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Particulate Matter Exposures under Five Different Transportation Modes during Spring Festival Travel Rush in China

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Abstract: Serious traffic-related pollution and high population density during the spring festival (Chinese new year) travel rush (SFTR) increases the travelers' exposure risk to pollutants and biohazards. This study investigates personal exposure to particulate matter (PM) mass concentration when commuting in five transportation modes during and after the 2020 SFTR: China railway high-speed train (CRH train), subway, bus, car, and walking. The routes are selected between Nanjing and Xuzhou, two major transportation hubs in the Yangtze Delta. The results indicate that personal exposure levels to PM on the CRH train are the lowest and relatively stable, and so it is recommended to take the CRH train back home during the SFTR to reduce the personal PM exposure. The exposure level to $PM_{2.5}$ during SFTR is twice as high as the average level of Asia, and it is higher than the WHO air quality guideline (AQG).

Keywords: Chinese spring festival travel rush; COVID-19; exposure; particulate matter

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1. Introduction

In-vehicle air quality can affect the exposure level of commuters. Those pollutants related to traffic emissions may include ultrafine particles (particles with aerodynamic diameter ≤ 100 nm, UFPs), fine particles (particles with aerodynamic diameter ≤ 2.5 µm, $PM_{2.5}$), black carbon (BC), carbon monoxide (CO), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs) [1]. Previous studies indicate that people spend about 5.5% and 7.6% of their day in vehicles and outdoors, respectively [2]. About 26.7% of commuters have the preference of choosing public transportations in Nanjing in recent years [3]. There is a population of 1.4 billion in China. During the Chinese spring festival travel rush (SFTR), workers and college students buy tickets to return home, which is the largest human migration on earth happening annually. The investigated SFTR started on 10 January 2020, with an estimate of 3 billion passengers over 40 days. Public transportation was fully loaded during the SFTR. In late December 2019, a novel coronavirus disease (COVID-19) broke out in Wuhan, Hubei province, China. Before the suddenly announced strict quarantine starting from 23 January 2020, many unknowns remain. COVID-19 is both deadly and highly transmissible. Recently, the airborne mode of COVID-19 transmission occurring primarily in indoor places has been recognized by many countries and research communities, suggesting proper mask use in transportation facilities such as cars and trains [4–8]. As of June 2021, the number of global confirmed cases is over 190 million, and the death toll is 3.9 million. Air pollution during transportation can have other adverse health effects, including respiratory and cardiovascular diseases and death [9]. A study by Goel et al. shows changes in traffic density for multiple weeks may not induce immediate $PM_{2.5}$ or BC exposure changes, but some toxic elements such as P, S, As, Cu, and Pb may change significantly [10]. Despite the exposure time in a vehicle being relatively limited, the chemical species and their concentrations can represent a significant health risk to commuters [11].

Large proportions of aerosol exposure are experienced during daily commuting trips due to heavy traffic, which contributes to a serious problem for public health [12,13]. High levels of $PM_{2.5}$ in traffic exposure are associated with systemic inflammatory response and respiratory injury [14,15]. The study of Xu et al. indicates that the carbonyl compounds emitted by private cars in Nanjing are harmful to passengers, and most people prefer to take public transports for convenience [16]. Commuting using light rail and the subway have potential health benefits when compared to driving on roadways for the general population [17]. Commuters' $PM_{2.5}$ exposure level in public transport modes is always impacted by wind speed and the number of passengers [18]. In addition, commuting via walking and bus has more exposure to a larger particle concentration and $PM_{2.5}$ mass concentrations for commuters in Beijing [19].

Traffic-related air pollution is a serious health risk, especially for susceptible people [20]. Heavy traffic and various public transport modes also increase the risk of cross-infection during the SFTR. However, in recent years, there have been no articles about the exposure risk of passengers on public transport during the SFTR. Public transportation is always fully or overloaded during the SFTR, as well as the roads and highways being congested. This study was conducted during the worst transportation scenario in Yangtze Delta, which is the most populated area in China. In this study, (1) the personal exposure to PM mass concentrations of five transportation modes was investigated. (2) PM mass concentrations were analyzed during and after the Chinese SFTR with the impact of the COVID-19 outbreak.

2. Methods

2.1. Sampling Routes

Nanjing Railway Station, servicing approximately 210,000 passengers daily during the SFTR, is the center of transportation and tourism in the Yangtze Delta [21]. Passengers are mostly made up of workers and students, and public transport is their first choice. Figure 1 shows the four routes of commuter monitoring data, namely NO.1, 2, 3, 4. The travel routes are connecting Nanjing Railway Station, Nanjing South Railway Station, Xuzhou Railway Station, Xuzhou East Railway Station, and Guanyin International Airport. Xuzhou Railway Station, as the main railway station, services approximately 33,200 passengers daily during the SFTR. Meanwhile, the Xuzhou Subway Line 1 is also selected as the typical route to approach Xuzhou East Railway Station for convenience, and it services approximately 85,700 passengers every day. A total of 1.06 million people is the highest single-day passenger volume of Nanjing Subway Line 3.

Table 1 shows the specific segments of the four routes during and after the SFTR. Table 2 summarizes the basic information of four selected travel routes, such as ventilation type, duration, and distance. Five transport modes are included, which are China railway high-speed train (CRH train), subway, bus, passenger car, and walking. Air conditioning (AC) is used in CRH trains, subways, and busses. The passenger car did not use AC (Non-AC), and the windows were opened (WO) when NO.1–3 routes are selected, but the car AC mode was on when NO.4 route is selected. The carriages of the CRH train and bus are fully loaded. In addition, walking is also considered open-air. There is a distance between Xuzhou Railway Station and Xuzhou Subway Station, and passengers walk along the street for about 24 min for the transfer. The NO.4 route was operated after the strictest quarantine was lifted, and students and workers were back in their original places. The other routes were operated during the SFTR with the beginning of the COVID-19 outbreak.

