

School Indoor Air Pollution Sources and Their Association with Respiratory Symptoms among Secondary School Students Aged 10 to 17 Years in Buea, Cameroon: A Cross-Sectional Study

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Abstract

Background: Indoor air quality in schools is a public health concern that has received limited attention in sub-Saharan Africa. Children spend a substantial proportion of their time in classrooms and are physiologically more vulnerable to airborne pollutants than adults. No studies had previously characterized classroom air quality or its respiratory health effects in secondary schools in Cameroon. **Objectives:** This study assessed sources of indoor air pollutants, including fine particulate matter (PM_{2.5}), carbon monoxide (CO), humidity and temperature, and determined their association with respiratory symptoms among students aged 10 to 17 years in secondary schools in Buea, Cameroon. **Methods:** A school-based cross-sectional study was conducted across ten secondary schools. A total of 1674 students were enrolled through consecutive and stratified random sampling. Sources of indoor air pollution such as PM_{2.5}, CO, temperature, and humidity were assessed using a validated WHO checklist comprising exposure indicators. CO levels were continuously monitored in six schools using Lascar EL-USB-CO data loggers. Respiratory symptoms were measured using the validated AstraZeneca Respiratory Symptom Ques-



tionnaire. Logistic regression was used to identify independent risk factors of respiratory symptoms. **Results:** All ten schools demonstrated high to very high PM2.5 checklist exposure (78.6% very high risk; 21.4% high risk), primarily driven by universal use of chalk and blackboards, dust accumulation, and absence of air filtration. Out of the 1674 participants, 46.8% (784) had a moderate risk exposure level to Humidity and temperature, 27.6% (462) had low risk, 17.4% (291) had High Risk, and 8.2% (137) had very high risk. One school recorded a mean CO level of 20.50 ppm, exceeding the WHO/EPA acceptable ceiling of 5 ppm. A total of 27.0% of students reported respiratory symptoms; of these, 73.0% were mild, 20.2% moderate, 5.8% severe, and 1.0% very severe. In multivariate logistic regression, significant independent predictors of respiratory symptoms included a prior diagnosis of respiratory disease (aOR 3.24, 95% CI 1.40 - 7.53; $p = 0.006$), presence of allergies (aOR 1.66, 95% CI 1.25 - 2.21; $p < 0.001$), and male sex (aOR 1.45, 95% CI 1.12 - 1.90; $p = 0.006$). PM2.5 and CO exposure risk levels were not significantly associated with respiratory symptoms in adjusted analyses. **Conclusions:** From this study, it was realized that secondary school students assessed by checklist exposure indicators to sources of indoor air pollution are exposed to PM2.5, temperature, and humidity ranging from moderate to very high-risk levels. Abnormal CO measurement was captured in 1 of the schools. Respiratory symptoms were associated with the level of exposure to temperature and humidity. Policy action to improve classroom air quality, replace chalk-based teaching tools, and systematically monitor indoor pollutants in Cameroonian schools is warranted.

Keywords

Indoor Air Quality, Particulate Matter, Carbon Monoxide,
Respiratory Symptoms, Secondary Schools, Cameroon, Adolescents

1. Introduction

Access to good air quality is fundamental to healthy living and cognitive development [1]. The World Health Organization (WHO) estimates that 91% of the world's population resides in areas where ambient air pollution exceeds guideline limits [2], and air pollution has been identified as a risk factor for cancer, diabetes mellitus, chronic respiratory diseases, stroke, and neurological conditions [3]. In 2010, air pollution ranked ninth among global risk factors contributing to the burden of disease [4].

Schools represent a particularly important indoor microenvironment. Students spend approximately 12% of their time in classrooms [5], within spaces that are substantially more densely occupied than other workplaces, with occupancy densities approximately four times that of office buildings [6]. Good indoor air quality (IAQ) in classrooms is therefore essential because it directly influences students' health, performance, alertness, concentration, and comfort [7]. Children are disproportionately vulnerable to airborne pollutants: their lungs remain in active development, they breathe greater volumes of air relative to their body mass, they

exhibit higher levels of physical activity, and they have a limited capacity to self-report environmental concerns [8] [9].

In Cameroon, air pollution is the fifth leading risk factor for premature mortality, accounting for an estimated 13,000 deaths annually, of which 6720 are attributed specifically to indoor air pollution [10]. The WHO estimates that solid fuel combustion for cooking and space heating constitutes the largest contributor to ambient air pollution in Cameroon, with 90% of rural households dependent on solid fuels [11] [12]. Despite this epidemiological context, no study had previously characterized indoor air quality in secondary school classrooms in Cameroon, nor examined its association with respiratory health outcomes in students.

