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Assessment of Health Risk from Exposure to Respirable Particulate Matter (RPM) among Motorcycle Taxi Drivers in Bangkok and Adjacent Provinces, Thailand

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ABSTRACT

Exposure to outdoor air pollutants, particularly respirable particulate matter (RPM), can cause adverse health outcomes. The cross-sectional study aimed to assess motorcycle taxi driver’s health risk from exposure to RPM. A total of 153 motorcycle taxi drivers were recruited in Bangkok and five adjacent provinces during May and June 2022. The standardized questionnaire for data collection contained exposure time (hour/day), frequency of exposure (days/years), duration of exposure (year), body weight (kg), and averaging time (days). The average RPM concentration from six provinces were assessed personal air sampling pumps and ranged from 0.006-0.031 mg/m^3. Bangkok showed the highest average RPM concentration (0.031 mg/m^3), followed by Pathumthani (0.028 mg/m^3), Samut Prakan (0.009 mg/m^3), Nakhon Pathom (0.008 mg/m^3), Nonthaburi (0.007 mg/m^3), and Samut Sakhon (0.006 mg/m^3), respectively. The Hazard Quotient (HQ) values for a non-carcinogenic risk to human health caused by RPM exposure in each province indicated a negligible risk (HQ=0.005-0.028). HQ averages (HQ=0.013) from all provinces were also at an acceptable level ($\leq$1). Not all motorcycle taxi drivers are safe from RPM exposure, although their exposure is within acceptable limits depending on their individual susceptibility. Therefore, this is the first report on quantifying exposure to RPM from personal air sampling and health risk assessment among motorcycle taxi drivers. These findings would be useful information for further preventing and controlling ambient air pollution including policies and strategies to mitigate the risks for motorcycle-taxi drivers and the other exposed populations.

1. INTRODUCTION

Outdoor air pollution is the leading cause of more than 3 million deaths and premature deaths worldwide each year (Thurston et al., 2017). Respirable particulate matter (RPM) is defined by its diameter for air quality regulatory purposes. Those with a diameter of 10 microns or less (PM_{10}) are inhalable into the lungs and can induce adverse health effects. Fine particulate matter is defined as particles that are 2.5 microns or less in diameter ($PM_{2.5}$). Therefore, $PM_{2.5}$ comprises a portion of PM_{10}. The World Health Organization (WHO) estimates that more than 90% of the world’s population lives in areas where air quality is below recommended values. From the literature review on air quality in Thailand during 2010-2020, it was found that the annual average concentration of PM_{10} and $PM_{2.5}$ mostly exceeded the Thailand and WHO standard especially in Bangkok and adjacent provinces (Pollution Control Department, 2022). Those areas are urban communities with dense populations and heavy traffic. The main source of PM_{10} and $PM_{2.5}$ in these areas is

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traffic (Pollution Control Department, 2022). Motorcycle taxi drivers are at risk of exposure to PM_{10} and $PM_{2.5}$ because they are likely to be directly exposed to air pollution. In addition, their working posture requires sitting on an open motorcycle, and the environment where the motorcycle taxi terminals are located on the roadside, which may affect their respiratory problems. Around 76.0% of them work in the central region of Thailand (Bureau of Highway Safety, Department of Highways, 2021). They must drive to pick up or drop off passengers outside buildings throughout their working hours, on average 10 hours per day, and ranging from 4-19 hours per day (Suebsuk et al., 2014). Therefore, there is more chance of exposure to ambient air pollution than in other occupations. In addition, previous studies have focused on commuter's exposure to BTEX in public transportation modes in Bangkok (Ongwandee and Chavalparit, 2010), occupational exposure of gasoline station workers to BTEX compounds in Bangkok (Tunsaringkarn et al., 2012), health risk levels to benzene, toluene, ethylbenzene, and xylenes (BTEX) and carbonyl compounds (CCs) inhalation exposure of traffic policemen working in the inner city of Bangkok (Kanjanasiranont et al., 2017), and BTEX exposure including health risk assessment among car park workers (Loonsamrong et al., 2017). There have also been studies to determine the relationship between personal factors and pulmonary function abnormalities in Indonesia, Malaysia as well as in Tak, Chiang Mai, and Bangkok in Thailand (Suebsuk et al., 2014; Kheunpeck and Tantipanchaporn, 2016; Damayanti et al., 2019; Putri Anis Syahira et al., 2020). These studies were unable to demonstrate exposure to RPM and health effects, making health surveillance of such occupations ineffective.