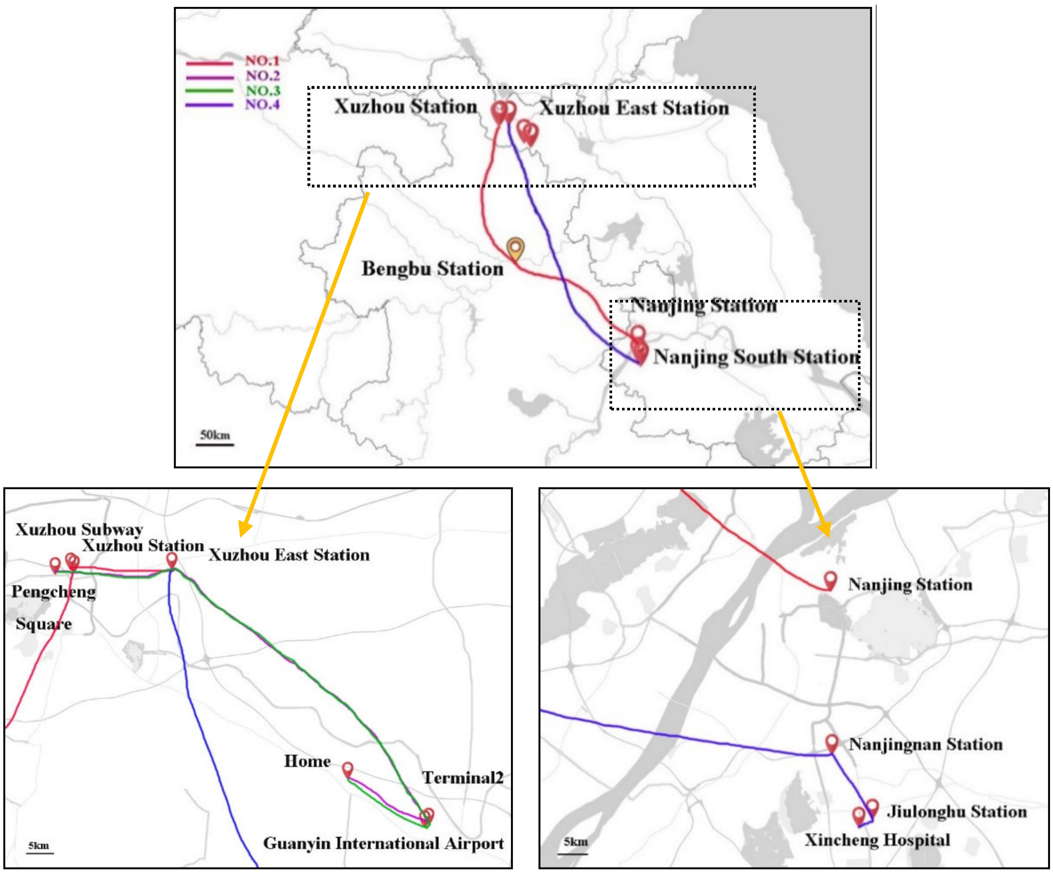


Figure 1. The selected route for different transport modes.

Table 1. The segments of travel routes during and after the SFTR.

Transportation Modes	NO.1 (19 January 2020)	NO.2 (21 January 2020)	NO.3 (21 January 2020)	NO.4 (6 May 2020)
CRH train 1	Nanjing-Xuzhou	-	-	Xuzhou East-Nanjing South
Walk	Xuzhou-Xuzhou Subway	-	-	Jiulonghu-Xincheng Hospital
Subway	Xuzhou Subway-Xuzhou East	Xuzhou East-Pengcheng Square	Pengcheng Square-Xuzhou East	Nanjing South-Jiulonghu
CRH train 2	Xuzhou East-Guanyin Airport	Guanyin Airport-Xuzhou East	Xuzhou East-Guanyin Airport	Guanyin Airport-Xuzhou East
Bus	Guanyin Airport-Terminal 2	-	Guanyin Airport-Terminal 2	-
Car	Terminal 2-Home	Home-Guanyin Airport	Guanyin Airport-Home	Home-Guanyin Airport

2.2. Measurements

In this study, personal exposure monitoring began when the researcher left school for winter vacation. The first experiment was performed on 19 January 2020 from 11:03 to 17:25 (NO.1). The second experiment was performed on 21 January 2020, from 10:06 to 18:23 (NO.2, 3). The third experiment was performed on 6 May 2020, from 09:58 to 13:39 (NO.4). The PM mass concentrations were measured using a portable air quality monitor (BoHu model BH1-B3, China), and the instrument's detailed information is shown in Table 3. This instrument uses the light scattering method to measure the PM from 0 to 1999 $\mu g \cdot m^{-3}$ (PM_1, $PM_{2.5}$, PM_{10}). This instrument has been calibrated against a TSI DustTrak 8532 for $PM_{2.5}$ indoor and outdoor use before the experiment (R2 = 0.89). Weather parameters such as temperature (T) and relative humidity (RH) were also measured by the same instrument. All collected data are stored in the memory card inside the instrument with a 1 min sampling interval.

Table 2. The information summary about travel routes.

Transportation Modes	Ventilation Type	Routes	Duration (min)	Distance (km)	Note
CRH train 1	AC	NO.1	150	283.5	-
		NO.4	222	283.5	-
Walk	Open air	NO.1	24	0.4	8 lanes in both directions
		NO.4	9	0.2	Single direction
Subway	AC	NO.1	27	9.0	-
		NO.2	30	9.0	-
		NO.3	33	9.0	-
		NO.4	20	8.9	-
CRH train 2	AC	NO.1	16	35.3	-
		NO.2	15	35.3	-
		NO.3	16	35.3	-
		NO.4	17	35.3	-
Bus	AC	NO.1	9	2.0	2 lanes in both directions
		NO.3	9	2.0	
Car	Non-AC+WO	NO.1	15	9.2	6 lanes in both directions
	Non-AC+WO	NO.2	20	9.2	
	Non-AC+WO	NO.3	23	9.2	
	AC	NO.4	34	9.2	

Table 3. Instrument information.

Instrument	Parameters Collected	Interval	Range	Accuracy
BoHu model BH1-B3	$PM_1/PM_{2.5}/PM_{10}$	1 min	0–1999 $\mu g \cdot m^{-3}$	±15%
	RH		0–100%	±5%
	T		−20–99 °C	±2 °C

The ambient PM mass concentration is usually affected by meteorological conditions. However, the in-cabin microenvironment in trains, passenger cars, subway cabins, and buses was mainly affected by the air conditioning systems when the doors and windows were tightly closed. The ambient relative humidity (RH) and temperature (T) mostly affected the walking exposure in our study. The air quality index (AQI) has been set up based on the ambient environment. However, in terms of personal exposure, the ambient and in-cabin exposure levels were both important because nowadays, people spend more time in microenvironments, such as buildings and cabins. The average temperature (T) and relative humidity (RH) of four transportation routes are summarized in Table 4. The outdoor T and RH during the walking mode were similar to the in-cabin conditions in this study. The cabin microenvironment in different transportation modes was affected by the air conditioning/ventilation systems, mostly when the cabin doors and windows were tightly closed.

