Commuter Exposure to Particulate Matter of Different Transportation Modes in Nanjing

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ABSTRACT

Exposure to particulate matter in traffic-related microenvironment is associated with commuters' health. However, commuter exposure assessments to particulate matter in China are limited. In this paper, the concentration levels of $PM_{2.5}$ and PM_1 in four commuting modes (subway, cycling, bus and walking) during the traffic rush hours in Nanjing are measured. Besides, the $PM_{2.5}$ inhalation doses are evaluated. The exposure levels to $PM_{2.5}$ and PM_1 of cycling, bus and walking are higher than the level of subway, and the $PM_{2.5}$ inhalation doses by cycling or walking are much higher than the doses by bus or subway. Thus, subway is the relatively healthy commuting mode while cycling and walking have more potential health risks.

INTRODUCTION

Urban air pollution is a public health risk that many modern cities face, particularly in developing countries like China. Particulate matter (PM) has been the major air pollutant in most Chinese cities (Yang et al. 2011), which results in high human exposure (Zhao et al. 2009; Zhou et al. 2012). Exposure to particulate matter is associated with an increase in allergic disorders, decreased lung function, cardiovascular disease, and death (Brook et al. 2010; Brunekreef and Holgate 2002; Dockery and Stone 2007; Padhi and Padhy 2008). Exposure to particulate matter in traffic-related microenvironment is closely related to potential health risks owing to the heavy traffic-related sources of particulate matter and the considerable commuting time. It has been reported that adult residents in China spend average 87min each day in traffic (MEP PRC 2013). However, commuter exposure assessments to particulate matter in China are still limited. Yu et al. (2012) studied commuter exposure to PM_1 by some common transportation modes in Shanghai, i.e. bus, walking, cycling, taxi and subway. Xu et al. studied commuter exposure to $PM_{2.5}$ and CO_2 inside high-speed rail carriages (2013) and in metro carriages of Shanghai metro system (2016). Yan et al. (2015) investigated commuter exposure to $PM_{2.5}$ and particle-bound PAHs in three transportation modes (walking, subway and bus) in Beijing. The commuter exposure assessments in Nanjing are still scarce.

In this paper, the concentration levels of $PM_{2.5}$ and PM_1 in four common commuting modes (subway, cycling, bus and walking) during the traffic rush hours in Nanjing are measured. Besides, the $PM_{2.5}$ inhalation doses for different commuting modes are evaluated.

METHODS

This study mainly focuses on a 2km long route of Zhongshan Road between Gulou and Xinjiekou, located in the center of Nanjing city, which is a representative and crowded route (Figure 1). The concentration levels of $PM_{2.5}$ and PM_1 in four common transportation modes, including subway, cycling, bus and walking (Figure 2), are sampled with a logging interval of 1 second in a one-way route between Gulou and Xinjiekou during morning, noon and evening traffic rush hours (morning rush hour: 7:00-8:00; noon rush hour: 12:00-13:00; evening rush hour: 17:00-18:00) for one week (from May 7 to May 13, 2017). The concentration levels are not recorded during the transfer between different transportation modes, e.g. waiting at the bus stop or subway station. Two portable and battery-operated instruments TSI DUSTTRAK II-Model 8532 are used to measure the concentration levels of $PM_{2.5}$ and PM_1. All the monitor instruments are placed in a backpack (Figure 3(a)). The monitor inlet of the instrument is extended by an external rubber tube so as to pump the ambient air in (Figure 3(b)). Totally 14 sets of available measurements are obtained, including 5 sets during morning traffic rush hours, 5 sets during noon traffic rush hours and 4 sets during evening traffic rush hours.
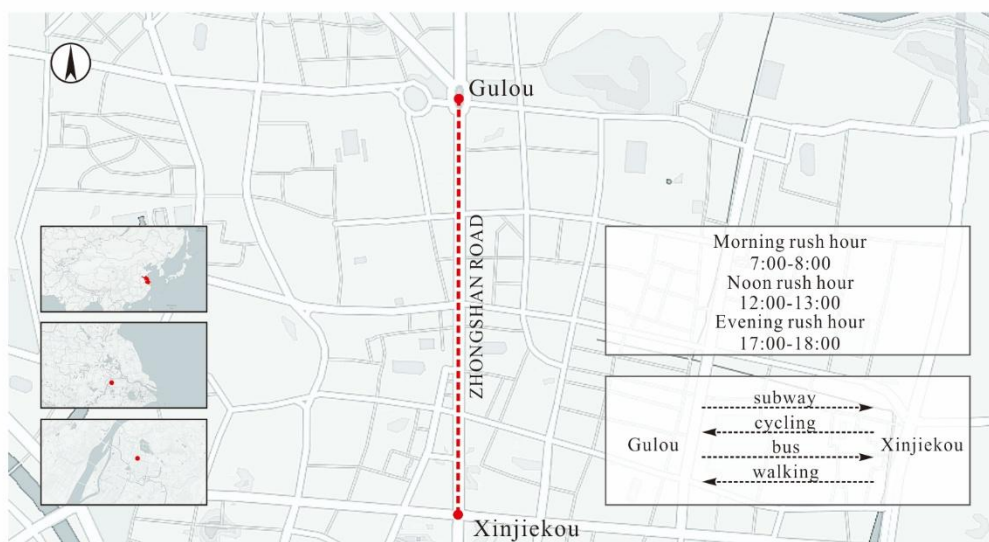

