

A Systematic Review on School Air Quality and Its Impact on Student's Health in Tropical Countries

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Abstract

Poor air quality in school areas has a negative impact on the student's health. Several studies in tropical countries have reported the risk exposure and environmental factors that were associated to the air quality in school areas. This paper presents a review of several case study research associated to air pollutants and environmental factors on the surrounding school environment and the health impact on students in tropical country. We selected and reviewed 18 research papers related to air quality in schools. The selection method was based on the inclusion and exclusion criteria. Throughout these studies, the most common source of air pollutants found in the classroom was particulate matter. Air quality in schools is affected by the distance between the school and the source of pollutants, ventilation, inhabitant, and season. Exposure to poor indoor air quality can increase health risk, respiratory problems, ocular problems, and students' absence from school.

Keywords: air pollutants, indoor air quality, school health, tropical

1. Introduction

Besides home, school is an important environment for children since they spend six to eight hours every day there. However, several researches focusing on the air quality at school suggested that poor air quality in the school environment could affect the students' health directly (e.g. respiratory problems) and indirectly (e.g. students absence from school) (Annesi-Maesano et al., 2013; Sasso et al., 2019). School children's age group is more vulnerable than adults to air pollution for several reasons, i.e., their higher respiration frequency, their higher physical activity, and their respiratory system is still developing (Annesi-Maesano et al., 2013).

The school air quality is related to the building condition, inhabitant, and surrounding environment. School buildings tends to have more inhabitants compared with office buildings, thus improper ventilation and building state could increase the risk of air pollution (Annesi-Maesano et al., 2013; Bo M et al., 2017; Zwoździak A et al., 2015). Because of its stable temperature, most of the school building in tropical country does not require heater and used natural ventilation instead. This allowed a higher air exchange rate and the outdoor air quality directly affecting the indoor air quality. Besides that, seasonal changes, temperature, and humidity variation may also affect the relationship between air pollution effects on health risk (Yap et al., 2019). In contrary with subtropical area, a tropical area has a wet and dry climate with a relatively stable temperature, which resulted in more stable annual air quality. This article aimed to study parameters and factors related to the school air quality and health impact on students in tropical countries.

2. Methods

We did a systematic article screening (Figure 1) on two online databases, i.e., Pubmed and Science Direct up to the second week of August 2019. We searched for research articles in English which were published during 2000 until 2019 by including keywords "air quality", "air pollution", "particulate matter", "nitrogen dioxide", "voc", "formaldehyde", "carbon dioxide", "carbon monoxide", "ozone", "hydrocarbon", and "school". We excluded the keywords "model" and "modeling" by using the advanced search option on those online databases. Next, we selected articles focused on tropical countries based on the information on the title and abstract. If this information were not available on the title and abstract, then the article was further excluded in the selection. We only studied

research articles from the last ten years which directly measured air quality in school with school children as its subject, therefore we also screened the methods and subject of the research.

In this article, we extracted data from the results of research articles without further analyzing study site, subject, pollutant agent, influencing factors, and health impact. Several articles that we found did not include and/or analyze those variables. Related data from locations other than the school were also not included in this article.

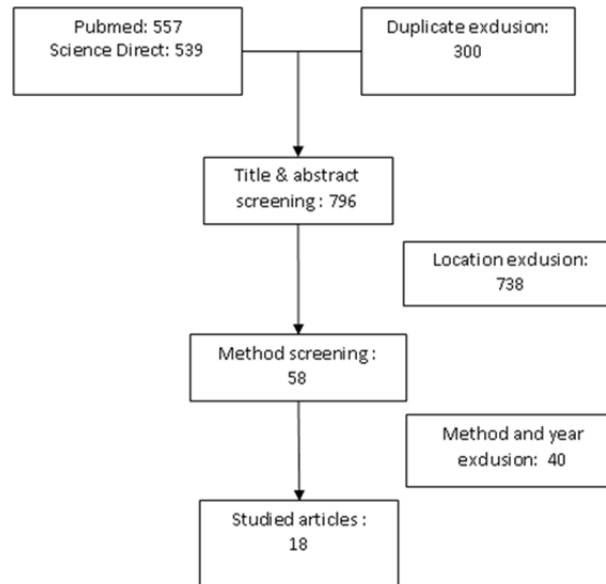


Figure 1. Research articles' screening scheme with the numbers of related articles

3. Results

3.1 Articles Characteristics

There were 18 articles selected in this study which were researches conducted in Malaysia (7), Brazil (6), and India (5). These studies focused on different school areas, i.e., preschool, primary, secondary, high school, and college. These schools were located in urban and suburban areas with different environmental characteristics that provide information on factors related to the school air quality. Several pollutants found which indicate the air quality were particulate matter, nitrogen oxide (NO₂), ozone (O₃), carbon dioxide (CO₂), carbon monoxide (CO), sulfur dioxide (SO₂), volatile organic compounds (VOCs), polycyclic aromatic carbons (PAHs), allergens, and airborne microorganisms. Meanwhile, researches on the students' health impact from the pollutant exposure were discussed in 11 articles with the children from the investigated school being the most subject.

