Research on Characteristics of Personal Exposure to Particles for Urban Commuters

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Contents

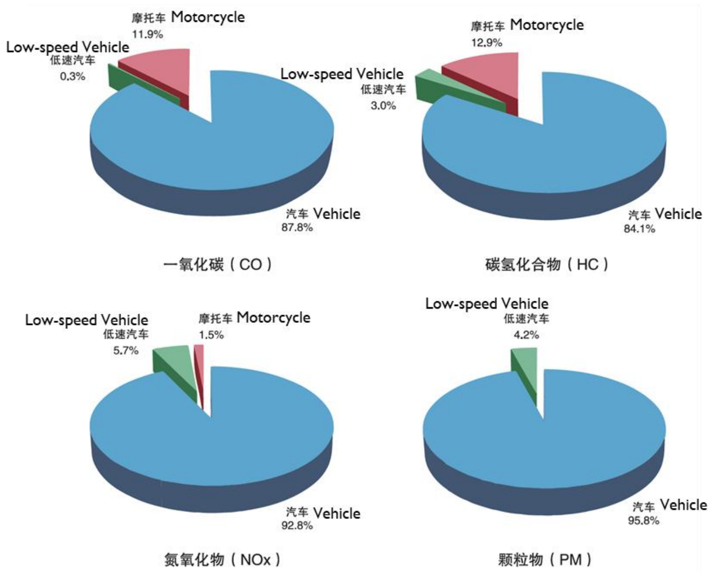
01

Background & Significance

Research background & Significance

Zero Emission

- **Severe environmental pollution caused by traffic emissions**

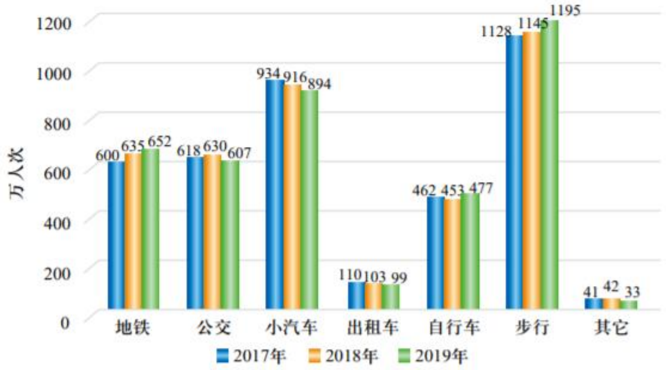


Data source: China Mobile Source Environmental Management Annual Report - 2020

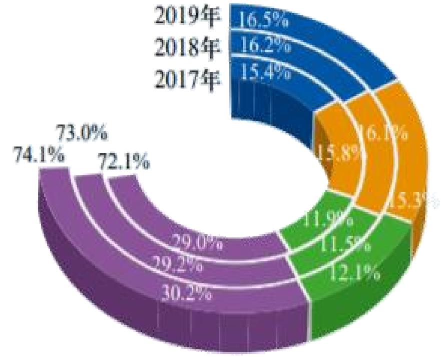
- **Commuting is the main body of urban traffic**

Data Source: Commuter Travel Characteristics in Beijing and Typical Regional Analysis - 2019

- **Non-motorized travel returns back to the public**



Travel volume of different traffic modes on working days in downtown Beijing



Composition of green travel modes in downtown Beijing

Data Source: Beijing Traffic Development Annual Report-2020

- **Increased national and public health concerns**
  - *Outline of the Healthy China 2030 Plan*
- **Lack of theoretical research on impact of commuting trip on people's health in China**

In the face of negative impacts, how can you quantify the risk of exposure to pollutants during commute trips and improve health benefits?

exposure to pollutants

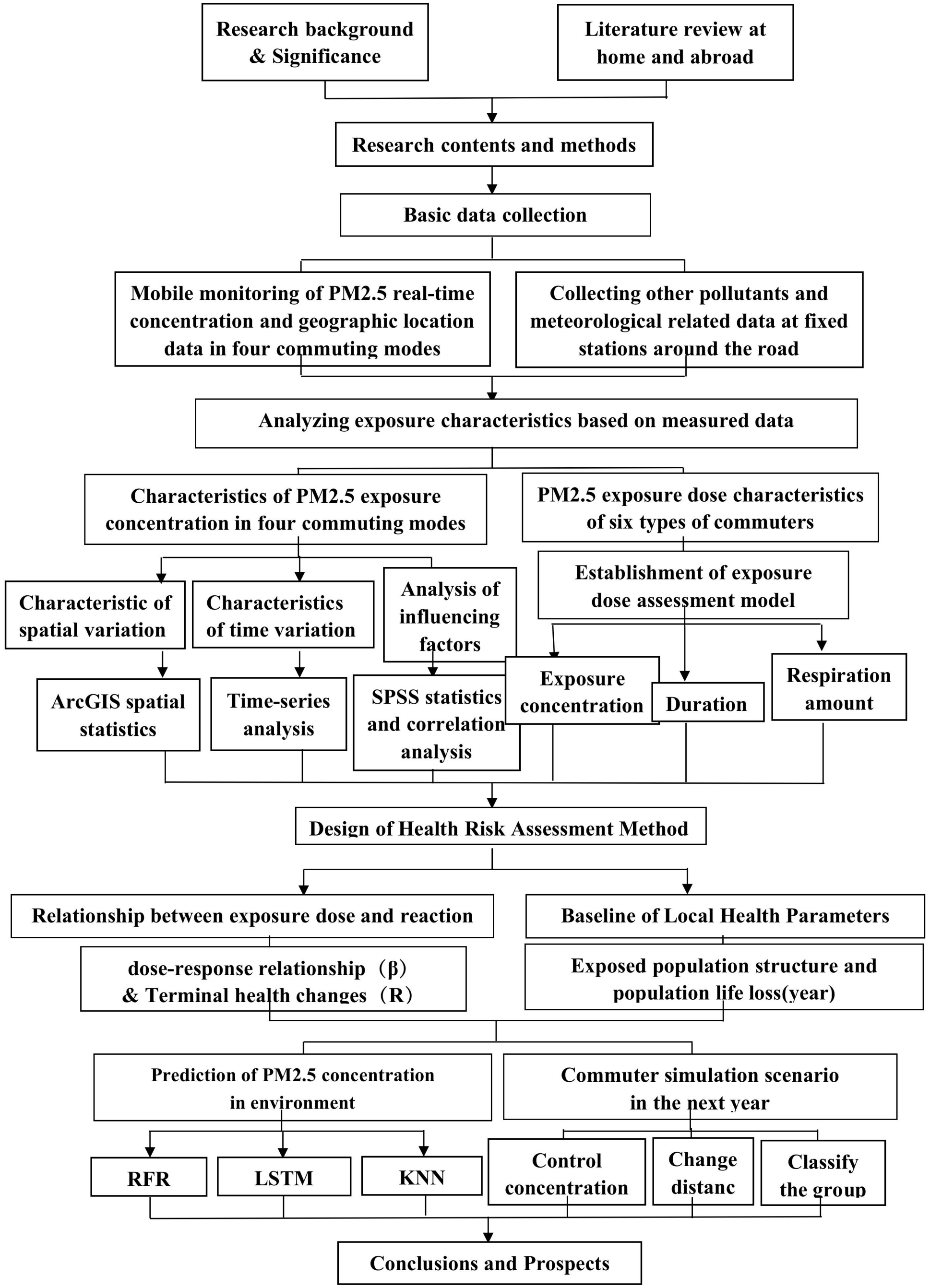
02

Methods & Techniques

研究内容和技术路线

- Data collection
- Concentration analysis of exposure environment
- Inhalation dose calculation
- health impact assessment
- Situation Simulation and suggestions

By population, mode, road grade, unit distance and time



Data collection design

■ Commuter mode：

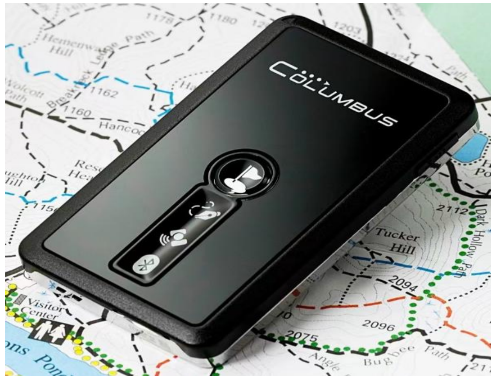
- ➢ Car, bus+walking, bicycle, electric vehicle

■ Data collection method：

- ➢ **Portable atmospheric particle concentration detector and GPS receiver**
- ➢ **Time (flat peak, peak on weekdays, etc.)**
- ➢ **Record the meteorological conditions during the collection period (such as wind direction, temperature, humidity, etc.)**

Collect PM2.5 real-time concentration per second

Portable atmospheric particle concentration detector



GPS receiver

Longitude and latitude of concentration collection spot

Data collection design

■ Route:

◆ Jiaoda East Gate－ Metro Station of Renmin University

■ Road condition analysis:

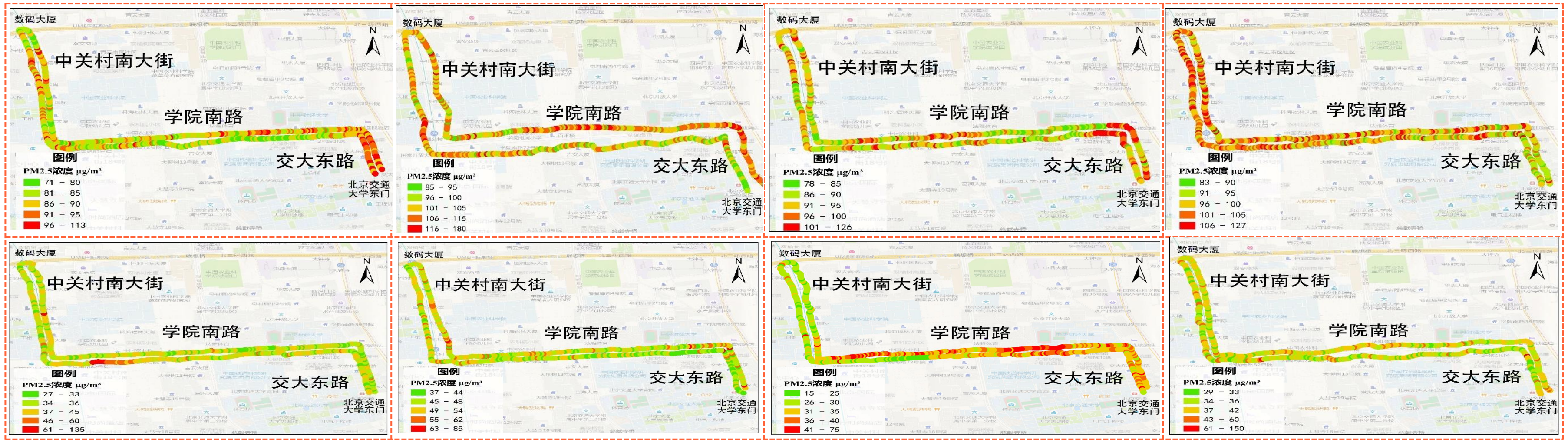
Road		Grade	length/km	Lane	Bus station	Crossing	Surroundings
Name	No.						
Jiaoda East Road	L1	branch	0.44	2	2	2	High density residential areas and shops
Xueyuan South Road	L2	secondary trunk road	2	4	4	4	High density residential area mixed with shops and restaurants
Zhongguancun South Street	L3	trunk road	1.2	8	2	2	Medium density business districts and office buildings with good greening facilities