Table 4. Average temperature (T) and relative humidity (RH).

Route	NO.1		NO.2		NO.3		NO.4	
	T/°C	RH/%	T/°C	RH/%	T/°C	RH/%	T/°C	RH/%
CRH train 1	23.0	41.0	-	-	-	-	25.7	47.9
Walk	20.9	31.5	-	-	-	-	26.2	48.7
Subway	20.1	38.6	13.5	52.1	15.3	53.7	25.9	50.5
CRH train 2	22.1	36.3	13.6	64.4	19.5	44.1	25.1	50.3
Bus	21.2	35.8	-	-	17.3	54.1	-	-
Car	19.0	43.7	12.9	52.0	18.0	49.2	25.3	48.6

The maximum speed of the CRH train is about 250 km/h. The Xuzhou Subway Line 1 started operation on 28 September 2019, and Nanjing Subway Line 3 has operated from 1 January 2015. The bus is free for the airport to shuttle passengers who get off from the Guanyin international airport. The private passenger car is a Mazda-6 four-door sedan with a 2.0 L engine (gasoline) and high-performance cabin air filter VF2018, which was used during SFTR. After the strictest quarantine was lifted, a new (less than 1 year) Lynkco-03 four-door SUV with a 1.5 L engine (gasoline) and a high-efficiency particulate air filter (HEPA) was driven from home to the Guanyin international airport. During exposure measurement, the instrument was positioned outside a laptop backpack and fixed with tape, which has no threat to the security check during the SFTR.

3. Results and Discussion

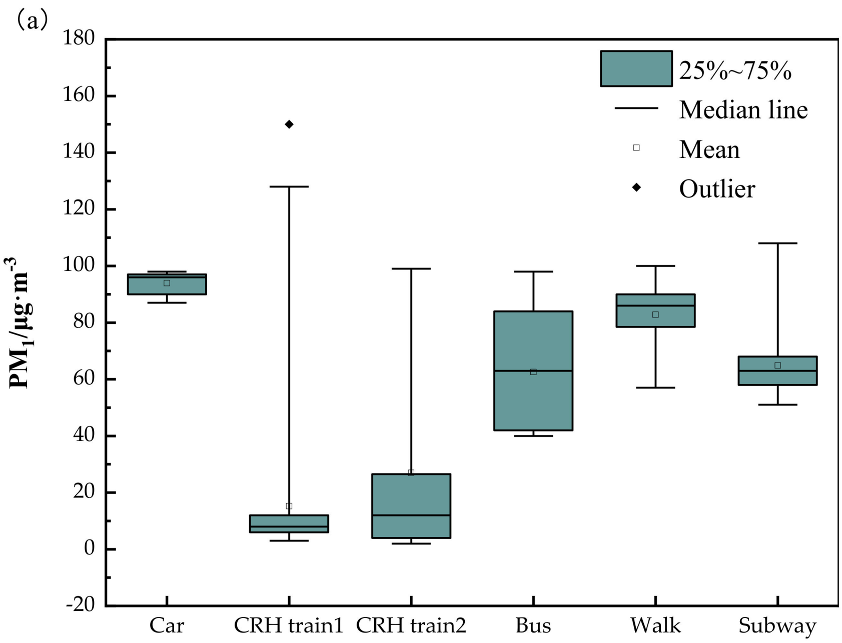
3.1. During the SFTR

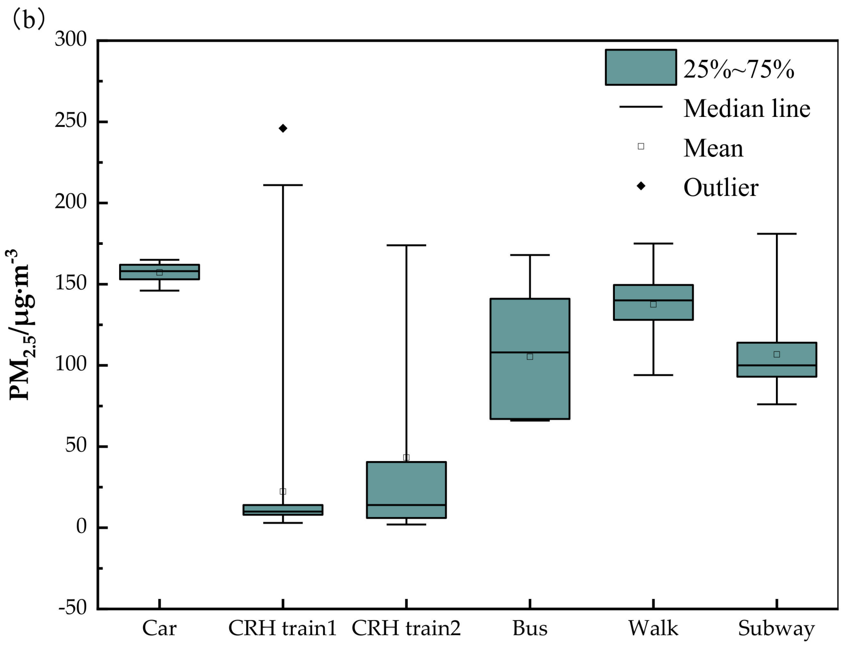
The World Health Organization (WHO) air quality guideline (AQG) for 24-h mean $PM_{2.5}$ and PM_{10} are 25 $\mu g{\cdot}m^{-3}$ and 50 $\mu g{\cdot}m^{-3}$, respectively. The AQG is the lowest level at which total cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ in the American Cancer Society study [22]. There is no related guideline of PM for the health of commuters in public transportations in China. Figure 2 shows the box plot of PM mass concentrations during the SFTR. Average PM_{10} mass concentrations of five different transport modes range from 23.4 to 202.3 $\mu g{\cdot}m^{-3}$.