Most of the research that we studied used a cross-sectional method and quantitatively measured the exposure on the study site. In this article, we did not limit the research design used and the sample collection methods, however, we only used the quantitative and primary pollutant exposure data. Risk and health impact being the primary data were gathered through different methods.

3.2 School Air Quality

Based on 18 articles studied, particulate matter was being analyzed in 13 articles (67%) from Malaysia, Brazil, and India. Other pollutants were NO₂, CO₂, CO, SO₂, O₃, allergens, and microorganisms (fungi and bacteria). Besides that, chemical particulate compounds such as metal and ion were also analyzed in several articles to determine the source of pollutants. The methods used to measure air pollutants were varied and most of the measurement period used was 24 and 8 hours. We provide the data of air quality analysis from the 18 articles in Table 1.

3.3 Health Impact

Based on the data from Table 1, health analysis was studied by measuring health risk on the subject, respiratory function, ECP and FeNO, health history questionnaire, and students' complaints. Health problems reported were respiratory problems, eye problems, and symptoms of *Sick Building Syndrome* (SBS). The inflammation on the respiratory tract on students was indicated by the increase in *Eosinophil Cationic Protein* (ECP) and *Fractional exhaled Nitric Oxide* (FeNO).

Table 1. Concentration of Air Pollution (2)

Nr.	Author (s)	Study location (s)*	Subject	Air pollutant (s)		Environmental factor (s)	Health impact
				Indoor	Outdoor		
1.	6	Primary school (1), Kuala Lumpur, - Malaysia	-	PM _{2.5} (24 hours (h)) 11.2 ± 0.45 µg/m ³ ; PM _{2.5} (8 h) 10.2 ± 0.45 µg/m ³ Others: metal (Al, Fe, Zn, Cr, Cd, Ni, Cu) and ion (Ca ²⁺ , Na ⁺ , K ⁺ , Ca ²⁺ , Mg ²⁺ , Cl ⁻)	PM _{2.5} (24 h) 11.4 ± 0.44 µg/m ³ ; PM _{2.5} (8 h) 8.35 ± 0.85 µg/m ³ Others: metal (Al, Fe, Zn, Cr, Cd, Ni, Cu) and ion (Ca ²⁺ , Na ⁺ , K ⁺ , Ca ²⁺ , Mg ²⁺ , Cl ⁻)	Location of school to the source of pollutants (traffic and industry), students' activity, and the building inhabitants	Non carcinogenic health risk HQ < 1, Carcinogenic health risk CR < 1
2.	7	School (1) and university (1), - Canoas, Brazil	-	Chemical compound PM _{2.5} (3 h): Cr, Fe, Mn, Ni, Si, Zn, Pb, Zr, Ca, - Cu, K, Cr, and Cd	-	Location of school to the source of pollutants (traffic and industry), indoor activities	-
3.	8	Secondary school (8), Johor Baru, Malaysia	Students (462, age 14-16)	CO ₂ (8 h) 492 µg/m ³ ; NO ₂ (24 h) 24.3 µg/m ³ ; Formaldehyde (24 h) 4.2 µg/m ³ ; VOC (4 h): <ul style="list-style-type: none"> • Toluene 17.5 µg/m³ • Ethylbenzene 1.9 µg/m³ • Xylene 85.4 µg/m³ • Limonene 5.4 µg/m³ • Benzaldehyda 2.0 µg/m³ 	CO ₂ (8 h) 440 µg/m ³ ; NO ₂ (24 h) 23.8 µg/m ³ ; Formaldehyde (24 h) 5.5 µg/m ³ ; VOC (4 h): <ul style="list-style-type: none"> • Toluene 17.5 µg/m³ • Ethylbenzene 1.9 µg/m³ • Xylene 86.7 µg/m³ • Limonene 5.4 µg/m³ • Benzaldehyde 2.7 µg/m³ 	-	Ocular and throat symptoms, fatigue
4.	9	Primary school (2), Pune, India	Students	PM ₁₀ (8 h) 263.9 µg/m ³ ; PM _{2.5} (8 h) 135.8 µg/m ³ ; O ₃ (8 h) 83.3 µg/m ³ ; CO (8 h) 268.4 µg/m ³ ; NO ₂ (8 h) 46.7 µg/m ³ ; SO ₂ (8 h) 9.2 µg/m ³ ; CO ₂ (8 h) 1249.11 µg/m ³ Others: metal (Ca, Mg, Na, K, Fe, Al, Ba, Mn, Cu, Zn, Co, Pb, Ni, Cr, and Cd)	PM ₁₀ (8 h) 166.6 µg/m ³ ; PM _{2.5} (8 h) 88.9 µg/m ³	Location of school to the source of pollutants (traffic), building inhabitants' activity, ventilation, building material, and season	Cold, cough, fever, eye and skin irritation, sore throat, and sneezing