Figure. 1. The research route of Zhongshan Road between Gulou and Xinjiekou.

Figure. 2. Four transportation modes: (a) subway, (b) cycling, (c) bus and (d) walking.

Figure. 3. The monitor backpack: (a) the monitor instruments, and (b) the monitor inlet.

RESULTS

Commuter exposure of different transportation modes

Figure 4 reveals the concentration levels of $PM_{2.5}$ and PM_1 in different transportation modes. The PM_1 concentration level is generally consistent with the $PM_{2.5}$ level in any case. According to Table 1, the fractions of PM_1 in $PM_{2.5}$ in different transportation modes are approximately 80%, a little lower than the results of Velasco and Tan (2016). The concentration levels of $PM_{2.5}$ and PM_1 in cycling, bus and walking trips are generally higher than the level in subway trips. Besides, the $PM_{2.5}$ and PM_1 concentrations in subway trips are relatively concentrated, while the concentrations in cycling, bus and walking trips are dispersed, which may be attributable to the ventilation and air condition systems operating inside the subway carriage (Martins, et al. 2015). It indicates that the outdoor exposure contributes a lot to the average exposure concentrations in subway trips at such traveling distances. Knibbs et al. (2011) indicated that the high concentration inside the bus is partially because of the opened window and indoor sources. Therefore, in this paper, the $PM_{2.5}$ and PM_1 concentrations inside the bus are highly impacted by the vehicle exhaust. The cycling and walking trips, which are completely outdoors, have the highest $PM_{2.5}$ and PM_1 concentrations overall. The concentration levels of particulate matters are generally consistent with the data measured in Shanghai (Yu et al. 2012).
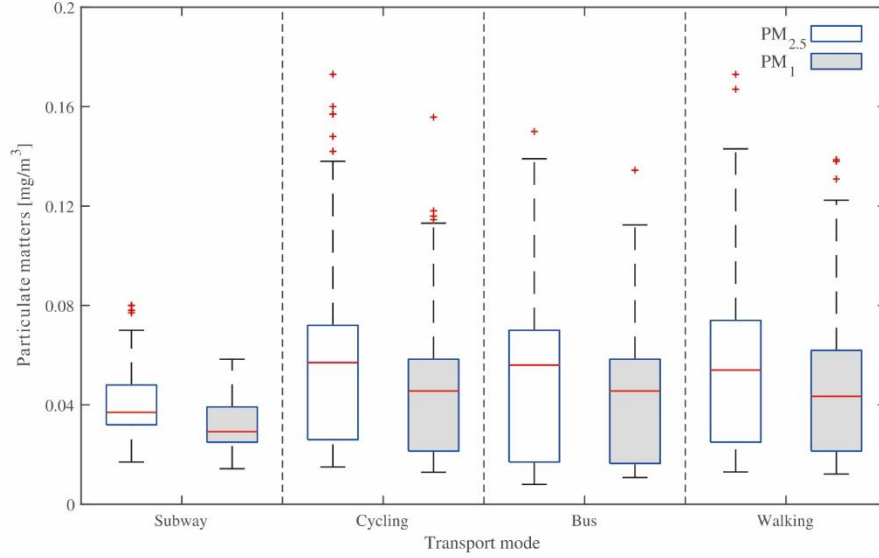
Figure. 4. Boxplots of the concentrations of PM$_{2.5}$ and PM$_1$ in different transportation modes. In each box, the mid-line shows the median value, the top and bottom of the boxes show the upper and lower quartiles (the 75th and 25th percentiles), and the top and bottom of the whiskers represent the 90th and 10th percentiles. The extreme values farther from the median than 1.25 times the whisker end are drawn with markers.

