PUBLIC HEALTH RESEARCH

Health Risk Assessment of PM_{10} exposure among Malaysian Adult Population based on Physical Activity Pattern

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ABSTRACT

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Introduction Most health advisories related to outdoor physical activity during haze are general in nature. The advisories normally advise everyone to reduce or limit prolonged exertion or heavy exertion without mentioning the acceptable duration for performing outdoor physical activity causing difficulty for public to decide to stop or cancel a particular outdoor or sport event. The aim of this paper is to determine the acceptable duration for performing outdoor physical activity pattern based on API level.

Methods Health risk assessment approach that comprises of hazard identification, exposure assessment, dose-response, and risk characterization steps were used to determine the potential inhaled dose and risk associated with performing the physical activity during haze. We have considered many factors that include time spent for physical activity patterns for Malaysian adult, age, physical intensity-specific inhalation rate (m^3/min), and the indoor/outdoor ratio of PM_{10}. A hypothetical exposure scenario of PM_{10} was created using the breakpoints of PM_{10} concentration for the calculation of respective API levels.

Results The association between physical activity pattern, API level and risk quotient were presented in the form of risk radar diagram. In general, based on the average estimate, everyone should avoid high intensity physical activity and moderate exertion when API reach $\geq$ 175 and > 200 respectively. Whereas, based on the high estimate, everyone should avoid high intensity physical activity and moderate exertion when API reach $\geq$ 135 and > 150 respectively. Below the said API, the duration for performing prolonged exertion and heavy exertion should be adjusted according to the API level as stated in the recommended maximum duration for performing physical activity.

Conclusions Reducing the physical activity is an effective strategy to lower the dose of inhaled pollutants and reduce the health risk during poor air quality. Based on the assessment, the recommended maximum duration for performing the physical activity based on API level was established as a guide for the authority or public to plan their activity during poor air quality.

Keywords Haze - PM10 - Physical activity - Risk assessment.

INTRODUCTION

Haze is almost an annual phenomenon, which deteriorates the air quality in Malaysia. The 2015 transboundary haze was the longest ever, beginning in August and lasted until the end of October 2015. It engulfed most of the states in Peninsular and North Borneo states of Malaysia. It caused difficulty and disturbances not only for the public to carry out their daily routines but also for the public and authorities to organize sport and other outdoor events. The most common advisories issued by authorities during haze includes stay indoors, reduce outdoor physical activities, and wear facemask to reduce exposure to the pollutants. To certain extent, an outdoor event may need to be cancelled. However, to date, there is no clear guideline as to when to stop or cancel public event or sports activities during haze based on the Air Pollutant Index (API).[1,2]

In the past, cancelling of an outdoor event was not without controversy and very much debated as the advisory given in the National Haze Action Plan (NHAP) 2014 was not tailored towards specific outdoor events.[2] Indeed different authority used different level of Air Pollutant Index (API) to delay or cancel outdoor events. For example, for a football match, it was up to the discretion of the marshal of the game to decide when to stop or cancel the game. Stopping or canceling a sport competition such as a football match create lots of logistic and financial problems to both the public (supporters), event management and competing teams alike, in the form of affected travelling, accommodation, meals and many others. Another complicated exposure scenario in Malaysia is during the Independent Day (Merdeka Day) celebration of, whereby most states will organize the parade that involve many categories of people - army, government agencies, Non-Governmental Organization, school children and the public. The parade normally takes a few hours. The time of the celebration of the Merdeka Day (31 August) coincide with the dry season where haze normally occurred: the Southwest Monsoon. Therefore, without a specific advice based on the API level, it is not easy for the relevant authority to cancel or stop the outdoor sport and other major public events.

Most of the current advice related to performing outdoor physical activity during haze are general in nature such as, when API become unhealthy, everyone should limit prolonged or heavy exertion outdoor.[1,2] Prolong exertion is defined as any outdoor moderate physical activity that is performed intermittently for several hours such as working in the yard for part of the day.[3] Whereas, heavy exertion is referred to high intensity physical activities such as jogging.[3] The question arises is how many hours of prolonged or heavy exertion is acceptable during haze?

It is always a challenging task to decide when to stop or cancel a particular outdoor public event during haze. From technical point of views, it is hard to produce a common advisory that applies to all type of the outdoor events. Each of the event may be associated with different duration of exposure and different level of physical activity intensity. For example, a public event, which mainly involves light to moderate physical activity intensity, is not the same as an event that involves high intensity physical activity such as sport events. Similarly, an outdoor camping that people spent most of their time outdoor including their nighttime is different with an event where people have to be outdoor only during certain period of the day. During physical activity, the volume of air intake can increase as much as 10 to 20 times over their resting level.[1] Physiological responses to physical activity includes increase ventilation and increase mouth breathing and by-therefore by-passing air filtration in the nasal passages, both of which increase personal exposure to unhealthy air[4]. Health benefit of cancelling or delaying outdoor events are presumptive effects of reducing those inhaled dose of pollutants when participating public or players do not participate in the outdoor events.

The aim of this paper is to evaluate health risk associated with particulate matter (PM_{10}) exposure among adult population based on the level and duration of physical activity, and thus it can be used as a guide to issue specific advisory related to the different intensity of physical activities.

METHODS

To assess health risk associated with the exposure during haze, we used a standard health risk assessment method, which consists of hazard identification, dose-response relationship, exposure assessment and risk characterization.