This study was conducted to address that evidence gap. The primary objective was to identify sources of indoor air pollutants, including fine particulate matter (PM_{2.5}), carbon monoxide (CO), and humidity and temperature, and to determine their association with respiratory symptoms among secondary school students aged 10 to 17 years in Buea, South West Region, Cameroon. This study will provide evidence on indoor air pollution sources and their potential impact on students' respiratory health in the selected schools, contributing to a better understanding of school indoor air quality in Cameroon.

2. Methods

2.1. Study Design and Setting

A school-based cross-sectional study was conducted between September 2024 to December 2025 in the Buea subdivision, Fako Division, South West Region of Cameroon. Ten secondary schools comprising both private and state-owned institutions were selected by consecutive sampling, prioritizing schools that were accessible and located close to main roads, a security precaution necessitated by the ongoing sociopolitical crisis in the South West Region. The participating schools are identified in this manuscript by anonymized letter codes (Schools A to J).

2.2. Study Population and Sampling

The study was conducted among students enrolled in selected secondary schools in Cameroon. In the Cameroonian education system, secondary education comprises the first cycle (Forms 1 - 5) and second cycle (Lower Sixth and Upper Sixth). Students may vary in age within each form due to differences in school entry age, repetition, or progression. The minimum sample size was calculated using the Yaro Yamane (2007) formula, $n = N/[1 + N(e)^2]$, assuming a population of $N = 250$ students per school and a margin of error of $e = 0.05$. This yielded a minimum of 154 students per school, and a total minimum sample of 1540 students across ten schools. Students were selected within schools through stratified random sampling based on proportional class representation. The final enrolled sample was 1674 students.

Students were eligible to participate if they were aged 10 - 17 years, enrolled in a participating school, present on the day of data collection, and had the required

parental/guardian consent. Parental/guardian consent forms were distributed in advance of data collection and returned as signed forms before students participated. Students also provided assent before participation. Students were excluded if they were younger than 10 years or older than 17 years, absent on the day of data collection, did not have the required parental/guardian consent, declined participation, or were enrolled in schools located in security-restricted zones.

2.3. Data Collection

2.3.1. Sources of Indoor Air Pollution

Sources of indoor air pollution were assessed using the validated WHO indoor environment health exposure indicator checklist [13]. The checklist comprised 22 closed-ended items (Yes/No): eight (8) items assessed PM_{2.5} exposure indicators, ten (10) items assessed humidity and temperature exposure indicators, and four (4) items assessed CO exposure indicators. For each affirmative response, one point was assigned. Final domain scores were scaled to 20: PM_{2.5} items were multiplied by 2.5, humidity and temperature items by 2, and CO items by 5. Total scores were categorized as follows: 0 - 5 (low risk), 6 - 10 (moderate risk), 11 - 15 (high risk), and 16 - 20 (very high risk).

2.3.2. Measurement of Carbon Monoxide (CO) Concentrations

Carbon monoxide (CO) concentrations were continuously monitored using Lascar EL-USB-CO data loggers (Lascar Electronics, UK), which recorded CO levels in parts per million (ppm). Devices were positioned one metre from walls and 1.2 metres above ground level, and monitored continuously for 24 hours per school. The device recorded CO at 10s intervals continuously for 24 hours monitoring period, yielding approximately 8640 observations per school. Where retrieval of the logger was delayed beyond the intended 24-hour period, observations beyond the predefined monitoring period were excluded. A 24-hour mean CO concentration was calculated for each school and assigned to all participating students within that school since CO exposure was measured at school level.

CO data were collected in six of the ten schools (Schools A to F); the four remaining schools (G to J) declined participation despite thorough explanation of the non-invasive nature of the monitoring equipment. CO measurements were evaluated against the WHO 2021 global air quality guideline average of 4mg/m³ (approximately 3.5 ppm) for 24 hours, defined as normal, and readings exceeding this threshold were classified as abnormal.

2.3.3. Respiratory Symptom Assessment

Respiratory symptoms were assessed using the validated AstraZeneca Respiratory Symptom Questionnaire (RSQ) [14], a four-item instrument that measures the frequency of shortness of breath, rescue inhaler use, activity limitation, and nocturnal awakening due to respiratory symptoms. Each item was rated on a five-point Likert scale, and the composite score was categorized as: mild (1 - 5), moderate (6 - 10), severe (11 - 15), or very severe (16 - 20). The questionnaire was self-administered by students in the classroom setting.

2.4. Quality Control

A pilot study was conducted prior to full data collection to assess instrument validity in the local school context. Research assistants received structured training to standardize data collection procedures. Data were captured using Open Data Kit (ODK) installed on mobile devices and stored securely within Kobo Toolbox using password protection.

