PERSONAL EXPOSURE ASSESSMENT OF FINE PARTICULATE MATTER FOR COMMUTERS IN HANOI

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ABSTRACT

Epidemiological studies showed that commuters exposed fine particles ($PM_{2.5}$) have adverse health effects and cause diseases. Comprehensive personal exposure studies have been limited in Vietnam. This study aimed to assess the exposure of $PM_{2.5}$ to motorcyclists and cyclists on some roads in Hanoi. Personal exposure samples were taken by the Airbeam sensor. Preliminary results showed that the exposure concentration of $PM_{2.5}$ for cyclists (105 µg/m^3) was higher than for motorcyclists (95 µg/m^3) and level of $PM_{2.5}$ in ambient air (34 µg/m^3). Influencing factors were also assessed in this study. $PM_{2.5}$ exposure concentration was the highest in the morning and decreased at noon and in the afternoon for both types of vehicles. Exposure concentrations of $PM_{2.5}$ highly fluctuated during peak hours. The bicyclists were at higher risk than the motorcyclists due to higher inhalation dose. The findings provide initial warnings about the health impacts to commuters to the managers to give timely interventions.

ĐÁNH GIÁ PHƠI NHIỄM CÁ NHÂN BỞI BỤI MỊN KHI THAM GIA GIAO THÔNG Ở HÀ NỘI

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TỪ KHÓA

Phơi nhiễm
Bụi mịn
Phương tiện giao thông
Liều lượng
Hà Nội

TÓM TẮT

Các nghiên cứu dịch tễ học chứng minh rằng, người tham gia giao thông phơi nhiễm với bụi mịn có thể gây những ảnh hưởng xấu tới sức khỏe và gây ra bệnh tật. Các nghiên cứu về phơi nhiễm cá nhân đối với những người tham gia giao thông chưa được thực hiện một cách đầy đủ và tương đối hạn chế ở Việt Nam. Nghiên cứu này nhằm mục đích đánh giá phơi nhiễm bởi $PM_{2.5}$ đối với người đi xe máy và xe đạp trên một số tuyến đường ở Hà Nội. Phơi nhiễm bụi cá nhân được lấy từ thiết bị đo bụi cảm biến Airbeam. Kết quả ban đầu cho thấy rằng, nồng độ phơi nhiễm của $PM_{2.5}$ đối với người đi xe đạp (105 µg/m^3) cao hơn người đi xe máy (95 µg/m^3) và nồng độ $PM_{2.5}$ trong không khí xung quanh (34 µg/m^3). Các yếu tố ảnh hưởng cũng được đánh giá trong nghiên cứu này. Nồng độ phơi nhiễm $PM_{2.5}$ được phát hiện cao nhất vào buổi sáng, và có xu thế giảm dần với buổi chiều và trưa đối với cả hai phương tiện giao thông. Nồng độ $PM_{2.5}$ phơi nhiễm dao động lớn trong giờ cao điểm. Người đi xe đạp có nguy cơ rủi ro cao hơn người đi xe máy do liều lượng hít thở bụi mịn lớn. Nghiên cứu đưa ra cảnh báo ban đầu về nguy cơ tác động sức khỏe đối với người tham gia giao thông cho những nhà quản lý đưa ra các biện pháp can thiệp kịp thời.

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1. Introduction

Air pollution is a global-scale problem while fine particulate matter ($PM_{2.5}$) is considered as a major cause of illnesses such as respiratory, heart disease, and stroke [1]. The global air quality report stated that seven million people were estimated to die each year due to the ambient air, in which 2.5 million deaths were from cardiovascular diseases and 1.4 million deaths due to lung-related diseases and lung cancer. WHO report stated that the mortality ratio for the patients associated with heart and lung diseases raised by 6-13% when $PM_{2.5}$ levels increased by 10 µg/m^3 [2].