When passengers commute using the subway and car, the exposure levels of PM_{10} mass concentrations are all higher and about twice as high as the results of Qiu et al. (subway: 58.2 $\mu g{\cdot}m^{-3}$; car: 95.9 $\mu g{\cdot}m^{-3}$; walking: 110.0 $\mu g{\cdot}m^{-3}$) [9]. However, when commuting on the bus, the exposure level to PM_{10} mass concentration in this study is similar to the results of Qiu et al. (123.6 $\mu g{\cdot}m^{-3}$) and Chan et al.(184.0 $\mu g{\cdot}m^{-3}$) [9,23]. The exposure level of passengers in a car and by walking is higher than other transport modes, and the mean PM_{10} mass concentrations of car and walking are 202.3 $\mu g{\cdot}m^{-3}$ and 164.5 $\mu g{\cdot}m^{-3}$, respectively. However, the average PM_{10} mass concentration of commuter exposure in CRH train1 is the lowest, which is one ninth of the commuting in car level. Average $PM_{2.5}$ mass concentrations for six segments are 20.2 $\mu g{\cdot}m^{-3}$, 137.5 $\mu g{\cdot}m^{-3}$, 97.7 $\mu g{\cdot}m^{-3}$, 43.8 $\mu g{\cdot}m^{-3}$, 118.9 $\mu g{\cdot}m^{-3}$, and 166.7 $\mu g{\cdot}m^{-3}$, when commuters travel by CRH train1, walk, subway, CRH train2, bus, and car, respectively. During the SFTR, the exposure levels of $PM_{2.5}$ mass concentrations in five tested transport modes are 2 to 4 times the results of other researchers, as shown in Figure 3 [9,19,24–28].

As Figure 3a shows the exposure level to particles when passengers take the CRH train, due to less research on pollution in CRH train cabins, this study makes a comparison with other electronic trains and diesel trains. According to Figure 3a, the exposure level in diesel trains are two times that in electronic trains [29]. Overall, the average exposure levels of electronic trains in Europe, China, and America are close, and they are 33.7 $\mu g{\cdot}m^{-3}$, 38.3 $\mu g{\cdot}m^{-3}$, and 22.5 $\mu g{\cdot}m^{-3}$, respectively [30–38]. In this study, the PM mass concentrations in the long-haul CRH train (CRH train1) are half of the short-haul CRH train (CRH train2). The fast speed (no more than 250 km/h) and frequent air exchange of the air conditioner might decrease the PM mass concentration.

Figure 3b indicates that the $PM_{2.5}$ mass concentration is close to 2.4 and 2 times higher in this study (141.1 μg·m^{-3}) when commuting via walking during the SFTR compared to the usual level in China (59.4 μg·m^{-3}) and Asia (71.7 μg·m^{-3}), respectively [9,13,19,24,25,39,40]. According to the study of Ozgen et al., the mean exposure level of SFTR in China is seven times that of Italy [40]. In India, PM pollution is more serious (234 μg·m^{-3}), which is 1.7 times that of China during the SFTR [41]. In addition, the pollution level of China's surrounding environment is getting worse compared with this study when commuting via walking, and 5.3 times that of the study of Yan et al. in Beijing (26.7 μg·m^{-3}) [19].





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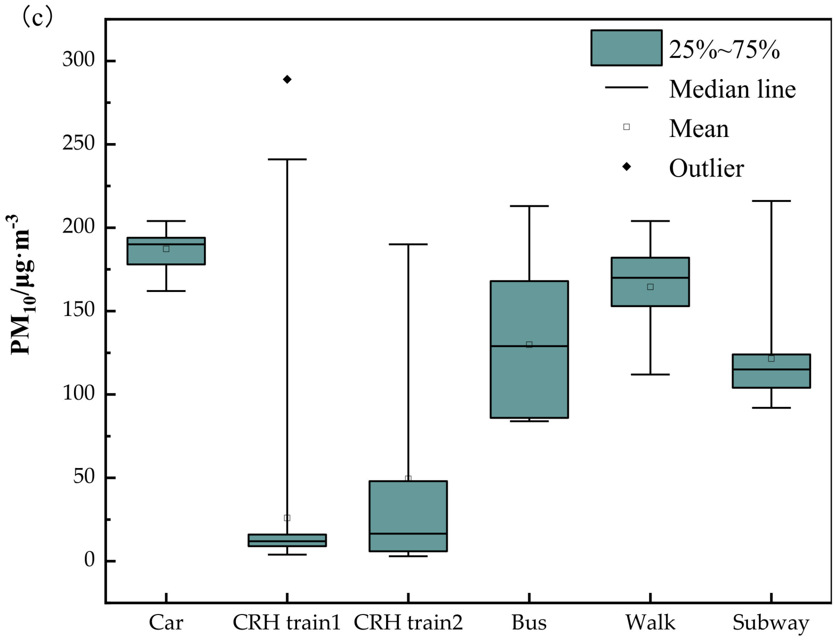
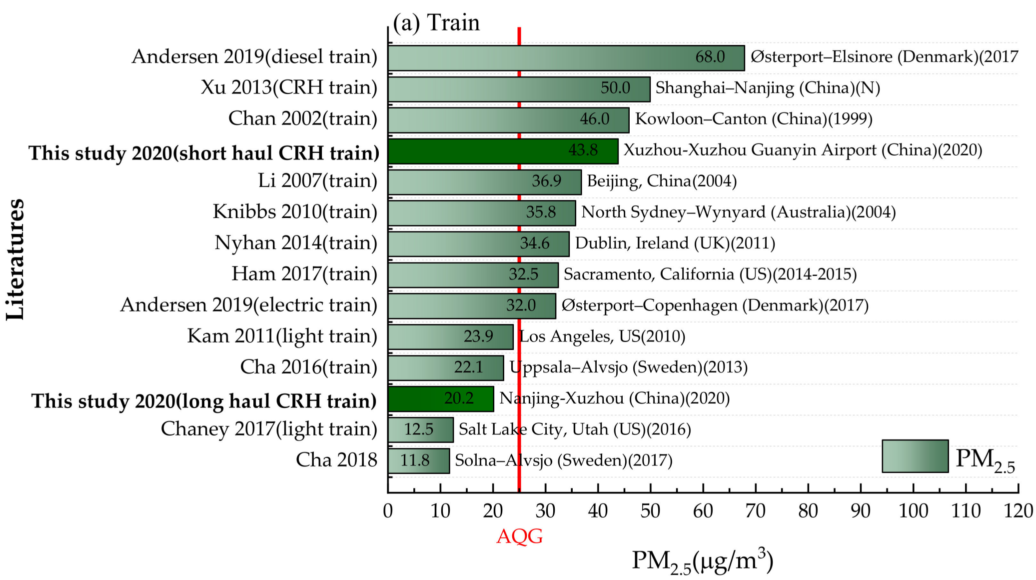


Figure 2. The box plot of PM mass concentrations during the SFTR: (**a**) PM_1; (**b**) $PM_{2.5}$; (**c**) PM_{10}.

