Indoor particulate matter levels in school classrooms and its association with asthma and allergic rhinitis in adolescents from Anuradhapura, Sri Lanka

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Abstract
Introduction: Indoor air quality significantly affects respiratory health, and particulate matter (PM) is a critical indoor air pollutant. The aerodynamic diameter of PM determines its depth of penetration along the tracheobronchial tree and resultant health effects.

Objectives: To assess indoor PM levels in classrooms and their association with asthma and allergic rhinitis symptoms among adolescent children.

Method: A descriptive cross-sectional study was conducted in 32 grade 8 classes from 6 selected secondary schools in the Anuradhapura municipal council area, Sri Lanka. Indoor PM levels, relative humidity, temperature, wet-bulb temperature, and dew point were measured using a video particle counter (VPC300, EXTECH®). International Study of Asthma and Allergies in Childhood was used to assess the prevalence of current wheezing, severe asthma and allergic rhinitis.

Results: Of the 32 selected classrooms, $PM_{0.3}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_5 and PM_{10} levels exceeded recommended levels in 30, 28, 26, 32, 30 and 30 classrooms, respectively. Highest mean counts of $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$ and PM_{10} among the 32 classrooms were 848,362±163,795, 533,648±138,542, 110,297±34,240, 15,634±16,817, 2394±2,284 and 974±211, respectively. The highest mean fine particulate matter level was more than 28 times the approved range. Maximum counts of $PM_{1.0}$ (176,048), $PM_{2.5}$ (56,237), and PM_{10} (2,025) were 20 times, 103 times and 29 times the approved ranges. Relative humidity and air temperature levels exceeded recommended levels in 27 and 32 classrooms, respectively. Dew point and wet bulb temperature ranged from 21.9°C to 31.6°C and 24.0°C to 26.3°C, respectively. The minimum $PM_{0.3}$ level detected in a classroom showed a positive correlation with the proportion of severe asthmatics in a classroom.

Conclusions: Indoor air quality in most classrooms was suboptimal and was significantly associated with severe asthma but not allergic rhinitis or current wheezing.
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(Keywords: Indoor air pollution, Particulate matter, Respiratory health, Asthma, Allergic rhinitis)

Introduction

Air pollution, broadly classified as ambient and indoor air pollution, is associated with 1 in 6 global deaths worldwide[1]. Particulate matter (PM), which are microscopic or macroscopic solid and liquid droplets suspended in the atmosphere, are critical indoor air pollutants. PM size determines adverse health effects because depth of penetration along the tracheobronchial tree depends on PM size[2]. The size of atmospheric particles is defined considering them to be spherical, and the diameter of the idealised sphere (aerodynamic diameter) is regarded as particle size. Depending on aerodynamic diameter, atmospheric particles are classified into three categories: coarse particles (diameter 2.5-10μm), fine particles (diameter 0.1-2.5μm), and ultrafine particles (diameter <0.1μm). Hairs in nostrils and nasal mucosa trap and remove coarse particles (PM_{10}). Fine ($PM_{2.5}$) and ultra-fine particles ($PM_{0.1}$) are inhaled easily.

High PM_{10} concentrations are associated with cough, decreased lung function, and reduced ventilatory capacity, whereas high $PM_{2.5}$ concentrations are associated with exercise-induced asthma and airway inflammation[3]. Detrimental health effects of $PM_{2.5}$ air pollution cause 0.8 million premature deaths, 6.4 million years of life lost and 65% of disease burden in Asian countries[4]. Both $PM_{2.5}$ and PM_{10} are associated with long-term effects on asthma prevalence, morbidity, and hospitalisations[5]. Ultrafine ($PM_{0.1}$) and fine particles ($PM_{2.5}$) can deposit deep in alveolar tissues, induce inflammation and even translocate into blood[6]. $PM_{0.1}$ particles induce comparatively more pronounced inflammatory reactions and are retained longer in the lung[7]. Fine and ultrafine particles are implicated in the pathogenesis of airway diseases, including asthma[8] and increased respiratory mortality[9].