Many studies of particulate matter personal exposure to the commuters with various vehicles have been carried out worldwide [3]-[6]. A study in California showed that exposure to $PM_{2.5}$ during commuting accounted for 28-55% of the total exposure level and bicyclists exposed the most [3]. The exposure level depends on the type of vehicles as well as the characteristics of the roads. Another research was also conducted in Arnhem, Netherlands to evaluate $PM_{2.5}$ exposure to bicycle riders on two roads with different traffic density. The results showed that the higher the traffic density of the road, the higher the exposure level and the more harmful it was to the health of commuters [5]. Other $PM_{2.5}$ exposure studies in high traffic density countries in Asia, such as India and Thailand, were also publised. These studies assessed the level of exposureamong buses, cars, and motorcycles at different periods of the day. The morning exposure level was higher than the evening for all vehicles in India [6]. Exposure to $PM_{2.5}$ during traveling by subway was the lowest, compared with buses, taxis, and motorcycles in Bangkok [7].

Currently, many big cities in Vietnam are facing high levels of $PM_{2.5}$. Monitoring data in recent years have shown that $PM_{2.5}$ concentrations in urban areas exceed national standards many days in a year [8]. Air pollutant emissions from traffic predominate in Vietnam due to increasing the number of vehicles, in which the motorcycles account for over 90% of total vehicles [9]. More than 60,000 people died in 2016 due to air pollution caused by heart disease, stroke, lung cancer, and chronic obstructive pulmonary disease were reported in 2016 [2]. However, studies on personal exposure by $PM_{2.5}$ have been limited. Most studies were evaluating the impact of air pollution on public health using concentration of $PM_{2.5}$ in ambient air, rather than personal exposure concentration. One of the most recent exposure studies conducted in Ho Chi Minh City in 2017 provided preliminary information on $PM_{2.5}$ exposure to the community. The personal exposure concentration of $PM_{2.5}$ was higher than the level of $PM_{2.5}$ in the ambient air at the stationary monitoring stations and it is noticeable that those values exceeded the threshold of the ambient air quality standard value in the QCVN 05:2013/BTNMT [8], [10]. Therefore, the impact on $PM_{2.5}$ exposure on commuters should be in attention. Studying personal exposure to $PM_{2.5}$ from traffic activities is practical and necessary to take any intervention to protect public health. The objectives of this study are *i)* to determine personal exposure concentration by $PM_{2.5}$ to bicycle and motorbike riders on some routes in Hanoi at rush hours; *ii)* to compare the concentrations of personal exposure with those of ambient air concentrations; and *(3)* to estimate $PM_{2.5}$ exposure level for each transportation mode.

2. Methodology

2.1. Site description

Five routes in Hanoi were selected, including major arteries (Giai Phong and Nguyen Trai), residential roads (Lines around Hoan Kiem Lake, and Ho Chi Minh Mausoleum), and internal lanes (Vinhome riverside urban area). Major arteries are the representative for a multi-lane, two-way route with a large number of vehicles. The residential road is mainly intersection roads, densely populated areas, and have many political, cultural, and commercial centers surrounded. Internal lanes in Vinhomes Riverside urban area are characterized as the background due to low impact from traffic activities and economic-industrial activities. The characteristics and locations of the routes are shown in Table 1 and Figure 1.

2.2. Sampling strategy

The personal exposure measurement by $PM_{2.5}$ was conducted by Airbeam sensors within the breathing zone during commuting, following the USEPA guideline [12]. The exposure measurement study was performed 3 times per day at rush hours (7:00 - 8:00, 13:00 - 14:00, and 17:00 - 18:00) continuously for three days on different routes from March to April 2018. The devices were worn on the chest (in the breathing zone) for the motorcyclists and bicyclists during sampling periods. The data was recorded minutely and the aircasting application was used to display the data and saved daily as MS excel format. GPS data acquired through the Longer GPX application has recorded the route as well as to determine the moving speed. The meteorological data (temperature, humidity, wind direction, wind speed) and $PM_{2.5}$in the ambient air were collected from the website [13], [14].