03

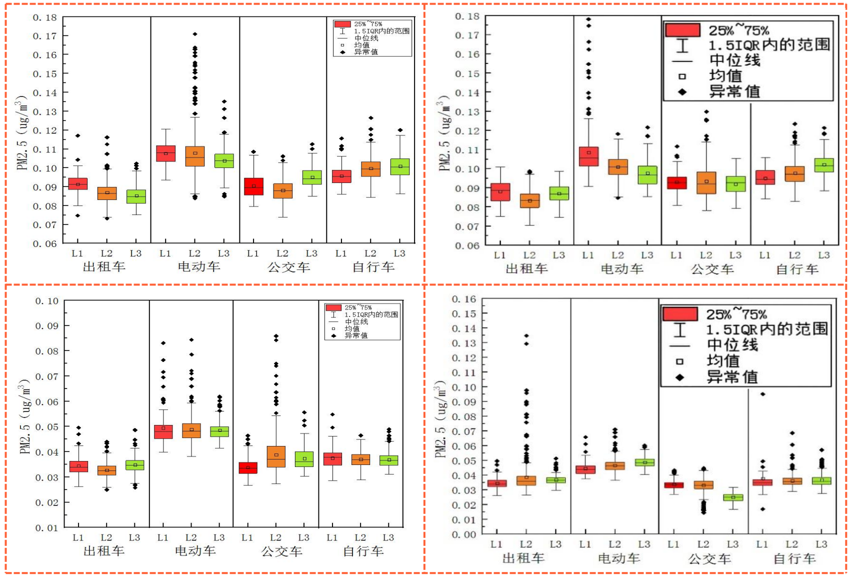
Research results

$PM_{2.5}$ exposure concentration analysis

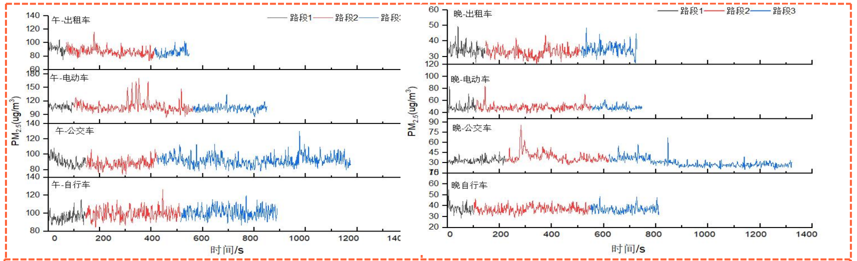
- Input real-time concentration data and geographic information data into ArcGIS

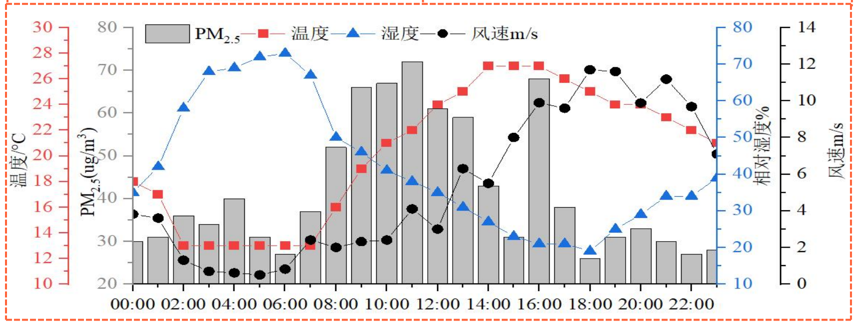


- Use statistics to process and compare

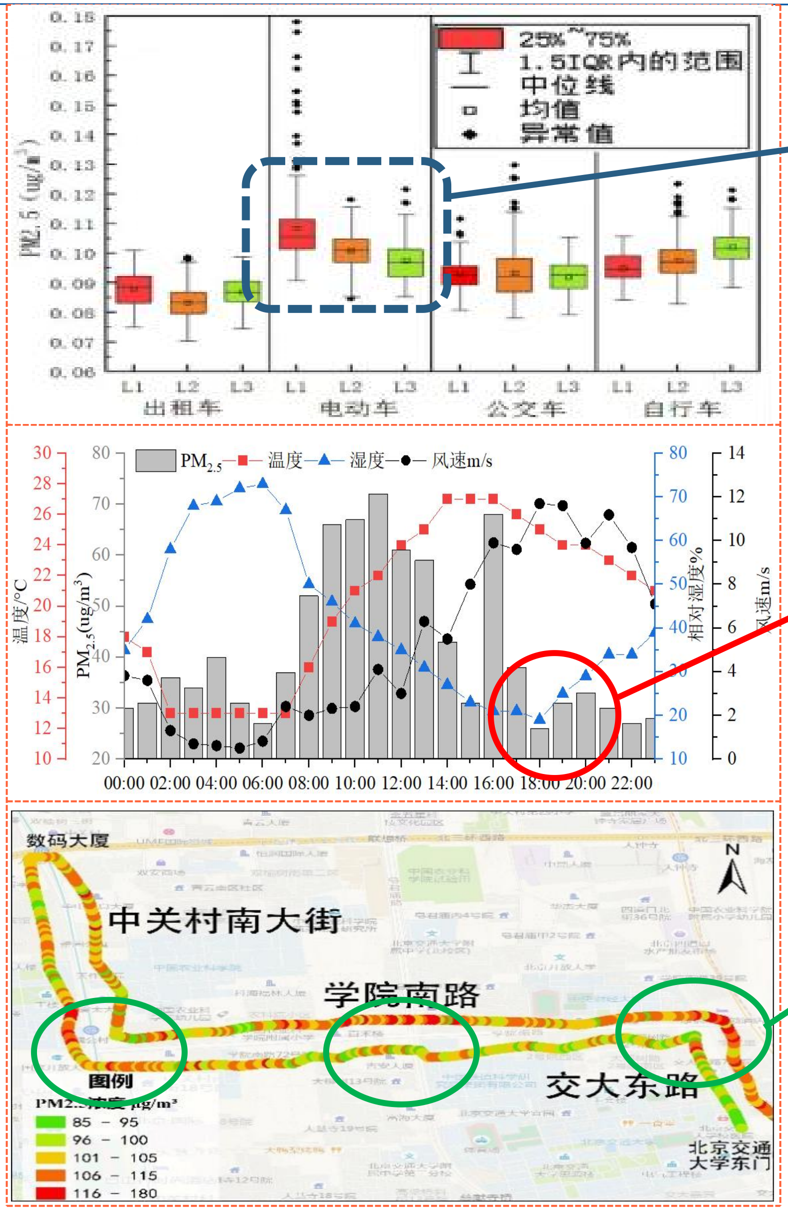


- Time series analysis and correlation analysis





$PM_{2.5}$ exposure concentration analysis



各通勤方式的$PM_{2.5}$浓度特征

■ $PM_{2.5}$ exposure concentration in different commuting modes:

- ➢ Exposure concentration of $PM_{2.5}$ in electric commuter mode is higher than that in other commuter modes;
- ➢ The measured $PM_{2.5}$ concentration in the respiratory area was 24% - 72% higher than the background concentration of $PM_{2.5}$.

■ $PM_{2.5}$ exposure concentration in different periods:

- ➢ Affected by the force 5 gale weather in the afternoon, the noon time of each commuting mode is higher than the peak monitoring period in the evening.

■ PM2.5 exposure concentration in different sections and spaces:

- ➢ Pollution hotspots often occur near intersections and road intersections;
- ➢ PM2.5 concentration is high in Jiaoda East Road and Zhongguancun South Street;
- ➢ PM2.5 concentration in the access road is higher than that in the return road.

Calculation of PM2.5 Inhalation Dose in Different Populations

Quantitative method (next year):

- Exposure dose model and evaluation parameters

$$D = \int \frac{1}{60} IR \times CdT$$

$$D_L = \frac{D}{L} \qquad D_t = \frac{D}{t} \qquad (1)$$

式中: D——Total inhalation dose (μg);

IR——respiration amount (L/min);

C——PM2.5 concentration value in respiratory area (μg · m^{-3});

T——Commuter duration (s);

L—— Road length (m);

t——Commuter time of a road section (s)。

$$IR = \frac{E \times H \times VQ}{1440} \qquad (2)$$

$$E = BMR \times N$$

式中: H——Oxygen consumption volume consuming unit energy, normally, 0.05L/kJ;

VQ——Ventilation equivalent, usually 27;

E——Energy consumed per unit time (kJ/d);

BMR——Basic metabolic rate (kJ/d);

N——The degree of energy consumption in different human activity intensity, which is a multiple of the basic metabolic rate.

Calculation of PM2.5 Inhalation Dose in Different Populations

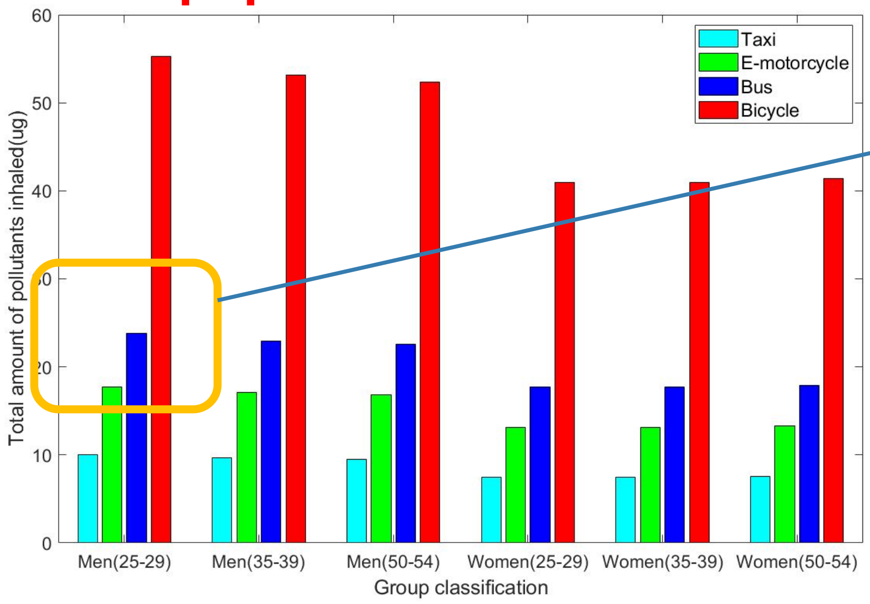
Groups of different commuters

Gender	Age/year old	Height/cm	Weight/kg	N（Bus、electric vehicle & taxi）	N（on foot）	N（bike）
Male	25-29	172.1	72.8	1.2	1.5	4
	35-39	170.4	74	1.2	1.5	4
	50-54	167.9	71.6	1.2	1.5	4
Female	25-29	159.8	56.7	1.2	1.5	4
	35-39	158.6	59.1	1.2	1.5	4
	50-54	157.2	60.8	1.2	1.5	4

