Research status and control measures of air pollutants in urban areas caused by traffic sources

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Abstract. With both the social and the economic development, air pollution has become a matter of high concern to both the public and the government. Vehicle exhaust emissions on traffic roads are the main source of urban air pollution in urban area, which poses a significant threat and impact on the health of urban residents. In order to solve the excessive urban pollutants in a better and more efficient way, reasonable and economic solutions should be investigated from the three aspects, including source identification, pollutant distribution and treatment measures. As for the distribution of pollutants in regional urban scale, this paper analyzes and summarizes the four influencing factors, including different urban layout schemes, meteorological conditions, roadside tree configurations and motor vehicle flows. The methods to study the distribution of air pollutants are summarized. Meanwhile, China has promulgated many standards and policies for the treatment of pollutants, which has achieved good results. To control urban pollutants from the root, it is necessary to look at the problem of urban pollutants from various aspects with appropriate methods, affordable human and material resources and reasonable relevant policies. This study provides a scientific support for control of traffic-related pollutants in urban area.

1.Introduction

With the rapid development of China's economy, the scale of cities is expanding day by day. The rapid rise of automobile exhaust emissions leads to the emergence of urban air pollution [1]. Moreover, reports from UN indicate that 47 per cent of the global population lives in urban areas. Urbanization has increased the demand for transportation, so air pollutants from motor vehicles have also increased [2]. According to the Ministry of Public Security, there were 390 million motor vehicles in China as of September 2021. It can be seen that the number of motor vehicles in China is huge, and motor vehicle exhaust emissions are an important source of air pollutant.

In recent decades, air pollution has become the most important environmental health hazard for the general population, and the increase of outdoor air pollution exposure directly or indirectly affects people's health outcomes [3].There are many kinds of air pollutants, among which the atmospheric particulate matter is widely concerned at home and abroad. PM_{10} has been shown to trigger inflammatory responses associated with its specific biological components, while $PM_{2.5}$ is thought to be more harmful because of its small size and its ability to enter the alveolar area [4]. As for the human nervous system, studies have shown that fine particles can enter the central nervous system of organisms and cause heart dysfunction and inflammation [5]. It is estimated that in 2017 ambient fine particulate matter ($PM_{2.5}$) associated with 2.9 million premature deaths [6]. Correiad [7] proposed the relationship between the reduction of fine particulate matter and the extension of life expectancy. A reduction of 10 $\mu g/m^3$ fine particulate matter will increase the average life expectancy by 0.35 years. Sidbom *et al.* [2] also explained the great harm to human body caused by exhaust pollution emitted by fuel engine. In addition, numerous epidemiological studies from different parts of the world have consistently linked atmospheric particulate matter with disease, including respiratory infections, ischemic heart disease and stroke [8].

Pollution caused by motor vehicle emissions in China's major cities in the urban pollutants accounted for a huge proportion. Table 1 shows the contribution rate of vehicle exhaust emissions to air pollution in many cities [9]. Driven by a variety of factors, traffic emissions around the world have been changing rapidly. According to the "China Mobile Source Environmental Management Annual Report (2020)" released by the Ministry of Ecology and Environment, PM emissions from motor vehicles accounted for 90% of the total pollutant emissions [9-10]. A high proportion of carbon emissions from transportation is not only a problem in China, but also a problem in many foreign cities. New York, London, Paris and other major international cities accounted for more than 1/4 of the carbon emissions from transport. For example, pollutants such as PM_{10} and $PM_{2.5}$ produced by London's transport accounted for more than 50% [11-14]. Therefore, under the national environmental background of the "dual carbon" target, it is a top priority to solve the air pollution caused

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by motor vehicle exhaust emissions. The following section will summarize the sources, diffusion and treatment of urban pollutants.

Table 1 Pollutant sharing rate of vehicle exhaust emissions in different cities in 2019

	Pollutant sharing rate (%)		
City	CO	NO_2	HC
Shanghai	86	57	95
Beijing	64	47	74
Tianjin	63	45	78
Chongqing	83	53	76
Shenzhen	88	60	92
Zhongshan	72	55	90

2. Analysis of urban pollutant sources

In the prevention and control process of urban pollutants, the first thing to think of is to prevent or weaken the generation of pollutants from the source and control the emission of pollution sources. Traditional source analysis methods include source list method, source model method and receptor model method, among which chemical mass balance model (CMB) and positive matrix factorization (PMF) are widely used [15]. The function of source analysis results is reflected in three aspects: firstly, rank the importance of sources and defining the prevention and control priorities; secondly, analyze the heavy pollution process online and judge the source and change of particulate matter in the heavy pollution process in real time; thirdly, the effect of prevention and control measures can be objectively evaluated according to the change of chemical composition and source contribution rate of particulate matter, regardless of meteorological factors, so as to provide a basis for timely adjustment of prevention and control strategies. There are many policy supports on source analysis in China, as shown in Table 2.