2.3. Exposure dose estimation

The amount of $PM_{2.5}$ inhaled to the respiratory system was calculated basing on $PM_{2.5}$ exposure concentration and USEPA exposure manual [15], the formulas were based on the equation (1-2):

$$D = PM \times VE \times t \quad (1)$$

$$VE = BMR \times MET \times VQ \times H \times \frac{1}{1440}\ (m^3/min) \quad (2)$$

Where: D: amount of $PM_{2.5}$ inhaled in the respiratory system (μg); PM: exposure concentration ($\mu g/m^3$) [this study]; VE: volume of inhaled air of an exposed person within one minute (m^3/min); t: exposure time (minutes) [this study]; BMR: metabolic rate (MJ/day) (BMR = 7.7 MJ/day for people aged 18-30) [15]; MET: factor associated with the activity of the exposed person (MET = 1.2 or 2 for light physical activity (motorcycling) or moderate activity (cycling), respectively [15]. VQ: ventilation coefficient (VQ = 27) [15]. H: volume of oxygen needed to make 1 KJ (H = 0.05 (L/KJ)) [15].

2.4. Data processing

This research used R software version 3.5.2 to conduct corelation analysis among research subjects by "paired sample t-test".

3. Results and discussion

3.1. Traffic density surveillance on routes

Traffic volume was determined simultaneously during personal exposure measurement by counting vehicles in the recorded video. High traffic density mainly occurred during rush hours in the morning (7h-8h) and afternoon (17h-18h). The traffic volume decreased at noon (13h-14h). The results presented that the traffic volumes of major arteries (Nguyen Trai and Giai Phong) were higher than residential roads (Lines around Hoan Kiem Lake and Ho Chi Minh Mausoleum) and internal lanes of Vinhome urban area. The number of vehicles on the route varied as follows: Nguyen Trai route (Morning: 18,379 vehicles/h; Noon: 10,908 vehicles/h); Afternoon: 16,852 vehicles/h) > Giai Phong route (Morning: 9,689 vehicles/h; Noon: 6,512 vehicles/h; Afternoon: 8,977 vehicles/h) > Ho Chi Minh Mausoleum lines (Morning: 6,614 vehicles/h; Noon: 4,699 vehicles/h; Afternoon: 6,571 vehicles/h) > Hoan Kiem Lake (Morning: 5,772 vehicles/h; Noon: 4,467 vehicles/h; Afternoon: 7,849 vehicles/h) > Internal roads (Morning: 253 vehicles/h; Noon: 132 vehicles/h; Afternoon: 336 vehicles/h). The large variation in traffic density was due to the difference in the structure, size, and type of the roads. The average speed was maintained at 12 km/h and 20 km/h for bicycles and motorbikes respectively. GPX software was installed on mobile phones for easy tracking and speed control.

3.2 Variation of exposure concentration of $PM_{2.5}$

The statistical values of the exposure concentration to $PM_{2.5}$ during traveling by bicycles and motorbikes show that the personal exposure levels to $PM_{2.5}$ of the motorcyclists varied from 32-190 µg/m^3 (mean value of 95 µg/m^3), whereas, those of $PM_{2.5}$ for the cyclists varied from 30-195 µg/m^3 (mean value of 105 µg/m^3). The concentration of $PM_{2.5}$ in the ambient air from the US embassy station varied from 15-83 µg/m^3 (mean value of 34 µg/m^3). Personal exposure levels by $PM_{2.5}$ for the cyclists in this study were higher than those in Ho Chi Minh City (64 µg/m^3) [11] and the Netherlands (72 µg/m^3) [5], wherease, the personal exposure concentrations of $PM_{2.5}$ to the motorcyclists were lower than those in Bangkok (136 µg/m^3) [8] and India (222 µg/m^3) [7]. In case in Ho Chi Minh City, the lower $PM_{2.5}$ concentrations in ambient air than those in Hanoi can lead less personal exposure concetrations to $PM_{2.5}$ despite more traffic modes. It is ascribed to prefered meterological and topographic conditions which may faciliate the air disperion. The exposure concentrations to $PM_{2.5}$ varied in different sampling locations due to disimalities on ambient air quality and characteristics of sampling, traffic, meterological and topographic conditions. In addition, personal exposure by $PM_{2.5}$ of cyclists and motorbikers were three times higher than $PM_{2.5}$ in the ambient environment, which were consistent with previous studies [11], [16].