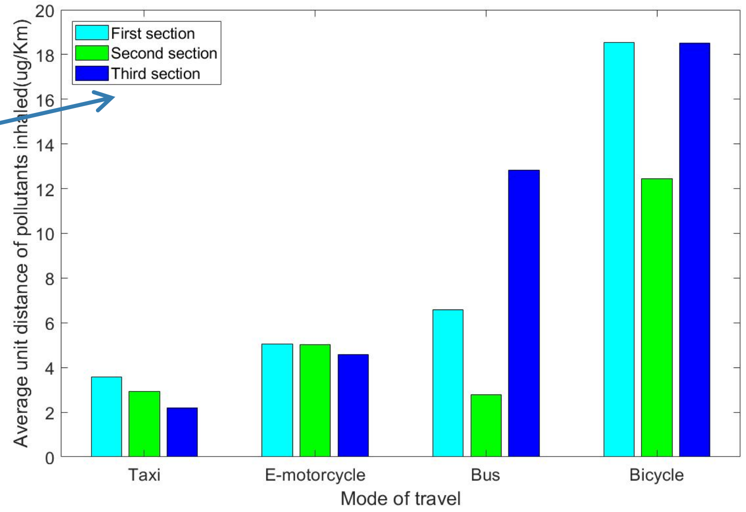
Age	Method of calculating BMR	
	Male	Female
<18	BMR =370＋20H＋52W－25A	BMR =1873＋13H＋39W－18A
18~30	BMR=63W＋2896	BMR=62W＋2036
30~60	BMR=48W＋3653	BMR=34W＋3538
>60	BMR =370＋20H＋52W－25A	BMR=1873＋13H＋39W－18A

Part of the data comes from the fifth national physique monitoring bulletin

- **Total inhalation amount of each population:**



- **Suction volume per unit distance of each road section:**



- Bike＞Bus＞electric vehicle＞Taxi;
- Male＞Female;
- The suction volume of trunk road and branch road is large.

Health Risk Assessment of Different Populations

Health impact assessment method

Dose-response model

Increased number of deaths

$$I = I_0 \times exp(\beta \times (D - D_0))$$

$$D_0 = 7.36 \times 10^{-6} \times C_0 \times IH \times T \qquad (1)$$

$$\Delta I = I - I_0 = I \times [1 - exp(-\beta \times (D - D_0))]$$

$$R = P \times \Delta I = P \times (I - I_0) = P \times I \times [1 - exp(-\beta \times (D - D_0))]$$

式中: I——Public health risk value under actual inhalation dose of PM2.5;

I_0——Benchmark for public health risk rounding under PM2.5 inhalation dose;

D——Actual inhalation dose of current PM2.5(μg);

D_0——Reference dose threshold for PM2.5 inhalation (μg);

C_0——Reference concentration threshold of PM2.5 (Here10μg/m³);

β——Dose-response coefficient;

IH——Average annual inhalation rate of individuals (normally4745m3/person);

ΔI——Changes in public health risks;

R——Terminal changes in public health due to changes in PM2.5 dose (increase in deaths)。

Disability Adjusted Life Year

$$DALY = P \times D \times EF \qquad (2)$$

reduced avarage life expandancy

式中: P——暴露人群 (人);

$DALY$——Disability Adjusted Life Year;

EF——Annual effect factor of health life loss (year/kg (PM2.5 inhalation dose)/100000 people)。

Health Risk Assessment of Different Populations

Composition of the age group of the permanent population in Haidian District

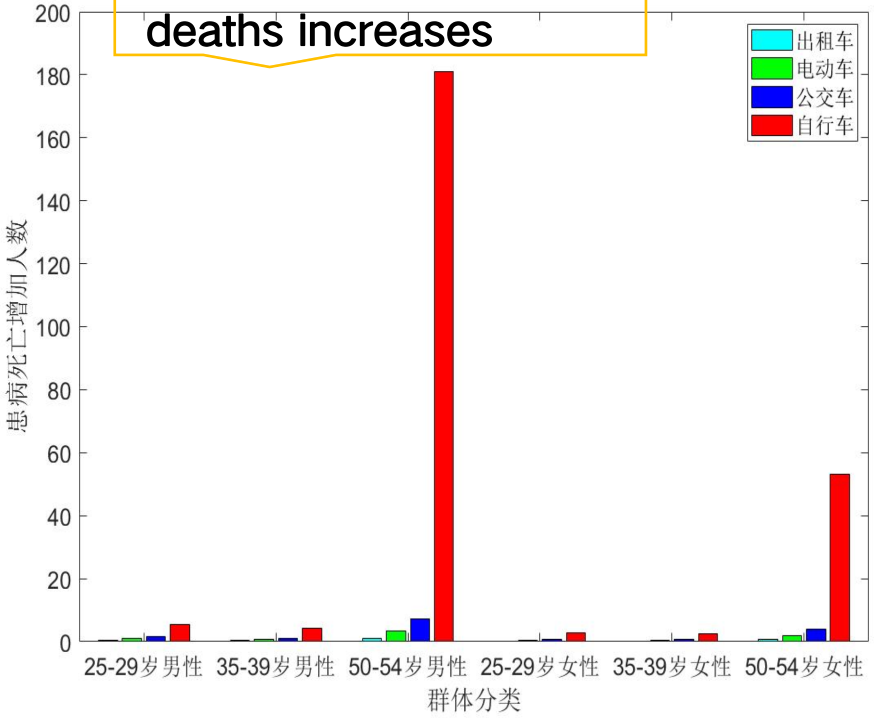
Age（岁）	Male	Female	Total
25-29	237320	207949	445269
35-39	137772	128193	265965
50-54	89304	85299	174603

- It is calculated that in the next year in Haidian District, the commuting time of about 40 minutes per day will lead to the health damage of commuters.

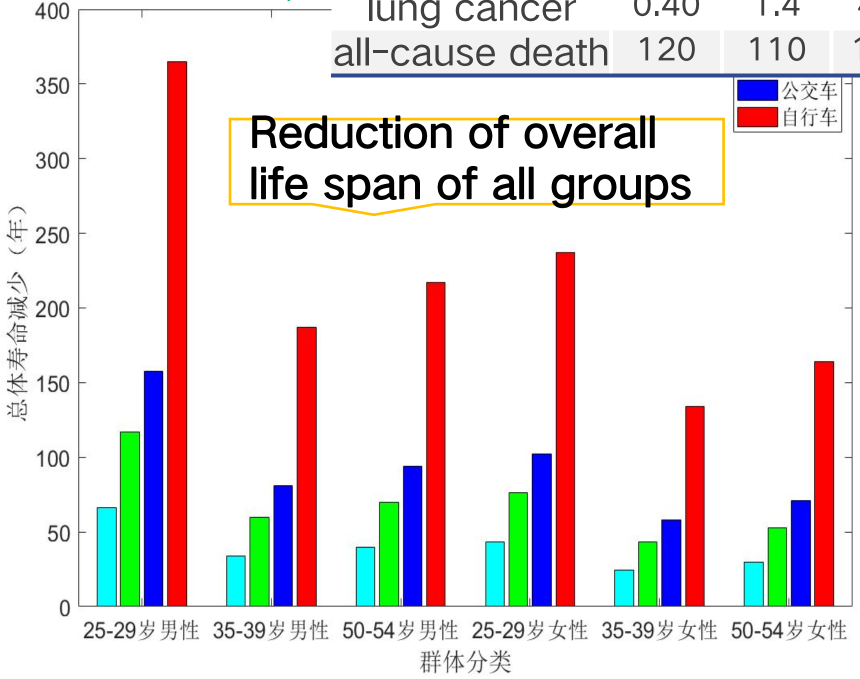
Dose response coefficient β & DALYEF

Cause	Age（岁） 25－34	35－39	40－44	45－49	50－54	55－59	60－64	65－69
β(death/ kg （PM2.5 inhalation dose）/ 100000 people)								
cardiovascular disease	0.13	0.27	0.56	1.1	2.1	3.8	2.4	3.9
lung cancer	0.0070	0.027	0.090	0.23	0.50	0.89	4.0	5.4
All-cause death	0.96	1.2	1.7	2.8	4.6	7.4	6.1	9.2
EF（year/ kg （PM2.5 inhalation dose）/100000 people）								
cardiovascular disease	16	24	38	63	100	150	77	100
lung cancer	0.40	1.4	4.0	9.3	17	27	100	120
all-cause death	120	110	110	150	200	280	190	230

number of all-cause deaths increases



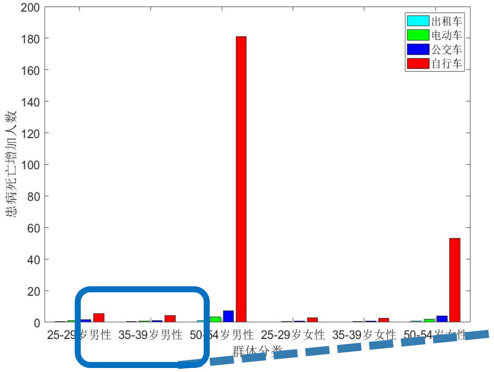
Reduction of overall life span of all groups



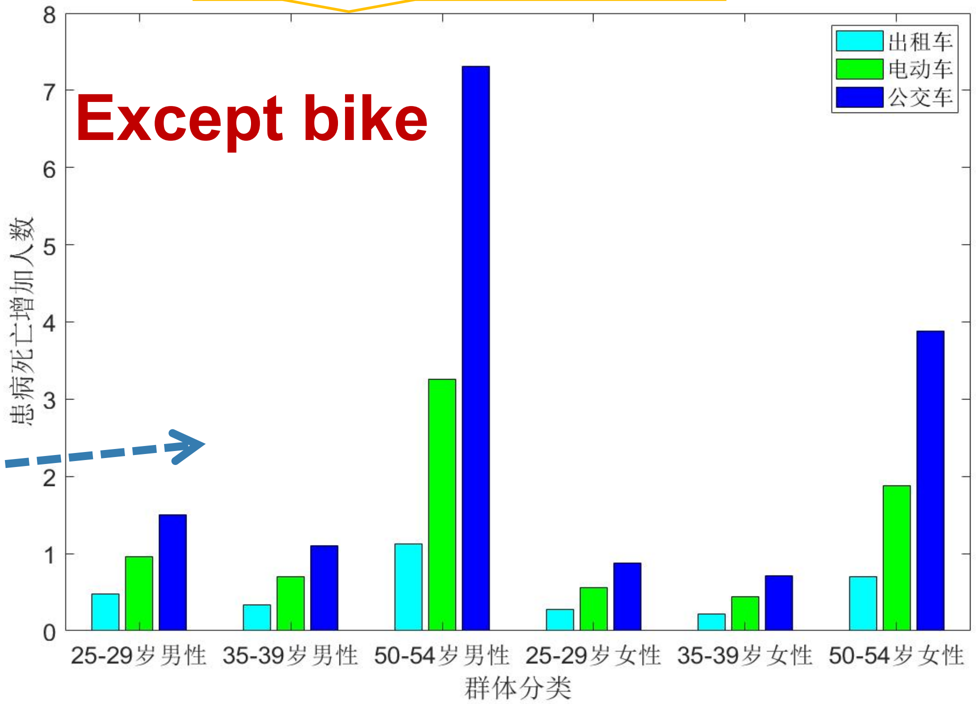
- **Bike > any other travel way**
- **Male > Female, Middle and Old people > Young peole；**
- **The average life expectancy of the middle-aged and elderly population decreased the most, 0.0024 years/person。**

