PUBLIC HEALTH RESEARCH

Health Risk Assessment of PM_{10} Exposure among School Children and the Proposed API Level for Closing the School during Haze in Malaysia

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ABSTRACT

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Introduction During haze, at what level should Air Pollutant Index (API) showed, public or private school be closed is not without controversy and is very much debated. Therefore, the aim of this paper is to objectively quantify the potential inhaled dose of PM_{10} associated with exposure at school and home microenvironments during haze. The result of the health risk assessment will be used to propose the API level for closing the school during haze episode.

Methods A hypothetical haze exposure scenario was created using the breakpoints of PM_{10} concentration for calculation of API and respective inhaled dose during haze. To determine the potential inhaled dose, we have considered many factors that include time spent for specific physical intensity at school and home microenvironments, age-specific and physical intensity-specific inhalation rate (m^3/min), and the indoor/outdoor ratio of PM_{10}. To calculate risk quotient (RQ), the inhaled dose was compared with the health reference dose computed based on the concentration of PM10 in the Malaysian Ambient Air Quality Standard.

Results When considering the specific exposure at each microenvironment (school and home), the potential inhaled dose of PM_{10} was substantially lower when school is closed for both primary and secondary school. The calculated risk quotient (RQ) indicates that primary school children are likely to be affected at slightly lower PM_{10} concentration (equivalent to API of 197) as compared to secondary school children. Short duration of high physical activity intensity during school breaks has contributed to a large proportion of inhaled dose among school children indicating the important to avoid physical activities during haze.

Conclusion Based on the assessment, taking into account the uncertainty of risk assessment methodology, we proposed school to be closed when API reach 190 for both primary and secondary schools. These findings and recommendations are only valid for naturally ventilated school and applicable in the context of the current API calculation system and the existing Recommended Air Quality Guideline values in Malaysia.

Keywords Haze - PM10 - School children - health risk assessment.

INTRODUCTION

Haze is an annual phenomenon that causes deterioration of air quality in Malaysia. In Malaysia, even though haze can emanate from domestic, most of the time severe haze events were attributed to open biomass burning and peat fires from neighboring country which produces transboundary smoke haze.[1] The recent transboundary haze was the longest ever, beginning in August and lasted till the end of October 2015. The haze had engulfed most of the states in Peninsular and South Borneo of Malaysia and also Singapore during that period.

A common public health recommendation issued by health authorities during haze episode include remaining indoors and reduce or avoid physical activities outdoor as it will reduce community exposure to air pollutants, mainly to the fine particulate matter. In addition to advice on staying indoors, public health recommendations also include using air conditioning especially those equipped with HEPA air filter as it can filter most of the fine particulate matter during haze.

However, at what level should of Air Pollutant Index (API) showed, public or private facilities be closed is not without controversy and is very much debated. During the recent episode of haze, Ministry of Education (MOE) had instructed for all schools affected by haze to be closed when the API reach 150 against the level of more than 200as stipulated in the National Haze Action Plan (NHAP) 2014.[2] This discussion was indeed arbitrary in nature as it was made in response to public pressure and demands. As a results of lowering the threshold for closing the school, most affected schools were closed for few times as the haze level fluctuated and causing difficulty for school teachers to reschedule classes and examination dates. Because of the unpredictable haze situation, some important examinations were continued even when the API level was above 150 (but below 200), and the students were provided and instructed to wear a facemask while taking their examination papers.

In the earlier version of NHAP (2006) and NHAP (edited 2012), the API level for closing the school was set at 400 and 300 respectively.[3,4] The reason it was reduced to 200 was that 400 and 300 is too high for children. Children represent one of the most susceptible subpopulations with regards to harmful effects of exposure to particulate matter less than ten micrometer diameter, $PM_{10.}$[5,6] As their physiological and immunological systems are still developing, children receive a higher dose of airborne particles relative to the lung size compared to adult.[6,7,8,9] However, the potential inhaled dose associated with the selected level of API and the risk was not properly quantified as no quantification of potential inhaled dose was done to associate the inhaled dose with the pollutants level and time spent in the school environment. Many studies have shown the importance considering children's exposures in different microenvironments such homes and school in order to obtain an accurate representation of children overall exposure.[10,11,12] Thus, failure to account for this potential exposure variation between outdoor and indoor environment may lead to exposure misclassification that could limit our ability to estimate accurately the health risk associated with PM exposure associated with a specific exposure microenvironment.[13] This is very important especially when a decision is to be made related to a particular exposure in a specific microenvironment which in this case is the school environment.