Figure 3c shows that the mean $PM_{2.5}$ mass concentration is 97.7 $\mu g \cdot m^{-3}$ when commuting on the subway during the SFTR, which is about 2.2, 2, and 1.6 times higher than the usual level in China (43.7 $\mu g \cdot m^{-3}$), Asia (47.95 $\mu g \cdot m^{-3}$, and Chile (62.4 $\mu g \cdot m^{-3}$), respectively [9,13,19,24,25,28,38–40,42]. When commuting on the subway, the exposure level to $PM_{2.5}$ mass concentration in this study is similar to the results of Ozgen et al. in Italy (91.1 $\mu g \cdot m^{-3}$), and the PM pollution on the subway is the most serious compared to other public travel modes in the study by Ozgen et al. in Italy [40]. In particular, in Milan, a well-known European hot-spot for PM pollution, which may contribute to the high and similar PM exposure level with China during the SFTR. As shown in Figure 3c, the PM pollution in China is more and more serious, and in particular during the SFTR. In addition, the subway is the primary choice for commuters' transit plans, which may do harm to the health of commuters and increase the exposure risk to COVID-19.



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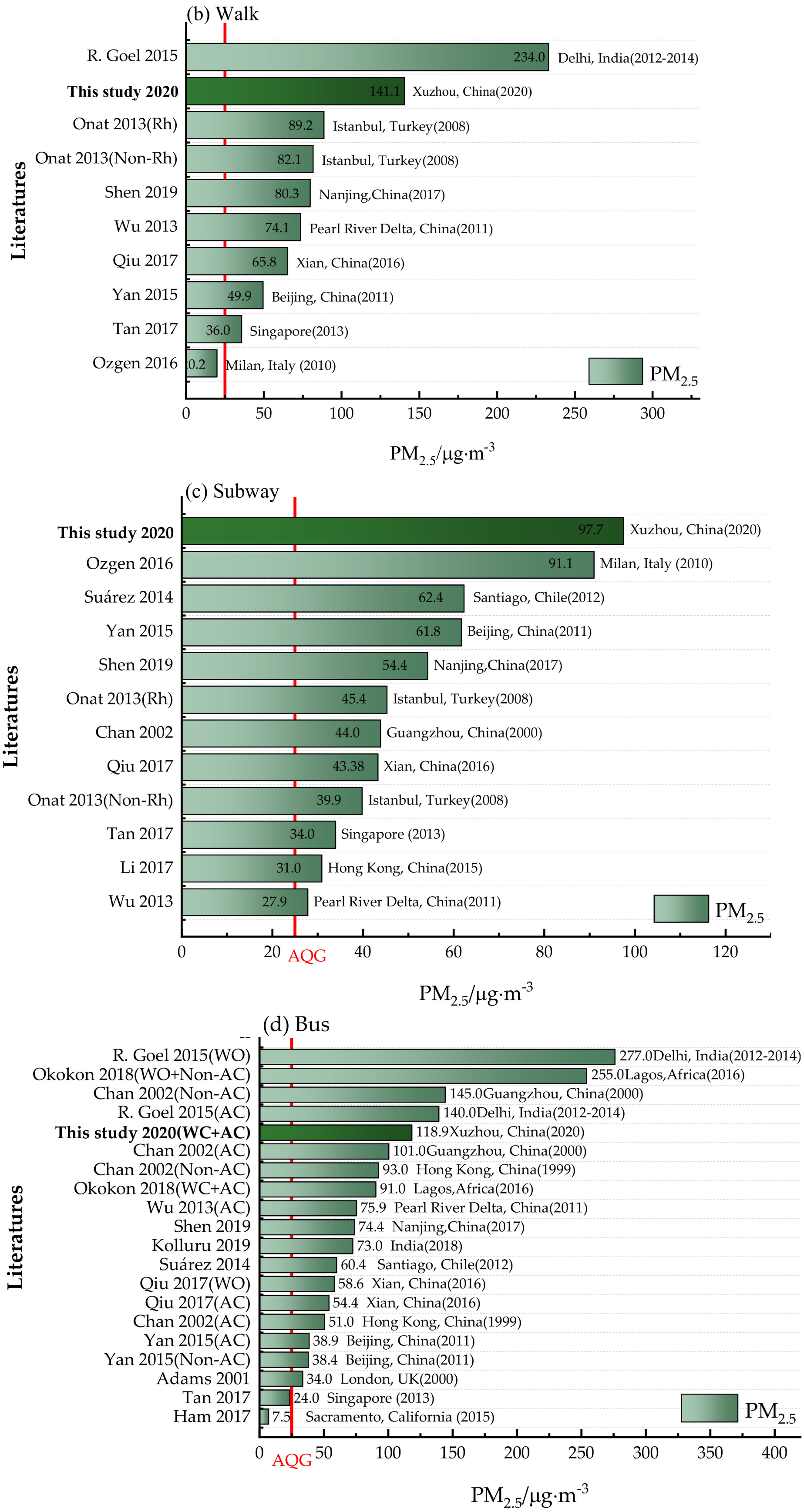

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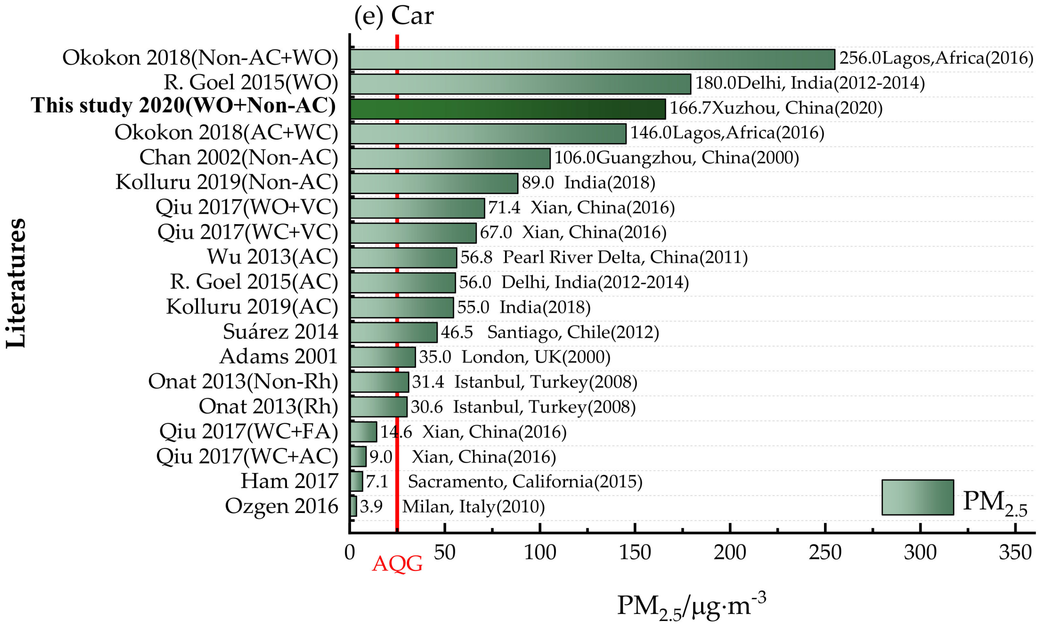