2.5. Statistical Analysis

Data were analyzed using IBM SPSS Statistics, version 25.0 (IBM Corp., Armonk, NY, USA). Sociodemographic, medical, and environmental characteristics were described using frequencies and percentages. CO measurement data were summarized using descriptive statistics (range, minimum, maximum, mean, standard deviation). Bivariate associations between independent variables and respiratory symptom prevalence were assessed using chi-square tests, with significance set at $p < 0.05$. All variables with a p -value of less than 0.2 in bivariate analysis were entered into a multivariate binary logistic regression model to identify independent predictors of respiratory symptom presence. Results are reported as adjusted odds ratios (aOR) with 95% confidence intervals (CI). Model fit was evaluated using the Nagelkerke R-squared statistic.

Respiratory Symptoms were treated as binary: symptomatic and asymptomatic. Symptomatic symptoms included any symptom recorded, while asymptomatic symptoms were recorded as those with “0” or no symptoms.

2.6. Ethical Considerations

Ethical clearance was obtained from the Institutional Review Board of the Faculty of Health Sciences, University of Buea, Cameroon (IRB approval number: [to be inserted]). Administrative authorizations were obtained from the Regional Delegations of Public Health, Secondary Education, and individual school administrations. Written informed consent was obtained from adult participants and from parents or legal guardians of minor participants; written assent was additionally obtained from minor participants themselves. Confidentiality was maintained throughout; participant data were anonymized and no information was shared with school administrations.

3. Results

3.1. Sociodemographic Characteristics of Study Participants

A total of 1674 students participated in the study. The majority were female ($n = 1101$; 65.8%) and aged 13 to 15 years ($n = 786$; 47.0%). Most students had spent two to four years in secondary school ($n = 913$; 54.5%), and the largest proportion was in Form 5 ($n = 638$; 38.1%). Most participants were in ground-floor classrooms ($n = 920$; 55.0%). The largest school contribution was from School C ($n = 389$; 23.2%). Full sociodemographic characteristics are presented in **Table 1**.

Table 1. Sociodemographic characteristics of study participants (n = 1674).

Variable	Category	Frequency (n)	Percentage (%)
Age	10 - 12 years	204	12.2
	13 - 15 years	786	47.0
	16 - 17 years	684	40.9
Gender	Female	1101	65.8
	Male	573	34.2
Years in secondary school	≤1 year	78	4.7
	2 - 4 years	913	54.5
	5 - 7 years	655	39.1
	8 - 10 years	28	1.7
Classroom level	Form 1	57	3.4
	Form 2	294	17.6
	Form 3	296	17.7
	Form 4	365	21.8
	Form 5	638	38.1
	Lower/Upper Sixth	24	1.5
Classroom building	Ground Floor	920	55.0
	First Floor	653	39.0
	Second Floor	101	6.0

3.2. Medical Characteristics

Among all participants, 142 (8.5%) reported a prior diagnosis of a respiratory disease, comprising asthma (n = 52; 3.1%), other unspecified conditions (n = 46; 2.7%), pneumonia (n = 25; 1.5%), and chronic obstructive pulmonary disease (COPD) (n = 19; 1.1%). A total of 101 participants (6.0%) reported current cigarette or tobacco smoking, and 321 (19.2%) reported having at least one allergy. Full medical characteristics are presented in **Table 2**.

Table 2. Medical characteristics of study participants (n = 1674).

Variable	Category	Frequency (n)	Percentage (%)
Diagnosed with respiratory disease	No	1532	91.5
	Yes	142	8.5
Type of respiratory disease	None	1532	91.5
Currently smokes	No	1570	93.8
	Yes	101	6.0
Smoking frequency	Never	1574	94.0
	Daily	46	2.7

Continued

	Thrice per week	22	1.3
	Twice per week	19	1.1
	More than 3 times per week	13	0.8
Has allergies	No	1352	80.8
	Yes	321	19.2

3.3. Respiratory Symptoms

Overall, 452 students (27.0%) reported the presence of respiratory symptoms, while 1, 222 (73.0%) reported none. Among symptomatic students, 73.0% had mild symptoms, 20.2% moderate, 5.8% severe, and 1.0% very severe. Shortness of breath was the most prevalent symptom; 23.7% of all participants reported experiencing it to varying degrees during the past four weeks. Activity limitation due to respiratory symptoms was reported by 20.7% and nocturnal awakening by 21.2%. Detailed symptom frequencies are presented in **Table 3**.

Table 3. Frequency of respiratory symptoms in the past four weeks (n = 1674).

Variable	Category	Frequency (n)	Percentage (%)
Shortness of breath during the day	Not at all	1278	76.3
	1 - 2 days/week	220	13.1
	3 - 6 days/week	55	3.3
	Once or twice every day	62	3.7
	Three or more times every day	59	3.5
Rescue inhaler use	Not at all	1490	89.0
	1 - 2 days/week	106	6.3
	3 - 6 days/week	23	1.4
	Once or twice every day	24	1.4
	Three or more times every day	31	1.9
Activity limitation due to symptoms	Not at all	1328	79.3
	1 - 2 days/week	188	11.2
	3 - 6 days/week	67	4.0
	Once or twice every day	60	3.6
	Three or more times every day	31	1.9
Nocturnal awakening due to symptoms	Not at all	1319	78.8
	1 - 2 nights/week	134	8.0
	3 - 6 nights/week	114	6.8
	Once or twice every night	60	3.6
	Three or more times every night	47	2.8

Overall Prevalence of Respiratory Symptoms

Out of the 1674 respondents, 1222 (73.0%) reported experiencing none of the respiratory symptoms, while 452 (27%) reported experiencing respiratory symptoms (**Figure 1**).