Table 1. PM$_{2.5}$ and PM$_1$ concentration and PM$_1$/PM$_{2.5}$ ratio of different transportation modes

Mode	PM$_{2.5}$(SD) [mg/m^3]	PM$_1$(SD) [mg/m^3]	PM$_1$/PM$_{2.5}$ [-]
Subway	0.038(0.011)	0.031(0.009)	0.80
Cycling	0.055(0.030)	0.044(0.022)	0.80
Bus	0.048(0.030)	0.040(0.022)	0.82
Walking	0.053(0.029)	0.043(0.021)	0.80
Overall	0.051(0.028)	0.041(0.021)	0.80

However, the concentration levels of PM$_{2.5}$ and PM$_1$ in subway trip are not always lower than the concentration levels in cycling, bus or walking trips. Figure 5 shows the PM$_{2.5}$ and PM$_1$ concentration levels in two days. The cycling, bus and walking trips exhibit generally consistent particulate matter concentration levels. During the morning traffic rush hour in May 7 (Figure 5(a)), the concentration levels of PM$_{2.5}$ and PM$_1$ in subway trip are much lower than the levels in cycling, bus and walking trips, as analyzed above, may due to the higher outdoor concentrations as well as the ventilation systems operating inside the subway carriage. However, during the morning traffic rush hour in May 9 (Figure 5(b)), owing to the low outdoor particulate matter concentrations, the PM$_{2.5}$ concentration levels in subway trip are actually higher than the levels in cycling, bus and walking trips. It indicates that the particulate matters produced by the crowded passengers may contribute a lot to the total particulate matters inside the subway carriage, particularly in the case of lower outdoor concentrations.
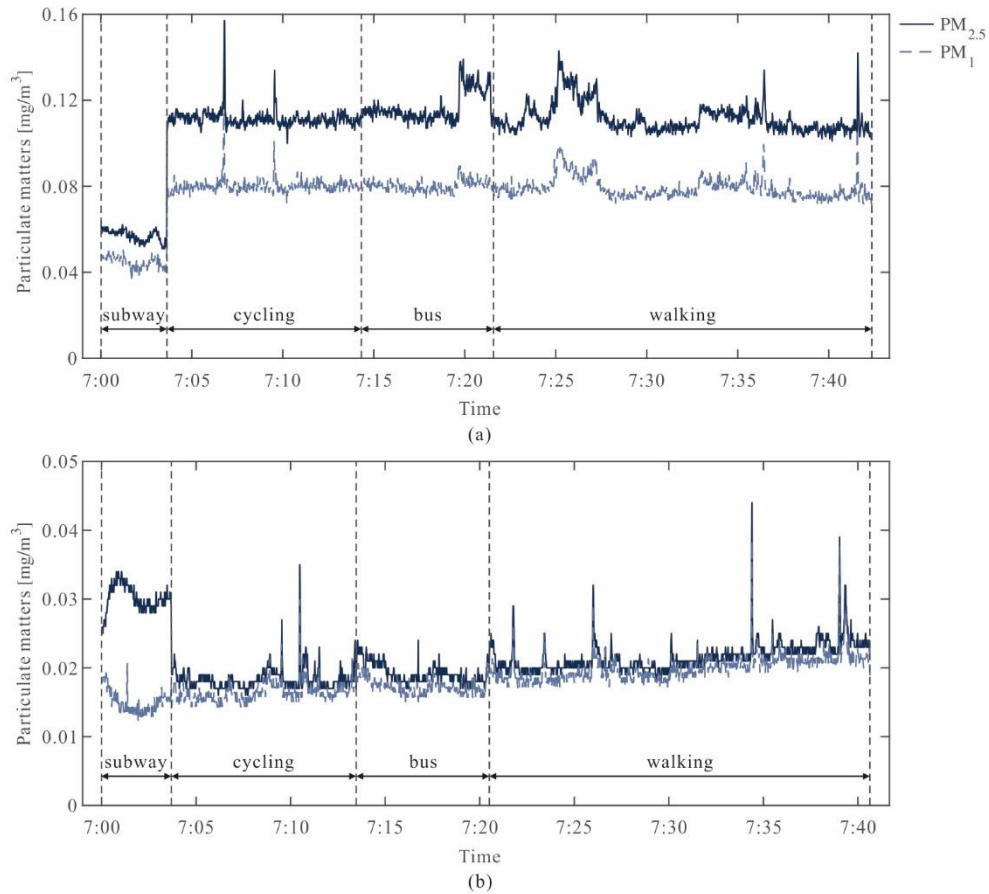
Figure. 5. The time series of $PM_{2.5}$ and PM_1 concentrations during (a) the morning traffic rush hour in May 7, 2017 and (b) the morning traffic rush hour in May 9, 2017.