In Malaysia, school typically starts at 7.30 am and ended at 1.30 pm. The children start arriving at school as early as 7.00 am and depart from school at 2.00pm. The aim of this paper was specifically to evaluate health risk associated with PM_{10} exposure among children at school environments during schooling hours and exposure at home environments.

METHODS

The key pollutant that determine the API level during haze

In this paper, we applied the risk assessment methodology to evaluate the intake and toxicology risk of PM_{10} exposure during haze among school children in order to review the API level for closing the school. PM_{10} was chosen because it is the predominant pollutants during haze that determine the level of API under the current API system in Malaysia. Even though $PM_{2.5}$ is of great health concern due to its smaller size in which it can travel deep into human lungs, in Malaysia $PM_{2.5}$ is not routinely measured and not currently counted for deriving the API. Therefore, for the purpose of decision making under the current air quality system, in this case the decision to close the school during haze, we focus on risk related to API and associated PM_{10} concentration.

The Air Quality Index (AQI or API in Malaysia) introduced by USEPA is the most popular air quality index and it is adopted by many countries around the world including Malaysia. The API runs from index value 0 to 500. The higher the API value is, the greater the level of air pollution, and hence greater is the health concern. An API value of 50 indicates that the air quality is good and is with little potential negative implication to the public health, while an API value over 300 represents hazardous air quality. An API value of 100 corresponds to the national air quality standard for the pollutant, a level which USEPA has set to protect public health. API values below 100 are generally considered as satisfactory air quality. When the API value is above 100, the air quality is considered to be unhealthy for certain sensitive groups of people.

Exposure scenarios

In order to evaluate the protective effect of staying at home as compared to exposure in the school microenvironment, two hypothetical exposure scenarios were used. Scenario 1 represents total exposure scenarios by summing exposure in school environment and exposure in the home environment. In Scenario 1, schools are opened as usual regardless of API levels. Scenario 2 represents total exposure in a day only come from home environments, whereby in this case the schools are closed, and the students are assumed to remain indoor at home. Due to lack of information about time spent in a vehicle per day, exposure during commuting is not accounted for in this assessment. Furthermore exposure in a vehicle represent only a very short duration, most of vehicles including school buses are air conditioned and the activities are sedentary. Thus it is unlikely to substantially affect the potential inhaled dose accumulated by children.

When estimating the exposure intake, a few assumption were made;

1. Indoor and Outdoor ratio of PM10 concentration at school environment

Indoor and outdoor PM_{10}concentration ratio (I/O ratio) at school environment is equal to one. It is assumed that there is no different in PM_{10} concentration inside the classroom and outdoor environment as most of the schools are naturally ventilated and the ratio of window to the overall classroom is more than 80% which allow a free flow of outdoor air into the indoor environment. This assumption is hypothetically correct as it is supported by finding from a recently published local study which consistently reported that the I/O ratio of PM_{10} in school environmentswas1.02 for both Putrajaya and Kuala Lumpur area[14]. Other studies have shown that the pollutants within classroom originated predominantly from an infiltration of outdoor sources and the level in the classroom is directly influenced by the increasing level of air pollutants outside the classroom.[15,16,17,18,19,20,21,22] This assumption is not valid for schools running with air conditioning system.

2. Indoor and Outdoor ratio of PM10 concentration at home environment

I/O ratio in a home environment is less than one during haze episode. Staying indoors at home is a better protective effect from haze as compared to staying at school environment with natural ventilation. Several studies have demonstrated that fine particulate matter (PM) infiltration efficiency (the fraction of the outdoor concentration that penetrates indoors and remains suspended) varies within a home and over time within a home.[23] To account for this exposure variation between outdoor and indoor, we used I/O ratio of PM to accurately measure the potential dose acquired by children during haze. As the I/O ratio reported by studies varies, we carefully selected only studies or findings that are relevant to our country for the purpose of our risk assessment (Table 1). Most studies reviewed, focused on I/O ratio of PM2.5 except study by Elliot et al 2008 which also include I/O ratio of PM10.[24] However, the study by Elliot et al 2008 which was conducted in Singapore did not report I/O ratio for indoor environments without air conditioning systems. This could be because of a very small percentage of school and home in Singapore that were not equipped with air conditioning. However, it was clearly mentioned that PM10 concentration was relatively lower thanPM2.5 in an indoor environment which indicates staying indoor can provide better protection to PM10 as compared to PM2.5 even in a naturally ventilated home. For studies conducted in non-tropical countries, we only took I/O ratio measured during summers which are more relevant to tropical climate. There are no local study reporting on I/O of PM2.5 and PM_{10} in home environment during haze period. For the purpose of health risk assessment in this paper, we decided to use PM_{10}I/O ratio of 0.6 and 0.38 for naturally and air conditioning ventilated home respectively.