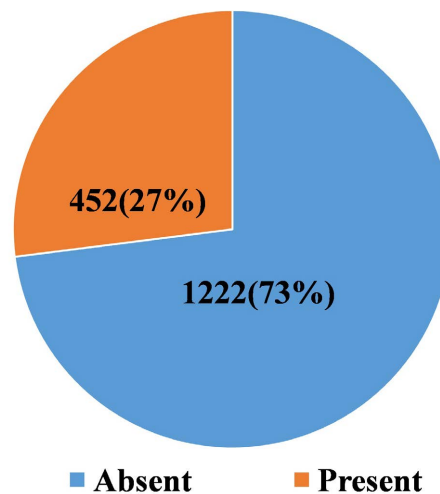


Figure 1. Overall prevalence of respiratory symptoms.

3.4. Exposure Sources of Indoor Air Pollution

3.4.1. PM2.5 Checklist-Based Exposures

All 1674 participants (100%) attended schools exposed to chalk, blackboards, benches, books, and pens were in universal use. Visible dust on surfaces was present in schools attended by 1469 (87.7%) participants. Well-furnished walls were reported in schools of 1520 (90.8%) participants, and cemented floors in 1420 (84.8%). Classroom crowding was reported by 780 participants (46.5%). No school used air conditioning or mechanical air filtration. As a result, all participants faced high or very high PM2.5 source exposure risk: 1315 (78.6%) at very high risk and 359 (21.4%) at high risk (**Table 4**).

Table 4. PM2.5 Checklist-based exposures.

Variable	Frequency (n= 1674)		Percentage (% Yes)
	Yes	No	
PM2.5 Sources			
1. Chalk used in classrooms	1674	0	100.0%
2. Blackboards used in classrooms	1674	0	100.0%
3. Dust visible on surfaces	1469	105	87.7%
4. Students crowded in classrooms	780	894	46.5%
5. Benches used for seating	1674	0	100.0%
6. Books and pens used for writing	1674	0	100.0%
7. Walls well-furnished	1520	154	90.8%
8. Floor well-cemented	1420	254	84.8%

Overall checklist exposure level of students to PM2.5

Out of the 1674 participants, 1315 (78.6%) had very high risk level of exposure to PM2.5 and 359 (21.4%) for high risk level of exposure (**Figure 2**).

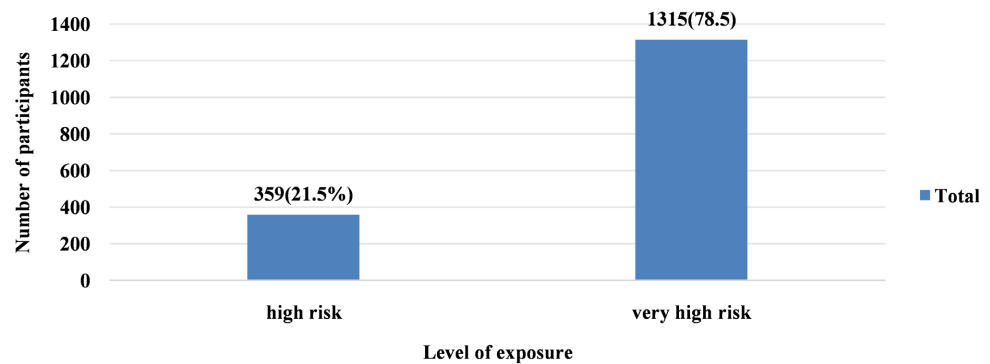


Figure 2. Checklist exposure level of students to PM2.5.

3.4.2. Humidity and Temperature Checklist-Based Exposures

Of all participants, 731 (43.7%) attended schools in hot and dry climate zones. Most schools were classified as well-ventilated (90.8%), and all schools opened windows regularly (100%). No school used air conditioning or mechanical heating (**Table 5**).

Table 5. Humidity and Temperature checklist-based exposures.