Hazard Identification

The key pollutant that determines the API level during haze

From various studies and our own experience, the predominant pollutants that contributed to the API level during haze are the coarse and fine particulate matter (PM_{10} and $PM_{2.5}$).[5,6] For the purpose of this health risk assessment, we focused on the impact of PM_{10} because it is the predominant pollutants during haze and it is included in the current API system in Malaysia to determine the level of API. Even though $PM_{2.5}$ is of significant health concern due to its smaller size which can travel deep into human lungs,[7,8] $PM_{2.5}$ is not routinely measured and is not currently part of the calculations to derive the API level in Malaysia. Therefore, for the purpose of decision making under the current air quality

monitoring system, we assessed the risk related to PM_{10} concentration.

Dose-response relationship

Malaysian Ambient Air Quality Standard (MAAQS)[9] as shown in Table 1 is used to represent the dose-response relationship since we are assessing the health risk within the framework of API in Malaysia. The threshold dose concept was applied, whereby dose or concentration of PM_{10} below the threshold (below the guideline value), there will be no health risk. Above the guideline value, the risk increases linearly with the increment of PM_{10} concentration. As the assessment focused on the daily exposure to poor air quality during haze, the guideline values for 24 hours exposure was used instead of the annual guideline value.

Table 1 Malaysian Ambient Air Quality Standard for PM_{10} and $PM_{2.5}$

Pollutants	Averaging Time	Unit	Ambient Air Quality Standard		
			IT-1 (2015)*	IT-2 (2018)**	Standard (2020)
Particulate Matter with the size of less than 10 micron (PM_{10})	Annual	$\mu g/m^3$	50	45	40
	24 Hour	$\mu g/m^3$	150	120	100
Particulate Matter with the size of less than 2.5 micron ($PM_{2.5}$)	Annual	$\mu g/m^3$	35	25	15
	24 Hour	$\mu g/m^3$	75	50	35

*Interim Target -1 for 2015 (Source: Malaysia Ambient Air Quality Standard)[9]
**Interim Target-2 for 2018, (Source: Malaysia Ambient Air Quality Standard)[9]

Exposure Assessment

Level of Exposure

The hypothetical exposure concentration was established according to the levels of PM_{10} used as the breakpoint for calculation of API as shown in Table 2. To obtain various PM_{10} concentration for the purpose of risk assessment, we generated the concentration of PM_{10} based on the equation for API calculation[10]. Many countries around the world including the Southeast Asia countries (including Malaysia) have been referring to the Air Quality Index (AQI or API in Malaysia) introduced by the United States Environment Protection Agency (USEPA) for the development of their air pollutants index.[11,12,13,14,15] The API ranges from index value of 0 to 500. The API value corresponds with the level of air pollution. The higher is the API value, the higher the level of air pollution. Hence the greater the health concern. An API value of 50 indicates that the air quality is good and has low potential for negative implications to the public health, while an API value of 101 to 150 is unhealthy for sensitive group; API of 151-200 is unhealthy for the general population; 201-300, very unhealthy, and over 300 represents hazardous air quality.[1,2] 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.

Table 2 Breakpoints of PM_{10} concentration and Equation for API [10]

API Range	Breakpoints of PM_{10} concentration, $\mu g/m^3$	Equation for API
	$X = PM_{10}$ (24 h average, $\mu g/m^3$)	
0-50	$0 < X \leq 54$	API = 0.9259 x X
51-100	$55 \leq X \leq 154$	API = 0.4949 x (X-55) + 51
101-150	$155 \leq X \leq 254$	API = 0.4949 x (X-155) + 101
151-200	$255 \leq X \leq 354$	API = 0.4949 x (X-255) + 151
201-300	$355 \leq X \leq 424$	API = 1.4348 x (X-355) + 201
301-400	$425 \leq X \leq 504$	API = 1.2532 x (X-425) + 301
401-500	$505 \leq X \leq 604$	API = 1 x (X-505) + 401

Indoor and outdoor exposure scenarios

To evaluate the exposure to PM10, we must consider a total exposure scenario by summing up the exposure upon staying outdoor and indoor in a day. Due to lack of information about time spent in a vehicle per day for local populations, exposure during commuting was not accounted for in this assessment.

When estimating the exposure intake, a few assumptions were made with regards to the indoor and outdoor concentration of the pollutants;

1. Indoor concentration of $PM_{10:}$ Indoor concentrations of PM_{10} equal to outdoor PM_{10} concentration if the windows are not properly closed. This assumption is hypothetically correct as it is supported by the findings from a recently published local study which consistently reported that the indoor/outdoor (I/O) ratio of PM_{10} in classrooms was 1.02 for both Putrajaya and Kuala Lumpur area.[16] Other studies have shown that the pollutants within a building originated predominantly from an infiltration of outdoor sources and the level is directly influenced by the increasing level of air pollutants outside the building.[17,18,19,20,21,22]