Health Risk Assessment of Different Populations

■ Different travel modes：

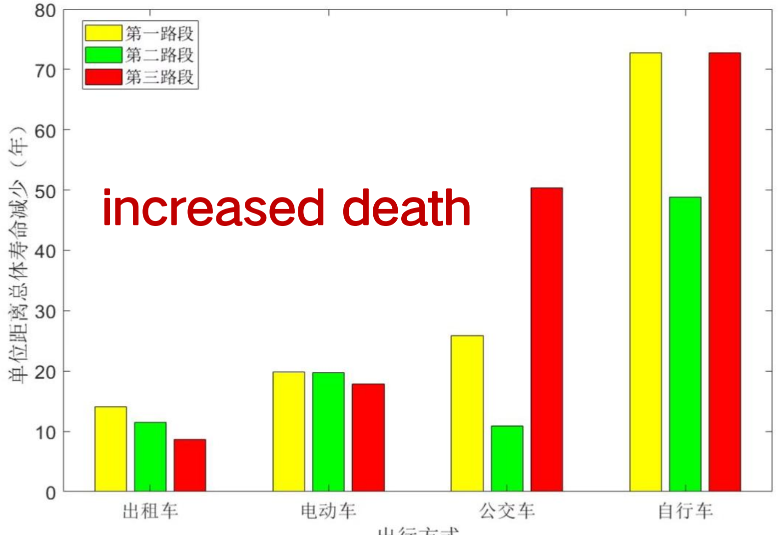


Increased number of all-cause deaths



- Increase in all cause-deaths：bus+walking>Electric vehicle>Taxi；
- Risk of chosing commuter road section：Branch road和Trunk road＞Secondary trunk road。Plus：Taxis have the highest risk of commuting on the branch road.

■ Section and unit distance:



Increased number of all cause deaths in male commuters aged 50-54

50 to 54 year old male commuting unit distance is reduced due to overall life expectancy

Situation Simulation

The number of males aged 35-39 in Haidian District (137772 people) was selected for simulation to analyze the increase rate of all-cause mortality caused by PM2.5.

$$ACM = \frac{ACD}{P} \times 100\%$$

式中: ACM——All cause mortality of a population;

ACD——Number of all cause deaths of a population (person);

P——The population base of a population (person)。

PM2.5 concentration change

Commuter distance change

Different commuters

Relevant parameters under different road conditions

Road type	Distance	Travel way	Speed（m/s）	$PM_{2.5}$ Concentration（μg/m³）
Branch	2.5km	Taxi	3.06	62.29
		Electric vehicle	4.07	74.81
		Bus	2.39	61.92
		Bike	3.62	65.66
Secondary trunk	2.5km	Taxi	5.46	60.73
		Electric vehicle	4.52	76.18
		Bus	5.08	63.45
		Bike	4.08	67.55
Trunk	2.5km	Taxi	5.61	60.82
		Electric vehicle	5.00	76.16
		Bus	5.26	60.65
		Bike	4.48	69.06

Situation Simulation

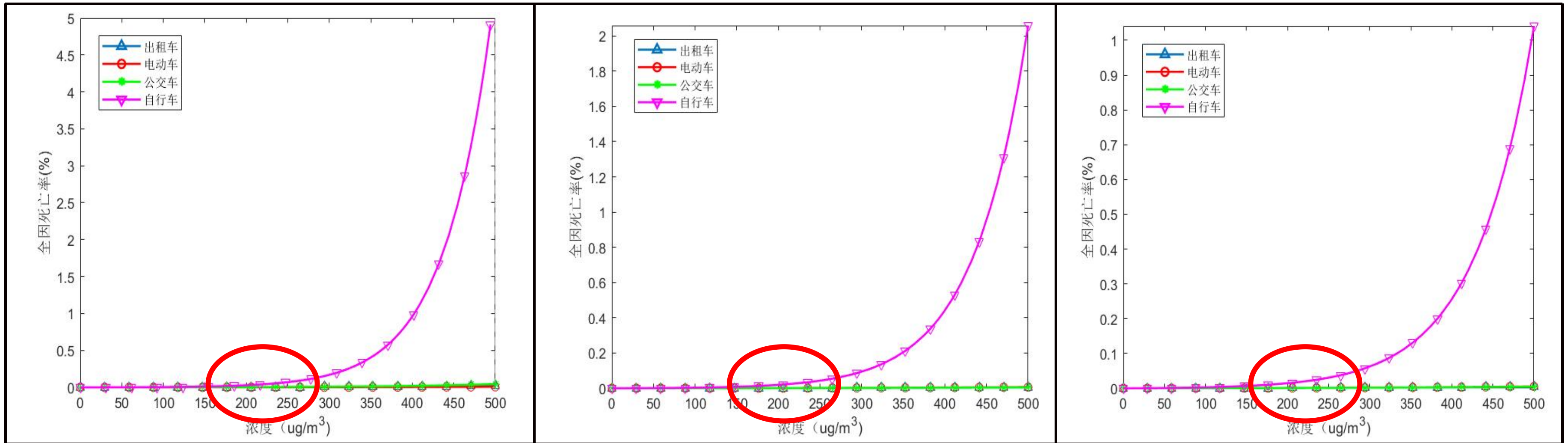
PM2.5 concentration change:

（1）When exposed to PM2.5 concentration exceeding 200 μ When g/m³, commuters are not recommended to travel by bike in all sections;

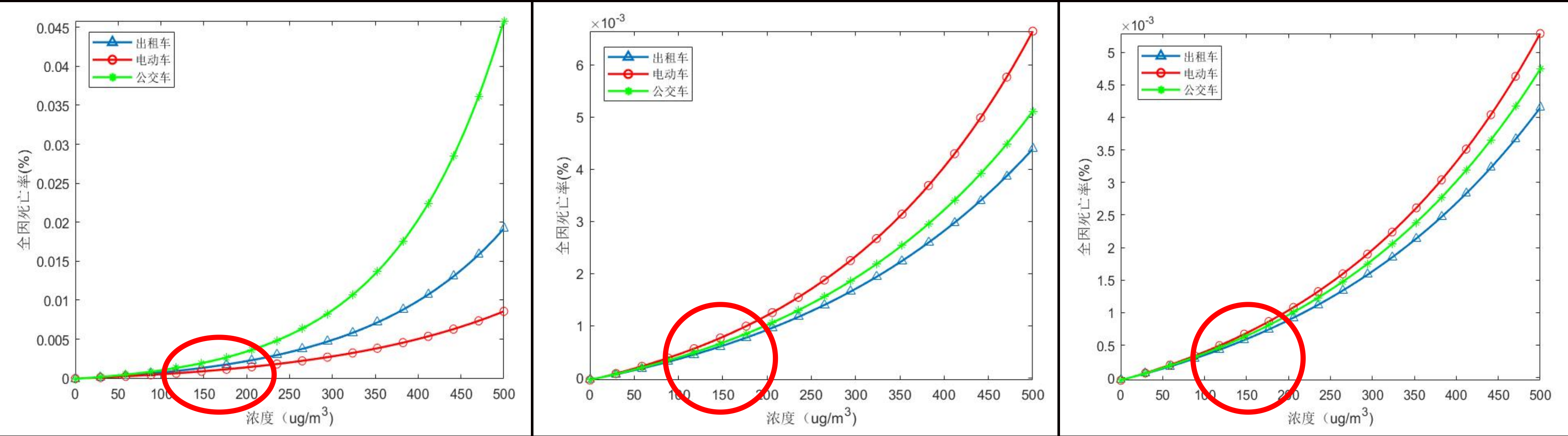
(2) When commuters choose to go to work from the branch road, it is recommended that they choose electric vehicles for travel;

(3) When commuting on secondary trunk roads and trunk roads, it is recommended that commuters choose taxis;

(4) The government departments should focus on the weather with high concentration of PM2.5 in pollution prevention and control.



（a）Branch road | （b）Secondary trunk road | （c）Trunk road



（d）Branch road（except bike） | （e）Secondary trunk road（except bike） | （f）trunk road（except bike）

The increase range of all-cause mortality with the increase of PM2.5 concentration

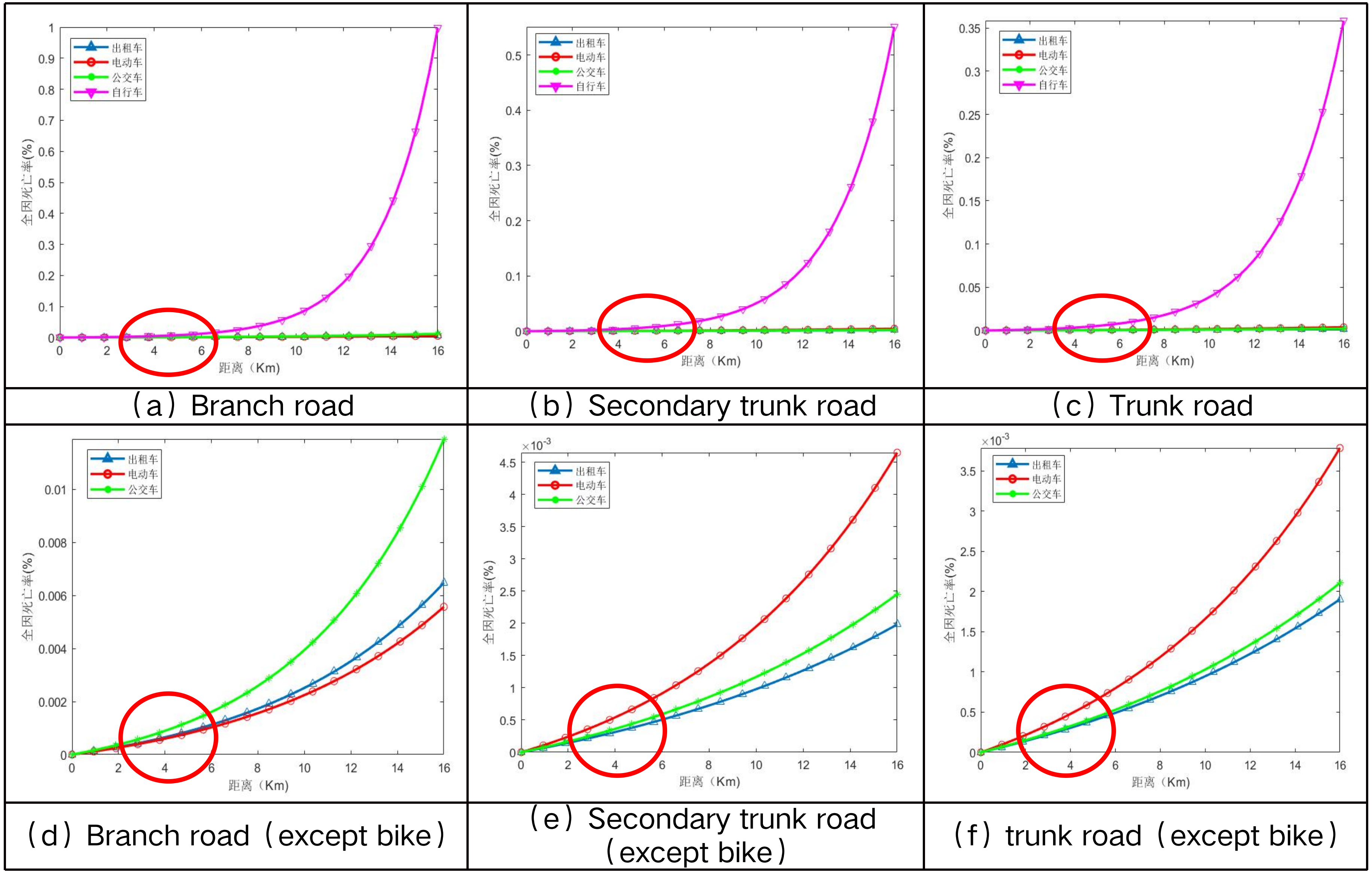
Situation Simulation

Commuter distance change:

(1) When the commuting distance exceeds 5km, commuters are not recommended to travel by bike.