Variable	Frequency (n = 1674)		Percentage (% Yes)
	Yes	No	
Humidity and Temperature Sources			
1. School located in a hot and dry climate area	731	943	43.7%
2. Classrooms well-ventilated	1520	154	90.8%
3. Windows opened regularly	1674	0	100.0%
4. Air conditioning used in classrooms	0	1674	0.0%
5. Heating sources used in classrooms	0	1674	0.0%
6. Frequent unexplained complaints of feeling sick, headaches, stomach-aches	528	1146	31.5%
7. Decline in academic performance	722	952	43.1%
8. Avoiding school	291	1383	17.4%
9. Abusing alcohol or other substances	817	857	48.8%
10. Change in sleep-wake patterns	616	1058	36.7%

Overall checklist exposure of study participants to Humidity and temperature

Checklist-based exposure risk distribution for humidity and temperature was: moderate risk 46.8% (n = 784), low risk 27.6% (n = 462), high risk 17.4% (n = 291), and very high risk 8.2% (n = 137) (**Figure 3**).

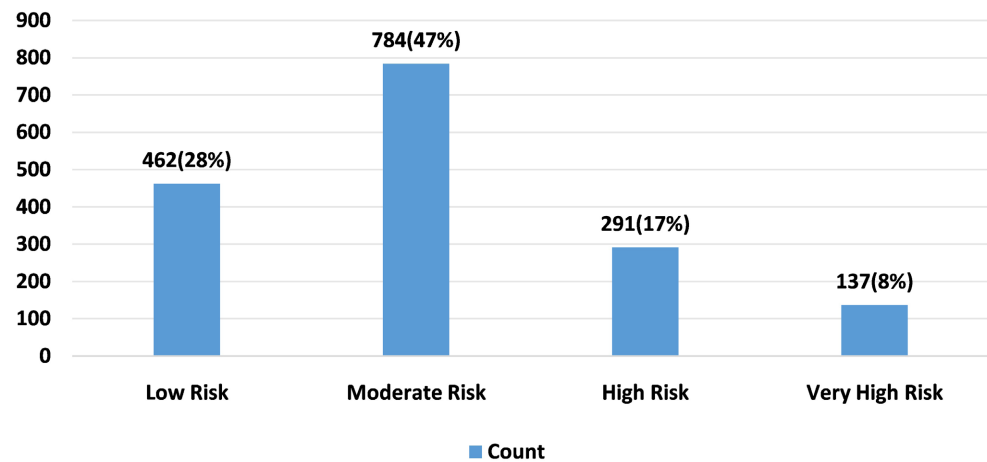


Figure 3. Overall checklist exposure of study participants to Humidity and temperature.

3.4.3. Carbon Monoxide Sources

Fuel-powered generators or equipment were present in schools attended by 1343 (80.2%) participants, cooking appliances in 1299 (77.5%), fireplaces or wood stoves in 1017 (60.0%), and vehicles idling near school premises in 675 (40.3%) (Table 6).

Table 6. Checklist CO sources.

Variable	Variable	Variable	Variable
Carbon Monoxide Sources			
1. Fuel-powered equipment or generators used in the school	1343	331	80.0%
2. Vehicles allowed to idle near the school	675	999	40.3%
3. Cooking appliances used in the school	1299	375	77.5%
4. Fireplaces or woodstoves used in the school	1017	657	60.0%

Overall checklist exposure of participants to carbon monoxide

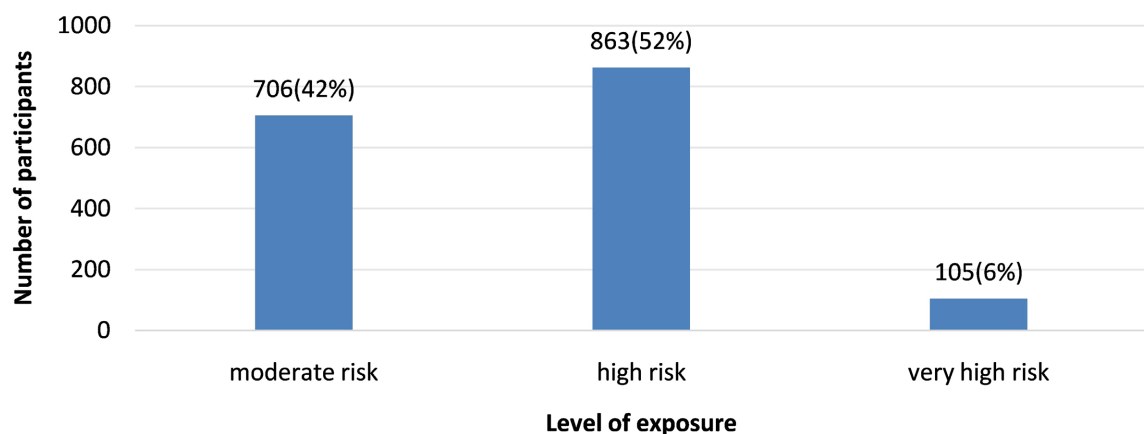


Figure 4. Overall exposure level of participants to carbon monoxide.

Out of 1674 participants, 51.6% (863) had a high-risk exposure level to carbon monoxide, 42.2% (706) had Moderate risk, and 6.3% (105) had a very high-risk level of exposure to carbon monoxide (**Figure 4**).