The $PM_{2.5}$ concentrations during different traffic rush hours (morning, noon and evening) are shown in Figure 6. The $PM_{2.5}$ concentrations during morning traffic rush hours are significantly higher than which during noon and evening traffic rush hours, which need further investigations and analyses.
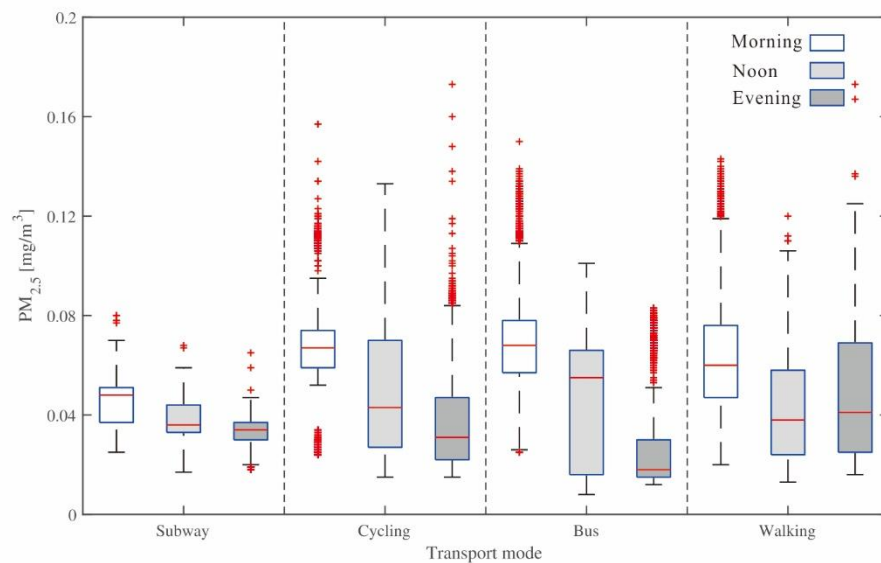

Figure. 6. Boxplots of $PM_{2.5}$ concentrations during different rush hours (morning, noon and evening). In each box, the mid-line shows the median value, the top and bottom of the boxes

show the upper and lower quartiles (the 75th and 25th percentiles), and the top and bottom of the whiskers represent the 90th and 10th percentiles. The extreme values farther from the median than 1.25 times the whisker end are drawn with markers.

The cycling and walking trips are completely outdoors. Therefore, the particulate matter concentrations measured in cycling and walking trips may partially represent the outdoor particulate matter concentrations in Nanjing. Figure 7 indicates that the outdoor $PM_{2.5}$ concentrations measured in this paper are generally consistent with the outdoor $PM_{2.5}$ concentrations released by the air quality monitoring stations in Nanjing (the PM_1 concentrations are not recorded by the monitoring stations), though the measured outdoor $PM_{2.5}$ concentrations are slightly higher, which may due to the heavy traffic-related sources of particulate matter.
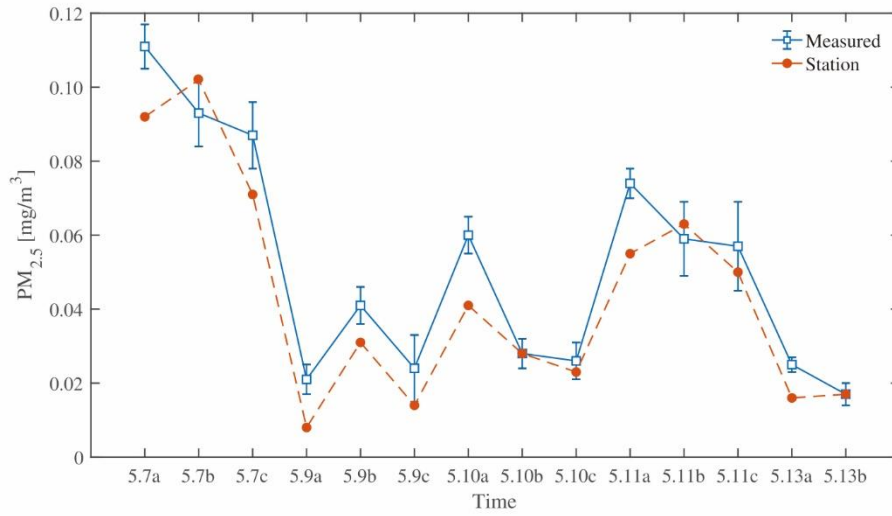