Assessment of health risk from exposure to RPM consists of four steps according to the USEPA (USEPA, 2022).

1) Hazard identification

This process is to identify the RPM exposure to a stressor which can cause an increase in the incidence of specific adverse health effects (e.g., pneumonia, emphysema, tuberculosis, cerebrovascular disease, chronic obstructive pulmonary disease, ischemic heart disease, acute lower respiratory tract infection). When motorcycle taxi drivers are inhaled the RPM into their bodies, and a specific process of absorption, distribution, metabolism, and excretion takes place. This process is called toxicokinetics (Phanprasit, 2014).

2) Dose-response assessment

The term exposure-response relationship describes either a dose-response or a concentration-response, or other specific exposure conditions. Typically, as the dose increases, the measured response also increases. At low doses there may be no response. The scientific information is evaluated for adverse health effect or response; the understanding of the response is called the mode of action. Based on this mode of action, the agency determines the nature of the extrapolation, either through non-linear or linear dose-response assessment. A nonlinear assessment uses a dose-response relationship whose slope was zero (i.e., no response) at a dose of zero. No-Observed-Adverse-Effect Level (NOAEL) is used as a reference dose for nonlinear assessment. However, in cases where NOAEL has not been experimentally demonstrated, the term of Lowest-Observed-Adverse-Effect Level (LOAEL) is used as the lowest or reference dose instead of the NOAEL. The reference dose (RfD) is an oral or dermal dose derived from the NOAEL or LOAEL by application of generally order of magnitude uncertainty factors (UFs). These uncertainty factors take into account the variability and uncertainty that are reflected in possible differences between test animals and humans, and variability within the human population. On the part of assessing linear dose response, in this type of assessment, there is theoretically no level of exposure for such a chemical that does not pose a small, but finite, probability of generating a carcinogenic response. The extrapolation phase of assessment does not use UFs; rather, a straight line is drawn from the point of departure for the observed data to the origin (where there is zero dose and zero response). The slope of this straight line, called the slope factor or cancer slope factor, is used to estimate risk at exposure levels that fall along the line. When linear dose-response is used to assess cancer risk, the cancer risk is determined by considering the exposure and slope factor.

3) Exposure assessment

Average Daily Dose (ADD) is used to describe the exposure assessment. The potential dose of a RPM is the product of the RPM concentration, inhalation rate, exposure time, exposure frequency, and exposure duration divided by the product of averaging time and body weight.

4) Risk characterization

This step is to summarize and integrate information from the proceeding steps of the risk assessment to synthesize an overall conclusion about risk.

Exposure to RPM affects health, thereby increasing the risk of acute and chronic respiratory disease and impaired lung function (Sonjai, 2001; Boonchu, 2005; Kheunpeck and Tantipanchaporn, 2016). At present, the number of registered motorcycles in Thailand has increased to approximately 21.7 million units (Statista, 2022). However, up to date, there is still a lack of studies assessing health risks from exposure to RPM of motorcycle taxi drivers. More evidence is still required to assess the health risk of RPM among motorcycle taxi drivers. Therefore, this study determined the assessment of health risk from exposure to RPM in the working environment among motorcycle taxi drivers in Bangkok and adjacent provinces in Thailand. The findings provided the crucial data based on health risk assessment to assist in proper prevention actions and controlling strategies.

2. METHODOLOGY

2.1 Study area

The motorcycle taxi drivers were selected from the central region of Thailand. Those areas included Bangkok, Pathum Thani, Samut Prakan, Samut Sakhon, Nonthaburi, and Nakhon Pathom. Bangkok and adjacent provinces occupy 7,762 km^2 with a population of 10,899,786 people and 5.6 million inhabitants respectively (National Statistical Office, 2021).