Descriptive statistics for CO concentrations measured continuously over 24 hours in six schools are presented in **Table 4**. Mean CO levels ranged from 0.01 ppm (School C) to 20.50 ppm (School D). School D recorded a 24-hour mean CO of 20.50ppm approximately 23.5mg/m³ exceeding the WHO 2021 24-hour air quality guideline of 4mg/m³ (**Table 7**).

Table 7. Descriptive statistics of CO concentrations measured over 24 hours in six monitored schools.

School	n	Range (ppm)	Min (ppm)	Max (ppm)	Mean $\pm$ SD (ppm)	WHO/EPA limit (ppm)	Classification
A	8646	30.0	0.0	30.0	0.02 $\pm$ 0.59	0.5 - 5	Normal
B	8646	322.5	0.0	322.5	2.82 $\pm$ 14.95	0.5 - 5	Normal
C	8646	10.0	0.0	10.0	0.01 $\pm$ 0.14	0.5 - 5	Normal
D	8646	229.5	0.0	229.5	20.50 $\pm$ 29.42	0.5 - 5	Abnormal*
E	8646	16.0	0.0	16.0	0.07 $\pm$ 0.57	0.5 - 5	Normal
F	8646	16.0	0.0	16.0	1.32 $\pm$ 2.02	0.5 - 5	Normal

Note: *Mean exceeds the WHO/EPA normal range of 0.5 - 5 ppm. SD = standard deviation.

3.5. Bivariate Associations with Respiratory Symptoms

3.5.1. Sociodemographic Factors

Chi-square analysis identified significant associations between respiratory symptoms and gender ($p = 0.022$), school attended ($p < 0.001$), classroom building level ($p = 0.023$), and educational form level ($p = 0.014$). Female students had a higher proportion of symptoms (28.8%) compared to male students (23.6%). School J had the highest symptom prevalence (51.0%). Age and years in secondary school were not significantly associated with symptom presence.

3.5.2. Medical Factors

A prior diagnosis of respiratory disease was strongly associated with symptom presence ($p < 0.001$): 64.8% of students with a prior diagnosis reported symptoms compared to 23.5% of those without. Allergy status ($p < 0.001$) and current smoking ($p < 0.001$) were also significantly associated with symptoms. Among current smokers, 52.5% reported symptoms compared to 25.3% of non-smokers.

3.5.3. Indoor Air Pollution Exposure

At the bivariate level, humidity and temperature checklist-based exposure risk level was significantly associated with respiratory symptoms ($p = 0.002$). PM_{2.5} exposure risk level ($p = 0.142$) and CO exposure risk category ($p = 0.073$) were not significantly associated with symptom presence. Full bivariate results are presented in **Tables 8-9**.

Table 8. Bivariate association of indoor air pollution exposure with respiratory symptoms (n = 1674).

Variable	Category	Symptomatic n (%)	Asymptomatic n (%)	p-value
PM2.5 Exposure	High Risk	273 (76.0%)	86 (24.0%)	0.142
	Very High Risk	949 (72.2%)	366 (27.8%)	
Humidity and Temperature	High Risk	220 (75.6%)	71 (24.4%)	0.002*
	Low Risk	308 (66.7%)	154 (33.3%)	
	Moderate Risk	597 (76.1%)	187 (23.9%)	
	Very High Risk	97 (70.8%)	40 (29.2%)	
Carbon Monoxide	High Risk	647 (75.0%)	216 (25.0%)	0.073
	Moderate Risk	495 (70.1%)	211 (29.9%)	
	Very High Risk	80 (76.2%)	25 (23.8%)	

Note: *p < 0.05. Statistically significant.

3.6. Multivariate Logistic Regression Analysis

The results of the multivariate logistic regression analysis are presented in **Table 7**. The final model explained 15.4% of the variance in respiratory symptom presence (Nagelkerke $R^2 = 0.154$). Three variables were independently and significantly associated with respiratory symptoms.

Students with a prior diagnosis of a respiratory disease had significantly higher odds of reporting symptoms compared to students without a diagnosis (aOR 3.24, 95% CI 1.40 - 7.53; p = 0.006). Students reporting allergies had 1.66 times higher odds of reporting symptoms than those without (aOR 1.66, 95% CI 1.25 - 2.21; p < 0.001). Male students had significantly higher odds of reporting respiratory symptoms than female students (aOR 1.45, 95% CI 1.12 - 1.90; p = 0.006).

Several schools showed significantly lower adjusted odds of symptom reporting compared to School A, including School H (aOR 0.29, 95% CI 0.14 - 0.61; p = 0.001), School J (aOR 0.19, 95% CI 0.06 - 0.59; p = 0.004), and Schools B, C, D, and F. Students in second-floor classrooms had lower odds of reporting symptoms, though this did not reach statistical significance (aOR 0.46, 95% CI 0.19 - 1.11; p = 0.084). Humidity and temperature exposure risk level, PM2.5 exposure risk level, smoking behaviour, classroom level, and years in school were not independently associated with symptoms.