2. Staying indoor with all windows are properly closed has a better protective effect from haze as compared to staying outdoor because of higher concentration of pollutants. Several studies have demonstrated that the 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.[23] To account for this exposure variation between indoor and outdoor, we used I/O ratio of PM to measure accurately the potential dose acquired by subject during haze. As the I/O ratio reported by various studies varies, we carefully select studies or findings that are relevant to Malaysia for our risk assessment (Table 3). Most studies reviewed and focused on I/O ratio of $PM_{2.5}$ except study by Elliot et al 2008 which also included I/O ratio of PM_{10}.[24] Nevertheless, 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 situation could be because of a very low percentage of schools and homes in Singapore that were not equipped with air conditioning. However, it was mentioned clearly that PM_{10} concentration was relatively lower than $PM_{2.5}$ in an indoor environment. For studies conducted in non-tropical countries, we only took the I/O ratio measured during summers which are more relevant to our tropical climate. There is no local study reporting on I/O of $PM_{2.5}$ and PM_{10} in home environment during haze period. For 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 3 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	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Home / I/O ratio during forest fire, summer, (Barn *et al* ., 2008)[25]	0.19	-	0.60	-
Home / exposure scenario not mentioned (Elliot *et al*., 2014)[24]	0.50	0.38	-	-
School / exposure scenario not mentioned (Elliot *et al*., 2014)[24]	0.20	0.18	-	-
Home / exposure scenario not mentioned (Ryan *et al.*, 2012)[26]	0.10 – 0.49	-	0.62	-
Schools / non-haze period (Mohamad *et al.,* 2016)[16]	-	-	-	1.02

Physical activity pattern and inhalation rate

Potential inhaled dose is mainly influenced by duration of exposure, the intensity of physical activities in different microenvironments and inhalation rate (IR) (m^3/min) of the age-specific population. As our assessment is related to short-term exposure to PM_{10} daily basis during haze, we used recommended short-term exposure IR values for adult and level of physical activity published by the US EPA (Table 4)[27]. The US EPA grouped activity intensity according to their Metabolite Equivalents (METs) values: Sedentary/passive (METs < 1.5), light intensity (1.5<METs<3.0), moderate intensity (3.0<METs<6.0), and high intensity (METs>6.0)[28].

In this health risk assessment, specifically for the calculation of inhaled dose for adult population, the highest age-specific IR that belongs to the age group of 51 to 60 years old was chosen. The rationale of choosing this age-specific IR value for the input of dose calculation was because it is more conservative and likely to be protective to the other adult age groups as well.

Table 4 Recommended short-term age-specific inhalation rate (m^3/min) for adult males and female combined by activity level[27].

Activity level	Age Group	Mean IR (m^3/minute) for 50^{th} percentile	Mean IR (m^3/minute) for 95^{th} percentile
Sleep	21- < 31 yrs	0.0043	0.0065
	31- < 41 yrs	0.0046	0.0066
	41- < 51 yrs	0.0050	0.0071
	51- < 61 yrs	0.0052	0.0075
	61- < 71 yrs	0.0052	0.0072
	71- < 81 yrs	0.0053	0.0072
	>81 yrs	0.0052	0.0070
Sedentary/passive	21- < 31 yrs	0.0042	0.0065
	31- < 41 yrs	0.0043	0.0066
	41- < 51 yrs	0.0048	0.0070
	51- < 61 yrs	0.0050	0.0073
	61- < 71 yrs	0.0049	0.0073
	71- < 81 yrs	0.0050	0.0072
	>81 yrs	0.0049	0.0070
Light intensity (1.5<METs<3.0)	21- < 31 yrs	0.0120	0.0160
	31- < 41 yrs	0.0120	0.0160
	41- < 51 yrs	0.0130	0.0160
	51- < 61 yrs	0.0130	0.0170
	61- < 71 yrs	0.0120	0.0160
	71- < 81 yrs	0.0120	0.0150
	>81 yrs	0.0120	0.0150
Moderate intensity (3.0<METs<6.0)	21- < 31 yrs	0.0260	0.0380
	31- < 41 yrs	0.0270	0.0370
	41- < 51 yrs	0.0280	0.0390
	51- < 61 yrs	0.0290	0.0400
	61- < 71 yrs	0.0260	0.0340
	71- < 81 yrs	0.0250	0.0320
	>81 yrs	0.0250	0.0310
High intensity (METs>6.0)	21- < 31 yrs	0.0500	0.0760
	31- < 41 yrs	0.0490	0.0720
	41- < 51 yrs	0.0520	0.0760
	51- < 61 yrs	0.0530	0.0780
	61- < 71 yrs	0.0470	0.0660
	71- < 81 yrs	0.0470	0.0650
	>81 yrs	0.0480	0.0680

Time spent for physical activity pattern of Malaysian adults: Findings from the Malaysian Adult Nutritional Survey (MANS)

Time spent for each type of physical activity level in a day (24 hours) is of paramount importance for the dose calculation and normally it varies by individual. However, for the health risk assessment, we used findings from population survey (Malaysian Adult Nutritional Survey; MANS 2003) to represent time spent for the physical activity pattern of Malaysia adults[29]. The latest MANS 2014[30] did not contain information on time spent by the types of physical activities that are required for health risk assessment. According to the MANS 2003, Malaysian adults spent majority of their time of the day (74%) in sedentary activities; doing light intensity activities (15%), and doing moderate to vigorous intensity activities (10%).[29] The details of the physical activity of Malaysian men and women are shown in Table 5. Unfortunately, the information on time spent indoor and outdoor among Malaysian adults was not available. Therefore, we assumed that sedentary activities such as sleeping, lying down, sitting, and personal care (approximately > 74 % of the total time per day) were performed indoor.

Table 5 Time spent by type of physical activity of Malaysian men and women combined[29]

Activities	Time spent (Mean Minutes, 95 % CI) (N = 13,867,950)
Sleeping and lying down	477.2 (473.6 – 480.7)

Sitting	586.8 (581.5 – 592.1)
Standing	170.6 (166.6 – 174.6)
Walking	137.5 (135.2 – 139.8)
Personal care activities	50.5 (49.8 – 51.2)
Climbing up and down stairs	2.1 (1.9 – 2.3)
Sports activities	7.9 (7.2 – 8.6)
Other activities	7.4 (6.4 – 8.4)

For the calculation of inhaled dose, because of complex exposure duration and physical activity pattern indoor and outdoor, we have to combine information from MANS and created a few exposure scenarios to suit the required time of exposure related to the events under assessment.