The indoor air quality of schools has attracted significant public attention in recent years[10]. Children and adolescents are more susceptible to airborne pollutants than adults because their developing lungs breathe in more air relative to their body size, and children are less able to communicate concerns regarding air pollution. Current evidence suggests that indoor PM exposure is associated with decreased lung function in children, which is a hallmark of asthma- a chronic obstructive airway disease characterized by reversible airflow limitation, airway inflammation, and airway hyper-responsiveness[11]. The mean worldwide symptom prevalence of wheezing in the

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last 12 months has changed slightly from 13.2% to 13.7% in adolescents (mean increase of 0.06% per year) of age 13-14 years and from 11.1% to 11.6% in children (mean increase of 0.13% per year) of age 6-7 years[12]. A rise in asthma symptoms in various regions has been revealed by the International Study of Asthma and Allergies in Childhood (ISAAC) globally, including Asia[12]. According to ISAAC, globally, the prevalence for current asthma in the 13–14-year age group was 14.1%[13]. A prevalence of asthma ranging between 29% and 32% has been identified in Southeast Asian countries[14]. Recent studies have shown that asthma is a significant public health concern in children of the Anuradhapura district and Sri Lanka from preschoolers to adolescents with prevalence of 7.2% (95%CI 5.7% to 8.9%)[15] and 15.3% (95%CI 13.1% to 17.6%)[16] respectively. Similarly, allergic rhinitis is a common medical condition affecting children of the region with a prevalence of 11.6% (95% CI 9.7–13.5%) from preschool age. Studies conducted in Sri Lanka to assess the effect of air pollution on asthma have focused mainly on the effect of dusty environments on asthma[17]. However, studies on how indoor PM air pollution in schools where adolescents spend most of their time affects asthma and allergic rhinitis in adolescents of Sri Lanka are lacking. Therefore, although air pollution is considered an emerging public health-related problem in developing countries, most countries, including Sri Lanka, do not have adequate data to sufficiently explore the effects of air pollution to properly plan and implement mitigation strategies[18].

Objectives

To assess indoor PM levels in classrooms of government secondary schools of Anuradhapura, Sri Lanka and their effect on asthma and allergic rhinitis.

Method

A descriptive cross-sectional study was conducted in government secondary schools in January 2023 to assess indoor PM levels in classrooms and their association with asthma and allergic rhinitis symptoms. Six of nine government secondary schools in the Anuradhapura municipal council area were selected using simple random sampling. All grade eight classes (n=32) of the six selected schools were included. Initially, classroom conditions, including roofing, flooring, fans, and ventilation area, were assessed. Recommended adequate ventilation area was considered as 5-9 square metres[19]. Temperature, humidity, dew point, wet-bulb temperature and indoor PM levels were measured using a video particle counter (VPC300, EXTECH™). PM levels with aerodynamic diameters 0.3µm, 0.5µm, 1.0µm, 2.5µm, 5.0µm and 10µm were measured. Data collection was conducted between 7.30am and 1.30pm in classrooms during school days when students were engaged in routine teaching-learning activities. VPC300® video particle counter was placed in the middle of the classroom. A single measurement was a 60-second cycle. Fifteen such cycles were taken during each recording, as recommended by the manufacturer. Three separate recordings were taken on different days, covering morning and afternoon.

The second component of the study was the assessment of the prevalence of asthma and allergic rhinitis. The minimum sample size of 932 participants was calculated with a precision of 2%, a dropout rate of 10% and a prevalence of 10.7% for asthma in this age group[16]. All students in the 32 classes of the six randomly selected government secondary schools were included in the study. Adolescents with learning disabilities or poor vision or hearing affecting comprehension of the explanation of the study and/or comprehension and answering the self-administered questionnaire were excluded from the study. Participant information sheets, consent forms, and assent forms were provided in native languages (Sinhala and Tamil) to parent(s) or guardian(s) and participants. Validated translations of the ISAAC questionnaire in native languages for children aged 13-14 years were used to assess the prevalence of current wheezing, severe asthma, and allergic rhinitis[20]. Standard definitions recommended by the ISAAC steering committee were used. *Allergic rhinitis* was having sneezing, runny nose, or blocked nose without cold or influenza in the past 12 months; *current wheeze* was having wheezing or whistling in chest in the past 12 months; and *severe asthma* was current wheezers with ≥ 4 wheezing episodes or wheeze affecting speech or ≥1 night per week sleep disturbance.