Personal exposure concentration to $PM_{2.5}$ during riding by bicycle and motorbike at different times is shown in Figure 2. $PM_{2.5}$ exposure concentrations for motorcycles were 112 µg/m^3, 90 µg/m^3, 84 µg/m^3 while those for bicycles were 119 µg/m^3, 105 µg/m^3 and 94 µg/m^3 in the morning, noon and afternoon, respectively. Exposure levels were the highest in the morning and lower in the afternoon and noon for both vehicle types. The difference in personal exposure concentrations may be due to meteorological factors, traffic volume and ambient air condition. The highest exposure concentration and ambient air in the morning may be due to a high volume of traffic in the morning (8162 vehicles/h), in the conditions of low temperature and wind speed (v_{tb}<1 m/s), high humidity, resulting in $PM_{2.5}$ elevation. The low temperature in the morning may cause the heat inversion, preventing the air mass below the ground to move up. Besides, high humidity also can make $PM_{2.5}$ adhere to create the coarse particles, facilitate the settling in the low atmosphere, consequently, concentration of particles tends to be higher [17]. Although the afternoon (rush-hour) also has a comparable traffic volume (8118 vehicles/h), the high wind speed (vtb = 5m/s) facilitates the dispersion, leading to a lower exposure concentration than in the morning. The variation of personal exposure concentrations to $PM_{2.5}$ in this study are consistent with the trend in India and China [6], [16].

Table 1. *Route for commuters by bicycle and motorcycle in Hanoi*

Type of Road	Road	Distance (km)	Route
Major arteries	Giai Phong	4.5	Giai Phong – Nuoc Ngam bus station
	Nguyen Trai	2	Nga Tu So to Khuat Duy Tien intersection
Residential road	Hoan Kiem lake lines	1.8	Trang Tien- Dinh Tien Hoang – Le Thai To- Hang Khay
	Ho Chi Minh Mausoleum lines	2.4	Dien Bien Phu – Hung Vuong – Thanh Nien
Internal lane	Internal lanes in Vinhomes Riverside	2.6	In Vinhomes riverside

Personal exposure to $PM_{2.5}$ during commuting depends on several factors such as number of vehicles (density), and microclimate conditions such as temperature (T), humidity (RH), wind speed (V). These influencing factors were all correlated and shown in Figure 3. $PM_{2.5}$ exposure concentrations of motorcyclists ($PM_{2.5}$ XM) were strongly correlated with those of bicyclists ($PM_{2.5}$ XD) (r = 0.76) and ambient air (DSQ) (r = 0.69), in which the correlation between motorcyclists and ambient air was medium (r = 0.43). It is attributable that $PM_{2.5}$ can be generated from the same source [15]. The correlation between vehicle volume and exposure concentration for motorcyclist (r = 0.51) and bicycle (r = 0.6) was moderate, but then a weak correlation was observed for vehicle volume and ambient air (r = 0.25). The correlation between temperature and $PM_{2.5}$ exposure as well as ambient $PM_{2.5}$ in the study was negative, meaning that the rising of temperature made $PM_{2.5}$ concentration decrease. There was not consistent correlation between humidity (RH) and exposure $PM_{2.5}$ concentration. These correlation results are consistent with personal exposure to the commuters in Turkey [18].