(2) For long-distance commuters, they can choose to travel by taxi or bus on trunk roads or secondary trunk roads.

(3) Traffic managers should optimize the road network structure and signal timing to reduce the additional pollutant emissions caused by traffic congestion.



（a）Branch road

（b）Secondary trunk road

（c）Trunk road

（d）Branch road（except bike）

（e）Secondary trunk road（except bike）

（f）trunk road（except bike）

The increase of all-cause mortality rate with the increase of commuting distance

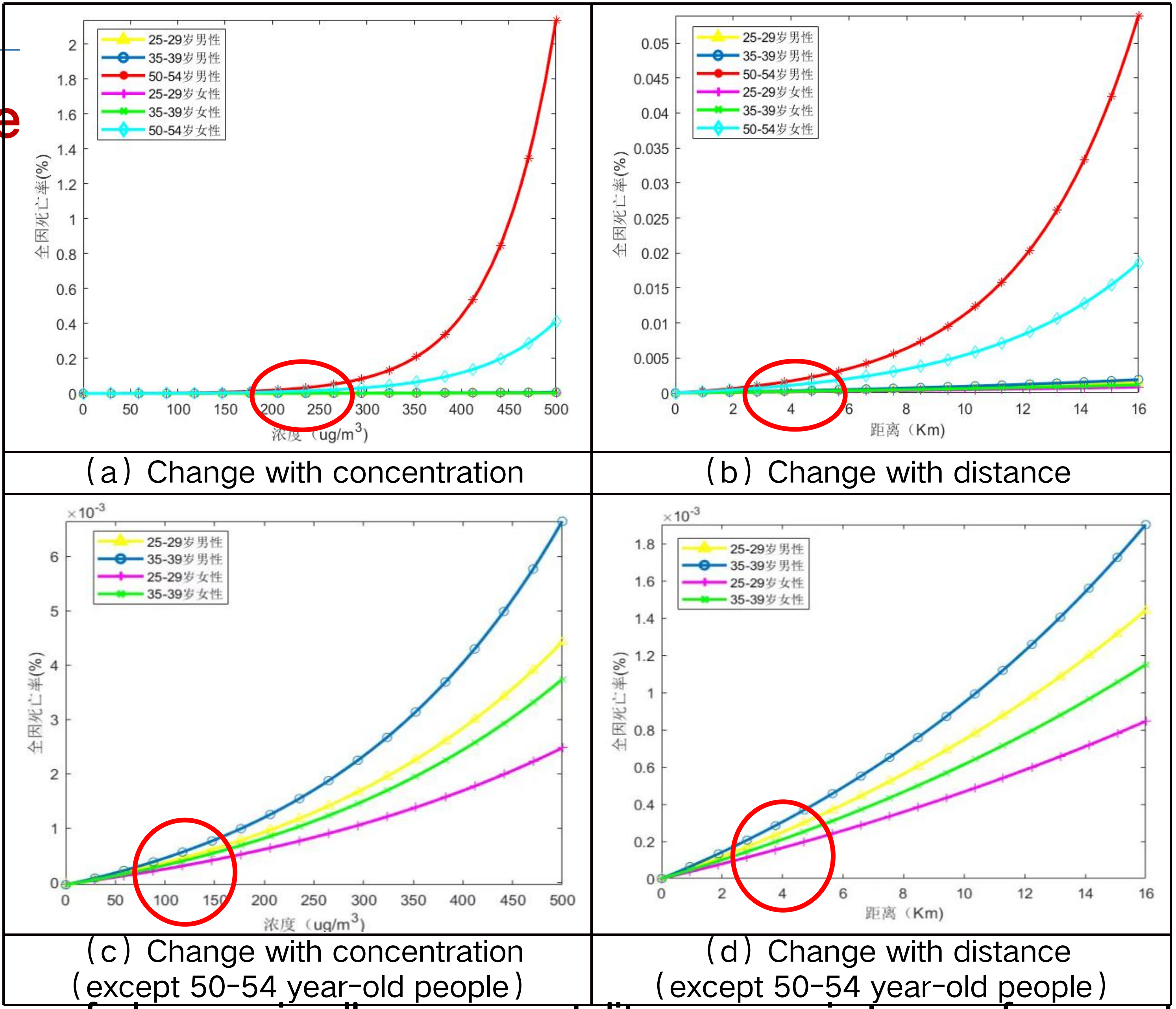
Situation Simulation

Commuter Simulation of Diffe Populations

Suggestions available:

（1） When PM2.5 concentration exceeds 200 μ When g/m3 or the distance is more than 5km, middle-aged and elderly people need to wear masks when commuting. Because under the same exposure dose of PM2.5, middle-aged and elderly people will bear higher risk than other people.

（2） The government should provide preferential commuting measures for the middle-aged and elderly.



（a）Change with concentration

（b）Change with distance

（c）Change with concentration（except 50-54 year-old people）

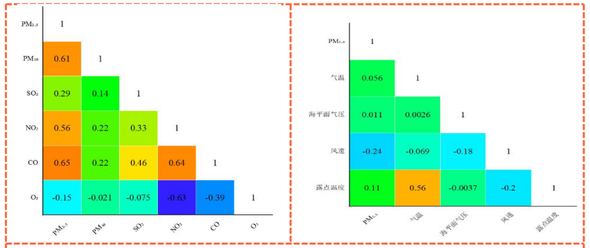
（d）Change with distance（except 50-54 year-old people）

Comparison of changes in all-cause mortality among six types of commuters

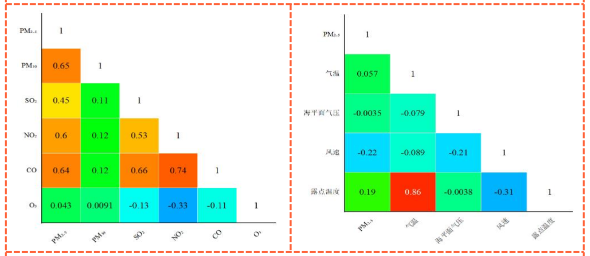
Prediction of environmental $PM_{2.5}$ concentration

36000 relevant background data from January 2018 to March 2022 were processed, and hourly average data at 7-9, 11-13, and 17-19 were extracted to predict PM2.5 background concentration data in the morning and evening peak hours and noon peak hours of future commuters.

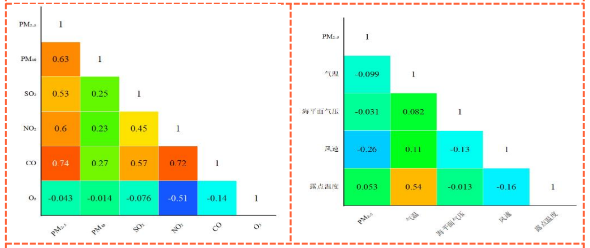
Correlation between PM2.5 and other pollutants and meteorological conditions



早（7-9时）



午（11-13时）



晚（17-19时）

Ratio of PM2.5 measured concentration to background concentration in respiratory area

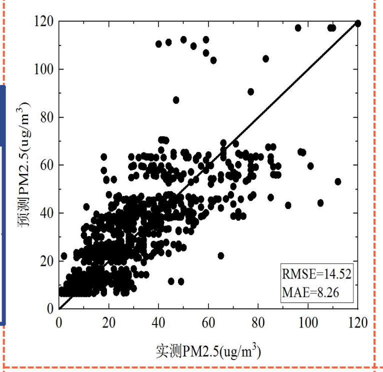
Time	Taxi	Electric	Bus	Bike
Noon flat peak	1.41	1.72	1.50	1.63
Evening peak	1.28	1.49	1.24	1.42

standardization: $$x^* = \frac{x - \bar{x}}{\sigma}$$

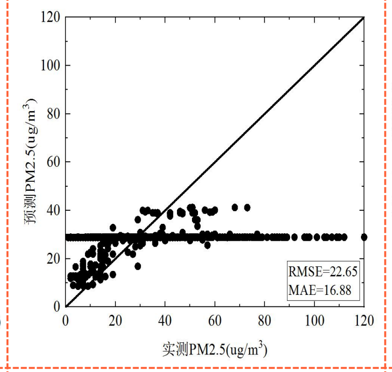
RMSE: $$RMSE = \sqrt{\frac{1}{n}\sum_{1}^{n}(r_i - p_i)^2}$$

MAE: $$MAE = \frac{1}{n}\sum_{1}^{n}|r_i - p_i|$$

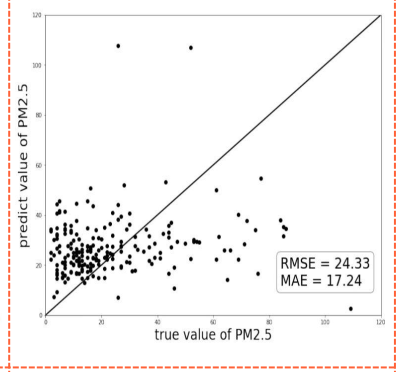
式中: $\bar{x}$——Mean value of initial sample data;
σ——Standard deviation of raw data;
x^*——Standardized value;
r_i——Predictive value;
p_i——Measured value。



RF Model

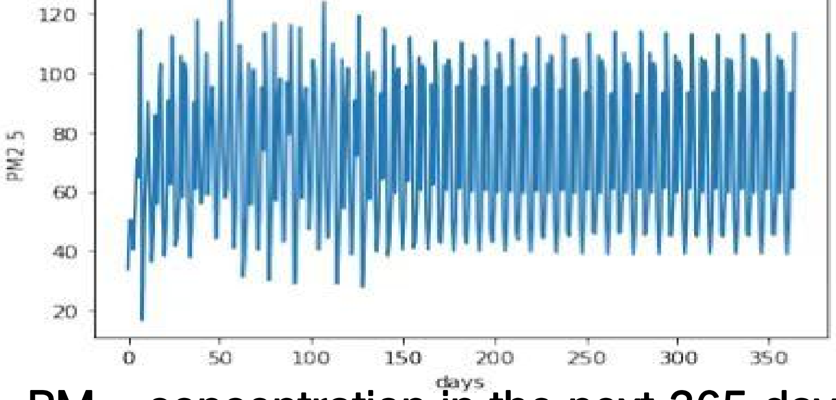


KNN Model



LSTM Model

Comparison between predicted value and measured value



$PM_{2.5}$ concentration in the next 365 days

04 Conclusions & Prospects

Conclusions and Prospects

Conclusions

- **PM$_{2.5}$Exposure Concentration：Electric vehicle has the highesthe exposure concentration of PM2.5, and the hot spot of pollution is near the road intersection.**

- **PM$_{2.5}$ inhalation dose：Bicycles are the highest, males are higher than females, and young people are higher than middle-aged and elderly people.**

- **Health risk assessment of different population：The commuting risk of men is higher than that of women, and that of middle-aged and elderly people is higher than that of young people.**

- **When PM$_{2.5}$ concentration exceeds 200 μ When g/m^3 or the distance is more than 5km, it is not recommended that middle-aged and elderly people travel by bike or electric vehicle.**

Prospects

- **Carry out comprehensive and large-scale experiments on respiratory capacity of different commuters to further improve the accuracy.**

- **The sports health benefits of bicycle travel and walking and the health damage caused by PM2.5 exposure should be comprehensively considered.**

Thanks

Commuter Exposure to Particulate Matter in Four Transportation Modes in Beijing, China

Abstract: To investigate the PM2.5 individual exposure levels and its influencing factors among urban commuters of different transportation modes, the typical daily commuting routes in urban areas of Beijing were selected, and the PM2.5 individual exposure concentrations of four transportation modes, namely, cabs, buses, bicycles, and electric motorcycles, were continuously measured by dust measuring instrument, and the influencing factors of individual PM2.5 exposure concentrations were analyzed. According to the results, bicycle commuters had the highest average daily PM2.5 exposure dose (69.13ug), followed by electric motorcycles, buses and cabs; individual PM2.5 exposure concentrations were higher during the peak commuting period than during the non-peak commuting period. In addition, ambient air quality monitoring data had a significant positive correlation with individual PM2.5 exposure concentrations. The results of the study may provide suggestions for commuters to choose a healthier transportation mode.