Figure. 7. The outdoor $PM_{2.5}$ concentrations measured in this paper and released by the air quality monitoring stations in Nanjing. The postfix -a indicates the morning rush hour, -b indicates the noon rush hour, and -c indicates the evening rush hour.

Inhalation doses of different transportation modes

Personal inhalation doses during the transportation trips are associated with transportation time, exposure concentration and inhalation rate, which can be calculated by

$$D = \int_{t1}^{t2} C(t) \cdot IR(t) \cdot dt \qquad (1)$$

where *D* stands for the inhalation dose, mg; *C(t)* is the real-time exposure concentration, mg/m³; *t1* and *t2* stand for the start and end time of exposure respectively; *IR(t)* is the inhalation rate, m³/min. The values of inhalation rate used in this paper are the mean values of the inhalation rates for the age groups between 6 and 80 years presented by Exposure Factors Handbook (USEPA 2011).

Table 2 shows the $PM_{2.5}$ inhalation doses of different transportation modes. Traveling by cycling or walking results in higher $PM_{2.5}$ inhalation doses than traveling by subway or bus, owing to higher exposure concentration levels, exposure times and inhalation rates. Subway has the least inhalation doses among all the transportation modes, thus is considered to be the relatively healthy commuting mode.

Table 2. PM$_{2.5}$ inhalation doses of different transportation modes

Mode	PM$_{2.5}$ [mg/m^3]	Exposure time [min]	Inhalation rate [m^3/min]	Inhalation dose [mg]
Subway	0.038	3.82	0.005	0.001
Cycling	0.055	10.66	0.026	0.015
Bus	0.048	7.76	0.005	0.002
Walking	0.053	21.43	0.012	0.014

DISCUSSION

According to the data measured in this paper, the exposure concentration levels to PM$_{2.5}$ and PM$_1$ of cycling, bus and walking are higher compared to the level of subway. Owing to higher exposure times and inhalation rate, cycling and walking exhibit much higher inhalation doses than the other modes. Subway, with low exposure level and inhalation doses, is considered to be the relatively healthy transportation mode. However, during the study period, the PM$_{2.5}$ concentrations of subway are still higher than the value recommended by USEPA (24h average: 0.035mg/m^3) and WHO (24h average: 0.025mg/m^3). Therefore, some necessary actions should be taken by commuters to prevent potential health risks caused by particulate matter, e.g. wearing masks, in any commuting mode.

In recent years, cycling and walking, as well as running, have been increasingly popular in China. Lots of people prefer cycling and walking not only as a commuting mode for short distances but also as a way to healthy life (Yu et al. 2012). Considering the potential health risks, cycling and walking are not recommended to be conducted during the traffic rush hour or near the busy streets.

CONCLUSIONS

Commuter exposure assessments to particulate matter in China are limited. In this paper, the concentration levels of PM$_{2.5}$ and PM$_1$ in four common transportation modes (subway, cycling, bus and walking) during the traffic rush hours in Nanjing are measured. Besides, the PM$_{2.5}$ inhalation doses are evaluated. The exposure concentration levels to PM$_{2.5}$ of cycling, bus and walking are higher than the level of subway, and the inhalation doses by cycling or walking are much higher than the doses by bus or subway, which indicates that subway is the relatively healthy commuting mode while cycling and walking have more potential health risks. Therefore, some necessary actions (e.g. wearing masks) are recommended to prevent potential health risks caused by particulate matter during the commuting trips, particularly during the cycling and walking trips.

ACKNOWLEDGEMENT

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