Table 1 Indoor-Outdoor ratio of particulate matter reported by various studies

Micro-environments / exposure scenario	I/O ratio of particulate matters			
	Indoor environment with air conditioning with HEPA filters usage / non HEPA filter		Natural ventilated indoor environments	
	PM2.5	PM10	PM2.5	PM10
Home / I/O ratio during forest fire, summer, Canada[25]	0.19	-	0.60	-
Home / exposure scenario not mentioned/ Singapore[24]	0.50	0.38	-	-
School / exposure scenario not mentioned/ Singapore[24]	0.20	0.18	-	-
Home / multicity study, US[12]	0.10 – 0.49	-	0.62	-
Schools / non-haze period / city of Kuala Lumpur and Putrajaya[14]	-	-	-	1.02

(Source: Reference No. 12, 14, 24 and 25)

Level of Exposure

The hypothetical exposure concentration was defined according to the levels of PM_{10} used as a breakpoint for calculation of API as shown in Table 2.

Table 2 Breakpoints of PM_{10} concentration and API range

API Range	Breakpoints of PM_{10} concentration, µg/m^3	Description
	X = PM_{10} (24 h average, µg/m^3)	
0-50	0 < X < 54	Good
51-100	55 $\leq$ X $\leq$ 154	Moderate
101-150	155 $\leq$ X $\leq$ 254	Unhealthy (sensitive group)
151-200	255 $\leq$ X $\leq$ 354	Unhealthy
201-300	355 $\leq$ X $\leq$ 424	Very unhealthy
301-400	425 $\leq$ X $\leq$ 504	Hazardous
401-500	505 $\leq$ X $\leq$ 604	Emergency level

(Source: DOE, 2015)[26]

Activity pattern, inhalation rate of children in school and home environment

Potential inhaled dose is mainly influenced by duration of exposure, intensity of physical activities in different microenvironments and inhalation rate (IR) (m^3/min) of children. As our assessment is related to short-term exposure to PM_{10} on a daily basis during haze, we used recommended short-term exposure IR values by age group and level of physical activity among children published by US Environmental Protection Agency (US EPA) 2011 (Table 3).[27] The recommended child-specific exposure factors/values is widely used by health risk assessors across the countries for estimation of exposure intake among children. The derivation of inhalation rate by US-EPA has taken into account several factors such as age, bodyweight, metabolic equivalents, and human activity.

Table 3 Recommended short-term inhalation rate (m^3/min) values (males and female combined)

Activity level	Age Group (year)	Mean IR (m^3/minute)
Sleep	6 to < 11	4.5E-03
	11 to < 16	5.0E-03
Sedentary	6 to < 11	4.8E-03
	11 to < 16	5.4E-03
Light intensity	6 to < 11	1.1E-02
	11 to < 16	1.3E-02
Moderate intensity	6 to < 11	2.2E-02
	11 to < 16	2.5E-02
High intensity	6 to < 11	4.2E-02
	11 to < 16	4.9E-02

(Source; US EPA, 2011)[27]

Potential Inhaled Dose of PM_{10}

Children exposure was calculated by using the general equation of potential dose for intake processes[27].This simple equation depends on the integration of the chemical intake rate (concentration of the particulate matter (C)), and inhalation rate (IR) over time (ET). According to US EPA, dose can be expressed as a total amount (with units of mass, e.g., mg) or as a dose rate in terms of mass/time (e.g., mg/day), or as a rate normalized to body mass (e.g., with units of mg of chemical per kg of body weight per day [mg/kg-day]).[27] In this assessment, intake dose is expressed as mass/time (µg/m^3 per day).

$$\text{Potential Dose (PD)} = \sum_i Ci \; X \; IRi \; X \; ETi$$

Where:

PD = Potential inhaled Dose (µg/m^{3}per day)

Ci = Concentration of PM_{10} (µg/m^3). For the purpose of this assessment, the exposure concentration of PM_{10} is equal to the breakpoints of PM_{10} concentration used for calculation of Air Pollutant Index (API) as shown in Table 2.

IRi = Inhalation Rate (m^3/min). The inhalation rate was used in accordance with EPA standard as recommended in the child-specific exposure factor handbook and has shown in Table 3.

ET= Exposure Time (min /day). Exposure time is the amount of time in which the children spent their time at school and home environment.

