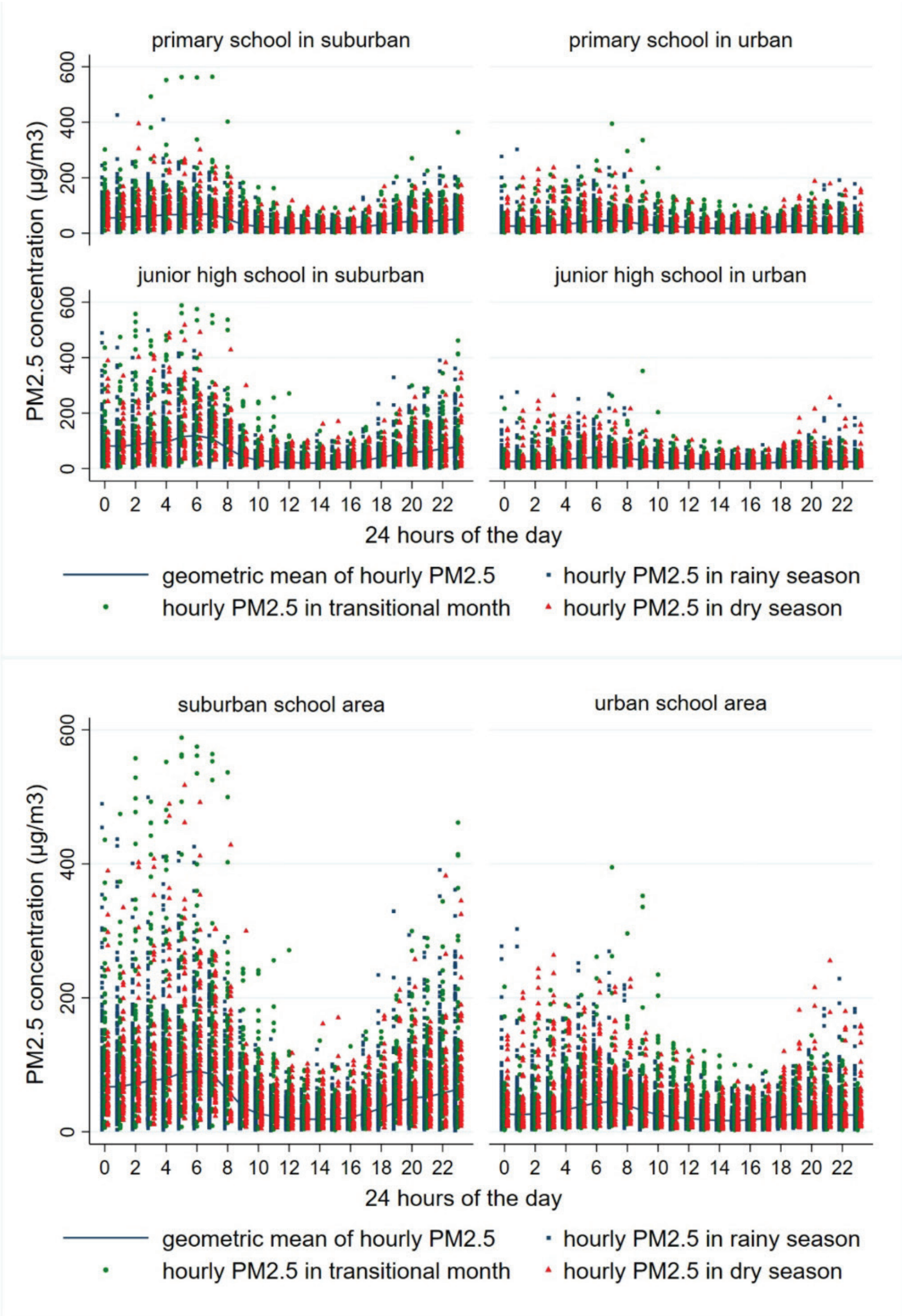

Figure 2 Distribution of $PM_{2.5}$ concentration (µg/m^3) throughout 24 hours over 5 months of observation by school location

The diurnal fluctuation of $PM_{2.5}$ is displayed in Figure 2. A rise in $PM_{2.5}$ levels starting at about 16.00 h leads to high values in the evening and at night and a subsequent drop from about 08.00 h. The lowest levels occur between 13.00 h and 15.00 h. It is noted that the evening time is the peak time for traffic activities such as school and work dismissal times.