5.	10	Secondary school (8), Penang, Malaysia	Students (368, 14-16 year)	DNA of <i>Aspergillus versicolor</i> 15 copy/g of dust, DNA of <i>Streptomyces</i> 7 copy/g of dust; CO ₂ (50-70 minutes): 425 µg/m ³	CO ₂ (1 h): 407 µg/m ³	Humidity	Wheeze, current asthma, airway infection, and increase level of FeNO (> 20 ppb)
6.	11	Primary school (3) and residences, Quito, - Brasil		<u>School</u> PM ₁₀ (7 days) 19.6 ± 13.6 – 26.7 ± 15.9 µg/m ³ ; PM _{10-2.5} (7 days) 5.73 ± 2.8 – 16.1 ± 11.6 µg/m ³ ; PM _{2.5} (7 days) 10.6 ± 4.9 -14.7 ± 15.6 µg/m ³ <u>Residence</u> PM ₁₀ (7 days) 33.1 ± 14.5 – 45.3 ± 34.8 µg/m ³ ; PM _{10-2.5} (7 days) 12.4 ± 7.9 -16.9 ± 21.1 µg/m ³ ; PM _{2.5} (7 days) 19.3 ± 14.6 – 29.0 ± 30.5 µg/m ³	<u>School</u> PM ₁₀ (7 days) 20.7 ± 3.7 – 24.2 ± 13.1 µg/m ³ ; PM _{10-2.5} (7 days) 12.4 ± 7.9 – 16.9 ± 21.1 µg/m ³ ; PM _{2.5} (7 days) 10.9 ± 3.2 – 13.2 ± 3.5 µg/m ³ <u>Residence</u> PM ₁₀ (7 days) 21.1 ± 7.3 – 25.1 ± 13.2 µg/m ³ ; PM _{10-2.5} (7 days) 8.2 ± 2.4 – 11.6 ± 6.6 µg/m ³ ; PM _{2.5} (7 days) 14.3 ± 10.1 – 12.5 ± 14.6 µg/m ³	Location of school to the source of pollutants - (traffic), ventilation	
7.	12	Primary school (2), Kuala Lumpur and - Putrajaya, Malaysia		<u>Urban</u> PM ₁₀ (8 h) 82 g/m ³ Others: ion (Ca ²⁺ , Na ⁺ , NO ₃ ⁻ , SO ₄ ²⁻ , K ⁺ , Mg ²⁺ , NH ₄ ⁻) and metal (Zn, Fe, Cr, Ni, Cu, Pb, V, Co, As, Cd) <u>Suburban</u> PM ₁₀ (8 h) 77 g/m ³ Others: NO ₃ ⁻ , Na ⁺ , SO ₄ ²⁻ , Ca ²⁺ , NH ₄ ⁺ , Mg ²⁺	<u>Urban</u> PM ₁₀ (8 h) 77 g/m ³ Others: ion (Na ⁺ , NH ₄ ⁺ , K ⁺ , NO ₃ ⁻) and metal (Zn, Cr, Co, Cu, Ni) <u>Suburban</u> Others: ion (SO ₄ ²⁻ , Na ⁺ , NH ₄ ⁺ , Mg ²⁺) and metal (Cd, Cr)	Location of school to the source of pollutants (traffic, construction site, biomass incineration, industry, and sea), building inhabitants' activity, and building material	Non-carcinogenic health risk HQ > 1
8.	13	Preschool (2), Selangor, Malaysia	Students (98, 5-6 years)	<u>Industry</u> PM ₁₀ (4 h) 126.00 µg/m ³ , VOCs (4 h) 0.02 ppm, fungi 361.00 CFU/m ³ ; and bacteria 275.00 CFU/m ³ <u>Suburban</u> PM ₁₀ (4 h) 126.00 µg/m ³ , VOCs (4 h) 0.02 ppm, fungi 361.00 CFU/m ³ ; and bacteria 275.00 CFU/m ³	-	Location of school to the source of pollutants (traffic)	Increase the risk of respiratory problems Industry: ECP 1.37 ng/mL Suburban: 0.66 ng/mL