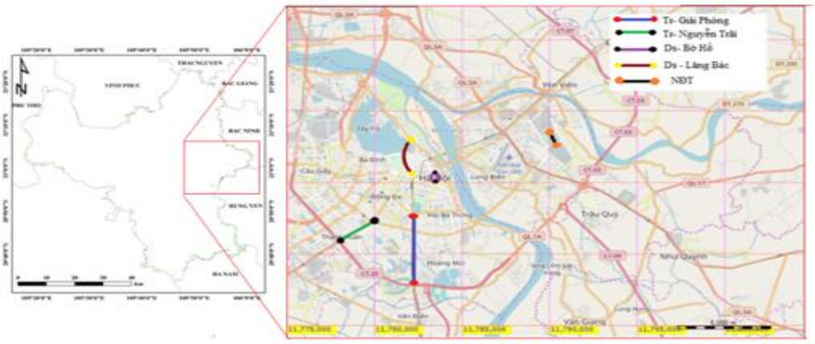

Figure 1. *Road and route of sampling campaign*

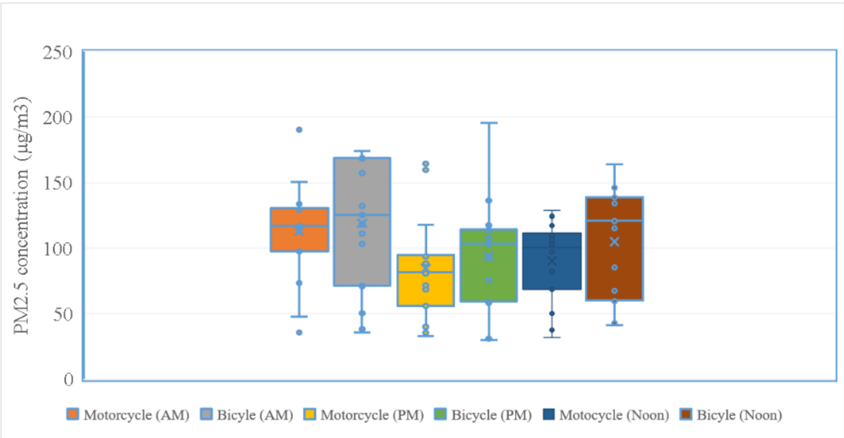

Figure 2. *Variation of PM2.5 by transportation mode*

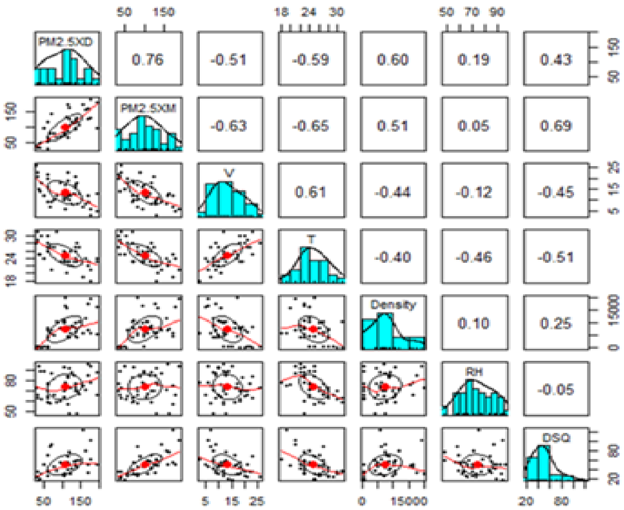

Figure 3. *Correlation matrix*

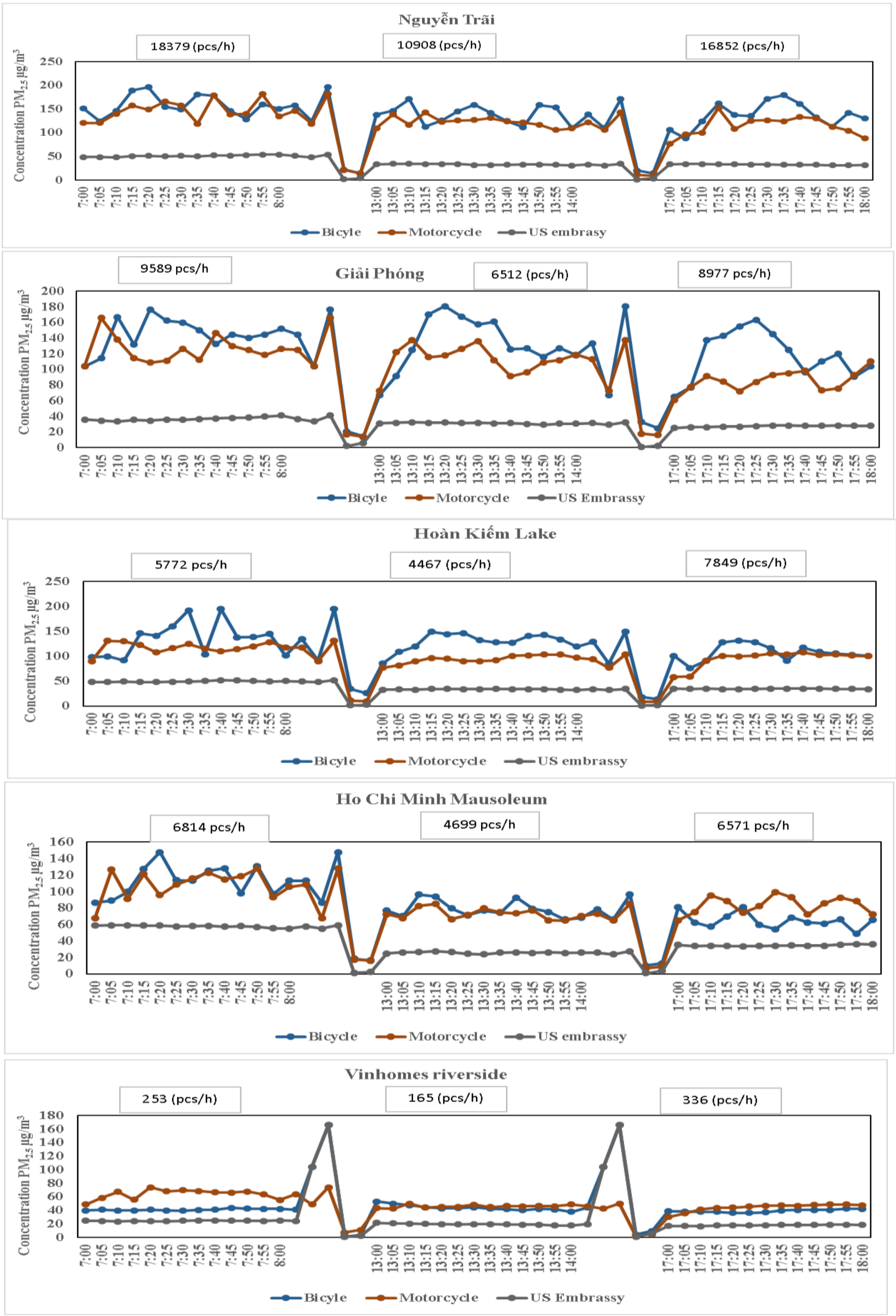

Figure 4. *$PM_{2.5}$ in different road and transporation mode*

3.3. Variation of exposure among different route

The exposure concentrations of $PM_{2.5}$ and $PM_{2.5}$ in ambient air are shown in Figure 4. The exposure concentrations of $PM_{2.5}$ for bicycle and motorcycle riders varied in different routes as following: Nguyen Trai > Giai Phong > Hoan Kiem > Ho Chi Minh Mausoleum > Vinhomes. The two routes (Nguyen Trai and Giai Phong) had the highest fleets at peak hours, while those at the background as Vinhome lanes were the lowest.

The variation coefficients were determined to assess the variation of the $PM_{2.5}$ exposure concentration for bicyclists and motorcyclists by time. The variation coefficients were in the range of 4-16%; 12-18%; 4-15% in the morning, afternoon and noon for the motorcyclists, respectively; whereas, those varied from 3-25%; 9-24%; 5-25% in the morning, afternoon and noon for the bicyclists, respectively. More significant variations were seen in peak hours, which agrees with the study in India [6]. Meanwhile, $PM_{2.5}$ concentration in the ambient air fluctuated slightly (1-3%). There is insignificant difference of $PM_{2.5}$ exposure between the two major arteries (Nguyen Trai and Giai Phong) and the residential roads (Hoan Kiem Lake and Ho Chi Minh Mausoleum lines). In contrast, a significant difference in the concentration of $PM_{2.5}$ was observed among major arteries, residential roads, and internal lanes (Vinhomes). Internal lanes (Vinhomes) could be regarded as an urban ground road. This area is far from residential areas, less impacts on outside traffic and industrial activities, and a new infrastructure system. It is worth noting that the exposure concentration of $PM_{2.5}$ for bicyclists and motorcyclists were higher than the ambient $PM_{2.5}$ at morning, noon, afternoon during sampling campaign. $PM_{2.5}$ exposure concentrations for bicyclists were greater than those of motorcyclists in major arteries and residential roads.