Keywords: Individual Exposure, PM2.5 Pollution, Commuting Patterns, Exposure Dose

1. Introduction

Traffic pollution has become one of the important sources of air pollution in many cities, and the emission of particulate matter, polycyclic aromatic hydrocarbons and other pollutants from traffic sources can cause negative effects on human health [1] long-term exposure to high emissions of traffic pollutants will lead to increased health risks such as lung cancer and cardiovascular diseases [2]. What's more PM2.5 has a tiny diameter and a large unit surface area, which can easily mix with toxic substances such as heavy metals. It has the characteristics of long existence and long transmission distance in the air, which has more serious effects on human health and air quality [3]. Many studies have shown that different commuting areas, especially those with dense urban traffic, are more seriously polluted by PM2.5; when collecting data on particulate matter emissions in Xi'an in 2018, Zhang Haidong et al. [4] found that the contribution of road-mobile sources to PM10 was 23.49%, while the contribution to PM2.5 had a proportion of 30.40%. With the number of motor vehicles in Beijing reaching 6.57 million in recent years, An Xinxin et al. studied the characteristics and source analysis of PM2.5 components in Beijing urban areas, and the results of source analysis based on PMF showed that the contribution of motor vehicle source emissions was 17% [5]. Shang J et al. [6] studied the characteristics of population exposure to particulate matter in urban and suburban areas of Beijing and found that PM2.5 exposure was significantly higher in urban centers than in suburban areas and determined that the source of PM2.5

exposure pollution was mainly from road traffic sources through source analysis. Kousa et al. [7] chose six European urban areas for PM2.5 exposure evaluation in the environment, focusing on exploring the association among individual exposure concentrations, microenvironmental concentrations and monitoring concentration site concentrations, and constructing the association among ambient concentrations inside and outside environmental monitoring sites to residential buildings and individual exposure concentrations during holidays. Wu Shaowei et al. [8] studied the exposure levels of pollutants in communities next to major roads in the northern part of Beijing city in winter, indicating that the highest average pollutant concentrations were found in roadside parks and the lowest in hospitals, with the largest contribution of pollutant sources being tailpipe emissions from cars on the roads. There is a necessity to study the effect of tailpipe emissions on individual exposure in dense urban traffic areas.

Individual pollutant exposure is also strongly related to the route, mode and time of traffic, mainly due to the different traffic routes and the different traffic modes causing different traffic pollution microenvironments. Luengo-Oroz J et al. [9] studied the exposure of bicyclists to ultra-fine powder (UFP) on different commuter routes in Edinburgh. Their results proved that buses and bicycle routes should be avoided and that bus and truck routes have relatively high UFP exposure concentrations. Zhong Hui et al. [10] compared PM10 exposure concentrations observed at bus stops with simultaneous ambient air monitoring stations in Guangzhou and concluded that the exposure concentrations of particulate matter near bus stops were significantly higher than in the surrounding environment. Lv Xiaojuan[11] et al. showed that the highest PM2.5 exposure was observed in bicycle commuters (27.2 ± 24.5 μg), followed by walking (23.8 ± 18.1 μg), with relatively low PM2.5 exposure in buses and subways. Maji K J et al. [12] compared road PM2.5 exposure in 11 transport microenvironments in Delhi, where PM2.5 exposure in the open rickshaw and sightseeing bicycle was about 30% higher than in windowed air-conditioned vehicles and subway and when bicycling the PM2.5 inhalation concentration per km was nine times higher in air-conditioned vehicles. Commuting time also has a large effect on exposure levels. Commuting time and transport congestion also affect individual exposure. Research on the spatial and temporal distribution characteristics of particulate matter concentrations in different commuting patterns is of great value in reducing the health burden of commuting populations exposed to the particulate matter microenvironment for long periods of time.

Pollutant concentrations in the transport microenvironment are related to various factors, such as urban meteorological conditions and ambient background concentration levels. Załuska M et al. [13] studied that indoor PM2.5 concentrations positively correlated with outdoor ambient air particle concentrations and temperature and relative humidity. Wang et al. [14] studied that PM2.5 concentration patterns were higher in winter than in summer in most Chinese cities. Zheng Jinlong et al. [15] investigated the background concentrations in Xi'an city in the winter and summer seasons, respectively, and measured that PM10 and PM2.5 concentrations were significantly higher in winter than in summer, with PM10 at 145.3 μg/m3 and PM2.5 at 109.3 μg/m3 in winter. In comparison, PM10 concentration decreased to 58.8 μg/m3, and PM2.5 decreased to 26.8 μg/m3 in summer. The city of Xi'an has typical northern climatic characteristics, with considerable differences in temperature and humidity as well as average wind speed and dominant wind direction in winter and summer, which result in varying concentrations of particulate matter in the atmospheric environment [16]. Whereas wind speed is the main influencing factor in meteorological conditions that can determine the rate of dispersion and deposition of particulate matter after emission, wind direction and road facility conditions together influence the process of pollutant dispersion or accumulation on the road. At present, a clear inverse relationship between wind speed and particulate matter concentration has been demonstrated in many studies: Kumar et al. [17] showed that pollutant concentrations will increase significantly with weaker wind speed. Buonanno et al. [18] found a strong negative correlation between wind speed and particulate concentration and further explored to obtain that the fine particulate concentration decreases more significantly with stronger wind speed than with larger particulate matter. Boarnet et al. [19] found that under weaker ventilation, fine particulate matter around the road would be more likely to accumulate and increase pollutant concentrations. Kaur [20] et al. confirmed that different wind directions and the layout of surrounding buildings and streets might lead to wind recirculation on the road, resulting in lower pollutant concentrations on the windward side of the road than on the leeward side.

The commuting population in large cities has a regular and continuous transport pattern and may face more severe health risks from long-term exposure to traffic emission pollution environment. Beijing, as one of the cities with a huge traffic volume, it is very meaningful to study the pollutant concentrations and exposure levels of commuters under different traffic modes and summarize the individual particulate matter exposure characteristics under each situation so as to suggest feasible and effective ways to improve the commuters' commuting health.

2. Data and Acquisition Methods

2.1 Routes of Sampling

To investigate the PM2.5 exposure of people with different ways of commuting, the commercial core area, residential area and university urban area in the Haidian District of Beijing with large commuting volume were selected as the experimental area as shown in Figure 1, with a large motor vehicle and non-motor vehicle traffic, and some roads are heavily congested, and there are no non-traffic source emissions from heavy industries around. Residents usually choose four commuting modes: cab, bus, bicycle and electric motorcycle. A typical commuting route is illustrated in Figure 1. Starting from point A at the east gate of Beijing Jiaotong University to the digital building in the Zhongguancun area, the route goes through three sections of Beijing Jiaotong University East Road (L1), South College Road (L2) and Zhongguancun South Street (L3) to point B of the digital building, and then returns to point A in the opposite direction of the sampled road. The one-way route length is about 3.64km, and the time duration of a single trip is about 10-30 minutes, which is related to the mode of transportation and the congestion of road conditions. The route contains streets with different road conditions, which can better reflect the PM2.5 exposure of different commuting modes. The characteristics of different road sections are described as follows, and detailed information is shown in Table 1.

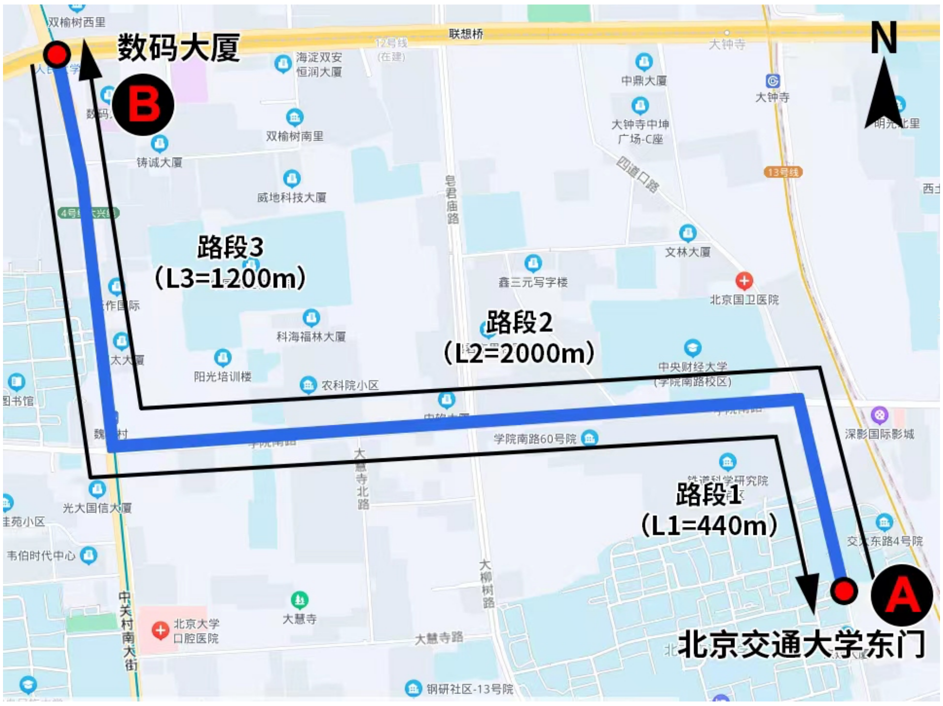


Figure 1 Study Area and Selected Routes

（a）L1 （b）L2 （c）L3

Figure 2 Realistic Image of Different Road Sections

Beijing Jiaotong University East Road (L1) is a two-way two-lane road with no separation of motor and non-motor, north-south direction; the section starts from the east gate of Beijing Jiaotong University to the intersection of Jiaotong University East Road and College South Road, the traffic congestion at this intersection is more serious, the intersection ratio is 0.51~0.79, the average intersection delay time is 37.11s, the traffic composition is mainly small cars, bicycles, etc.