9.	14	Schools Agra, India	(10), Students (300)	<p><u>Roadside</u></p> <p>PM₁₀ (6 h) 264.91 ± 33.73 µg/m³; PM_{2.5} (6 h) 81.85 ± 13.06 µg/m³; PM_{1.0} (6 h) 55.43 ± 11.12 µg/m³</p> <p>Others: Mg²⁺ > Ca²⁺ > K⁺ > Na⁺ > NO₃⁻ > SO₄²⁻ > Cl⁻ > F⁻</p> <p><u>Residence</u></p> <p>PM₁₀ (6 h) 261.11 ± 45.48 µg/m³; PM_{2.5} (6 h) 78.33 ± 12.44 µg/m³; PM_{1.0} (6 h) 53.20 ± 9.59 µg/m³</p> <p>Others: Mg²⁺ > Ca²⁺ > K⁺ > NO₃⁻ > Na⁺ > SO₄²⁻ > Cl⁻ > F⁻</p>	<p><u>Roadside</u></p> <p>PM₁₀ (6 h) 240.96 ± 38.08 µg/m³; PM_{2.5} (6 h) 75.14 ± 16.37 µg/m³; PM_{1.0} (6 h) 51.48 ± 12.19 µg/m³</p> <p>Others: Mg²⁺ > Ca²⁺ > K⁺ > NO₃⁻ > Na⁺ > SO₄²⁻ > Cl⁻ > F⁻</p> <p><u>Residence</u></p> <p>PM₁₀ (6 h) 235.51 ± 34.48 µg/m³; PM_{2.5} (6 h) 71.95 ± 14.55 µg/m³; PM_{1.0} (6 h) 48.62 ± 11.97 µg/m³</p> <p>Others: Mg²⁺ > Ca²⁺ > K⁺ > NO₃⁻ > SO₄²⁻ > Na⁺ > Cl⁻ > F⁻</p>	<p>Location of school to the source of pollutants (traffic, building inhabitants' activity, ventilation)</p>	<p>Asthma or respiratory problems, cold, flu, itching, eye irritation, shortness of breath, headache, and dizziness</p>
10.	15	Preschool Araraquara, Brazil	(30), Students (750, 4-5 years)	<p>4-5 TSP</p>	-	<p>Pre-harvest burning activity (biomass burning)</p>	<p>Respiratory problems which impacted on students' absence in school</p>
11.	16	Secondary school Bandar Baru Bangi and Putrajaya, Malaysia	(3), -	<p>PM₁₀ (8 h) 31 µg/m³; PM_{2.5} (8 h) 18 µg/m³; PM₁ (8 h) 16 µg/m³; CO₂ (8 h) 502 ppm; CO (8 h) 0.3 ppm</p>	<p>PM₁₀ (8 h) 46 µg/m³; PM_{2.5} (8 h) 38 µg/m³; PM₁ (8 h) 35 µg/m³; CO₂ (8 h) 486 ppm; CO (8 h) 0.8 ppm</p>	<p>Location of school to the source of pollutants (traffic, industry), building inhabitants' activity, temperature, humidity</p>	-
12.	17	Primary school Delhi, India	(1), -	-	<p>PM₁₀ (24 h) 222.2 ± 111.3 µg/m³; PAH 103.3 ± 50.4 ng/m³</p>	<p>Location and season</p>	<p>Carcinogenic health risk PAH ILCR 3.18 × 10⁻⁶</p>
13.	18	Secondary school Johor Bahru, Malaysia	(8), Students (462, 14-16 years)	<p>CO₂ (50-70 minutes) 380–690 ppm; LPS 40.62 nmol/g; MUA 23.39 µg/g; Ergosterol 2.66 µg/g; allergens from cats (Fel d1), dogs (Can f 1), or horses (Ecu cx) were undetected; <i>Bloomia tropicalis</i> (Blo t), house dust mite allergens 61 CE/g of dust (Der p 1, Der f 1, Der</p>	-	-	<p>Daytime breathlessness, respiratory infection, and doctors diagnosed asthma</p>