3.4. Exposure levels of $PM_{2.5}$

The inhalation doses of $PM_{2.5}$ during commuting by motorcycle and bicycle depended on physical activities. According to the USEPA's physical activity classification (2011), riding a motorbike is considered a light activity, and riding bicycle is medium activity. The parameters were referenced from the USEPA exposure handbook [15] and field measurements. The exposure doses during riding bicycle and motorbike were estimated by the formulas (1,2). The exposure doses by $PM_{2.5}$ during riding motorcycle and bicycle were presented in Figure 5. The temporal variation of the exposure doses of $PM_{2.5}$ were due to different exposure concentrations of $PM_{2.5}$ at different moments during riding motorbike and bicycle. The personal doses of $PM_{2.5}$ in the morning, noon, afternoon were 63 µg/h, 47 µg/h and 44 µg/h for the motorcyclists and 116 µg/h, 78 µg/h and 88 µg/h for the bicyclists, respectively. The higher dose of $PM_{2.5}$ for a bicyclist was due to a higher inhalation rate for heavier physical activity.

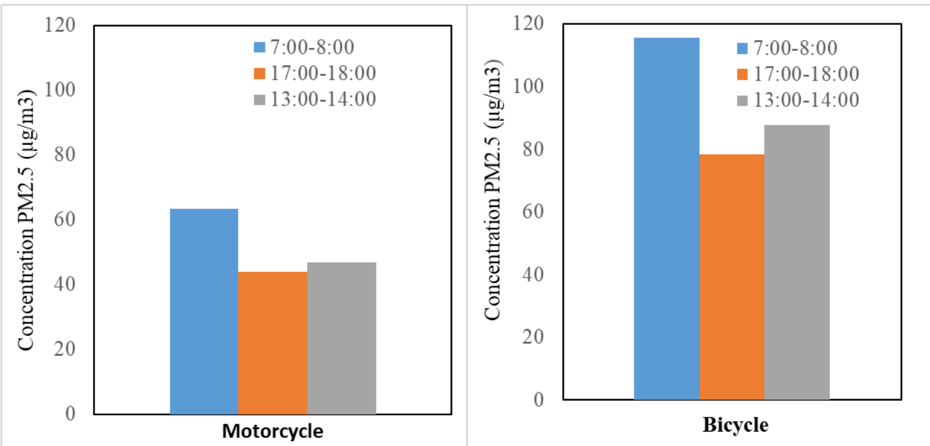

Figure 5. *Exposure dose of $PM_{2.5}$ in different transportation mode*

In comparison with other studies, the inhalation dose to $PM_{2.5}$ for a motorbike rider in this study is lower than in India study [7]. Meanwhile, the inhalation dose of $PM_{2.5}$ during cycling is nearly two times higher than the China study [3]. The highest doses were seen in the morning, then were lower in the afternoon and at noon. The $PM_{2.5}$ inhalation doses in major arteries (Nguyen Trai and Giai Phong) were highest, followed by residential roads (Hoan Kiem Lake and Ho Chi Minh Mausoleum lines) and internal lanes (Vinhomes). The different doses are likely to the variations in exposure concentrations, means of transport, and the conditions of the route. Some initial results in this study aim at proposing early warnings about potential health impacts during commuting by different transportation modes, helping agencies and authorities to give timely appropriate solutions.

4. Conclusion

The study was conducted to initially assess personal concentration of $PM_{2.5}$ for the commuters by riding bicycle and motorcycle in Hanoi. Many influencing factors on personal exposure levels of $PM_{2.5}$, such as RH, V, T, density of traffic modes and the characteristics of several routes were reported in this study. Personal exposure concentrations and doses of $PM_{2.5}$ in the morning were higher than those at noon and in the afternoon. The highest exposure concentrations of $PM_{2.5}$ were seen in major arteries, whereas the lowest was seen in the internal lanes. Personal exposure levels of $PM_{2.5}$ during riding bicycle and motorcycle were higher than those in the ambient air. In the scope of the study, the cyclists were suffering more risk than motorcyclists due to higher exposure dose. Even, bicycle riding is a friendly transportation mode due to not using fuel. However, recommendations should be made to address the risks as well as encourage bicyclists to use the roads at appropriate times and promote effective protection solutions.

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