Table 2 China's policy on source parsing

Year	Policy
2013	"Technical Guide for Source Analysis of Atmospheric Particulate Matter (Trial) "
2014	"Joint Work Plan for Research on Sources of Air Pollutants in Key Cities of China"
2015	1. "The research work about be atmospheric pollutant source in 2015 notice" 2. "The atmospheric fine particles a source emissions inventory compile technical guidelines (trial) " 3. "The road motor vehicle air pollutants emission inventory compile technical guidelines (trial)"

There are a lot of researches on source analysis at home and abroad. Chinese research institutions have built and improved a new source analysis model for source analysis. For example, the PMF model and CMB model were coupled to build the PMF-CMB complex receptor model, and the receptor model to analyze the contribution of secondary particles was also established for the problem of secondary particle pollution [15]. Kazım *et al.*[16] used bivariate polar graph method to identify and characterize individual sources of PM_{10}, SO_2, NO_x and CO pollutants in Karadnitz urban areas, and concluded that the main sources of pollutants are more man-made. Jia [17] proposed embedding unsteady adjoint equations modeled by large eddy simulation (LES) into Bayesian inference framework to develop a new STE method. This method reduces the huge storage requirements of unsteady simulation and provides more accurate source term estimation through wind tunnel experiments. Ma [18] combined classical Gaussian model with Machine Learning Algorithms (MLA) algorithm, and the prediction results of the new models are greatly improved. Wang *et al.* [19] proposed an inverse analysis method for real-time monitoring of pollutant diffusion based on fuzzy adaptive Kalman filter and weighted recursive least squares algorithm. Ratier *et al.* [20] provided preliminary work and help for pollution source analysis by sampling local soil lichens and analyzing the composition of metal chemical substances. Lai *et al.* [21] integrated some air quality models, including diffusion model and grid model, using the initial meteorological field provided by weather research and forecast models. Simulation analysis shows that if traffic sources are reduced by 20% and 30%, $PM_{2.5}$ concentration in Taichung will decrease by 4.3% and 6.6%, respectively. Deshmukh *et al.* [22] conducted a study in the Kansas metropolitan area using mobile monitoring to describe spatial variability and gradients of air pollutants to determine the contribution of multiple sources to community-level air quality in a complex urban environment, with measurements focusing on nitrogen dioxide, black carbon, and ultrafine particulate matter.

3.Study on distribution of urban pollutants

China's urbanization rate has accelerated significantly from 10.6% in 1949 to 58% in 2017 [23]. If we could analyze the causes and mechanisms affecting the diffusion of pollutants clearly, we may effectively control the diffusion routine of pollutants. Urban street canyonis one of the most important spatial forms and characteristics in modern cities. City street is formed by continuous buildings on both sides of the relatively long and narrow canyon. Because of the blocking effect by the buildings on either side of the street in the canyon, emission from motor vehicle is difficult to diffuse. The self-purification capacity will be reduced if the space configuration is unreasonable. So people in the street canyon are exposed to the pollutant for a long time [24-27]. The diffusion and distribution of air pollutants in street canyons are significantly related to three-dimensional morphology of street canyons, street tree configuration and vehicle flow [28]. Therefore, studying the distribution characteristics of atmospheric pollutants in urban street canyons and revealing the regulation mechanism of three-dimensional morphology, street tree configuration and motor vehicle flow on air pollutants can provide a scientific basis for the improvement of air pollution in urban area.

3.1 Influence of urban street-canyon morphology on the distribution of air pollutants

Urban street canyon refers to a long and narrow space composed of roads and buildings on both sides of a city [29]. The three-dimensional form of urban street canyons can be represented by pattern index, such as building height, street canyons direction, building undulation, building volume, floor area ratio, sky openness and aspect ratio (H/W) (Figure 1) [30]. Among them, building undulation refers to the difference between the maximum height and the minimum height of all buildings; Building volume is the sum of the volumes of all buildings; Floor area ratio is used to reflect the intensity of land development and environmental quality within a certain range. Aspect ratio is a two-dimensional index used to describe the density of a building in relation to its height [31]. H/W=1 is called ideal street canyon, H/W<0.5 is broad street canyon, H/W>2 is deep street canyon [31-32]. The sky openness is used to describe the part of the visible sky or open canyon space in the street canyon, and its value ranges from 0 to 1. 0 represents the completely blocked street canyon space, while 1 represents the completely open street canyonspace [26,33]. The elevation of buildings on both sides of the street canyon will hinder the visibility of the sky and reduce the sky openness [34].