Scenario 1: Outdoor high intensity physical activities

Since our main interest was to calculate the risk associated with high physical intensity activities, we created scenarios that consisted of a different duration of high physical activities performed ranging from 5 minutes to 90 minutes, modified accordingly by the time spent for moderate physical activities to maintain 10 % total time for moderate to vigorous activities. For example, if a person performed 45 minutes of high physical intensity activity, the time for moderate activity will be set approximately at 105 minutes. The time spent for moderate activity reduces with the increase in time for high physical intensity activity and vice versa. The time spent for light physical activities and sedentary/passive including sleeping was approximately set as recommended by MANS data (74 % and 15 % for sedentary/passive and light intensity activities respectively). The subjects spent approximately 74 % of their time indoor.

Scenario 2: Outdoor moderate intensity physical activity such public event like celebration of Merdeka Day celebration, or public gathering activities

Under this scenario, our main interest is to calculate the risk associated with time spent for performing moderate physical intensity outdoor (prolonged exertion). We simulate up to five hours of moderate physical intensity activity with a short duration of high physical intensity (5 minutes). The time spent for sedentary/passive including sleeping activities was maintained at 74 % that mainly occurred indoor.

Characterizing the risk

Estimating the Potential Inhaled Dose of PM_{10}

The potential inhaled dose was calculated 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) 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).

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) indoor and outdoor. 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 the recommended EPA standard as recommended in the exposure factor handbook as shown in Table 3.

ET = Exposure Time (min /day). Exposure time is the amount of time in which the subject spent their time performing physical activities indoor and outdoor.

Health Risk

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

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

Where;

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

Health Reference Value: During haze the dominant pollutant that determines the API level is PM_{10}. Hence, we used the Malaysian Ambient Air Quality Standards (MAAQS) value of 120 µg/m^3 for 24 hours exposure to PM_{10} as the health reference concentration for calculating the health risk during haze.

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 = MAAQS value ($\mu g/m^3$)/day x IR (m^3/day)

Whereby;

IR (m^3/day): The default recommended average inhalation rate for adults (male and female combined), is 20 m^3/day. The IR of 20 m^3/day was also used as a default inhalation rate value by the ICRP, US EPA and WHO for their risk assessment.[31,32]

RESULTS

The result of risk assessment is presented in the form of risk radar diagram that includes two independent variables (The duration (min) of physical activity and API level) and one dependent variable (risk quotient). The value of Risk Quotient (RQ) is on the axial axis starting from zero at the center. RQ value of more than one; indicate the possibility of developing health effects. If API line crossed the RQ one, it indicates the maximum acceptable duration for performing physical activity outdoor at that particular API level. In general, as the API level and the duration of physical activity performed increases, the risk of developing health effects also increases (RQ > 1).

The risk radar diagram for performing high intensity physical activity is shown in Figure 1 and Figure 2. Based on the risk radar diagram, for a high estimate as shown in Figure 1, RQ for API 135 exceeded even at zero minutes of heavy exertion. Whereas, for API 105, RQ exceeded one when the duration of heavy exertion is 90 minutes. These finding indicate that all vigorous or high intensity physical activity should be avoided when API > 135, whereas, for API below 135, heavy exertion still can be performed with limited duration (min). In contrast, based on average estimate as shown in Figure 2, all vigorous or high intensity physical activity should be avoided when API > 175 as the RQ exceeded one even when performing very short (less than 5 minutes) high intensity physical activity. Based on the risk radar diagram (Figure 1 and 2), we computed the recommended maximum duration for performing high intensity physical activity as shown in Table 6.

Table 6 Recommended maximum duration of high intensity physical activity based on API level

Maximum duration of high intensity physical activity (minutes)	Level of API for performing heavy physical activity based on average and high estimate of Inhalation Rate (m^3/min)	
	Average/ 50^{th} Percentile Inhalation Rate (m^3/min)	95^{th} Percentile Inhalation Rate (m^3/min)
90	140	105
70	150	110
60	155	115
40	160	120
20	165	125
10	170	130
Avoid all heavy physical activity	$\geq$175	$\geq$135

The risk radar diagram for performing prolonged exertion or moderate intensity physical activity is shown in Figure 3 and 4. Prolonged exertion can be performed up to for 5 hours (300 min) at API $\leq$ 101 and $\leq$ 130 for high (95^{th} Percentile) and average (50^{th} Percentile) estimate respectively. The acceptable duration for performing prolong exertion reduces with increasing API level. Based on the risk radar diagram (Figure 3 and 4), we computed the recommended maximum duration for performing moderate intensity physical activity as shown in Table 7.