Data analysis

For outlier detection, the distribution of the PM levels was assessed graphically and quantitatively. No outliers were detected. We assessed the mean, standard deviation, minimum and maximum of $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$, and PM_{10} levels in all 32 classrooms and compared them with the recommended indoor PM ranges. Safety cut-off values for PM recommended by the manufacturer were used (Table 1)[21]. Recommended temperature and humidity ranges perceived as "comfortable" were 22.8-26.1°C and 30- 65%, respectively[22,23]. We used the chi–square test to determine the association of the minimum, maximum, and mean PM levels with the proportion of students having symptoms of asthma and allergic rhinitis, with a significance at a p-value less than 0.05.

Table 1: ***Recommended indoor particulate matter levels***

Channel (µm)	Good	Caution	Hazard
0.3	0-100,000	100,001-250,000	250,001-500,000
0.5	0-35,200	35,201-87,500	87,501-175,000
1.0	0-8,320	8,321-20,800	20,801-41,600
2.5	0-545	546-1,362	1,363-2,724
5.0	0-193	194-483	484-966
10	0-68	69-170	171-340

Ethical considerations: Ethical approval was obtained from the Ethics Review Committee of Faculty of Medicine and Allied Sciences, Rajarata University of Sri Lanka (ERC/2022/43) and administrative approval from the provincial and zonal directors of education and the principals of the respective schools. Informed written consent was obtained from parent(s) and/or guardian(s) and assent from the adolescents.

Results

The conditions of the 32 classrooms of the 6 government schools selected for study are presented in Table 2. The common roofing and flooring materials were clay roof tiles (53.1%) and cement (56.3%). Ventilation area was adequate in all classrooms. Although the maximum acceptable temperature was exceeded in all 32 classrooms, ceiling fans were found in only 12 (37.5%) classrooms (Figure 1). The maximum acceptable relative humidity level was exceeded in 27 (84.4%) classrooms. Dewpoint ranged from 21.9-31.6°C.

Table 2: ***Condition of classrooms of the government secondary schools from Anuradhapura municipal council area (n=32)***

School	Roof	Floor	Ceiling fan	Wall fan	Mean door area (m^2)	Mean window area (m^2)	Type of board	Mean temperature (°C)	Mean relative humidity (°C)	Mean dew point (°C)
A	Clay roof tiles	Red cement	0	0	0.408	1.185	Blackboard	29.0	70.8	22.6
B	Concrete	Red cement	5	6	0.324	1.713	Blackboard	28.5	74.9	23.8
C	Clay roof tiles	Cement	2	0	0.291	2.638	Blackboard	30.0	67.5	2.4
D	Clay roof tiles	Cement	0	4	0.324	2.201	Blackboard	29.2	78.5	24.8
E	Clay roof tiles	Red cement	0	0	0.321	3.370	Blackboard	28.5	69.6	21.9
F	Concrete	Cement	14	0	0.444	1.981	Greenboard	29.6	73.8	31.6