			<p>m 1), and cockroach allergens was low 5 CE/g of dust</p> <p>Total fungal DNA 1.76 x 10⁵ CE/g of dust</p>		
14.	19	School (7), Curitiba, Brazil	<p><u>Urban</u></p> <p>24 hours BTEX (benzene 1.5 µg/m³, toluene 3.9 µg/m³, ethylbenzene 1.2 µg/m³, m-, p-xilene 2.9 µg/m³, o-xilene 0.97 µg/m³); NO₂ 17.64 µg/m³; SO₂ 1.83 µg/m³</p> <p><u>Suburban</u></p> <p>24 hours BTEX (benzene 1.4 µg/m³, toluene 48 µg/m³, ethylbenzene 3.9 µg/m³, m-, p-xilene 4.3 µg/m³, o-xilene 1.4 µg/m³); NO₂ 8.56 µg/m³; SO₂ 0.90 µg/m³</p> <p>Others: Si, Ca, Al, Cl, S, K, Zn, Cd</p>	<p><u>Urban</u></p> <p>24 hours BTEX (benzene 1.4 µg/m³, toluene 2.9 µg/m³, ethylbenzene 0.89 µg/m³, m-, p-xilene 2.4 µg/m³, o-xilene 0.61 µg/m³); NO₂ 17.37 µg/m³; SO₂ 2.55 µg/m³</p> <p><u>Suburban</u></p> <p>24 hours BTEX (benzene 1.8 µg/m³, toluene 4.2 µg/m³, ethylbenzene 0.64 µg/m³, m-, p-xilene 2.3 µg/m³, o-xilena 0.89 µg/m³); NO₂ 8.03 µg/m³; SO₂ 0.89 µg/m³</p> <p>Others: Si, Ca, Al, Cl, S, K, Zn, Cd</p>	<p>Location of school to the source of pollutants (traffic, petrochemical industry), ventilation</p>
15.	20	School (1), Chennai, India	<p>TSP (24 h) 149.63 ± 39.71 – 170.08 ± 55.28 µg/m³; Cl⁻ (24 h) 3.18 ± 1.98 – 3.65 ± 2.65 µg/m³;</p> <p>Others: metal (Al, Fe, Ca, K, Mg, Na, Ba, Cr, Cu, Mn, Mo, Ni, Sr, Ti, V, Zn) and ion (SO₄²⁺, NH₄⁺, NO₃⁺, Na⁺, Cl⁻, Ca²⁺, K⁺, Mg²⁺)</p>	<p>Location of school to the source of pollutants (traffic)</p>	
16.	21	School (1), Chennai, India	<p>PM₁₀ (8 h) 95 ± 61 – 149 ± 69 µg/m³; PM_{2.5} (8 h) 32 ± 16 – 61 ± 29 µg/m³; PM₁ (8 h) 18 ± 9 – 43 ± 24 µg/m³; CO (8 h) 0.10 ± 0.18 - 0.11 ± 0.14 ppm; CO₂ (8 h) 307.38 ± 21.25 – 387.77 ± 44.97; bacteria: 443 cfu/m³; VOC was undetected</p>	<p>Location of school to the source of pollutants (traffic), ventilation, and season</p>	

17.	22	Primary school (1), Alta Floresta, Mato Grosso, Brazil	Students (309, 6-15 - years)	PM _{2.5} (24 h) 24.34 ± 19.25 µg/m ³	Location of school to the source of pollutants (local and distant biomass burning)	Increase in PM _{2.5} 10 mg/m ³ lung function 0.29 l/min (95% CI: 0.52 -0.07)
18.	23	High school (3), Bhilai-Durg, Chhattisgarh, India	Students (22, 16-18 years); Staff (30, 25-55 years)	PM ₁₀ (24 h) 47.66 ± 12.5 - 217.46 ± 17.2 µg/m ³	PM ₁₀ (24 h) 36.4 ± 8.75 - 97.4 ± 12.2 µg/m ³	Location of school to the source of pollutants - (traffic and iron factory)

*numbers of school(s) studied

4. Discussion

4.1 Tropical School Air Quality

Particulate matter (PM)

Particulate matter is one of the most common air pollutants which indicates the school's air quality. Studies in India reported a higher indoor PM concentration than outdoor; which exceeded both national air quality and WHO standards (Jan et al., 2017; Habil et al., 2015; Jyethi et al., 2014; Chithra & Nagendra, 2013; Srimuruganandam & Nagendra, 2011; Chithra & Nagendra, 2012). Smaller size PM concentration was also found higher indoor (Chithra & Nagendra, 2012). The indoor PM concentration found in Malaysian studies was also higher than outdoor and exceeding the WHO standards (PM₁₀), however, it was still under the national air quality threshold (PM₁₀, PM_{2.5}). Meanwhile, studies in Brazil did not found a higher PM concentration (PM₁₀, PM_{2.5}) which exceeded the air quality threshold. However, several schools reported a higher indoor PM concentration compared with outdoor.