Table 7 Recommended maximum duration of moderate intensity physical activity based on API level

Maximum duration of for performing moderate intensity physical activity (minutes)	Level of API for performing moderate physical activity (prolong exertion) based on average and high estimate of Inhalation Rate (m^3/min)	
	50 Percentile Inhalation Rate (m^3/min)	95 Percentile Inhalation Rate (m^3/min)
300	130	101
240	140	110

190	160	120
150	170	130
120	180	140
Limit moderate physical activity less than 90 minutes	200	150
Avoid all moderate physical activity	≥200	≥150

Figure 1 Risk radar diagram showing the relationship between risk quotients for performing high intensity physical activity (Minutes) based on 95th percentile inhalation rate value during haze as measured by API level

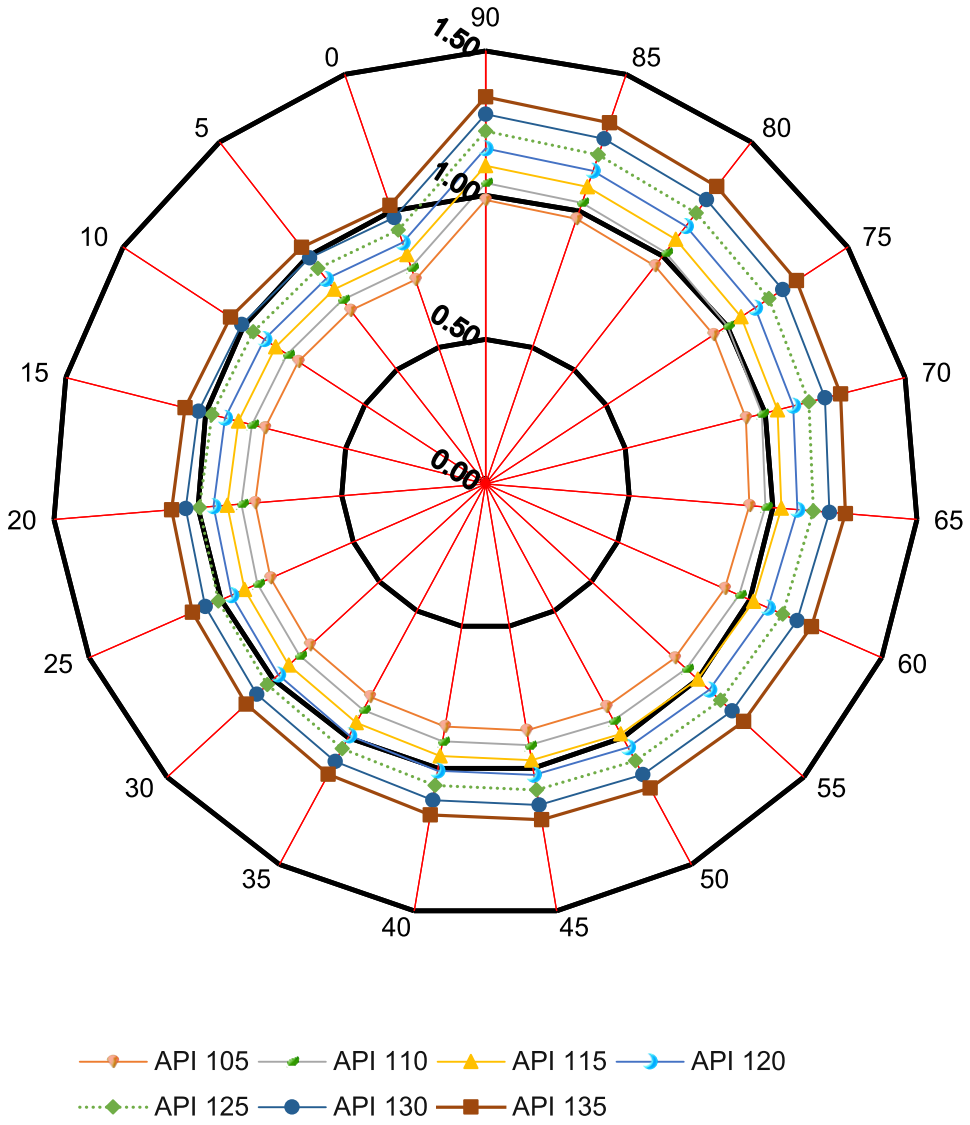


Figure 2 Risk radar showing the relationship between risk quotients for performing high physical intensity (Minutes) based on 50th percentile (average) inhalation rate value during haze as measured by API level