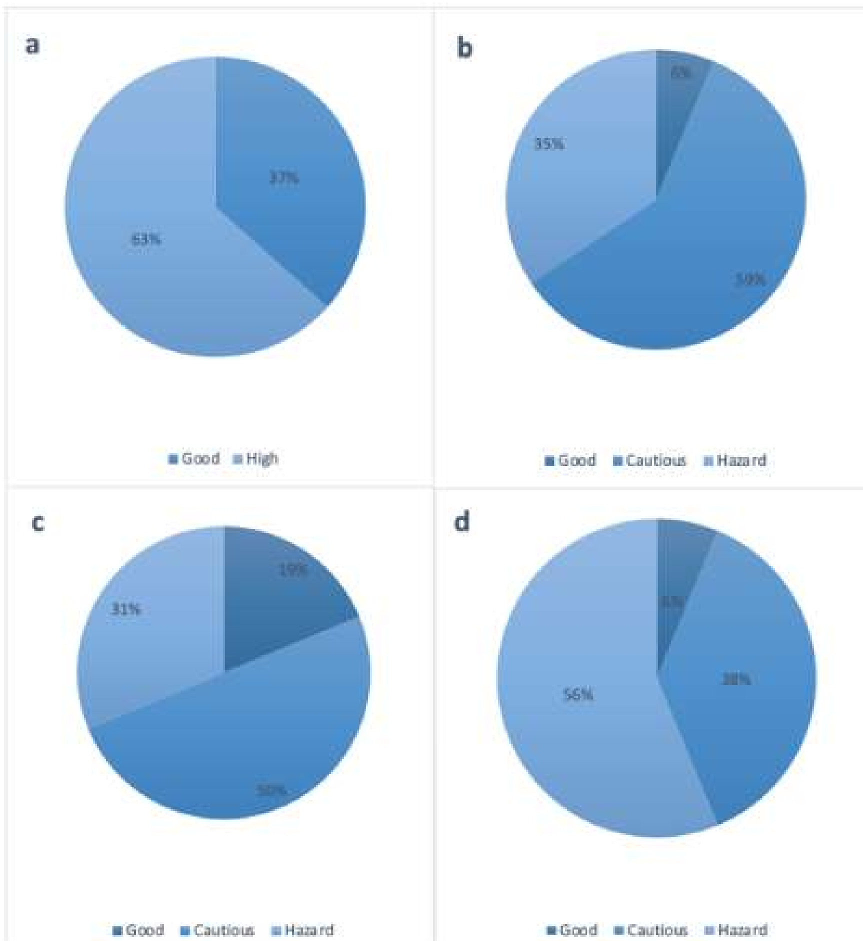

Figure 1: ***(a) Percentage of classrooms in the recommended levels of humidity levels. Percentage of classes in good, cautious and hazardous levels of PM for (b) $PM_{0.3}$ (c) $PM_{1.0}$ and (d) PM_{10}***

Mean levels of $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$, and PM_{10} exceeded the recommended level in 30 (93.8%), 28 (87.5%), 26 (81.3%), 32 (100%), 30 (93.8%) and 30 (93.8%) classrooms, respectively (Table 3). Highest mean counts of $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$ and PM_{10} among the 32 classrooms were 848,362±163,795, 533,648±138,542, 110,297±34,240, 15,634±16,817, 2394±2,284 and 974±211, respectively. The highest mean fine PM level was more than 28 times the approved range. Maximum counts of $PM_{1.0}$ (176,048), $PM_{2.5}$ (56,237), and PM_{10} (2,025) were 20 times, 103 times and 29 times the approved ranges (0-8320, 0-545 and 0–68). Individual minimum recordings of $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$ and PM_{10} were 70,173, 19,035, 3,832, 664, 87 and 31, respectively. The lower limits of the caution and hazardous levels for minimum $PM_{2.5}$ were exceeded in 32 and 30 classrooms, respectively (Table 4).

Table 3: ***PM measurements of government secondary schools from Anuradhapura municipal council area (n=32)***