Study population characteristics and school-related conditions

A total of 1,125 schoolchildren were invited to participate in the survey. Fifty-seven schoolchildren and their parents (5.0%) refused to participate, 10 (1.0%) students were absent when the questionnaire was completed, and 25 (2.0%) responses were excluded owing to less than 50 percent completion of the questionnaire. There were 1,033 (92.0%) valid questionnaires in the final analysis.

The characteristics of the target population are described in Table 2. The proportions of the participants were approximately equally distributed in terms of sex, age, and student grade in the two school areas. Over 70.0% of the schoolchildren had a similar economic status to other households in their community. In both areas, nearly half of the children were overweight or obese, and around 40.0% had experienced infection with COVID-19 in the previous 12 months. A small percentage of children reported an allergy to food, followed by that to fur and pollen. The schoolchildren at suburban schools had a higher prevalence of the underlying medical conditions than those in the urban schools (6.3% versus 3.0%).

School-related conditions are reported in Table 3. The most commonly reported mode of transport to and from school in both areas was by motorcycle (around 70.0%). However, urban schoolchildren more commonly traveled on foot and attended school only in the morning or in the afternoon, while suburban children more commonly traveled by public bus and attended school throughout the whole day. Extra classes out of normal school hours were more commonly attended by urban children.

Differences in period prevalence of respiratory symptoms by area, schoolchild characteristics, and school-related conditions

Table 4 shows the prevalence of symptoms related to wheezing and rhinitis in the previous 12 months. Between 20.6% (suburban) and 16.9% (urban), children reported wheezing in the previous 12 months, with the corresponding percentages for rhinitis of 55.7% and 61.5%. Neither of these differences was statistically significant. Subcategories of wheezing and rhinitis also did not differ significantly between the two areas.

Regarding sociodemographic characteristics, wheezing was shown to be more common among children who had an allergy to fur (30.8% vs. 17.9%) and both wheezing and rhinitis were more common among those who experienced COVID-19 infection during the previous year (23.5% vs. 15.8%, p-value=0.002 and 62.1% vs 57.1%, p-value=0.017, respectively) (Table 5). Among school-related conditions, children who traveled to and from school by public bus or spent as long as or longer than 15 minutes on the road more commonly reported wheezing in the previous year (34.2% vs. 18.0%, p-value=0.010 and 20.5% vs. 12.2%, p-value=0.014, respectively). The higher prevalence of wheezing among those traveling by bus was also evident when the analysis was confined to suburban schoolchildren. Both wheezing and rhinitis prevalences were significantly higher among children who attended extra classes out of normal school hours (wheezing 22.7% vs. 14.9%, p-value=0.001 and rhinitis 62.6% vs. 55.0%, p-value=0.014) (Table 6).

Table 2 Sociodemographic characteristics among schoolchildren by school location in Ho Chi Minh City, Vietnam

Variable	Suburban (N=506) n (%)	Urban (N=527) n (%)	p-value
Sex			0.231
Female	250 (49.4)	280 (53.1)	
Male	256 (50.6)	247 (46.9)	
Age (years)			0.582
9	111 (21.9)	105 (19.9)	
10	105 (20.8)	122 (23.2)	
11	150 (29.6)	166 (31.5)	
≥12	140 (27.7)	134 (25.4)	
Grade			0.626
Grade 4	124 (24.5)	128 (24.3)	
Grade 5	97 (19.2)	118 (22.4)	
Grade 6	156 (30.8)	156 (29.6)	
Grade 7	129 (25.5)	125 (23.7)	
BMI			0.890
Underweight	22 (4.4)	22 (4.2)	
Normal weight	240 (47.4)	257 (48.8)	
Overweight	143 (28.3)	138 (26.2)	
Obese	101 (20.0)	110 (20.9)	
Allergy			
Food allergy	47 (9.3)	55 (10.4)	0.536
Fur allergy	33 (6.5)	32 (6.1)	0.766
Pollen allergy	26 (5.1)	15 (2.9)	0.059
Infected with COVID-19 previous 12 months[$] (yes)	217 (43.7)	205 (39.8)	0.214
Underlying medical condition (yes)	32 (6.3)	16 (3.0)	0.012
The family's economic status[$]			0.083
Poorer than most other households	76 (15.5)	95 (18.7)	
Same as most other households	348 (70.9)	364 (71.7)	
Wealthier than most other households	67 (13.6)	49 (9.6)	