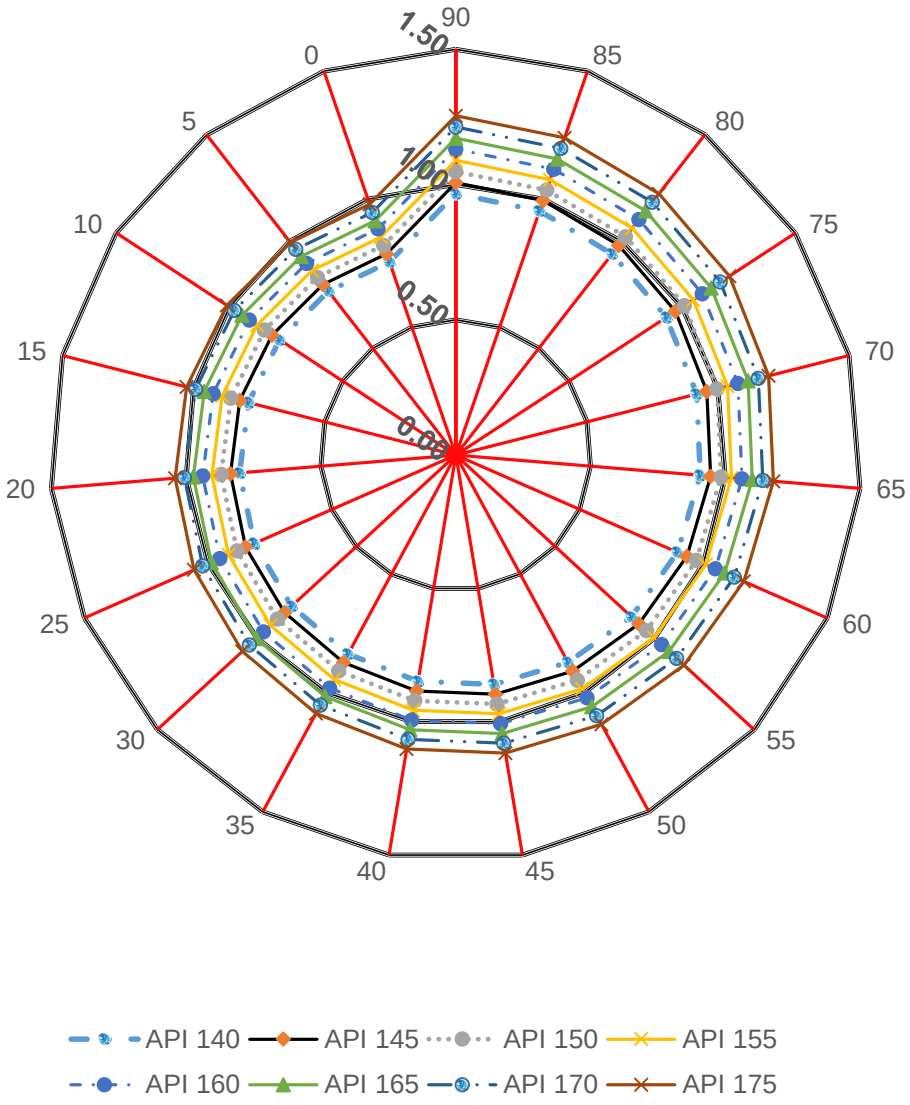


Figure 3 Risk Radar showing the relationship between risk quotients for performing outdoor moderate physical intensity (Minutes) based on 95th percentile inhalation rate (m^3/min) value during haze as measured by API level

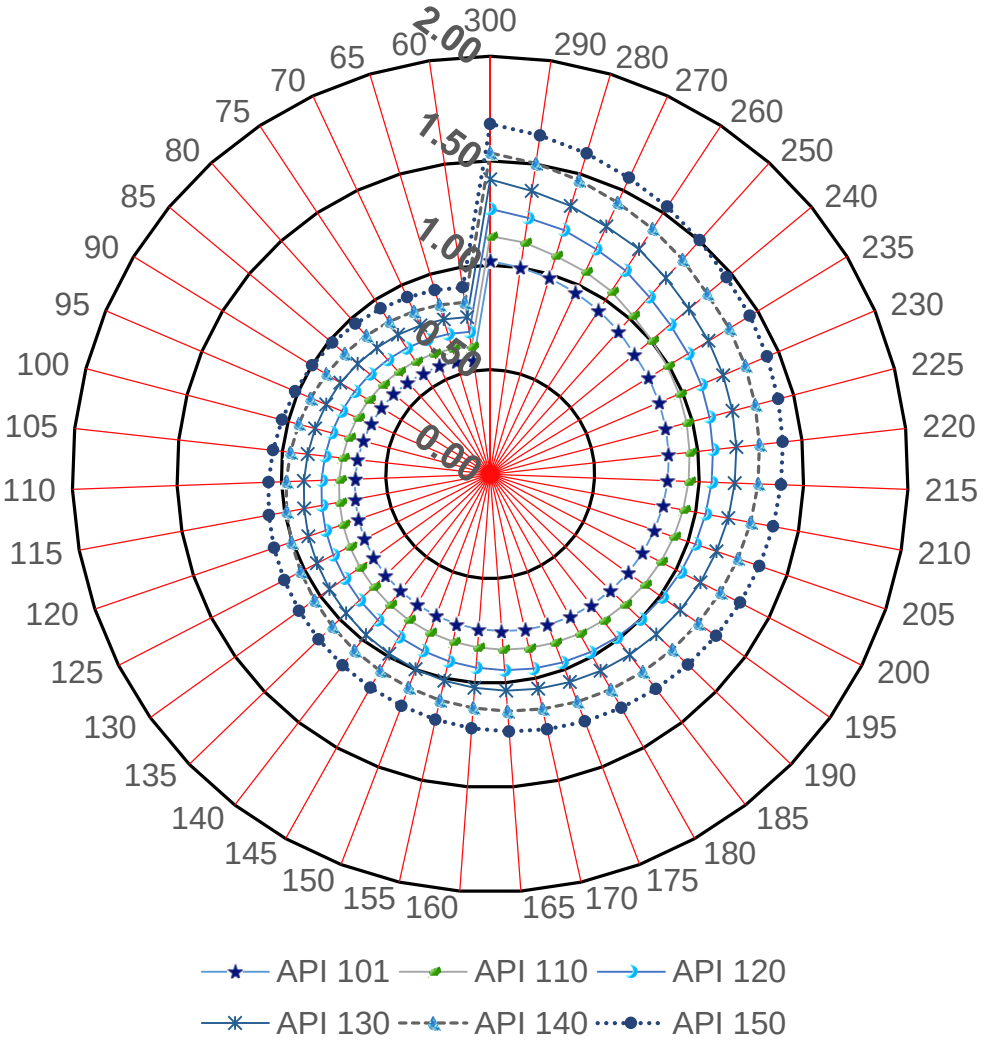
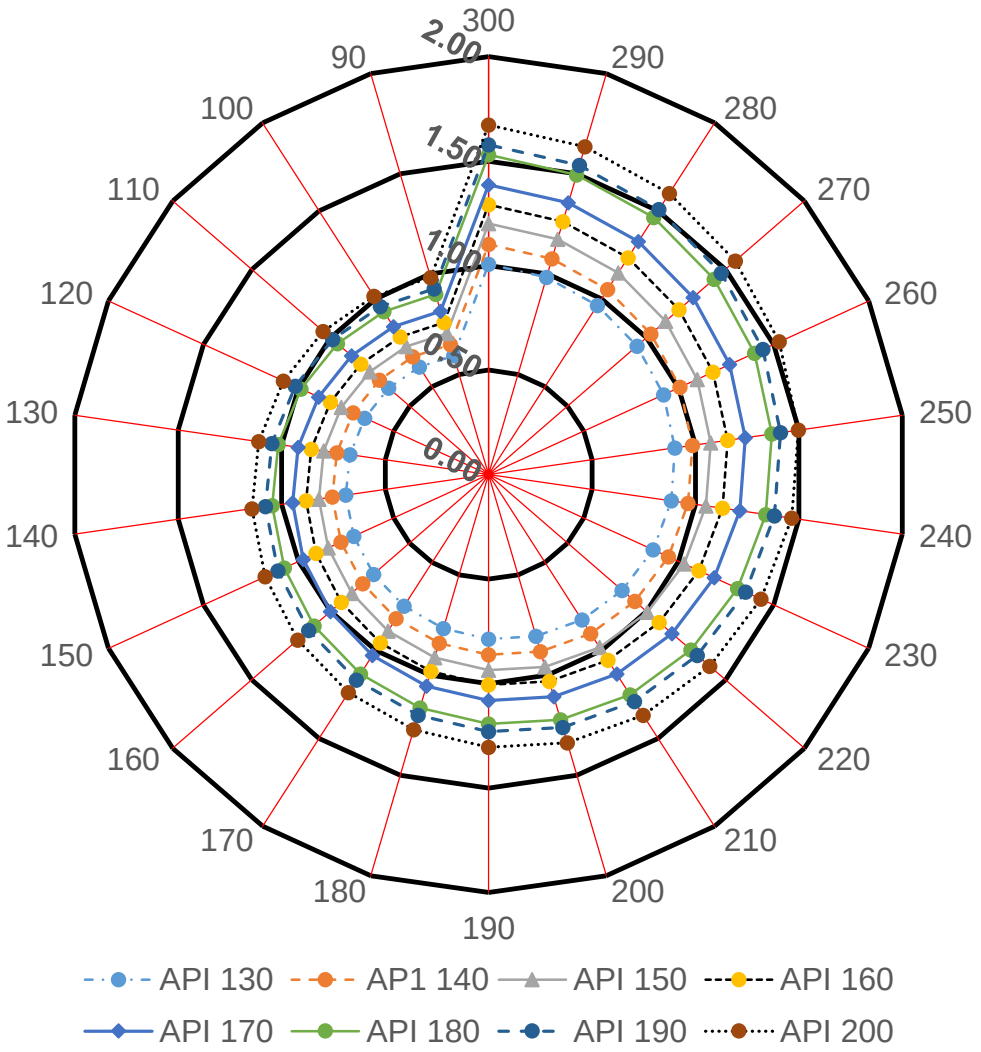