School	Particulate matter size (μm)	Particulate matter level			
		Mean	Highest	Lowest	Standard deviation
A	0.3	248,154	1,528,212	75,259	220,346
	0.5	84,046	1,027,885	21,930	118,925
	01.0	19,660	414,829	4,533	39,668
	02.5	4,609	157,049	740	14,134
	05.0	717	15,791	79	2,016
	10.0	265	4,763	23	646
B	0.3	147,727	667,740	35,352	108,498
	0.5	48,069	64,408	10,892	49,284
	01.0	10,559	44,695	2,265	7,864
	02.5	2,350	11,853	455	1,997
	05.0	445	2,723	48	460
	10.0	184	1,098	21	195
C	0.3	129,688	309,684	52,379	52,647
	0.5	42,232	142,742	18,448	18,896
	01.0	10,851	47,635	3,989	6,409
	02.5	2,782	14,839	650	2,192
	05.0	595	3,745	29	599
	10.0	272	1,813	26	291
D	0.3	256,388	2,312,448	61,053	300,755
	0.5	91,307	1,441,899	19,352	161,790
	01.0	17,967	291,911	4,328	32,040
	02.5	2,789	38,524	650	4,155
	05.0	357	3,479	65	426
	10.0	137	965	19	147
E	0.3	91,621	212,521	42,971	33,342
	0.5	25,867	66,020	12,294	10,268
	01.0	5,297	12,169	2,465	1,882
	02.5	966	2,031	461	341
	05.0	153	470	63	79
	10.0	63	225	19	38
F	0.3	495,659	3,230,671	43,934	651,632
	0.5	236,356	2,279,762	15,530	392,689
	01.0	48,794	487,702	3,268	77,001
	02.5	7,632	65,225	626	10,084
	05.0	1,014	6,047	83	1,200
	10.0	382	2,310	39	464

Table 4: ***Particulate matter levels in classrooms by days and classrooms***

Particulate matter size (μm)	By number of days *(n=96)*			By classroom *(n=32)*		
	Good n (%)	Cautious n (%)	Hazard n (%)	Good n (%)	Cautious n (%)	Hazard n (%)
0.3	29 (30.2)	45 (46.9)	22 (22.9)	02 (06.3)	19 (59.4)	11 (34.4)
0.5	32 (33.3)	44 (45.8)	20 (20.8)	4 (12.5)	17 (53.1)	11 (34.4)
1	33 (34.4)	44 (45.8)	19 (19.8)	6 (18.8)	16 (50.0)	10 (31.3)
2.5	01 (01.0)	19 (19.8)	76 (79.2)	0 (0)	02 (06.3)	30 (93.8)
5	22 (22.9)	42 (43.8)	32 (33.3)	02 (06.3)	16 (50.0)	14 (43.8)
10	23 (23.9)	32 (33.3)	41 (42.7)	02 (06.3)	12 (37.5)	18 (56.3)

The overall prevalence of current wheezing, severe asthma and allergic rhinitis in the study population was 23.7% (n=244, 95% CI 21.1–26.4), 157 (15.3%; 95% CI 13.1–17.6) and 25.9% (n=266, 95%CI 23.2-28.6), respectively (Table 5). The minimum $PM_{0.3}$ level detected in a classroom showed a positive correlation with the proportion of students in the classroom having severe asthma (*p*=0.01, Spearman correlation=0.46). The correlations between $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$, PM_{10} with prevalence of current wheezing and allergic rhinitis were not statistically significant. Detailed information on the epidemiology of asthma is published elsewhere[18].

Table 5: ***Prevalence of current wheeze, severe asthma, and allergic rhinitis in secondary government schools in the municipal council area, Anuradhapura, Sri Lanka (n=1029)***

School	Current wheeze n (%)	Severe asthma n (%)	Allergic rhinitis n (%)
A	43 (17.6)	22 (19.8)	53 (19.9)
B	52 (21.3)	16 (14.4)	55 (20.6_
C	38 (15.5)	21 (18.9)	54 (20.3)
D	53 (21.7)	28 (25.2)	52 (19.5)
E	0 (0)	0 (0)	04 (01.5)
F	58 (23.7)	24 (21.6)	48 (18.0)

Discussion

This is the first descriptive cross-sectional study conducted regarding indoor PM levels in classrooms of schools in the dry zone of Sri Lanka. It revealed that all the measured indoor PM concentrations from $PM_{0.3}$ to PM_{10} in most classrooms of government schools located in the Anuradhapura municipal council area exceed recommended levels. The maximum PM counts recorded were at least 20 times greater than recommended levels for all PM levels. The level of smallest sized particulate matter ($PM_{0.3}$) measured in this study correlated positively with the proportion of children with severe asthma in a classroom.