[$]In the results, the actual denominators were lower since subjects with missing answers were excluded (less than 4%)

Discussion

$PM_{2.5}$ concentration in the study setting

The levels of $PM_{2.5}$, with G.M. of around 61 μg/m^3 in the suburban school areas and 31μg/m^3 in the urban school areas, are higher than the WHO recommended safe level of $PM_{2.5}$ of 15 μg/m^3 24-hour average for no more than 3 to 4 days per year[4]. This recommended safe level was exceeded even during the rainy months of August and September when ambient dust levels were lower. The distribution of $PM_{2.5}$ concentrations in 2022 for the entire HCMC extracted from the single air quality monitoring station operated by the US Consulate, located in the centre of Ho Chi Minh City (District 1), also showed levels in excess of the WHO standard threshold during the rainy season months and much higher levels during the dry season months (Supplementary Table 1). Although $PM_{2.5}$ data in this study were collected for only 5 months at the study setting, a similar pattern was found. To the extent that the $PM_{2.5}$ levels recorded during the five months of study represent the levels throughout the year in rainy, transitional, and dry seasons, it can be inferred that the overall air quality is moderately unhealthy. In the dry season in the early morning $PM_{2.5}$

Table 3 Characteristics of the school-related conditions among schoolchildren by school location in Ho Chi Minh City, Vietnam

Variable	Suburban (N=506) n (%)	Urban (N=527) n (%)	p-value
The transport mode to school			
Motorcycle	358 (70.8)	369 (70.0)	0.833
Electric bicycle/bike	78 (15.4)	74 (14.0)	0.542
Walk	21 (4.2)	87 (16.5)	<0.001
Public buses	41 (8.1)	0 (0.0)	<0.001
Car/taxi	10 (2.0)	3 (0.6)	0.043
Others	4 (0.8)	3 (0.6)	0.386
Official school time			<0.001
Only in the morning	156 (30.8)	274 (52.0)	
Only in the afternoon	129 (25.5)	253 (48.0)	
Whole day	221 (43.7)	0 (0.0)	
Total time on the road in typical day			0.077
<15 mins	77 (15.9)	103 (20.2)	
≥15 mins	408 (84.1)	407 (79.8)	
Having the extra class (yes)	208 (41.1)	294 (55.8)	<0.001

[$]In the results, the actual denominators were lower since subjects with missing answers were excluded (less than 4%)

Table 4 Prevalence of symptoms related to wheezing and to rhinitis in the previous 12 months by school location

Respiratory symptoms	Total (N=1,033) n (%)	School location		
		Suburban N=506 n (%)	Urban N=527 n (%)	p-value
Wheezing and associated- symptoms				
Wheezing in last 12 months	193 (18.7)	104 (20.6)	89 (16.9)	0.131
≥4 of wheeze attacks in last 12 months	53 (5.1)	30 (5.9)	23 (4.4)	0.255
Sleep disturbances due to wheezing in last 12 months	60 (5.8)	29 (5.7)	31 (5.9)	0.917
Speech limitation due to wheezing in last 12 months	37 (3.6)	15 (3.0)	22 (4.2)	0.295
Rhinitis and associated- symptoms				
Rhinitis in last 12 months	606 (58.7)	282 (55.7)	324 (61.5)	0.061
Rhinitis accompanied by itchy-watery eyes in last 12 months	180 (17.4)	86 (17.0)	94 (17.8)	0.722
Rhinitis interfere with daily activities	91 (8.8)	43 (8.5)	48 (9.1)	0.729

Table 5 The prevalence of wheezing and of rhinitis in the previous 12 months by sociodemographic characteristics