In Malaysia, primary and secondary school children spend approximately 30 % of their time (7 hours/day: 7.00 am until 2.00 pm, taking into account time before and after class for about 1 hour) at school during school days from Monday to Friday. Therefore, calculation of potential inhaled dose should take into account the exposure to these specific school environments. As potential inhaled dose is influenced by the intensity of physical activity in specific microenvironments, for the purpose of risk assessment, as there is no publish data related children activity pattern at school, we derived the exposure duration and physical activity intensity as shown in Table 4 based on our best expert opinion. It is assumed that children behavior or physical activity level during breaks is more difficult to control when they are at school because of peer-influence. They tend to play, run and jump together with their friends especially during a break, and after class while waiting for their parent.

Table 4 Timetable and child activity pattern at school and home

Time	Microenvironment	Activities at school	Intensity
	We assumed that no physical exercise classes were allowed during haze		
07:00 - 07:30	Arrival	Walking, playing	Light
07:30 - 09:30	Classroom	Seated (talking/listening)	Sedentary
09:30 - 10:00	Break	Running/fast walking/playing	High
10:00 - 13:30	Classroom	Studying	Sedentary
13:30 - 14:00	Leaving school	Running, fast walking, playing	High
	Home		
	These activity pattern is only applicable during haze period		
14:00 - 18:30	Various	Lunch, resting, watching TV, playing game, homework	Sedentary
18:30 - 19:00	Various	Playing	High
19:00 - 22:00	Various	Dinner, watching TV, Studying, playing game	Sedentary
22:00 - 06:30	Bedroom	Sleeping	Sleep
06:30 - 07:30	Various	Preparing for going to school including breakfast	Light

Health Risk

The risk quotient (RQ) is calculated based on the following formula;

RQ = Potential inhaled Dose (µg/m^3 per day) / Health Reference value (µg/m^3 per day)

Where;

RQ$\leq$ 1: exposure to hazard that is not considered a threat to public health; RQ >1: Exposure to hazard is likely to pose a threat to public health.

Health Reference Value; During haze the dominant pollutant that determine the API level is PM_{10}, hence ,we used the Malaysian Ambient Air Quality Standards 2013 (MAAQS) value of 150 µg/m^3 for 24 hours exposure to PM_{10} as the health reference concentration for calculating the health risk during haze[28]. To estimate the probability of adverse effects, we then converted PM_{10} reference concentration (MAAQS Value) to reference dose using the conversion equation as follows;

Health Reference Value (µg/m^3) = MAAQS value (µg/m^3) x IR (m^3/day)

= 150µg/m^3 x IR (m^3/day)

Whereby;

For primary school children, IR (m^3/day) is the combined inhalation rate (male and female) for children age 10 years old, which is 15.8 m^3/day. This IR value has taken into account the time spent for different activity pattern of children[29].

For secondary school children, IR (m^3/day) is the combined inhalation rate (male and female) for children age 15 years old, which is 18 m^3/day. This IR value has taken into account the time spent for different activity pattern of children[29].

RESULTS

Potential inhaled dose of PM_{10} related to school and home environments

Figure1 represents the potential inhaled dose in a home and school environments. The line "school opened" represent the total inhaled dose per day taking into account the dose inhaled at school environments and the dose inhaled at home environments (after school) if school remain open during haze. Whereas, if schools are closed during haze, "school closed (AVH)" line represents the inhaled dose accounted for only at home environments with air conditioning ventilation and the "school closed (NVH)" line represents the inhaled dose accounted for only at home environments with natural ventilation (school closed). The total inhaled dose per day is substantially lower among children who stay at home when exposure at school environments is not accounted (school closed). The inhaled dose further reduced when children stay at home ventilated with air conditioning system. Further analysis on inhaled dose by specific physical activity intensity at school environments, show that a large proportion of potential inhaled dose (47 %) is contributed by a short duration of moderate and high physical activity intensity during schools breaks.