Table 9. Multivariate logistic regression analysis: independent predictors of respiratory symptoms.

Variable	Category	aOR	95% CI	p-value
Gender	Female (ref)	1.00		
	Male	1.45	1.12 - 1.90	0.006
Classroom building	First Floor (ref)	1.00		
	Ground Floor	0.60	0.31 - 1.16	0.129
	Second Floor	0.46	0.19 - 1.11	0.084

Continued

	A (ref)	1.00		
	B	0.38	0.20 - 0.72	0.003
	C	0.45	0.25 - 0.81	0.008
	D	0.34	0.16 - 0.75	0.007
	E	0.74	0.27 - 1.97	0.541
School	F	0.47	0.25 - 0.87	0.015
	G	0.82	0.39 - 1.70	0.588
	H	0.29	0.14 - 0.61	0.001
	I	0.42	0.21 - 0.88	0.020
	J	0.19	0.06 - 0.59	0.004
Prior respiratory diagnosis	No (ref)	1.00		
	Yes	3.24	1.40 - 7.53	0.006
Allergies	No (ref)	1.00		
	Yes	1.66	1.25 - 2.21	<0.001

Note: aOR = adjusted odds ratio; CI = confidence interval; ref = reference category. Bold p-values indicate statistical significance ($p < 0.05$).

4. Discussion

This cross-sectional study provides the first systematic assessment of indoor air quality and its association with respiratory symptoms in secondary school students in Cameroon. Across ten schools enrolling 1674 students in Buea, we found that all students faced high or very high PM_{2.5} checklist-based exposure risk, one school recorded critically elevated CO concentrations, and 27% of students reported respiratory symptoms of varying severity. Individual-level susceptibility factors, including prior respiratory disease diagnosis, allergies, and male sex, were the strongest independent predictors of symptom presence.

4.1. Checklist-Based PM_{2.5} Exposure in Cameroonian Classrooms

The finding that all ten schools exhibited high or very high PM_{2.5} checklist-based exposure risk is consistent with emerging evidence on classroom air quality in low-income settings. A study similarly demonstrated that indoor PM_{2.5} concentrations in schools in comparable resource-limited contexts exceeded WHO guidelines [15]. The dominant sources identified in our study chalk and blackboards (100% of schools), visible dust accumulation (87.7%), and crowded classrooms (46.5%) are well-documented contributors to classroom particulate matter in settings where dust-generating teaching materials are universally used. This contrasts markedly with higher-income country contexts; another study in London reported that air purifiers reduced indoor particulate concentrations by up to 57% in schools where chalk had already been largely replaced by digital and whiteboard-based teaching materials [16]. The absence of any air conditioning or mechanical

ventilation across all participating schools further limits the dilution or removal of airborne particles.

4.2. Checklist-Based Temperature/Humidity Exposure

Regarding humidity and temperature sources, 4 (40.0%) schools were located in hot and dry climate areas. Also, 9 (90.0%) schools were well-ventilated, and all (100.0%) regularly opened their windows. However, none (0.0%) of the schools used air conditioning or heating sources. Out of the 1674 participants, 46.8% (784) had a moderate risk exposure level to Humidity and temperature, 27.6% (462) had low risk, 17.4% (291) had High Risk, and 8.2% (137) had a very high risk level of exposure to humidity and temperature. However, this was different from a study done in South Africa [17] reported high levels of classroom temperature. This could be due to the fact that the classrooms in our study were well ventilated.

4.3. Carbon Monoxide Hazard

The detection of a mean CO level of 20.50 ppm in one school (School D) is a finding of considerable public health significance. This value exceeds the WHO/EPA normal range ceiling of 5 ppm by a factor of four, and the recorded maximum concentration of 229.5 ppm at that location presents a risk of acute toxicity. In comparison, a study [18] reported mean CO levels of 0.8 ppm among primary school and college students in a comparable study context. The likely contributors to the elevated CO in School D include the combination of fuel-powered generators, cooking appliances, and the school's physical positioning relative to vehicle traffic. The inability to collect CO data from four schools due to administration refusal is itself a noteworthy finding: it suggests limited awareness of, or resistance to, environmental health surveillance in some school administrations, and underscores the need for regulatory frameworks that mandate air quality monitoring in educational institutions.

4.4. Respiratory Symptom Burden

The prevalence of respiratory symptoms in this study (27.0%) is consistent with the broader evidence base indicating that a significant minority of school-age children experience respiratory health impairment attributable to indoor air pollution exposure. The finding that nearly 7% of symptomatic students (representing approximately 1.9% of the total sample) experienced severe or very severe symptoms is clinically important, as these students may be experiencing meaningful educational disruption and unmet healthcare needs. Fsadni *et al.* (2018) reported similar patterns of respiratory health impact associated with school air quality in Mediterranean school children [19].