Particulate matter composition and concentration was highly varied and depended on several factors, e.g., indoor and outdoor source of pollutants, outdoor weather, air exchange rate related with natural ventilation, penetration factor and deposition mechanism, and resuspension. Based on the articles that we studied, most schools were exposed to pollutant sources from outdoor (e.g., traffic road, industry) and indoor (e.g., building material, schoolroom furniture, and particulate matter attached to students' clothes). Rough PM (PM₁₀) concentration was significantly higher when the classroom was occupied. Smaller-sized PM (PM_{2.5} dan PM₁) were affected by the indoor and outdoor source of pollutants (Mohamad et al., 2016; Chithra & Nagendra, 2014).

Several researches also did an analysis of chemical composition (i.e., metal and ion) of particulate matter that indicates the source of pollutants. In tropical countries with forests and plantations throughout the year, biomass burning activity was one of the most significant PM sources. Researches in Malaysia and Brazil found ion K⁺ as one of PM components related to wood burning in residential area and farming activities (e.g., slash and burn land clearing method, burning of agriculture waste, especially from palm oil plantations (Mohamad et al., 2016; Habil et al., 2015).

The concentration of PM was also related to the seasonal variations. Researches in India have reported a higher indoor PM concentration during winter compared with summer. This was due to the low temperature and stable atmospheric condition during winter (Chithra & Nagendra, 2012), changes in inhabitants' activity, and changes in the air exchange rate as a response to the weather change. In winter, resuspension of PM increased because students spend more time indoor and natural ventilation opening decreased, leading to PM indoor accumulation (Jan et al., 2017). Research on ambient air in India by Jyethi et al. (2014) reported a higher outdoor PM concentration in summer. The high concentration of PM₁₀ can be explained by the high frequency of dust storm and crust resuspension in Delhi. Ambient PM₁₀ concentration was predicted to be lower during the wet season, due to high humidity and high precipitation rate (Jyethi et al., 2014).

Total Suspended Particulate (TSP)

There were only two researches from Brazil and India which analyzed TSP pollutant. The increase in TSP concentration caused by pre-harvest sugarcane biomass burning was related to the increase of students' absence in Brazil during March until June. In India, TSP composition which indicates the source of pollutants was not related to indoor sources, but outdoor sources, i.e., fossil fuel burning activity, biomass burning, and sea salt (Chithra & Nagendra, 2013).

The TSP concentration also showed seasonal variations with maximum concentration during winter due to the inversion condition and low mixing height appeared in that period which could cause a considerable amount of air pollutants to accumulate in the lower part of the atmosphere. Minimum TSP concentration was observed during summer due to better dispersion conditions, such as strong wind and temperature. In the wet season, the mean indoor daily TSP was lower. During this period, wind velocity became way lower compared to the other seasons. Low wind velocity resulted in a low rate of air exchange, which in turns supported the accumulation of indoor PM (Chithra & Nagendra, 2013).

Nitrogen Dioxide (NO₂)

Based on four articles studied, the concentration of indoor and outdoor NO₂ in India, Malaysia, and Brazil was varied. Several locations showed a higher NO₂ than WHO annual standards 40 µg/m³ (Jan R et al., 2017; Godoi et al., 2013; Norback et al., 2017; Raysoni et al., 2017). Research in Malaysia (Norback et al., 2017) showed that this high indoor NO₂ concentration in classrooms was related to students' ocular symptoms and fatigue. The source of

NO₂ pollutant in this Malaysian study was fossil fuel burning and biomass burning from palm oil plantations (Norback et al., 2017).

Research in Brazil reported that the increase in NO₂ concentration was related to the traffic emission and industrial activity (Godoi et al., 2013). Schools in the urban areas nearby a busy traffic area showed a higher concentration of NO₂ compared with schools in the suburban areas. In India, indoor NO₂ concentration exceeded the annual WHO standards and was higher in summer. There was no source of NO₂ in the indoor school environment, therefore air current from the traffic activity outside was probably the main source of it. The concentration of NO₂ coincides with the traffic activity, i.e., higher during morning and afternoon and almost constant during the day (Jan et al., 2017).