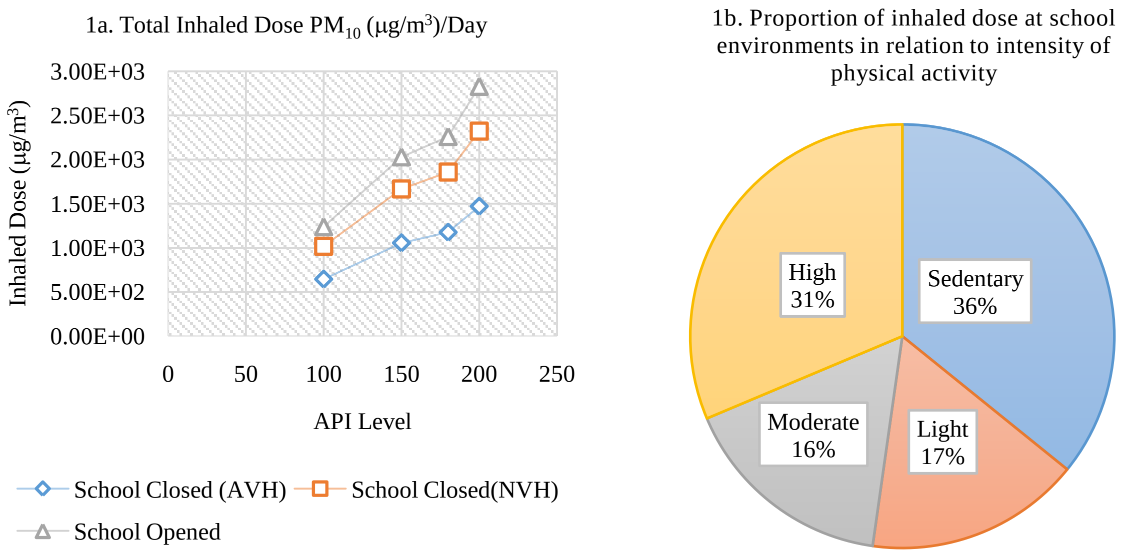

Figure 1 1a. Potential inhaled dose per day by school status (opened or closed), 1b. Proportion of inhaled dose by specific physical activity intensity at school environment

Health risk

The calculated risk quotient (RQ) and inhaled dose are presented in Table 5and Table 6 and the graphical presentation of the RQ are illustrated in Figure2 and Figure 3 for primary and secondary school children respectively. The RQ of respective PM_{10} concentration for both primary and secondary schools revealed that RQ is higher when school is opened. RQ value is more than one, which indicate the possibility of developing health effects when the API level is 197 for primary and slightly higher for secondary school as compared to when school is closed. As the API level increases, the probability of developing health effects increases and at API level of 200, if a school is opened, the probability of children developing health effects of haze is 18.5 % and 47 % higher as compared to if they were staying at naturally ventilated home and air conditioning ventilated home. In another word, staying at home offer a better protection from the haze to children. The protective effect is even bigger if their home is equipped with air conditioning system which limit the infiltration of outdoor air into the indoor environments.

Table 5 Potential dose of exposure to PM_{10} concentration and risk quotient (RQ) in different microenvironments among primary school children

PM_{10} ($\mu g/m^3$)	API level	Potential Inhaled Dose in different microenvironments ($\mu g/m^3$)					RQ		
		School Open			School Closed		School Opened	School Closed	School Closed
		School (a)	Home (b)	Combined (c) = (a + b)	Home (NVH)	Home (AVH)		Home (NVH)	Home (AVH)
155	101	6.23E+02	6.15E+02	1.24E+03	1.02E+03	6.43E+02	0.52	0.43	0.27
254	150	1.02E+03	1.01E+03	2.03E+03	1.66E+03	1.05E+03	0.86	0.72	0.45
283	180	1.14E+03	1.12E+03	2.26E+03	1.85E+03	1.17E+03	0.95	0.78	0.50
296	193	1.19E+03	1.17E+03	2.36E+03	1.94E+03	1.23E+03	1.00	0.82	0.52
300	197	1.21E+03	1.19E+03	2.40E+03	1.97E+03	1.24E+03	1.01	0.83	0.53
354	200	1.43E+03	1.40E+03	2.83E+03	2.32E+03	1.47E+03	1.19	0.97	0.62
424	300	1.70E+03	1.68E+03	3.39E+03	2.78E+03	1.76E+03	1.43	1.17	0.72
504	400	2.03E+03	2.00E+03	4.03E+03	3.30E+03	2.09E+03	1.70	1.39	0.82

Table 6 Potential dose of exposure to PM_{10} concentration in different microenvironments among secondary school children

PM_{10} ($\mu g/m^3$)	API level	Potential Inhaled Dose in different microenvironments ($\mu g/m^3$)					RQ		
		School Open			School Closed		School Opened	School Closed	School Closed
		School (a)	Home (b)	Combined (c) = (a + b)	Home (NVH)	Home (AVH)		Home (NVH)	Home (AVH)
155	101	7.16E+02	6.79E+02	1.39E+03	1.14E+03	6.43E+02	0.52	0.42	0.24
254	150	1.17E+03	8.88+E02	2.06E+03	1.42E+03	1.05E+03	0.76	0.63	0.39
283	180	1.27E+03	1.24E+03	2.47E+03	2.02E+03	1.17E+03	0.94	0.77	0.44
296	193	1.37E+03	1.30E+03	2.66E+03	2.17E+03	1.23E+03	0.99	0.81	0.45
300	197	1.39E+03	1.31+E03	2.70E+03	2.20E+03	1.24E+03	1.00	0.82	0.46
354	200	1.64+03	1.55E+03	3.19E+03	2.60E+03	1.47E+03	1.18	0.96	0.54
424	300	1.96+03	1.86E+03	3.82E+03	3.11E+03	1.76E+03	1.41	1.15	0.68
504	400	2.33+03	2.21E+03	4.54E+03	3.70E+03	2.09E+03	1.68	1.37	0.77