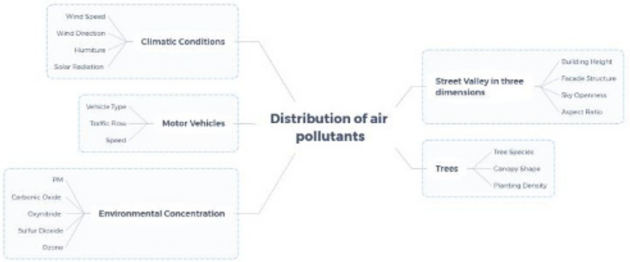

Fig. 1 Influencing factors of atmospheric pollutants distribution in street canyon

The three-dimensional morphology of urban street canyons affects the airflow field in street canyons, and then influences the diffusion of air pollutants [35]. When the wind direction is perpendicular to the building, the flow pattern in the street canyon will form three typical wake flow fields: isolated rough flow, wake interference flow and sliding flow. When the wind direction is parallel to the building, the increase of the aspect ratio of street-canyons is conducive to the increase of airflow outflow, the decrease of retention area and the increase of ventilation efficiency [36]. Jiang *et al.* [37] divided urban form parameters into Building Density (BD), Floor Area Ratio (FAR) and Average Building Height (AH), as well as indicators related to urban microclimate, such as Spatial Openness (SO), Standard Deviation of Building Height (SDH), Mean Building Volume (MBV) and Degree of Enclosure (DE). Through CFD simulation and field monitoring, five morphological parameters have significant influence on neighborhood air quality.

The air flow in real street canyons is a more complex three-dimensional unsteady irregular turbulent motion, whose magnitude and direction are random [38]. In view of this, scholars carried out a study on the correlation between three-dimensional morphology of urban street canyons and atmospheric pollutant concentration. Xu *et al.* [39] believed that the increase of building height and vegetation coverage would lead to the increase of $PM_{2.5}$, and the increase of building density, building width and urban fraction would reduce $PM_{2.5}$ concentration. Therefore, the use of compact urban layout to reduce building height and increase building density, building width and urban fraction would help improve urban air quality. Silva *et al.* [40], through simulations and wind tunnel tests, found that the average pollutant concentration at pedestrian height for single-block types was 80% lower than the estimated value for the independent building types, which had the highest pollutant concentration. Hang *et al.* [41] studied the influence of aspect ratio and length of street-canyons on ventilation, and the results showed that reducing aspect ratio or increasing street-canyons' length could promote the removal of atmospheric pollutants at the same height.

Roof shape, balcony and other building facade geometry are also the key factors affecting the diffusion of air pollutants in street canyon. Through CFD simulation experiment, Murena *et al.* [42] believed that balcony depth and horizontal distance between balconies in deep street canyon would influence the diffusion of atmospheric pollutants by affecting air flow and mass transfer rate in street canyon. Allegrini [43] believes that sloping roofs can improve the ventilation effect in street canyons better than horizontal roofs. Zheng *et al.* [44] believe that the existence of building balconies can strongly change the airflow pattern in street canyons, especially the balconies on windward facades.

3.2 Impact of street tree configuration on the distribution of air pollutants

The mechanism of street trees on air pollutants includes dust retention, re-suspension, absorption and diffusion [45-46]. In the street canyon environment, the effects of street trees on air pollutants are complex and may be positive or negative [23]. On the one hand, street trees can act as porous material, influencing local atmospheric diffusion patterns and promoting the deposition and removal of air pollutants [28]. On the other hand, street trees may become obstacles to wind flow and reduce ventilation, leading to an increase in the concentration of local air pollutants [47].

The effect of street trees on air pollutants is related to the crown shape and structure of street trees [48]. Hong *et al.* [49] pointed out that the reduction rate of $PM_{2.5}$ concentration by different canopy shapes was cylindrical, spherical and conical from high to low. Other scholars concluded that the greater the canopy porosity of street trees, the better the air circulation, the more conducive to the diffusion of air pollutants [50].