Ozone (O₃)

We found only one article related to O₃ in tropical schools during the past ten years. Research in India by Jan *et al.* (2017) reported that the indoor O₃ concentration did not exceed WHO standards 100 µg/m³. Ozone gas was formed by sun-derived photochemical reactions and other gas pollutants (e.g., nitrogen oxide and VOC) in the atmosphere, therefore the presence of O₃ inside a classroom was caused by airflow containing pollutant O₃ from the outside (Jan et al., 2017; WHO, 2006). This explains why schools in the busy traffic area were exposed to indoor O₃ which increased slowly after sunrise, reaching its maximum concentration during the day, and slowly decreasing in the afternoon. Besides that, the concentration of O₃ was found positively correlated with the temperature. In summer months, the O₃ concentration was higher because solar radiation is higher in summer than winter (Jan et al., 2017).

Carbon Monoxide (CO)

Researches on CO pollutant in tropical schools of Malaysia and India showed a small concentration of CO which did not exceed the national air quality standards. In every indoor school point of sampling, the CO concentration was always lower compared with the outdoor. The source of CO sampled was mainly incomplete combustion of fuel from the traffic vehicle and household waste burning in the surrounding school areas (Razali et al., 2015). The indoor CO concentration was only sampled during traffic peak hours (Chithra & Nagendra, 2012). Results of researches in India showed a consistent trend with Malaysia, i.e., indoor CO concentration was always lower compared with outdoor. The CO concentration pattern was negatively correlated with the wind velocity, i.e., the higher wind velocity increased dispersion and diluted the ambient concentration which in turn lowering indoor CO concentration (Chithra & Nagendra, 2012).

Carbon Dioxide (CO₂)

Researches in Malaysia showed a higher indoor CO₂ concentration, even though it did not exceed the national air quality standards. Researches in India showed contrary results; the indoor CO₂ concentration was higher than 1000 ppm, exceeding the ASHRAE air quality standards (Jan et al., 2017). The observed concentration of CO₂ showed a daily pattern with a higher concentration that coincides with the school active period (i.e., when students started to enter the classroom). This showed that the respiratory activity of the students being the main source of indoor CO₂. Besides that, the airflow coming from outside the classroom also affected the indoor CO₂ concentration. The fact that the indoor CO₂ concentration did not exceed the air quality standard showed that the ventilation system has supported the air exchange, thus CO₂ did not accumulate inside the classroom (Razali et al., 2015; Norback et al., 2017).

The study has also reported that the CO₂ concentration was negatively correlated with the temperature and positively correlated with the air humidity. This found to be related to the openings in the ventilation system which allows air to be exchanged when the temperature changes, thus affect the relative indoor air humidity (Razali et al., 2015; Norback et al., 2017). Besides that, seasonal variations showed an increase of CO₂ concentration in winter. During the winter, low wind velocity affects the airflow coming from the outside of the classroom, thus CO₂ accumulates indoor. The main outdoor source of CO₂ concentration found was biomass burning from the surrounding area (Razali et al., 2015).

Sulfur Dioxide (SO₂)

Researches in India and Brazil have reported that the indoor and outdoor SO₂ concentration was lower than WHO standards (i.e., 20 µg/m³ in 10 minutes or 500 µg/m³ in 24 hours). Considering that the main source of SO₂ was fossil fuel burning and industrial activity, there was no significant correlation between the indoor and outdoor SO₂ concentration at the urban school with high traffic activity and suburban school with petrochemical industrial activity (Godoi et al., 2013). The SO₂ pollutant has a similar source and seasonal pattern as CO₂ (Jan et al., 2017).

Volatile Organic Compounds (VOCs)

Volatile Organic Compounds group consist of various hazardous carbon gas, however, the most frequently studied was BTEX (benzene; toluene; ethylbenzene; and o-, m-, p-xylenes). The BTEX is often found in gasoline and has a high solvability and toxicity, thus posing a high risk to human health. Research by Wesley et al., 2015. in Malaysia found no significant correlation between indoor and outdoor VOCs concentration at the schools in urban and suburban areas, however, the VOCs concentration was significantly correlated with the increase in students' respiratory inflammation (Wesley et al., 2015). Other research in Malaysia which specifically studied other indoor VOCs (i.e., formaldehyde, xylene, toluene, ethylbenzene, limonene, benzaldehyde, cyclohexane, methylcyclohexane, chlorobenzene, and para-dichloro-benzene) concluded that the source of those indoor VOCs was from the outdoor environment. Other research in Brazil with urban and suburban schools showed a consistent BTEX compound pattern. Both researches found a higher concentration of xylene and toluene compared with other detected VOCs (Norback et al., 2017; Godoi et al., 2013). The main source of VOCs found was incomplete fuel combustion, petrochemical industrial activity, and probably waste from farming and forest activity. Other Malaysian studies have also reported the VOCs emission from palm oil plantation and forest (Tawfiq & Aroua, 2016; Hewitt et al., 2009).