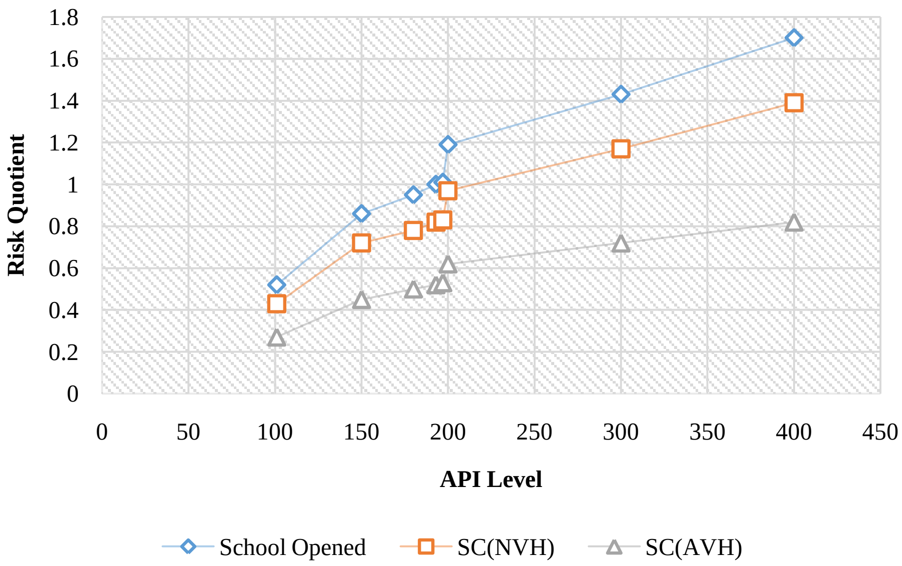

Figure 2 Calculated Risk Quotient for primary school children

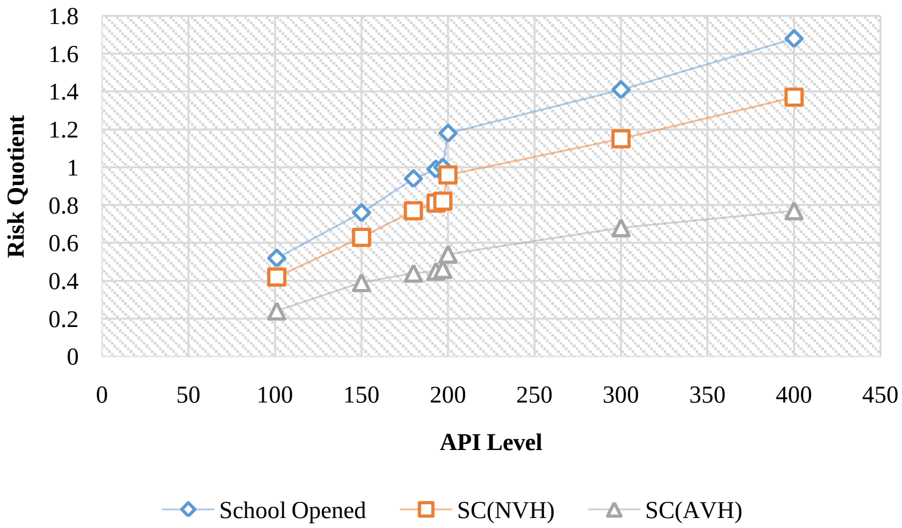

Figure 3 Calculated Risk Quotient for secondary school children

DISCUSSION

The potential inhaled dose findings highlight the importance of staying indoors at home during haze for school children. Relatively in a day, children spend about 30 % of their time at school environment and the potential dose associated with it is almost equal to a longer exposure time at home. A higher proportion of dose associated with shorter exposure at school environment as compared to the dose inhaled at home environments is largely contributed to a higher physical activity and a higher level of particulate matter in school environments. It is a well-known fact that the physical activities contributed to a high potential dose due to the increasing inhalation rate (m^3/min) and changing mode of breathing from through the nose to through the mouth. The amount of particulate matter inhaled during physical activities is five times greater than the amount inhaled during sedentary activity. Moreover, during exercise, the inhaled air is taken in predominantly through the mouth which has limited filtration effect.[30,31] This finding indicates the importance of avoiding any physical activity outdoor during unhealthy air quality. The finding also highlighted the important of being at home during haze episode as it will help to reduce the dose inhaled by children. The concentration of PM is further reduced when a house is ventilated using air conditioning system, which will subsequently lower the dose inhaled by children. These findings were solely based on the assumption made on the ratio of indoor-outdoor PM_{10} obtained from various studies during forest fires as shown in Table 1. However, this finding is not valid for school environment equipped with air conditioning system.

It is also important to note that besides a higher PM_{10} concentration, a higher physical intensity contributed a lot to a higher inhaled dose at school environments. Besides advising children to stay at home, other public health measures are equally important to protect children health during haze episode, children should avoid going outdoor and avoid any physical activities that could increase their respiratory rate. Wearing of appropriate face mask is also equally important to reduce the inhaled dose and subsequently reduce the possibility of developing adverse health effects.

This health risk assessment showed that API 197 is associated with RQ of >1, indicating that primary school children are likely to experience health effects as a result of exposure to PM_{10} concentration if the API level is 197 and above. A slightly higher level of API is observed to pose health effect for secondary school children. However, taking into account uncertainty in conducting risk assessment we suggest that API level of slightly lower than 197 to be taken as the cutoff point to close the school. Thus, we propose API level of 190 is used as the level to close the school. The uncertainty of the risk assessment can be from various factors which include the use of data from oversea studies for inhalation rate and I/O ratio of particulate matter. The physical structure of school and houses in another country might be different with schools and houses in Malaysia. The current NHAP Guidelines of 200 is considered too high as the risk is already too obvious in this situation (RQ 1.19). Whereas, the level of 150 used by Ministry of Education in the 2015 haze episode is considered too low which may compromised on important school events such as National Examination Week. Under such condition, advisory on the use of face mask may be adequate.