Figure 3. The $PM_{2.5}$ mass concentration of different transportations in the literature: (**a**) Train; (**b**) Walk; (**c**) Subway; (**d**) Bus; (**e**) Car. Rh stands for rush hours. Non-Rh stands for non-rush hours. WC + VC stands for all windows and vents being closed. AC + WC stands for all windows closed, air condition on recirculation. WC + FA stands for all windows closed, AC system on fresh air mode.

When commuting on the bus, the windows are all closed with the air conditioner working. The mean level of $PM_{2.5}$ mass concentration is 118.9 $\mu g \cdot m^{-3}$ during the SFTR in this study. As shown in Figure 3d, the measured mean $PM_{2.5}$ mass concentration during the SFTR is 1.6 times that of the regular time in India and the non-SFTR in China, 1.5 times that of the regular time in Europe, and 3.5 times that of the United States [9,19,23–25,28,34,38,39,43,44]. According to Yan et al., whether working or not, the air conditioner is not a critical factor influencing the exposure level of passengers on the bus (AC: 38.9 $\mu g \cdot m^{-3}$; Non-AC:38.4 $\mu g \cdot m^{-3}$) [19]. However, the study of Chan et al. issued in 2002 indicates that the exposure level of a Non-AC bus (145.0 $\mu g \cdot m^{-3}$) is 1.4 times that of an AC bus (101.0 $\mu g \cdot m^{-3}$) in Guangzhou [23]. In addition, the exposure level to $PM_{2.5}$ mass concentration on the bus is similar to the results of Okokon et al.'s study, which was researched in Africa when commuting on the bus with the AC on and the windows closed (91.0 $\mu g \cdot m^{-3}$) [45]. When the bus windows were opened in Non-AC mode, higher exposure levels to $PM_{2.5}$ mass concentration were found in Okokon et al.'s study (255.0 $\mu g \cdot m^{-3}$), which are 2.1 and 2.8 times that of this study and Okokon et al.'s study in AC mode [45], respectively. However, similar exposure levels were obtained in the WO mode bus (58.6 $\mu g \cdot m^{-3}$) and AC mode bus (54.4 $\mu g \cdot m^{-3}$) in the study of Qiu et al. [9]. Due to more serious ambient pollution in Africa compared to China, which contributes to more difference between the inside and outside of the bus.

In this study, when commuting in a car with WO and VC mode during the SFTR in 2020, the mean exposure level to $PM_{2.5}$ mass concentration is 166.7 $\mu g \cdot m^{-3}$, which is 2.3 times that of Qiu et al.'s study [9]. However, when the car windows are all closed with FA, VC, or AC modes, a lower exposure level was found in Qiu et al.'s study, as shown in Figure 3e [9]. Furthermore, the mean exposure level of commuting in a car is similar to commuting via walking, which is 3, 4.3, 24, and 2.3 times that of Non-SFTR, UK, US, and India, respectively [9,23–25,28,34,41,43–45].

In summary, the exposure levels to $PM_{2.5}$ on public transport are apparently higher than AQG. Short-term exposure to $PM_{2.5}$ can trigger cardiovascular disease-related mortality and nonfatal events, which also can affect healthy human lymphocyte subsets [46,47]. Therefore, it is critical for commuters, for instance, to wear a facial mask to decrease the risk of pollutants exposure and avoid inhalation of PM into the lungs. In this study, workers and students were found to have higher exposure levels to PM mass concentrations when commuting via subway, bus, car, and walking during the SFTR. Although the average PM mass concentrations of commuting by car are the highest, the standard deviations (SDs) of them are the lowest. Car windows are opened during the non-AC mode, which can provide a relatively stable in-cabin microenvironment. The mean exposure level to particles is lowest in the CRH train, and following is the subway, bus, walking, and car. While the SDs of PM mass concentration are higher than the average, which is contributed to by the speed of the CRH train suddenly slowing down when approaching the destination, the pollutants in the ambient air will enter the cabin via AC system or by air pressure. Therefore, it is recommended that the passengers choose the better combination of CRH train and subway during the SFTR.

The time series of the CRH train1, CRH train2, subway, and the car started from the closing of the cabin door to reopening. When walking, the researchers are exposed to the open environment. According to Figure 4a,d time series PM mass concentrations in CRH trains are similar. When CRH trains approached destinations, about 100 times PM mass concentrations were monitored in the cabin microenvironment. The study of Adams et al. indicates that wind speed negatively affects the PM mass concentration [43].

As shown in Figure 4, the gaps of PM_1, $PM_{2.5}$, PM_{10} in CRH train1 and CRH train2 are the smallest when the cabin door is closed compared to other transportation modes. As shown in Figure 4b, the mean PM mass concentrations decrease when walking into the subway and preparing to check out under the ground from 13:52 to 13:54. After the safety check, the mean PM mass concentrations increased from 13:54 to 13:58, which might be affected by passengers' activities. Figure 4b,c,e indicate that the exposure levels to particles via subway and bus are similar to commuting via walking during the SFTR. In addition, there are more fluctuations in the PM mass concentrations when commuting via subway, which may be contributed to by frequent stopping (9 stops) during operation. Figure 4e shows a little higher PM mass concentration from 17:01 to 17:04, which might be affected by the fresh air mode of the air conditioner and the number of passengers, which can introduce more particles into the bus. When the bus door opened, passengers aboard the bus experience a personal exposure level to PM mass concentrations similar to commuting via walking (Figure 4b) and car (Figure 4f).