Polycarbon Aromatic Hydrocarbons (PAHs)

The source of PAHs pollutant found in the articles that we studied was incomplete fossil fuel and biomass burning. As shown by research in India, the source of PAHs in the school environment was incomplete fossil fuel and coal burning. The PAHs concentration was affected by changes in temperature, precipitation, and air humidity. The higher concentration of PAHs was shown in the winter period, followed by the wet season period, and the lowest in the summer (Jyethi et al., 2014).

Allergens and microorganisms

Exposure to airborne allergens and microorganisms will affect the immunity responses and caused respiratory symptoms. In the tropical countries with a constant warm temperature and high air humidity throughout the year, allergens (e.g., house dust mite) and microorganisms (e.g., fungi and bacteria) also present throughout the year. Research in Malaysia found a significant correlation between the presence of fungi *Aspergillus* and *Streptomyces* with the indoor air humidity (Norback et al., 2017; Wesley et al., 2015). Another research in Malaysia reported a low level of several allergens which dominated by house dust mite in the classroom dust (Norback et al., 2014).

Health impact on students

To understand health symptoms related to various pollutant exposure in the school environment, articles studied in this study have estimated the health risk, studied the health history, and measured biological indicators (e.g., FeNO and ECP).

Non-carcinogenic and carcinogenic health risk

Several researches showed that contaminated PM (by heavy metal and PAHs) can directly enter the human body through inhalation or direct contact with skin and oral, thus increasing the risk of diseases (i.e., cardiovascular, respiration, lung cancer), especially in school children which suffered from long-term exposure effect. Pollutant controlling program in the school is badly needed to counter this problem (Othman et al., 2019; Mohamad et al., 2016; Jyethi et al., 2014).

Respiratory symptoms

Respiratory symptoms were the most common health risk caused by air pollution. Researches studied reported the relationship between several respiratory problems with air pollutant agents. The exposure to PM related with various respiratory symptoms on students, especially in schools located nearby the source of pollutants (i.e., traffic, industry, biomass burning). Besides that, ocular symptoms, fatigue, headache, rhinitis, and SBS (*Sick Building Syndrome*) have been reported to be directly correlated with the indoor air quality which did not fulfill the requirements indicated by indoor exposure to NO₂, VOCs and PM.

The prevalence of respiratory symptoms related to air pollutants was also measured by a certain biomarker (i.e., FeNO and ECP) to reduce the bias in health history which were gathered through students' questionnaire. Research in Malaysia with 386 students found the relation between the increase in FeNO (> 20 pbb) concentration to respiratory symptoms which indicates lower airway inflammation due to mold *Aspergillus* exposure and the classroom dampness (Norback et al., 2017). Another research in preschools located in urban and suburban areas of Malaysia found that the increase in ECP which indicates upper airway inflammation was related to exposure to VOC, PM₁₀, and indoor microorganisms (Wesley et al., 2015).

The health symptoms mentioned above have impacted the students' absence in school, especially younger students.

Research in Brazil found that students' absence was related to the increase in PM concentration. These indicate that the poor air quality at school can affect the students' productivity and the quality of the education system in tropical countries.

5. Conclusion

The indoor school environment in the tropical countries has been exposed to various pollutants, i.e., particulate matter, nitrogen oxide, ozone, carbon dioxide, carbon monoxide, sulfur dioxide, volatile organic compounds, polycyclic aromatic carbons, allergens, and microorganisms. There were several environmental factors related to the pollutants' exposure, e.g., location of the school to the source of pollutants, ventilation system, building inhabitants, and meteorological factors related to the season. Several pollutants were exceeding the limit of air quality standards and directly related to several health symptoms, especially diseases related to the respiratory system. Even though some pollutants were under the air quality limit, several health symptoms still occurring. More importantly, exposure to pollutants has directly affected students' absences in school, thus control in pollutants at the school environment is urgently needed to protect the students' health and the education system's quality.

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Competing Interests Statement

There is no conflict of interest inflicted in this study.

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