It is very important to note that this assessment is valid in the context of current API calculation system used in Malaysia. If there is any changes in the formula for calculation of API, in MAAQS value for PM10 is revised or PM2.5 parameter is used instead of PM10 for calculation of API during haze, the risk has to be recalculated.

CONCLUSION

The present health risk assessment findings indicate that the exposure of PM_{10} in school environments could potentially contribute to a higher inhaled dose among children during haze. The calculated risk quotient exceed 1 when API reach 197 for primary school. Hence, after considering uncertainty in risk assessment methodology, in order to protect the children from the adverse effects of haze and to give a better opportunity for them to stay in a better indoor environments at home, the school should be closed when API reach 190.

However, the above findings and recommendation are not valid for schools equipped with a proper air conditioning system. The above findings are also valid in the context of the current Malaysia API system.

REFERENCES

1. Mahmud M. Assessment of atmospheric impacts of biomass open burning in Kalimantan Borneo during. Atmos. Environ. 2013; 78: 242-249.
2. Department of Environment, Malaysia. National Haze Action Plan (revised, 2014).
3. Department of Environment, Malaysia. National Haze Action Plan (revised, 2006).
4. Department of Environment, Malaysia. National Haze Action Plan (revised, 2012).
5. Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S. Indoor air quality and sources in schools and related health effects. J. Toxicol Environ. Health B. 2013; 16:491-550.
6. Schuepp K, and Sly PD. The developing respiratory tract and its specific needs in regard to ultrafine particulate matter exposure. Pediatr.Respir.Rev. 2012; 13: 95-99.
7. Foos B, Marty M, Schwartz J, Bennett W, Moya J, Jarabek AM. Focusing on children's inhalation dosimetry and health effects for risk assessment: an introduction. J Toxicol Environ Health. 2008; 71:149-165.
8. Burtscher H, and Schuepp, K. The occurrence of ultrafine particles in the specific environment of children. Paediatr. Respair. Rev. 2012; 13:89-94.
9. Mazaheri M, Clifford S, Jayaratne R, Megat Moktar M.A, Fuoco F, Buonanno G, and Morawska L. School children's personal exposure to untrafine particles in the urban environment. Environ. Sci. Technol. 2014, 48:462-487.
10. Slezakova K, Texeira C, Morais S, Carmo Pereira M. Children's indoor exposures to ultrafine particles in ana urban area: camparison between school and home environments. Journal of Toxicology and Environmental Health, Part A. 2015; 78: 886-896.
11. Elbayoumi M, Ramli NA, Noor Faizah Fitri Md Yusof, Wesam al Madhoun. An exposure level of fine particulate matter in various schools in Gaza Strip, Palestine,