Variable	Total n (%)	Wheezing in the previous 12 months (N=193)		Rhinitis in the previous 12 months (N=606)	
		n (%)	p-value	n (%)	p-value
Sex			0.634		
Female	530 (51.3)	102 (19.3)		322 (60.8)	0.161
Male	503 (48.7)	91 (18.1)		284 (56.5)	
Age (years)			0.260		0.213
9	216 (20.9)	47 (21.8)		120 (55.6)	
10	227 (22.0)	33 (14.5)		135 (59.5)	
11	316 (30.6)	61 (19.3)		199 (63.0)	
≥12	274 (26.5)	52 (19.0)		152 (55.5)	
Grade			0.454		0.257
Grade 4	252 (24.4)	50 (19.8)		138 (54.8)	
Grade 5	215 (20.8)	32 (14.9)		129 (60.0)	
Grade 6	312 (30.2)	62 (19.9)		195 (62.5)	
Grade 7	254 (24.6)	49 (19.3)		144 (56.7)	
BMI			0.278		0.150
Underweight	44 (4.3)	6 (13.6)		19 (43.2)	
Normal weight	497 (48.1)	84 (16.9)		295 (59.4)	
Overweight	281 (27.2)	56 (19.9)		162 (57.7)	
Obese	211 (20.4)	47 (22.3)		130 (61.6)	
Food allergy			0.291		0.129
No	931 (90.1)	170 (18.3)		539 (57.9)	
Yes	102 (9.9)	23 (22.6)		67 (65.7)	
Fur allergy			0.010		0.314
No	968 (93.7)	173 (17.9)		564 (58.3)	
Yes	65 (6.3)	20 (30.8)		42 (64.6)	
Pollen allergy			0.076		
No	992 (96.0)	181 (18.3)		582 (58.7)	0.987
Yes	41 (4.0)	12 (29.3)		24 (58.5)	
Infected with COVID-19 previous 12 months			0.002		0.017
No	590 (58.3)	93 (15.8)		337 (57.1)	
Yes	422 (41.7)	99 (23.5)		262 (62.1)	
Underlying medical condition			0.250		0.801
No	985 (95.3)	181 (18.4)		577 (58.6)	
Yes	48 (4.7)	12 (25.0)		29 (60.4)	
The family's economic status$			0.341		0.878
Poorer than the other households	171 (16.6)	38 (22.2)		101 (59.1)	
Same as the other households	712 (68.9)	126 (17.7)		423 (59.4)	
Wealthier than the other households	116 (11.2)	24 (20.7)		66 (56.9)	

$In the results, the actual denominators were lower since subjects with missing answers were excluded (less than 4%)
BMI=body mass index, COVID-19=coronavirus disease 2019

Table 6 Prevalence of wheezing and of rhinitis in the previous 12 months by school-related conditions

Variable	Total n (%)	Wheezing in the previous 12 months (N=193)		Rhinitis in the previous 12 months (N=606)	
		n (%)	p-value	n (%)	p-value
School location			0.131		0.061
Suburban	506 (49.0)	104 (20.6)		283 (55.7)	
Urban	527 (51.0)	89 (16.9)		324 (61.5)	
The transport mode to school					
Motorcycle			0.399		0.532
No	306 (29.6)	62 (20.3)		175 (57.2)	
Yes	727 (70.4)	131 (18.0)		431 (59.3)	
Electric bicycle/bike			0.718		0.357
No	881 (85.3)	163 (18.5)		522 (59.3)	
Yes	152 (14.7)	30 (19.7)		84 (55.3)	
Walk			0.570		0.585
No	925 (89.6)	175 (18.9)		540 (58.4)	
Yes	108 (10.5)	18 (16.7)		66 (61.1)	
Public buses			0.010		0.323
No	992 (96.0)	179 (18.0)		585 (59.0)	
Yes	41 (4.0)	14 (34.2)		21 (51.2)	
Car/taxi			0.759		0.137
No	1020 (98.7)	191 (18.7)		601 (58.9)	
Yes	13 (1.3)	2 (15.4)		5 (38.5)	
Official school time			0.663		0.263
Only in the morning	430 (41.6)	75 (17.4)		265 (61.6)	
Only in the afternoon	382 (37.0)	76 (19.9)		216 (56.5)	
Whole day	221 (21.4)	42 (19.0)		125 (56.6)	
Total time on the road in typical day$			0.010		0.223
<15 mins	180 (17.4)	22 (12.2)		98 (54.4)	
≥15 mins	815 (78.9)	167 (20.5)		484 (59.4)	
Having the extra class			0.001		0.014
No	531 (51.4)	79 (14.9)		292 (55.0)	
Yes	502 (48.6)	114 (22.7)		314 (62.6)	

$ In the results, the actual denominators were lower since subjects with missing answers were excluded (less than 4%)

levels were shown to frequently reach 300-400 μg/m^3 in urban setting and 500-600 μg/m^3 in the suburban setting.