The WHO recommends the use of $PM_{2.5}$ as an indicator and a $PM_{2.5}/PM_{10}$ ratio of 0.5 (50%) is used to derive an appropriate PM_{10} guideline value [22]. This ratio of 0.5 is close to that typically observed in urban areas in developing countries and at the bottom of the range (0.5–0.8) found in urban areas in developed countries [22]. For the five transport modes, PM ratios consist of PM_1/PM_{10} and $PM_{2.5}/PM_{10}$, as shown in Figure 5. Figure 5 indicates $PM_{2.5}/PM_{10}$ are all higher than the typical guideline value of the WHO, which shows more $PM_{2.5}$ on public transportation in China. In this study, the PM_1/PM_{10} and $PM_{2.5}/PM_{10}$ in CRH train1 are the highest, and they are 68.2% and 87.4%, respectively. These ratios on CRH trains and the subway are significantly higher than that of the other three transport modes, which indicates that there are more fine particles on CRH trains and the subway. When the cabin door is closed, the air conditioner exchanges cabin air for passengers. According to the study on traffic environmental pollution exposure of Yu Nu et al., the exposure levels of road traffic pollution sources $PM_{2.5}$, and ultrafine particles (UFPs) were significantly correlated with the increase of the body's oxidation marker malondialdehyde among taxi driver groups in Los Angeles [48]. The PM_1/PM_{10} and $PM_{2.5}/PM_{10}$ on the bus are the lowest, and they are 48.2% and 80.8%, respectively. Although the ventilation on the bus is supported by an air conditioner, the air filtration performance is not good. Considering the health of passengers, the bus driver should change the air conditioning filter regularly. Overall, the $PM_{2.5}/PM_{10}$ in the microenvironment of the subway, bus, car, and walking are all higher than PM_1/PM_{10}, and the exposure levels to fine particles are most serious on CRH trains and the subway, which is similar to the study of Qiu et al. [9].

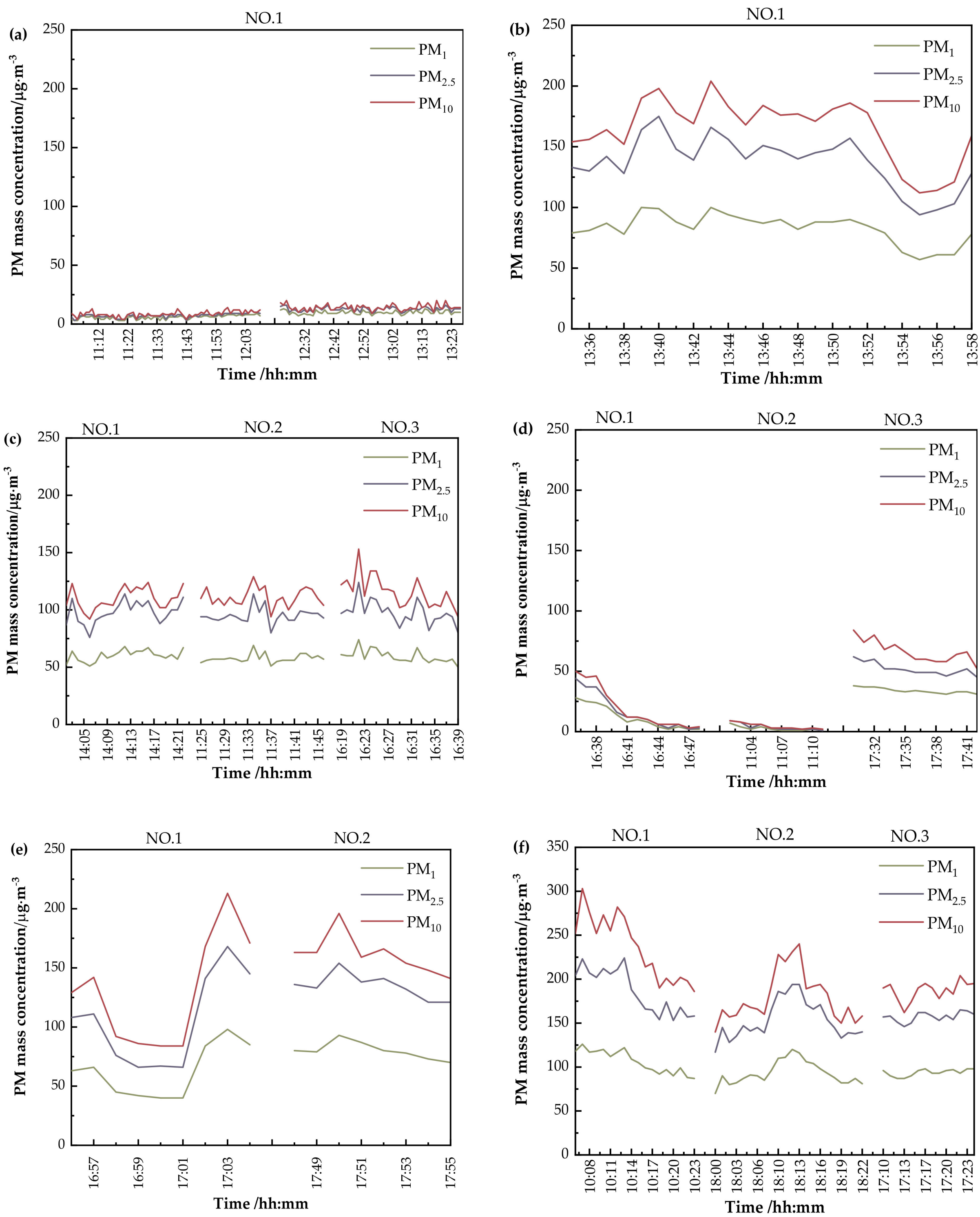

Figure 4. The PM mass concentrations in time series for different transport modes during the SFTR: (**a**) CRH train1; (**b**) Walk; (**c**) Subway; (**d**) CRH train2; (**e**) Bus; (**f**) Car.

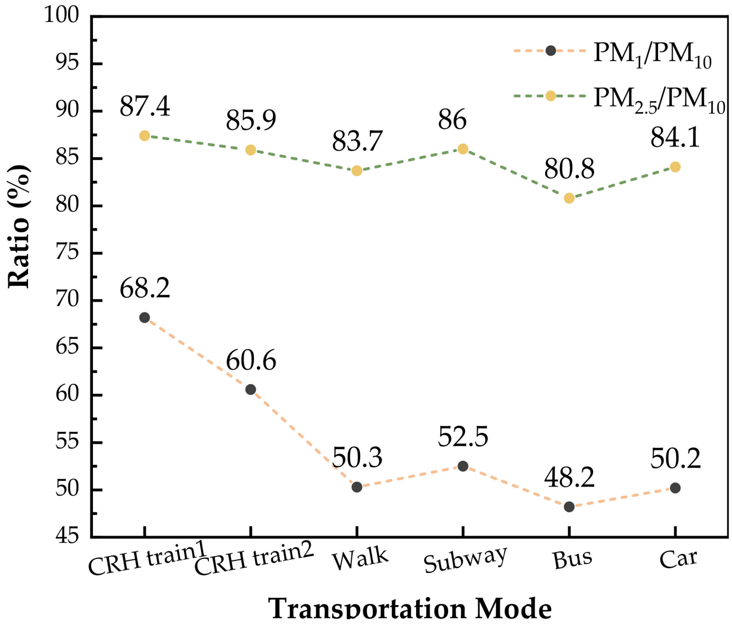

Figure 5. The PM ratios with PM_{10}.