South College Road (L2) is a two-way four-lane four-width road in the east-west direction, which includes the intersection of Daliushu Road, Zaojunmiao Road and South College Road. The intersection parking ratio during the morning and evening peak periods is 0.51 times, and the average delay is 30.26s. There are more residential buildings around, and its traffic composition is mainly small cars and bicycles, etc.

Zhongguancun South Street (L3) is a two-way eight-lane four-lane road separated by machine and non-machine, running from north to south, which has the most serious congestion in the morning and evening peaks, the highest intersection parking ratio of 0.73 to 0.8 times, and the highest intersection delay time of 32.29 to 52.63 seconds, passing through more commercial activity areas, with traffic composed mainly of small cars and buses, etc. The relevant information for the different road sections of the selected routes is presented in Table 1.

Table 1 Road Section Information

The selected section of road		Road Grade	Length/km	Number of Lanes	Bus Stops	Number of Intersections	Surrounding Environment
Name of the Road	Serial Number						
Beijing Jiaotong University East Road	L1	Branch Road	0.44	2	2	2	High-density residential areas and stores
College South Road	L2	Collector Road	2	4	4	4	High-density residential area with a mix of stores and restaurants
Zhongguancun South Street	L3	Arterial Road	1.2	8	2	2	Mid-density shopping area and office building with good afforest facilities

2.2 Sampling Schedule

The experimental data were collected for one consecutive week from June 12 to June 18, 2022, with three times daily sampling, which was conducted during the morning and evening peak periods (7:30-9:30, 17:00-19:00) and non-peak period (11:30-14:00) to compare the changes of individual PM2.5 exposure concentrations at different times, and the monitoring period included weekends and workdays (Monday to Friday).

2.3 Sampling Devices

The PM2.5 concentration in this experiment was collected and monitored by SidePak^{TM}AM520 individual exposure dust measuring instrument from TSI, USA. The instrument uses the light scattering operating principle to monitor the mass concentration of 0.1 ~ 10μm particles. It has a long tube that can be carried around and placed at the mouth and nose, thus monitoring the real-time PM2.5 concentration in the human breathing zone with a 1s interval. Geographic location information is collected by the Explorer V-900 plug-in multifunctional navigation recorder, which simultaneously records the latitude and longitude information of the PM2.5 concentration collection point. During the monitoring period, trained sampling personnel, wearing both instruments, record PM2.5 real-time concentrations and GPS data for each transportation mode simultaneously. During the simultaneous period, the urban air quality pollution data were collected from the regional air pollution monitoring station (Wanliu station in Haidian District, 2.8 km from the study area), and meteorological data were obtained from the China Meteorological Administration.

2.3 The Calculation of Exposure Dose

The data from the measuring instrument will be imported into the computer and checked for outliers, which can be considered outliers if the difference between two adjacent monitoring data is greater than ten times. The individual average exposure concentration is the arithmetic mean of all data from different modes of commuting per day. Differences in individual inhalation particle concentrations are influenced by their own characteristics and commuting activity levels. The individual exposure dose is assessed by commuting time and exposure concentration levels, and the exposure dose is calculated by the following formula:

$$D = \int \frac{1}{60} IR \times CdT$$

In formula:

D——Total Inhalation Dose to Human（μg）;

IR——Breathing Volume（L/min）;

C——Concentration Values of PM2.5 in the Breathing Zone（μg /m^3）;

T——Commuting Duration（s）;

3. Results and Discussion

3.1 Individual exposure concentrations under different commuting modes

Analyzing the average daily PM2.5 individual exposure concentrations and ambient PM2.5 concentrations for different transportation modes during the monitoring period, the trends of PM2.5 individual exposure concentrations and ambient concentrations for each transport mode were basically consistent during the monitoring period. Among different transportation modes, the maximum and minimum daily average exposure concentrations were 120.56 μg/m^{-3} for bicycles and 4.40 μg/m^{-3} for the cab, respectively. The highest average exposure concentration of PM2.5 during the sampling period was for the bicycle with a concentration of (69.13±26.31) μg/m^{-3}, and the lowest exposure concentration was for the cab (69.13±26.31) μg/m-3. The maximum value of PM2.5 for each transportation mode is concentrated on the sixth day, while the atmospheric ambient PM2.5 concentration is relatively high; the minimum value is concentrated on the third day, and the ambient PM2.5 concentration is relatively low as well. According to the "Ambient Air Quality Standard" (GB3095-2012), PM2.5 daily average concentration of 75g/m3, the daily average exposure concentrations of all transportation modes exceeded the standard to varying degrees, with the highest and lowest being cabs and buses, with exceedance rates of 57.5% and 41.2 %, respectively.

Table 3.1 Average Daily Individual $PM_{2.5}$ Exposure Concentration and Inhalation during the Monitoring Period

Date	Day1		Day2		Day3		Day4		Day5		Day6		Day7	
	Conc.	Total Volume	Conc.	Total Volume	Conc.	Total Volume	Conc.	Total Volume	Conc.	Total Volume	Conc.	Total Volume	Conc.	Total Volume
Cab	51.11	4.40	47.44	5.19	34.79	7.23	40.12	14.65	63.74	10.86	118.13	23.04	76.40	10.29
Bus	66.55	22.81	59.68	17.49	31.40	14.53	53.12	17.23	74.74	26.23	105.87	37.57	71.63	21.82
Bicycle	65.62	66.00	61.14	52.44	31.90	41.79	52.98	51.62	80.62	82.03	110.95	120.56	70.19	69.45
Electric Motorcycle	73.08	14.80	65.67	13.80	31.07	8.29	54.38	12.54	81.66	17.53	108.31	28.31	75.35	15.84
Ambient air	16.29		18.00		14.96		21.54		24.08		40.17		34.54	

The particle inhalation concentrations of commuting routes of different modes of transportation, it can be seen that the total particle inhalation of bicycles is significantly higher than other modes of transportation, with an average exposure concentration of (69.13 ± 26.31) ug, which is about six times higher than that of cabs, which have a low total inhalation, followed by buses and electric motorcycles. Particle inhalation is influenced by the traffic microenvironment, and the bicycle exposure concentration is higher than in other commuting modes, probably due to the non-motorized lane and motor vehicle exhaust emissions from motor vehicles driving in the motor vehicle lane and being in an area of high pollutant concentration during the proximity to the bus stop. In contrast, cabs have the lowest total inhalation, which may be related to the air conditioning filtration system during vehicle operating, which reduces most of the particulate matter and thus reduces the total inhalation.

3.2 Individual Exposure Concentrations on Different Commuting Sections of Roads

Transport routes have a more significant impact on the exposure concentration of particulate matter, and data analysis shows that each transportation mode is exposed to higher exposure concentrations than other routes when passing on the L1 route, mainly due to the impact of the motorized and non-motorized lanes of the L1 route branch roads not being separated, the slow driving speed and the higher emissions of exhaust pollutants. The secondary road of the L2 route and the main road of the L3 route had higher traffic volumes, and the overall exposure concentrations were not significantly different. In terms of the direction of traffic, the PM2.5 exposure concentrations were higher on the way there than on the way back on each road section. The highest exposure concentration is (150.50±15.46) ug/m3 for each commuting mode when going by cab transportation mode at the peak of the L1 road section. At the same time, the electric motorcycle is affected by motor vehicles and bus exhaust emissions, and the exposure concentration is higher, especially in the L1 route, and the return exposure concentration reaches (70.87±29.62) ug/m3 in the peak period. The higher exposure concentration of cabs throughout indicates that in the high proportion of parking, traffic congestion, open-window exposure environment, individual particulate matter exposure concentration is instead higher, bicycle transportation exposure concentration is instead lower, mainly due to the convenience of bicycle transportation, subject to motor vehicle road congestion, parking idling motor vehicle exhaust emissions are lower.

Table 3.2 Individual Exposure Concentrations by Commuting Mode on Different Roads

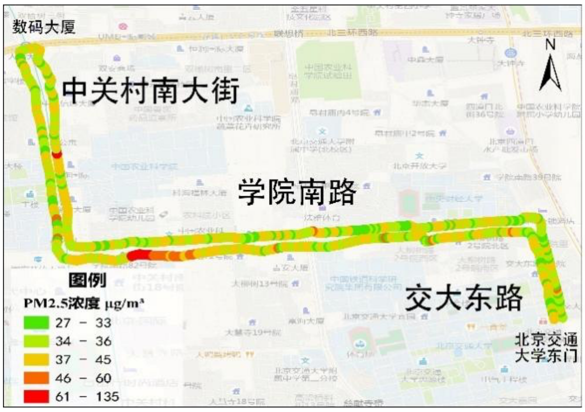
	Time Period	L1		L2		L3	
		Go	back	Go	back	Go	back
Cab	Morning Peak Hours	150.50±15.46	81.72±13.54	119.86±13.94	84.62±7.03	102.60±7.63	95.85±8.5
	Midday Sub-peak Hours	60.14±10.05	/	59.13±8.02	/	62.19±7.20	/
Bus	Morning Peak Hours	69.74±6.98	67.50±6.93	69.36±5.90	64.53±6.05	70.94±6.53	67.43±6.9
	Midday Sub-peak Hours		60.77±8.16		58.13±6.49		67.89±7.0
Bicycle	Morning Peak Hours	68.07±5.88	70.68±7.27	67.76±6.20	70.06±6.27	69.31±14.69	70.15±6.1
	Midday Sub-peak Hours	64.39±5.45	/	63.90±7.81	/	65.49±5.86	/
Electric Motorcycle	Morning Peak Hours	71.27±5.62	76.87±9.51	70.45±6.10	74.10±7.73	71.24±6.20	72.85±5.7
	Midday Sub-peak Hours	/	67.26±12.33	/	62.94±6.01	/	65.54±5.8

3.3 Spatial and Temporal Distribution Characteristics of Particle Exposure Concentration

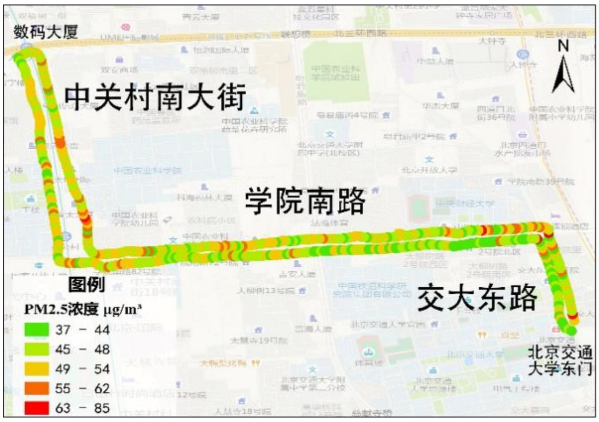
The spatial distribution characteristics of PM2.5 concentrations in different road sections during non-peak and peak periods are analyzed, as shown in Figures 1 and 2. Each color in the heat map represents a certain concentration interval of PM2.5, and the darker the color represents the higher PM2.5 concentration and more serious pollution. It can be seen that the pollution hotspot areas of each commuting mode are often found near intersections and road intersections, especially at L1 sections and L2-L3 intersections.