2.2 Study design and participants

This cross-sectional study was used in 153 motorcycle taxi drivers who worked to pick up or drop off passengers outside buildings. The study was conducted from May to June 2022. The participants were all over 20 years old motorcycle taxi drivers who were chosen through random sampling. The recruitment process was based on the inclusion and exclusion criteria. These criteria for the study are shown in Table 1.

Table 1. Inclusion and exclusion criteria for a cross-sectional study of motorcycle taxi drivers

Inclusion criteria	Exclusion criteria
Over 20 years of age	Diagnosis of chronic respiratory disease or any other chronic respiratory disease
Motorcycle taxi drivers who worked in ambient outdoor more than one year in Bangkok and adjacent provinces	Having an intermittent period working outdoor such as a stopping to work for other jobs outdoor and moving to indoor for doing work
Thai nationality and able to speak Thai language	Refusal to give informed consent

All participants must have a negative result for COVID-19 with a screening antigen test kit prior to interview and RPM measurement.

2.3 Data collection and instruments

The questionnaires were developed and adopted from previous studies by researchers which were approved by 3 experts before data collection with IOC; 0.70-1.00. Questionnaires were completed by face-to-face interviews with all participants. Exposure time (hour/day), frequency of exposure (days/years), duration of exposure (year), body weight (kg), and averaging time (days) were assessed via questionnaires.

The exposure to RPM of participants was measured using personal air sampling pumps with an aluminum cyclone and PVC membrane filter of 5.0 µm pore size (UNIVERSAL PCXR8, SKC, Inc., USA). Personal air sampling pumps were calibrated and set up at 2.5 L/min; NIOSH Method 0600 using the gravimetric (filter weight) technique for analyzing the mass of RPM in the air (National Institute for Occupational Safety and Health, 1998). After RPM samples were completed, questionnaires were collected and analyzed.

2.4 Data analysis

The data were analyzed with the statistical program Statistical Package for Social Sciences (SPSS version 23). Descriptive statistics were used for analyzing the data. Furthermore, health risk assessment was conducted by using data analysis from the questionnaires and RPM measurements. The RPM concentration limit of 3 mg/m^3 (inhalation slope factor) was used as a reference concentration for this study (USEPA, 2019). The equation parameter in Equation (1) was used to describe the potential dose of RPM among motorcycle taxi drivers.

$$\text{Average Daily Dose (ADD)} = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT} \quad (1)$$

Where; ADD=Average Daily Dose (mg/kg·day); C=RPM concentration (mg/m^3); IR= Intake rate (m^3/h);

ET=Exposure time (h/day); EF=Frequency of exposure (days/year); ED=Duration of exposure (year); BW=Body weight (kg); AT=Averaging time (days).

Hazard Quotient (HQ) was used to describe risk to human health caused by RPM exposure. HQ was the ratio of the potential exposure to RPM and the level at which no adverse effects are expected, as shown in Equation (2). HQ less than or equal to 1 indicates that adverse effects are not likely to occur, and thus can be considered to have negligible hazard. HQ greater than 1 are not statistical probabilities of harm occurring.

$$HQ = \frac{ADD}{RfC} \quad (2)$$

2.5 Ethical approval

Ethical approval to conduct this study was received from the Human Research Ethics Committee of Thammasat University, No.3. Ethical approval number 031/2565, and the approval date was April 29, 2022.

3. RESULTS AND DISCUSSION

3.1 Demographics information for health risk assessment

Table 2 shows the demographic information of the participants. Data collection was grouped by the six areas, consisting of Bangkok (BKK), Pathumthani (PTT), Samut Prakan (SPK), Samut Sakhon (SKN), Nonthaburi (NBI), and Nakhon Pathom (NPT). The distribution of the collected sample was determined by the density of motorcycle taxi drivers. BKK collected the most samples (37.3%), followed by SPK (22.2%), PTT (13.7%), NBI (9.8%), SKN (10.5%), and NPT (6.5%). There were 153 participants, including 7 females and 146 males. The results showed that 41.8% of the male participants were between 50-59 years old, 39.9% of the participants had never smoked before. Most of the participants (58.8%) had more than 10 years of experience in this occupation and took 11 hours a day to perform their work almost every day. Almost all of the participants used respiratory protection equipment while performing work. The types of respiratory protective equipment used by the participants were surgical masks (92.2%), hygienic masks made from cotton (7.8%), muslin masks (7.8 %), N95 masks (3.9%), and buff masks (2.6%), respectively.