4.5. Risk Factors of Respiratory Symptoms

The finding that individual susceptibility factors prior to respiratory disease diagnosis (aOR 3.24), allergy status (aOR 1.66), and male sex (aOR 1.45) were the

strongest independent predictors of symptoms, while PM_{2.5} and CO exposure risk levels were not independently significant in adjusted analyses, warrants careful interpretation. This pattern does not diminish the importance of the exposure findings; rather, it reflects the complex relationship between aggregate environmental exposure and symptom expression in a population with heterogeneous susceptibility.

The observed association between male sex and higher odds of respiratory symptoms (aOR 1.45) is consistent with findings from [20], who reported higher asthma rates in males in a Vietnamese school-based study. This contrasts with findings from household-based studies in Cameroon, which have reported greater female vulnerability, likely reflecting the greater domestic exposure to cooking smoke among women and girls, an exposure pathway that is not present in the school setting examined in our study.

The strong school-level variation in symptom odds, with seven schools showing significantly protective associations relative to School A, suggests that unmeasured school-specific factors including physical infrastructure, proximity to traffic, school management practices, and possibly health-seeking behaviour among students play an important moderating role. School A's elevated symptom burden may relate to its proximity to a main road, although this hypothesis requires further investigation.

4.6. Strengths and Limitations

This study has several strengths. It is, to our knowledge, the first study to systematically characterize classroom air quality in Cameroonian secondary schools and to examine its association with respiratory symptoms in a large, representative sample. The use of continuous environmental monitoring (Lascar CO data loggers), validated instruments (WHO checklist and AstraZeneca RSQ), and robust multivariate analytic methods strengthens the credibility of the findings. The large sample size ($n = 1674$) provides adequate power to detect associations.

Important limitations must be acknowledged. Firstly, CO monitoring was not possible in four of ten schools due to lack of authorization attributed to fear of the unknown, which may have introduced selection bias in the environmental exposure analysis. Secondly, PM_{2.5} analyses were restricted to source checklist-based risk scoring rather than measured concentration data. Thirdly, the cross-sectional design precludes causal inference, and residual confounding by unmeasured factors cannot be excluded. Fourthly, the AstraZeneca RSQ was originally designed for adult asthma and COPD patients, and its applicability to adolescent school populations may not fully capture the spectrum of respiratory manifestations in this age group. Furthermore, school selection was limited and influenced by security conditions prevailing in the South West Region, potentially restricting the generalizability of findings to accessible urban and peri-urban schools. Lastly, students were clustered within the six schools and environmental exposures were measured at the school level. The primary logistic regression did not explicitly

model within-school correlation. Given the small number of schools, school-level effects could not be reliably estimated within the available analytical framework.

5. Conclusion

Secondary school students in Buea, Cameroon, have a high risk of checklist-based exposure to PM_{2.5} sources within their classrooms, driven by chalk-based teaching practices, dust accumulation, and the absence of air filtration. One school presented a CO concentration constituting an acute public health hazard. More than one-quarter of students reported respiratory symptoms, with individual susceptibility factors prior respiratory disease, allergies, and male sex being the strongest independent predictors. These findings have direct policy implications. Replacement of chalk and blackboard systems with dust-free alternatives, installation of passive or active ventilation in classrooms, and mandatory environmental monitoring in schools are all warranted interventions. Urgent investigation and remediation of the CO source at the affected school is essential. Furthermore, health screening programs targeting students with respiratory diagnoses and allergies should be considered as a priority response within school health services. This study demonstrates that school-based indoor air quality research is both feasible and informative in low-resource settings, and provides the evidence base needed to initiate national policy dialogue on classroom air quality standards in Cameroon. Future longitudinal or interventional studies employing direct pollutant concentration measurements across all schools and validated paediatric respiratory symptom instruments would substantially strengthen this evidence base.

Ethics Approval and Consent to Participate

Ethical clearance was obtained from the Institutional Review Board, Faculty of Health Sciences, University of Buea (2025/1915-03/UB/SG/IRB/FHS). Written informed consent was obtained from all adult participants and from parents or legal guardians of minor participants. Written assent was obtained from minor participants.

Availability of Data and Materials

The datasets used and analyzed during this study are available from the corresponding author on reasonable request.

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Author Contributions

LKK conceived and designed the study, led data collection, performed the formal

data analysis, and drafted the original manuscript. **KS** contributed to the study methodology. **SS** performed model validation. **AGL** and **BA** provided supervision throughout the study. **GJG** contributed to data curation. **KMZ** and **VTH** managed project administration. **ANW** and **CPK** contributed to software development. **NKC** contributed to data visualization and formal analysis. All authors reviewed, revised, and approved the final version of the manuscript.

Conflicts of Interest

The authors declare no competing interests.

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