International Journal of Environmental Protection. 2013; 3(12): 15-22.
12. Ryan E.Allen, Sara D. Adar. Ed Avol, Martin Cohen, Cynthia L. Curl, Timothy Larson, L-J. Sally Liu, Lianne Sheppard and Joel D Kaufman.. Modeling the residential infiltration of outdoor PM2.5 in the multi-ethinic study of athrosclerosis and Air pollution, Environmental Health Perspectives. 2012; 120:824-830.
13. Sarnat JA, Wilson WE, Strand M, Brook J, Wyzga R, Lumley T. Panel discussion review:session one-exposure assessment and related errors in air pollution epidemiologic studies. J Expo Sci Env Epid. 2007; 17:S75-S82.
14. Noorlin Mohamad, Mohd Talib Latif and Md Firoz Khan. Source apportionment and health risk assessment of PM10 in a naturally ventilated school in a tropical environment. Ecotoxicology and Environmental Safety. 2016; 124: 351–362 (Impress).
15. Diapouli E, Chaloulakou A, Mihalopoulos N, Spyrellis N. Indoor and outdoor PM mass and number concentrations at schools in the Athen area. Environ. Monit. Assess. 2008; 136: 13–20.
16. Krugly E, Martuzevicius D, Sidaraviciute R, Ciuzas D, Prasauskas T, Kauneliene V, Stasiulaitiene I, Kliucininkas L. Characterization of particulate and vapor phase polycyclic aromatic hydrocarbons in indoor and outdoor air of primary schools. Atmos. Environ. 2014; 82: 298–306.
17. Reche C, Rivas I, Pandolfi M, Viana M, Bouso L, Alvarez-Pedrerol M, Alastuey A, Sunyer J, Querol X. Real-time indoor and outdoor measurements of black carbon at primary schools. Atmos. Environ. 2015; 120: 417–426.
18. Canha N, Almeida SM, Freitas MDC, Trancoso M, Sousa A, Mouro F, Wol-terbeek HT. Particulate matter analysis in indoor environments of urban and rural primary schools using passive sampling methodology. Atmos. En-viron. 2014; 83: 21–34.
19. Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air. 2003; 13: 53–64.
20. De Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: In-dicators based on health risk assessment to single out critical issues. Int. J. Environ. Res. Public Health. 2013; 10: 6273–6291.
21. Hassanvand MS, Naddafi K, Faridi S, Arhami M, Nabizadeh R, Sowlat MH, Pourpak Z, Rastkari N, Momeniha F, Kashani H, Gholampour A, Nazmara S, Alimohammadi M, Goudarzi G, Yunesian M. Indoor/outdoor relationships of PM10, PM2.5, and PM1 mass concentrations and their water-soluble ions in a retirement home and a school dormitory. Atmos. Environ. 2014; 82: 375–382.
22. Razali NYY, Latif MT, Dominick D, Mohamad N, Sulaiman FR, Srithawirat T. Concentration of particulate matter, CO and CO2in selected schools in Malaysia. Build. Environ. 2015; 87: 108–116.
23. Chen C, and Zhao B. Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. Atmos Environ. 2011; 42(2):275-288.
24. Elliot T, Gall Jin Zhou, Victor Chang, and Willion Zararoff. Indoor exposure to outdoor pollution in a tropical environment. Center for Research in Energy Systems Transformation; 2014.
25. Barn P, Larson T, Noullett M, Kennedy S, Copes R, and Brauer M. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. Journal of Exposure Science and Environment Epidemiology. 2008; 18: 503-511.
26. Department of Environment, Malaysia. Draft Final Report on Review of Air Pollution Index 2015.
27. U.S. EPA. Exposure Factors Handbook 2011 Edition (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F; 2011.
28. Department of Environment, Malaysia. Malaysia Ambient Air Quality Standards; 2013.
29. International Commission on Radiological Protection (ICRP). ICRP Publication 89: Basic anatomical and physiological data for use in radiological protection: reference values. International Commission on Radiological Protection; 2002.
30. Daigle C, Chalupa D, Gibb F, Morrow P, Oberdorster G, Utell M and Framptom M. Ultrafine particle deposition in human during rest and exercise. Inhalation Toxicology. 2003; 12(6): 539-552.
31. US-EPA, Exposure Handbook, Vol 1. National Centre for Environmental Assessment, Washington, D.C; 1997.