3.2 Parameters of the ADD and HQ for RPM

HQ was used to describe the potential exposure to RPM in terms of average daily dose and level at which no adverse effects were expected, also known as the reference dose. Both ADD and HQ for RPM in each province are shown in Table 3.

Table 2. Demographics of the participants by six provinces (n=153).

Characteristics		No. (%) of participant						
		BKK	Adjacent provinces					Total
			NBI	PTT	SPK	SKN	NPT	
Gender	Male	55 (96.5)	14 (93.3)	20 (95.2)	33 (97.1)	15 (93.8)	9 (90.0)	146 (95.4)
	Female	2 (3.5)	1 (6.7)	1 (4.8)	1 (2.9)	1 (6.2)	1 (10.0)	7 (4.6)
Age (year) x̄±SD (min.-max.) = 50.75±10.38 (20.0-79.0)	20-29	4 (7.0)	0 (0.0)	1 (4.8)	1 (2.9)	1 (6.3)	0 (0.0)	7 (4.6)
	30-39	11 (19.3)	0 (0.0)	3 (14.3)	0 (0.0)	1 (6.3)	0 (0.0)	15 (9.8)
	40-49	16 (28.1)	2 (13.3)	3 (14.3)	12 (35.3)	5 (31.1)	4 (40.0)	42 (27.5)
	50-59	21 (36.8)	7 (46.7)	13 (61.8)	12 (35.3)	8 (50.0)	3 (30.0)	64 (41.8)
	≥60	5 (8.8)	6 (40.0)	1 (4.8)	9 (26.5)	1 (6.3)	3 (30.0)	25 (16.3)
Smoking history	Never-smoker	30 (52.6)	5 (33.3)	3 (14.3)	14 (41.2)	7 (43.8)	2 (20.0)	61 (39.9)
	Current smoker	24 (42.1)	6 (40.0)	10 (47.6)	8 (23.5)	2 (12.4)	8 (80.0)	58 (37.9)
	Former smoker	3 (5.3)	4 (26.7)	8 (38.1)	12 (35.3)	7 (43.8)	0 (0)	34 (22.2)

Table 2. Demographics of the participants by six provinces (n=153) (cont.)