3.2. After the SFTR

Figure 6a is the radar chart of the mass concentration of PM_1, $PM_{2.5}$, and PM_{10} on different transportation from Nanjing to Xuzhou during the SFTR. Figure 6b is the return route from Xuzhou to Nanjing after the SFTR. The results show that the mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} are reduced by varying degrees in different modes except for the CRH train1 after the SFTR. For instance, the $PM_{2.5}$ mass concentration is reduced by 2.6, 2.2, and 5.9 times for walking, subway, and car, respectively. However, the PM_1, $PM_{2.5}$, and PM_{10} mass concentrations did not show much variation for the CRH train1 and CRH train2 during and after the SFTR. Although the strictest quarantine was removed and passengers returned, the factories in China have not yet been fully restored. Therefore, the exposure level is apparently lower than during the SFTR, and NASA stated: the industrial shutdown caused a significant improvement in global air quality affected by COVID-19.

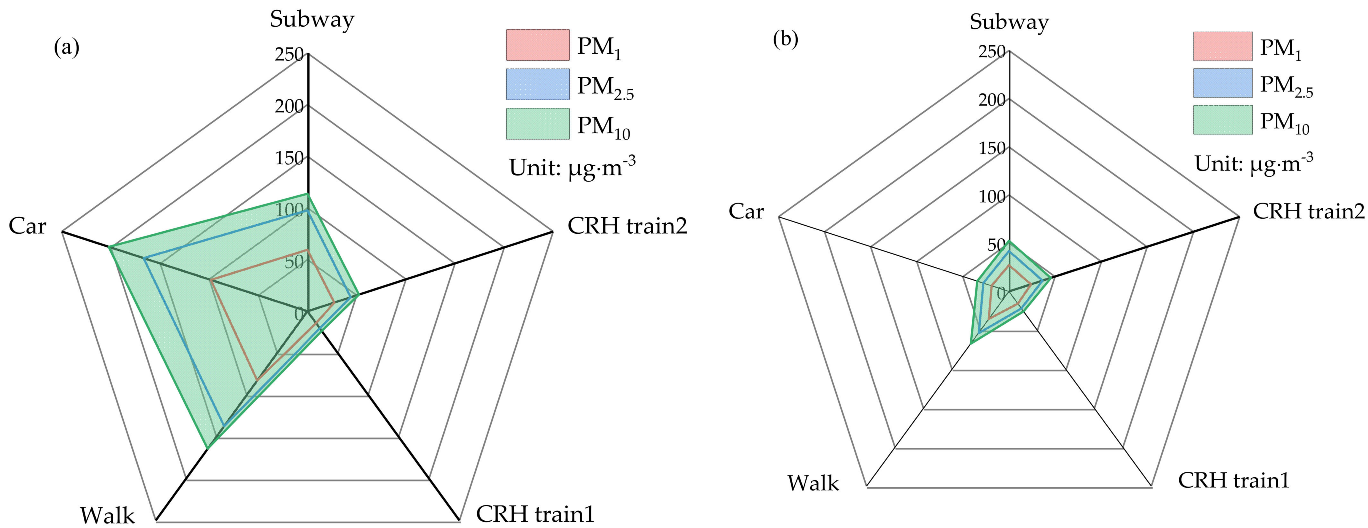

Figure 6. PM mass concentration in different transport modes: (**a**) during the SFTR; (**b**) after the SFTR.

The results of *t*-tests among different modes during and after the SFTR are shown in Table 5. There are no significant differences among the PM_1, $PM_{2.5}$, and PM_{10} mass concentrations on the CRH train1 and the CRH train2 during and after the SFTR (Sig > 0.05). However, there are significant differences among the PM_1, $PM_{2.5}$, and PM_{10} mass concentrations for the subway, car, and walking, during and after the SFTR (Sig < 0.05). For the long-haul CRH train (> 1 h), the exposure level to $PM_{2.5}$ on the CRH train1 (21.77 µg m^{-3}) is lower than the AQG. For the short-haul CRH train (< 20 min), the exposure level to $PM_{2.5}$ in CRH train2 (36.41 $\mu g \cdot m^{-3}$) is similar to the AQG. As mentioned above, the CRH trains are always fully loaded during and after the SFTR, and it maintains high-speed operation (≤250 km/h) for the long term. The microenvironment of the CRH train is more stable than subway, car, and walking. Therefore, it is recommended for passengers to take the CRH train during the SFTR to lower the PM exposure level.

Table 5. The results of *t*-tests among different modes during and after the SFTR.

	PM_1			$PM_{2.5}$			PM_{10}		
	t	df	Sig	*t*	df	Sig	*t*	df	Sig
CRH train1	−0.19	194.25	0.85	0.15	194.98	0.88	0.12	204.45	0.91
CRH train2	0.36	17.46	0.72	0.45	17.33	0.66	0.22	18.21	0.83
Subway	13.46	45	0.00	12.81	45	0.00	10.78	45	0.00
Car	21.46	40.24	0.00	42.68	45.47	0.00	34.13	45.94	0.00
Walking	8.40	42	0.00	17.87	29.39	0.00	16.61	30.64	0.00

4. Conclusions

This study monitors personal exposure using different transport modes during and after the SFTR. Commuters have the lowest personal exposure to PM on the CRH trains. The $PM_{2.5}$ mass concentration is reduced by 2.6, 2.2, and 5.9 times for walking, subway, and car, respectively, while there is no change on CRH train1 and CRH train2 during and after the SFTR. The results of *t*-tests indicate that personal exposure level is relatively stable in the CRH trains, and it is no more than the WHO guideline (AQG). Personal exposure to particles is similar to commuting by walking if the air conditioning filter is not replaced in time. Therefore, to reduce personal exposure for passengers, the CRH train is the best choice during the SFTR.

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