Contrary to expectations, the suburban $PM_{2.5}$ levels in this study were significantly higher than the urban levels. Whether this is true over a wider scale cannot be judged as only one suburban district and one urban district were included. A likely explanation for the elevated $PM_{2.5}$ levels in the selected suburban setting may be the proximity of the schools to an industrial park and factories. Furthermore, the suburban schools were located only about 20 m from major roads that carried large numbers of container trucks importing and exporting materials and goods to and from the industrial park. In addition to the container traffic, these nearby roads also carry many other types of vehicles, including motorcycles, trucks, cars, and other large vehicles, and experience frequent congestion, especially during the rush hours in the morning and evening (Supplementary Figure 1).

By contrast, the urban primary and junior high schools were situated relatively far from major roads (approximately 400 m and 60 m respectively). These urban roads experience a high density of traffic only in the morning and evening rush hours. Thus, it is likely that the diurnal pattern of high $PM_{2.5}$ in the evening, night, and early morning could be explained by the variation over the 24 hours in traffic on nearby roads, with the suburban setting experiencing the added burden of $PM_{2.5}$ pollution from the container traffic and the related industrial park. It is of interest, also, that heavy goods vehicles, including container vehicles, are permitted to lawfully travel on the roads only between 22.00 h and 07.00 h.

Prevalence of symptoms related to wheezing, rhinitis

Respiratory symptoms were recorded in terms of occurrence or non-occurrence in the previous year. Hence, any temporal variation and possible relationship with the seasonal and diurnal variations in $PM_{2.5}$ concentration (as measured at the location of the selected schools) could not be explored; only the comparison of period prevalence between suburban and urban settings could be analyzed. While the data indicated a higher period prevalence of wheezing in the suburban setting and a higher period prevalence of rhinitis in the urban setting, neither of these differences was statistically significant.

The overall prevalence of wheezing and rhinitis symptoms in the last 12 months in the current study was approximately 19.0% and 59.0%, respectively. These levels are higher than those reported in earlier studies in other cities in Southeast Asia. A study in 2003 of Vietnamese children aged 5 to 11 in Ha Noi reported wheezing and rhinitis prevalences within the previous year of approximately 15.0% and 27.0%, respectively[18]. In Thailand, in 2017, the corresponding period prevalences were reported to be approximately 14.0% and 44.0%, respectively[19].

The high period prevalences found in our study could be a result of an interplay of environmental, genetic, and lifestyle factors[20–22]. However, the high level of $PM_{2.5}$ in schools exceeding the threshold prescribed by WHO may be an important contributor. Our study did not aim to directly assess a causal relationship between $PM_{2.5}$ and the occurrence of respiratory symptoms as the periods corresponding to $PM_{2.5}$ measurement and assessment of respiratory symptoms were not concurrent. However, the study provides baseline data on particulate air pollution and schoolchildren's respiratory health that may inform the design of future studies aimed at identifying causal relationships. In terms of the environment, Vietnam has recently experienced massive growth in urbanization and industrialization accompanied by tremendous economic development since 1986 following the implementation of economic reform programs. However, environmental degradation has been reported. For instance, in the period of Vietnam's economic reform from 1986 to 2018, CO_2 emissions increased nearly tenfold, from 0.25 to 2.45 tons of CO_2 per capita[23].