Figure 4 Risk Radar showing the relationship between risk quotients for performing outdoor moderate physical intensity (Minutes) based on 50th percentile inhalation rate (m^3/min) value during haze as measured by API level



DISCUSSION

The rationale for conducting this risk assessment of exposure to particulate matters during poor air quality is to approximately determine the acceptable duration to perform a different type of physical activity outdoor during haze. The assessment may provide a guide for the authorities or public to decide for organizing or canceling an outdoor public event or sport event during haze. In general, most of the advisories issued by authorities do not explicitly mention the acceptable duration for performing physical activity outdoor. The advisories normally used a subjective word such as reduce, minimize or limit prolonged or heavy physical activity when API become unhealthy and avoid prolonged or heavy exertion when API become very unhealthy.[1,2] What does it means by "reduce or limit" prolonged physical activity or heavy exertion? When API reach a certain level, for how many hours or minutes should public limit their outdoor activity? Due to subjectivity of the word used, and the fact that time spent and pattern of physical activity are different by type of event, has caused difficulty and confusion for the authority to decide when to cancel or postpone the outdoor public event or sport event. For example, in a football match normally the players would be spending 90 minutes performing high intensity physical activity outdoor. Whereas, other sport games such as outdoor lawn bowling, petanque and

shooting may only involve light to moderate intensity physical activity for several hours. Similarly, for a public event, such as the celebration of Merdeka Day may involve prolonged exertion that lasts for several hours.

There were no published epidemiological studies that examine the association between the duration of outdoor physical activity during haze and health risk. Thus, to determine the risk associated with the duration of performing physical activity outdoor during haze, we employed a risk assessment methodology as described in the method section. It is a well-known fact that the time spent and the type of physical activities performed contribute to the potential dose inhaled by an individual due to the increasing inhalation rate (m^3/min) and changing the mode of breathing from the nose to the mouth, which the latter has limited filtration effect.[33] During exercise, an individual can increase their air intake as much as 10 to 20 time over their resting level.[1] Thus, knowing the approximate acceptable duration for performing physical activity outdoor is a paramount importance to modify the schedule or limit the time spent for physical activities outdoor.