High values of PM2.5 concentrations exist during the morning and evening peak periods when bicycles and electric vehicles are moving to and from all road sections, with concentrations above 100 μg/m^3, especially in the L2-L3 road sections. These roads are mainly surrounded by many restaurants and stores, residential areas and the university district, where the density of residents is high and where pedestrians often gather, and bicycles and electric bikes are important commuting tools for the residents in the area. The large number of tailpipe emissions caused by a large number of vehicles on the road and indoor cooking fumes on the roadside are the main sources of pollution that cause exposure hotspots for commuters during this time. For cabs and buses, the locations with high concentrations are mainly found in the L1 section and intersection locations, and buses have more points with high pollution values than cabs in the L2 section. The reason is that there are several bus stops in the L2 road section, the bus will stop and transfer frequently, the vehicle acceleration and idling process produces large emissions, and in a short period of time, the pollutants inside the vehicle cannot be quickly diluted by the air exchange system and the air outside the vehicle, people will be directly exposed to the exhaust gas emitted inside the vehicle, so it will produce a larger exposure concentration of commuting pollutants. There are relatively few high-value PM2.5 pollution points on the L3 road section, with a PM2.5 concentration range of 70-90μg/m^3, mainly located near the back intersection area. This road section has more spacious lanes, the vehicles run smoothly, the buildings are medium density gathering, and the afforest is relatively good so that the exhaust generated by the previous vehicle will be diluted quickly, and the exhaust will not be channeled into the vehicle through the ventilation system of a vehicle behind, thus making the exposure concentration of PM2.5 pollution relatively low in this road section when the crowd takes cabs and buses.

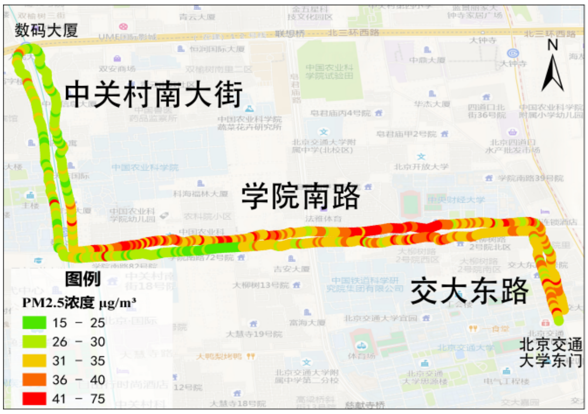
The PM2.5 exposure concentrations of all commuting modes during the midday sub-peak period were significantly reduced, especially the PM2.5 pollution concentrations of bicycle and electric vehicle commuting were significantly reduced for each road section. However, the PM2.5 pollution from buses and cabs is still relatively high, and in the L2 section, due to more bus stops and frequent stops, passengers taking buses are still exposed to a densely distributed area of high PM2.5 pollution values, with concentrations ranging from 36-75 μg/m^3. The L3 road section has wide and smooth traffic, with PM2.5 concentrations ranging from 15-30μg/m^3 for each commuting mode.



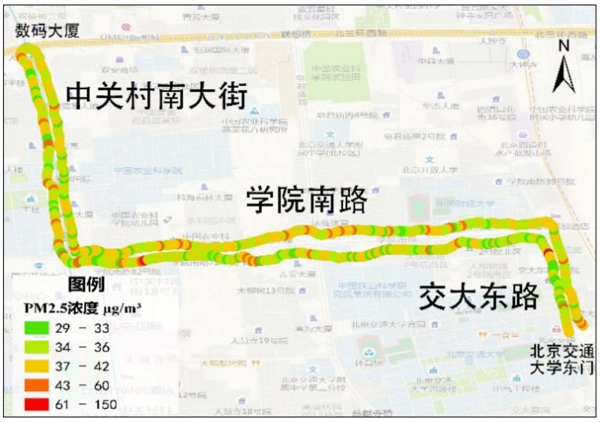
Cabs



Electric Bikes

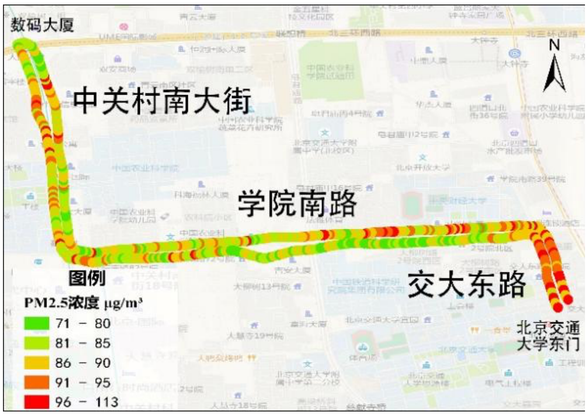


Buses

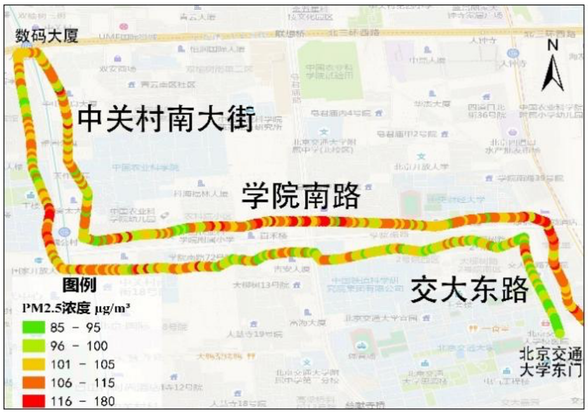


Bicycles

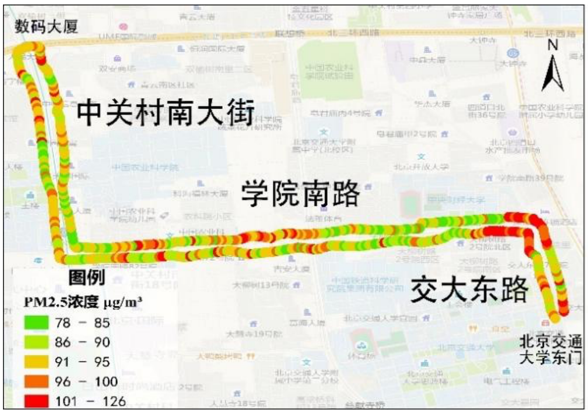
PM2.5 Heat Map for Non-peak Period



Cabs



Electric Bikes



Buses

Bicycles

PM2.5 Heat Map during Peak Period

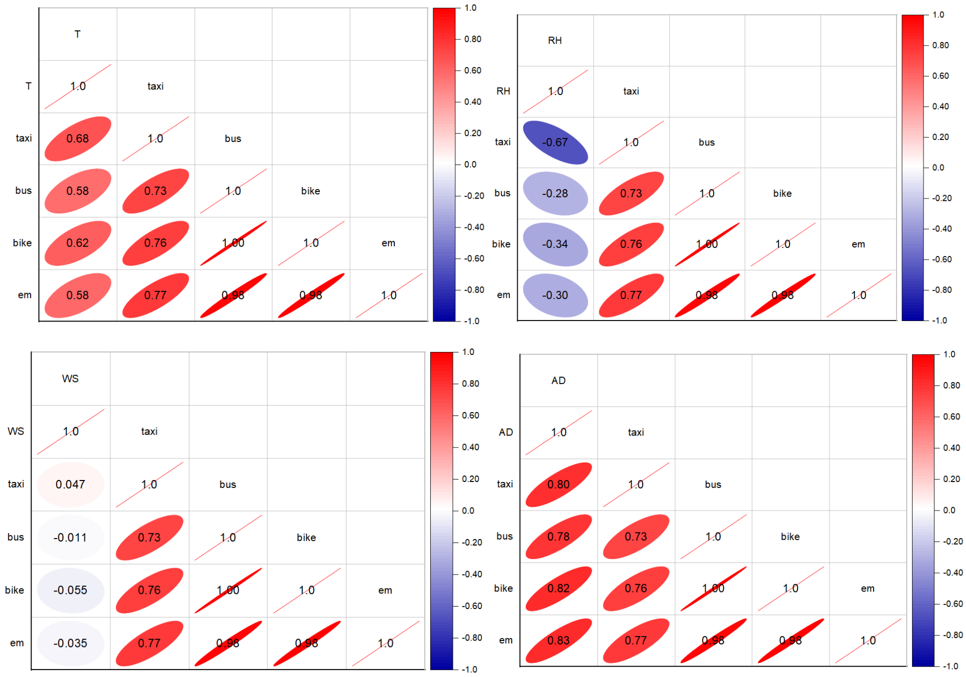
3.4 The Meteorological Conditions Influence on Individual PM2.5 Exposure Concentrations

The correlations between meteorological factors such as temperature, humidity, wind speed and rainfall and individual PM2.5 exposure concentrations for different transportation modes were analyzed, and whether there was a significant relationship between them through correlation analysis. From Table 3.3, it can be seen that there is a significant positive correlation between temperature and ambient air particulate matter concentration for different transportation modes. At the same time, wind speed and humidity have a weak negative correlation for different transportation modes. Wind speed has a small effect on individual particulate matter exposure concentration in this study because the wind speed is static and light during the sampling period. Regarding different transportation modes, cabs are more influenced by temperature and humidity conditions, while ambient air pollution concentrations more influence motorcycles and bicycles.

PM2.5 ambient concentrations were also positively correlated with transportation mode, especially for bicycle and motorcycle commuting modes, which significantly affected PM2.5 individual exposure concentrations. The results of Wu, DL et al. using linear model analysis showed that temperature, transportation conditions and wind speed contributed 27.3% of the exposure concentration for commuting mode, while relative humidity and wind speed were important determinants of road mode, contributing 14.1%.

Table 3.3 Relationship between Meteorological Conditions and PM2.5 Exposure Concentration during the Observation Time

	taxi	bus	bike	em
TEM/℃	0.68	0.58	0.62	0.58
RH%	-0.67	-0.26	-0.34	-0.30
Wind Speed	0.047	-0.011	-0.055	-0.035
Background Concentration	0.8	0.78	0.82	0.83



4. Conclusion

(1) Their choice of transportation mode significantly influenced the PM2.5 exposure of commuters. During the monitoring period, the individual exposure mass concentrations of atmospheric PM2.5 for different modes of transportation were cab > bus > motorcycle > bicycle, while particulate matter inhalation was higher for bicycle and motorcycle, which was mainly influenced by the long exposure time and activity status of the bicycle.

(2) From the perspective of commuting routes, the L1 road section is not separated between motor and non-motor. There are intersections close to residential areas. The

road section has a higher exposure concentration and inhalation of each mode of passage. At the same time, the L3 express lane traffic conditions are good, motor vehicle exhaust emissions of pollutants are relatively low, exposure concentration and inhalation are small, and exposure concentration spatial and temporal distribution characteristics likewise indicate that cabs and buses in close proximity to intersections congested roads, exposure concentration are higher.

(3) Commuting time also affects individual exposure concentrations, morning and evening peak periods and non-peak atmospheric PM2.5 individual exposure concentrations. Except for commuting time, background pollutant concentrations have a strong positive correlation with exposure concentrations during each commuting mode, and meteorological conditions such as temperature, humidity, and wind speed have inconsistent effects on exposure concentrations of the four commuting modes. Among them, the temperature was positively correlated with each commuting mode row, and the higher temperature was also an essential factor in pollution formation.

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