World Health Organization global air quality guidelines state that the safe levels of $PM_{2.5}$ and PM_{10} within 24 hours are 15µg/cu mm and 45µg/cu mm, respectively[24]. In Sri Lanka, safe levels of $PM_{2.5}$ and PM_{10} within 24 hours are set at a higher level of 50µg/cu mm and 100µg/cu mm, respectively[20]. The current study shows that indoor PM levels of most school classrooms of the selected schools in the Anuradhapura municipal council area exceed the recommendations. A study in Kandy, Sri Lanka, reported that PM_{10} levels in schools outside city limits were lower (3-hour average, 84µg/cu mm) compared to schools within city limits (3-hour average, 121µg/ cu mm)[18] However, direct comparisons with current study results cannot be made due to the different units used in the studies.

Exposure to high $PM_{2.5}$ concentrations is associated with reduced lung function in children[25] and exposure to high ultrafine particles was associated with worsening asthma in children[26]. Similarly, the smallest sized particulate matter ($PM_{0.3}$) levels assessed in the current study positively correlated with the proportion of severe asthmatics in a classroom while larger particulate matter was not associated with the proportion of adolescents with current wheezing or allergic rhinitis. This highlights the necessity of future studies assessing the ultrafine particulate matter levels ($PM_{0.1}$) in assessing the indoor air quality. Furthermore, due to the multifaceted nature of asthma and allergic rhinitis with genetic, immunological, environmental, hygienic and exposure to risk factors playing critical roles in developing asthma or allergic rhinitis, the role and the contribution of PM in the pathogenesis requires further extensive study. However, the current study did not assess acute exacerbations and daily variation of symptoms based on the dynamic changes in the levels of PM, which is an interesting avenue for a future study to explore.

In naturally ventilated classrooms, the activities of occupants inside classrooms contribute more to indoor levels of PM_{10}, whereas $PM_{2.5}$ and $PM_{1.0}$ were primarily influenced by outdoor concentrations[27]. Major sources of PM in European, American, and Asian schools were indoor, outdoor, and both indoor and outdoor sources, respectively[28]. Indoor PM_{10} during school hours originate mainly from students re-suspending dust from interior surfaces and fabric[29]. $PM_{2.5}$ measurements in classrooms originated indoors from frequent resuspension of soil particles, organic (skin flakes, clothes, fibres) and calcium-rich particles (chalk and building deterioration) and outdoor sources (vehicle emissions and road dust)[30]. Although the causes of indoor PM are not assessed in the current study and require further exploration, these factors may explain the high levels of indoor PM in these classrooms located in the Anuradhapura municipal council area.

Higher air temperatures and higher dew-point temperatures, as found in the classrooms of these schools located in the municipal council area of Anuradhapura, which is in the dry zone of Sri Lanka, contribute to higher indoor PM_{10} count mainly through the voluntary opening of windows, which is also a common practice observed in the current study[31]. Higher air temperatures also induce the formation of secondary fine particles, which may have contributed to the high PM levels detected in this study[32]. Furthermore, temperature and humidity have a strong impact on the perception of indoor air quality, mainly through the respiratory cooling effect. When the respiratory cooling effect decreases to a certain level, air will be perceived as very poor, irrespective of its pollutant level[33]. The effect of relative humidity on indoor $PM_{2.5}$ concentrations also depends on the airtightness of building[34]. When airtightness – how well the room is protected against air leaks - is low, as apparent in the classrooms in this study, the high relative humidity levels do not lower PM concentrations because the infiltration speed of outdoor PM is increased due to indoor and outdoor air exchange.

This study had strengths and limitations. It assessed the PM levels in 32 classrooms among six of the nine schools located in the Anuradhapura municipal council area, providing an accurate representation of PM levels in the classrooms of this area. These readings were obtained during January and can provide an accurate understanding of PM levels in the dry season. However, it cannot be used to determine annual PM levels. This study did not assess the causes of indoor PM levels. Further studies are needed to determine the sources of indoor PM.

Conclusions

Indoor PM concentrations in most classrooms of government schools in the Anuradhapura municipal council area exceeded recommended levels. Maximum PM counts were at least 20 times greater than recommended levels. The minimum $PM_{0.3}$ level positively correlated with the proportion of students in a classroom having severe asthma but not allergic rhinitis or current wheezing.

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