Characteristics		No. (%) of participant						
		BKK	Adjacent provinces					Total
			NBI	PTT	SPK	SKN	NPT	
Work experience (year) $\bar{x}$±SD (min.-max.) = 12.24±9.05 (1.0-40.0)	<5	19 (33.3)	3 (20.0)	8 (38.1)	6 (17.6)	4 (25.0)	1 (10.0)	41 (26.8)
	5-10	9 (15.8)	0 (0)	4 (19.0)	6 (17.6)	1 (6.3)	2 (20.0)	22 (14.4)
	>10	29 (50.9)	12 (80.0)	9 (42.9)	22 (64.8)	11 (68.7)	7 (70.0)	90 (58.8)
Work hour (hour per day) $\bar{x}$±SD (min.-max.) = 11.89±2.75 (3.0-18.0)	<8	4 (7.0)	1 (6.7)	3 (14.3)	2 (5.9)	1 (6.3)	1 (10.0)	12 (7.8)
	≥8	53 (93.0)	14 (93.3)	18 (85.7)	32 (94.1)	15 (93.7)	9 (90.0)	141 (92.2)
Working day per week (days) $\bar{x}$±SD (min.-max.) = 6.61±0.92 (2.0-7.0)	≤6	6 (10.5)	3 (20.0)	3 (14.3)	3 (8.8)	0 (0)	1 (10.0)	32 (20.9)
	7	51 (89.5)	12 (80.0)	18 (85.7)	31 (91.2)	16 (100.0)	9 (90.0)	121 (79.1)
Respiratory protection equipment while work performing	Use	56 (98.2)	15 (100.0)	21 (100.0)	34 (100.0)	16 (100.0)	10 (100.0)	152 (99.3)
	Not use	1 (1.8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.7)
Types of respiratory protection equipment	Surgical masks							
	Yes	54 (94.7)	15 (100.0)	19 (90.5)	30 (88.2)	14 (87.5)	9 (90.0)	141 (92.2)
	No	3 (5.3)	0 (0)	2 (9.5)	4 (11.8)	2 (12.5)	1 (10.0)	12 (7.8)
	Hygienic masks made from cotton							
	Yes	1 (1.8)	0 (0)	2 (9.5)	4 (11.8)	5 (31.3)	0 (0)	12 (7.8)
	No	56 (98.2)	15 (100.0)	19 (90.5)	30 (88.2)	11 (68.7)	10 (100.0)	141 (92.2)
	Muslin masks							
	Yes	6 (10.5)	0 (0)	1 (4.8)	2 (5.9)	1 (6.3)	2 (20.0)	12 (7.8)
	No	51 (89.5)	15 (100.0)	20 (95.2)	32 (94.1)	15 (93.7)	8 (80.0)	141 (92.2)
	N95 masks							
	Yes	1 (1.8)	0 (0)	4 (19.0)	0 (0)	1 (6.3)	0 (0)	6 (3.9)
	No	56 (98.2)	15 (100.0)	17 (81.0)	34 (100.0)	15 (93.7)	10 (100.0)	147 (96.1)
	Buff masks							
	Yes	0 (0)	0 (0)	3 (14.3)	0 (0)	1 (6.3)	0 (0)	4 (2.6)
	No	57 (100.0)	15 (100.0)	18 (85.7)	34 (100.0)	15 (93.7)	10 (100.0)	149 (97.4)

The average RPM concentration from six provinces ranged from 0.007-0.031 mg/m^3. BKK showed the highest average RPM concentration (0.031 mg/m^3), followed by PTT (0.028 mg/m^3), SPK (0.009 mg/m^3), NPT (0.008 mg/m^3), NBI (0.007 mg/m^3), and SKN (0.006 mg/m^3), respectively. The RPM concentration of all areas did not exceed the OSHA (5 mg/m^3) and ACGIH (3 mg/m^3) standards. Additionally, the overall average RPM exposure concentration among motorcycle taxi drivers was 0.015 mg/m^3, and the maximum RPM exposure concentration was 0.365 mg/m^3. This is the first report on RPM exposure concentration among motorcycle taxi drivers by using air personal sampling. Most previous studies collected data on RPM concentration from ambient air (ChooChuay et al., 2020; Kirwa et

Table 3. Parameters of the ADD and HQ for RPM in each province

Parameter	Unit	BKK		Adjacent provinces										Total	
				PTT		SPK		SKN		NBI		NPT			
		Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
C	mg/m^3	0.031	0.365	0.028	0.099	0.009	0.025	0.006	0.024	0.028	0.099	0.008	0.018	0.015	0.365
IR	m^3/hr	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
ET	hr/day	12.4	18.0	11.1	15.0	12.1	16.0	11.4	16.0	11.1	15.0	10.7	13.0	11.6	18.0
EF	day/year	316.8	336.0	316.8	336.0	316.8	336.0	326.4	336.0	316.8	336.0	326.4	336.0	316.0	336.0
ED	year	29.00	30.00	34.00	35.00	29.00	30.00	28.00	30.00	34.00	35.00	38.00	40.00	31.17	40.00
BW	kg	69.90	120.00	67.10	100.00	74.00	100.00	72.50	105.00	67.10	100.00	59.00	71.00	69.17	120.00
AT	day	9,187	10,080	10,771	11,760	9,187	10,080	9,139	10,080	10,771	11,760	12,220	13,440	9,832	13,440
ADD	mg/kg-day	0.084	0.832	0.070	0.226	0.022	0.061	0.014	0.056	0.070	0.226	0.022	0.050	0.038	0.832
HQ	-	0.028	0.277	0.023	0.075	0.007	0.020	0.005	0.019	0.023	0.075	0.007	0.017	0.013	0.277

al., 2021; Ibrahim et al., 2021; Glenn et al., 2022; Wright et al., 2023; Dondi et al., 2023), which did not demonstrate their outdoor workers had been exposed to RPM. The advantage of personal air sampling showed the participants were actually exposed to respirable dust when compared to ambient air pollution sampling. Therefore, personal air sampling study has a clearer relationship to the health risk, especially in the respiratory system among outdoor workers than area sampling.