Apart from the link between the prevalence of respiratory symptoms and fur allergy and experience of COVID-19 infection, which are to be expected, we also identified differences in respiratory symptom period prevalence across certain school-related conditions, namely time on the road travelling to school, travelling to and from school by bus and attending extra classes out of normal school hours. While only suburban children travelled between home and school by public bus, those who did so reported a higher prevalence of wheezing than suburban school children who travelled by other means. One possibility is that schoolchildren children travelling by bus, which is usually open and diesel-powered, are more exposed to traffic-related air pollution and/or spend longer time on the road. It is reported that exposure to black carbon, a component of fine particles produced from incomplete combustion, especially from diesel-powered vehicles has negative health impacts such as acute respiratory inflammation, wheezing, and asthma[24,25].

The finding that children attending extra classes out of normal school hours had a higher period prevalence of both wheezing and rhinitis is interesting. Extra/tutor classes are a popular way for parents to provide their children with additional academic support outside of regular school hours in Vietnam, and they can involve a wide range of subjects, including mathematics, science, and language arts, among others, and necessitate additional time in school or at outside academic institutes. However, these after-school extra classes may be contributing to the high frequency of asthma and other respiratory issues among children owing to an increased exposure to air pollution. Children who go to extra school tend to commute more on the road and, as after-school classes in Vietnam are usually held in the late afternoon or early evening, at a time of day that the $PM_{2.5}$ levels are rising. Although attending extra classes out of normal school hours was more common among urban schoolchildren, its relationship with increased prevalence of wheezing was more pronounced among the suburban (27.4% vs 15.8%, OR=2.02) than the urban children (19.4% vs 13.7%, OR=1.51), albeit not statistically significant between areas. However, this is consistent with the higher evening $PM_{2.5}$ levels in the suburban setting compared with the urban setting.

Limitations

First, individual-level exposures to $PM_{2.5}$ were not measured for each child and the period of environment monitoring was not concurrent with the period pertaining to symptom occurrence. Therefore, our data do not purport to demonstrate a causal relationship between $PM_{2.5}$ and respiratory symptoms. Second, home- and other out-of-school-based exposures were not included in this analysis. Third, this study depended on children and their families to self-report symptom occurrence in the previous 12 months, opening opportunity for inaccurate recall. Fourth, as this was a school-based study, it was not possible to ask about the child's use of medications such as controllers or bronchodilators which might confound the events. The study looked into respiratory symptoms regardless of the clinical diagnosis of asthma by a doctor. Nevertheless, these descriptive findings offer a basis for further in-depth investigation of the network of causal factors associated with the occurrence of respiratory symptoms in schoolchildren in HCMC.

Conclusion

The concentrations of $PM_{2.5}$ in urban (G.M.=31 µg/m^3) and suburban schools (G.M.=61.2 µg/m^3) exceed the WHO standard (24-hour average: 15 µg/m^3) and are particularly high in the evening, night-time, and early morning. The prevalence of wheezing and rhinitis in suburban vs urban were 20.6% vs. 16.9%, and 55.7% vs 61.5%, respectively. The prevalence of wheezing was higher among those travelling by bus and those spending longer time on the road (≥15 minutes). The prevalence of wheezing and that of rhinitis were both higher among schoolchildren having been infected with COVID-19 and attending extra classes out of normal school hours. Interestingly, the extra classes are usually held in the evening when $PM_{2.5}$ levels are increasing.

Acknowledgement

The authors thank the Department of Education and Training, the Department of Health, and four schools in HCMC for facilitating data collection. We thank the schoolchild participants and their parents for their vital participation in the study. We also thank the local research team members (University of Medicine and Pharmacy at Ho Chi Minh City) for their support in organizing the survey and data collection. We also thank Ph.D. Thai Khanh Phong works at the Queensland Alliance for Environmental Health Sciences (QAEHS), The University of Queensland, Australia as a technical consultant in research. We thank D&LCrop company for the support in installing, exporting data, and maintaining the air quality monitoring system at the four study sites.

Funding sources

This work was supported by the 2021 PSU-Faculty of Medicine International Student Graduate Scholarships, Prince of Songkla University, and the United States Agency for International Development (USAID) via the Long-Term Assistance and SErvices for Research Partners for University-Led Solutions Engine (LASER PULSE) program. The contents herein are those of the authors and do not necessarily reflect the views of USAID, LASER PULSE, or the United States Government.

Conflict of interest

The authors have no conflicts of interest relevant to this article to disclose.

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