Based on the risk radar diagram computed, we derived the recommendation as a guide to the public (Table 6 and Table 7). The rationale to present both health risk assessment results based on the 50th percentile and 95th percentile IR values was to provide an option for decision makers to choose the appropriate API for their guideline. In general, according to EPA, the 95th percentile IR value represent unusually high estimate which is not representative of IR for the general population. Therefore, these values should be used with caution when estimating exposure intake and risk.[27] Based on the 95th percentile IR, the public should avoid all heavy physical activity outdoor when the API reaches 135. In contrast, the calculated risk based on the 50th percentile IR values, suggest that the public should avoid performing high intensity physical activity at a much higher API level which is 175. Below the said API level, the duration for performing high intensity physical activity such as sport activity should be reduced according to the incremental level of API. For a football match that requires 90 minutes to end, the match should be delayed or stopped when API is more than 140. This finding is relatively more stringent than a guide produced by Spokane Regional Health District (2015)[34] which limit the vigorous activity for up to two hours when API become unhealthy (150). Comparison with other guidelines cannot be made as most advice are non-specific, which stated that everyone should limit and avoid heavy exertion outdoor when air quality becomes unhealthy (150) and very unhealthy respectively without mentioning the acceptable time (Table 8).

For prolonged exertion activity or moderate intensity physical activity, the recommended maximum duration based on API level is shown in Table 6. According to EPA, 2014 prolonged exertion is defined as any outdoor activity that is performed intermittently for several hours that cause an increase in breathing than normal. Based on 50th percentile IR value, the calculated risk consistent with advisory issued by EPA, 2016, whereby everyone should avoid prolong exertion or heavy exertion when API become very unhealthy (API >200). However, for API 101 to 200, there was no specific recommendation for performing prolonged exertion stated in the advisory issued by EPA. Most advisories are only giving general advice to reduce or limit prolonged exertion without mentioning the approximate acceptable time. Our finding indicates that if API reaches 130 (average estimate) and 101 (high estimate), the public can continue doing moderate intensity physical activities up to 5 hours and the duration is reduced according to the incremental of API level.

In general, our health risk assessment finding was consistent with the current advisory issued by US EPA, 2016[1] and NHAP 2014[2] except that those advisories were lacking in term of time-specific advice about the duration of physical activity when API become unhealthy. This health risk assessment has contributed to coming out with the recommended maximum duration for performing either moderate or high intensity physical intensity during poor air quality based on API level. Table 8 shows the details advisory related to the physical activity during poor air quality.

Table 8 Comparison between the current advisory and commentary based on health risk assessment pertaining to the performing physical activity outdoor

API Category	Existing Advisory (EPA, 2016; NHAP 2014)[1,2]	Our complementary to the existing advisory based on the finding from health risk assessment
Unhealthy for sensitive group (101-150)	Sensitive group: people with heart disease, respiratory disease, children and elderly - Limit prolonged exertion - **Avoid** physical exertion Everyone:	Sensitive group: should comply with existing advisory. Based on risk radar diagram computed, we provided a guide on

	- should **reduce** or **limit** prolonged or heavy exertion	how long someone can spend their time outdoor doing physical activity as mentioned in Table 5 and Table 6: The recommended maximum duration for performing physical activity during poor air quality. With the approximate maximum acceptable time for performing physical activity pattern, it will facilitate public or relevant agency to organize or cancel an outdoor event during poor air quality
Unhealthy (150-200)	Sensitive group: - should **avoid** prolonged or heavy exertion Everyone: - should **reduce** or **limit** prolonged or heavy exertion - However, there is no clear guide on how someone should reduce or limit their physical activity	
Very unhealthy (201-300)	Everyone: - should **avoid** prolonged or heavy exertion	Everyone: - should comply with existing advisory.
Hazardous (> 300)	Everyone: - should **avoid** any outdoor activity	Everyone: - should comply with existing advisory.

Limitation of the study: It is very essential 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, or MAAQS value for PM10 is revised or PM2.5 parameter is used instead of PM10 for the calculation of API during haze, the risk need to be recalculated. This finding is mainly applicable for healthy Malaysian adult as we used data from MANS for obtaining the information on physical activity pattern. The sensitive group should comply with the existing advisory. The used of IR values derived from other population groups may also introduce uncertainty to the health risk assessment results for Malaysian adult. In addition, the assessment is valid if the public continues to maintain at least 74 % of their time indoor. Therefore, when air quality reduced, the public is advised to be outdoor only when necessary. When stay at home, keep doors and window closed to prevent contamination from outdoor pollutant during poor air quality or haze. The Public are strongly advised to use air conditioning system with higher efficiency filters to further improve the indoor air quality. Avoid smoking or burning activities that can further increase the level of indoor air pollutants.

CONCLUSION

The present health risk assessment provides a more specific advice related to the duration of performing the outdoor physical activity during poor air quality. In general, based on the average estimate, everyone should avoid the high intensity physical activity and prolonged exertion when API reach $\geq$ 175 and > 200 respectively. Whereas, based on high estimate, everyone should avoid high intensity physical activity and prolonged exertion when API reach $\geq$ 135 and > 150 respectively. While at a lower API level, the duration of physical activity should be reduced according to the respective API level. The computed risk radar and the recommended maximum duration for performing physical activity provide valuable guides for public or relevant authority to organize or considering postponing an outdoor activity depending on the type of the event and API level. The above findings are valid in the context of the current Malaysia API system and suitable for Malaysian adult.

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