In Bangkok and adjacent provinces, the health risk assessment for RPM was concerned with the health impact of exposure to pollutants. HQ values were used to calculate the non-carcinogenic risk of RPM exposure. Non-carcinogenic risk refers to all adverse health effects in an organism caused by environmental factors other than cancer. This risk is calculated based on the ADD and took the reference values or RfC doses (3 mg/m^3; inhalation slope factor) into account. Table 3 indicates the ADD values for motorcycle taxi drivers in Bangkok and adjacent provinces.

The average ADD value (0.084 mg/kg-day) from RPM exposure in Bangkok was higher than each of the adjacent provinces (PTT, SPK, SKN, NBI, and NPT), and the overall average ADD value (0.038 mg/kg-day) from exposure to RPM in the adjacent provinces was lower than the Bangkok average. In addition, the maximum ADD value (0.832 mg/kg-day) from RPM exposure in Bangkok was higher than in any of the adjacent provinces and also it was observed that the average HQ values for motorcycle taxi drivers from inhalation RPM exposure ranged from 0.005-0.028, while the maximum HQ values ranged from 0.016-0.277. All areas for data collection showed average and maximum HQ values of between 0.013 and 0.277. The average and maximum HQ values from RPM exposure in Bangkok were higher than the adjacent provinces. However, the HQ values of all areas were less than 1.0 which indicated a low hazard risk. The low hazard risk results may be due to the sampling period overlapping with the rainy season in Thailand, which can affect RPM concentrations. This is an important parameter for HQ values. This result differed from the previous studies (Yunesian et al., 2019; Algarni et al., 2021; Neamhom et al., 2021; Gruszecka-Kosowska et al., 2021; Tian et al., 2022; Sah, 2023) which stated that particulate matter from resuspended dust (PM10 and PM2.5) caused a higher health risk. Those studies collected data during the winter and summer seasons.

For uncertainty of source-specific risks, HQ is sensitive for different variables, because they are dominated by components with different uncertainties. Moreover, these findings were consistent with previous studies (Thongthammachart, 2018; Mbazima, 2022; Zhou et al., 2023). These studies revealed that HQ values for $PM_{2.5}$-bound polycyclic aromatic hydrocarbons (PAHs) from the atmosphere were far lower than 1 for all populations, which was considered to have negligible hazard. In addition to $PM_{2.5}$-bound PAHs, it was also found that the ecological risk assessment of PM_{10} exposure was gradually acceptable risk in almost all data collection areas. A few data collection areas were found to be of high risk to human health. However, the human health risk for people in sensitive groups would be risk from exposure to RPM in Bangkok and adjacent provinces (Arphorn et al., 2018; Amnuaylojaroen et al., 2022).

4. CONCLUSIONS

Outdoor air pollution is a leading cause of death and premature death globally. Motorcycle taxi drivers are most at risk associated with occupational exposure to ambient air pollution in urban areas. They must drive to pick up or drop off passengers outside buildings throughout their working hours, on average 12 hours per day, ranging from 3-18 hours per day. Therefore, there is a greater chance of exposure to ambient air pollution than in other occupations. RPM was measured in Bangkok and adjacent provinces during the rainy season in Thailand. Bangkok indicated the highest average RPM concentration. The HQ values for Bangkok and adjacent provinces indicated a negligible risk ($HQ \leq 1$). Most of the motorcycle taxi drivers were without adverse health effects because these values are at acceptable levels. However, some of them may have adverse health effects due to individual sensitivities. Motorcycle taxi drivers might have a decreased lung function from direct exposure to RPM in their work environment. Even though exposure to RPM is minimal, it is continuous exposure that gradually causes long-term effects on lung function. Our research assists in conveying prevention measures to delay lung dysfunction in motorcycle taxi drivers.

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