3.3 Impact of motor vehicle flow on the distribution of air pollutants

Automobile exhaust is one of the main sources of air pollutants in urban street canyons. Motor vehicles produced by the height of the atmospheric pollution content mainly for 0~0.3m, and 1.5~2.0m from ground[36]. At present, some scholars have classified motor vehicles, such as gasoline engine and diesel engine, and analyzed the correlation between them and contribution rate of air pollutant concentration. The results show that high-emission vehicles are the main cause of aggravating air pollution in street canyon[51]. Shi *et al.* [52] found in their study that it takes about 7s for a vehicle traveling at a uniform speed to reach a stable state of DIFFUSION of

VIT and exhaust pollutants. At the same time, it is suggested that a "healthy distance" of 8m should be maintained between vehicles based on the diffusion range of tail gas emission of wake in steady state. Others argue that cars parked on the side of a street affect the air flow in the canyon and cause air pollution[53].

3.4 Influence of meteorological factors on distribution of atmospheric pollutants in street Canyon

The effect of street-canyon morphology on air pollutants is related to wind direction. Studies have shown that the concentration of air pollutants in the leeward side is significantly higher than that in the windward side [54]. Miao *et al.* [26] show that the correlation between wind direction and atmospheric pollutant concentration is significantly higher than wind speed. Huang *et al.* [55] made a comparative analysis of the difference in atmospheric pollutant concentration when the angle between street-canyons and wind direction was 0°, 15°, 30°, 45°, 60°, 75° and 90°, and the results showed that the pollutant concentration on the leeward side of street-canyons was the highest when the angle was 75°. In addition, the effect of street trees on air pollutants is also related to wind speed [55]. Compared with vertical direction, the removal efficiency of atmospheric particulate matter was higher when street trees were parallel to the main wind direction [23]. When the wind speed was low, the removal efficiency of coarse particles from street trees was higher than that of fine particles [23].

Solar radiation and temperature change in street canyon also affect the distribution of air pollutants in street canyon. The shading of the building structures on both sides of the street canyon and the heating of the walls caused by the solar radiation will change the thermal stratification and thermal buoyancy, enhance or weaken the ventilation and turbulence in the street canyon, and change the diffusion of atmospheric pollutants [56]. Liu *et al.* [57] study on CO and photochemical pollutants and solar radiation in street canyon showed that solar radiation of different intensities would change the air flow in street canyon.

The effect of street-canyon morphology and street trees on air pollutants is related to relative humidity. There is a significant positive correlation between atmospheric particulate concentration and relative humidity in street canyon, and the correlation increases with the decrease of particle size [26]. Compared with coarse particles, the increase of relative humidity contributes to the collision and coalescence of fine particles, leading to the increase of fine particle concentration [58].

Seasonal changes also have an impact on the urban street canyon microenvironment. Through simulation and experimental verification, Dong *et al.* [59] believed that the pollutant removal performance was poor and the pollutant concentration was high in summer afternoon. Summer morning and winter night were the two worst times, with 87 % and 77 % of residual pollutants trapped in street canyons and residential areas, respectively.

4. Air pollution control

In order to solve the nationwide air pollution, the country continues to promote the construction of ecological civilization. In this regard, China has carried out a series of measures for $PM_{2.5}$ pollution control. The national air quality improved significantly [60].

China has made strict requirements for motor vehicle emissions, which harvested good results. In June 2013, Chinese goverment approved the "Atmosphere Ten Articles", which emphasizes the pollution prevention and control of mobile sources, proposes control measures from new vehicle emission standards, fuel quality standards, traffic management and other aspects, and gradually forms a comprehensive motor vehicle control system integrating "vehicle-oil-road" [61]. Since then, China's vehicle emission standards continue to tighten. In 2016 and 2018, China released national VI standards for light vehicles and heavy vehicles respectively [62-63]. The limits of particulate matter (PM) and carbon monoxide (CO) of light vehicles in VI light vehicleb are 0.003 g/km and 0.5 g/km respectively, which are 40% and 50% lower than the corresponding standard value of EURO VI. At the same time, the vehicle emission supervision system has been improved. For example, in 2017, China issued HJ 857-2017, *On-board Measurement Methods and Technical Requirements for Exhaust Pollutants of Heavy Gasoline Vehicles and Gas fuel Vehicles*, which is used for emission supervision of new cars and on-board vehicles [60]. Because of the issue of the above regulations and national policy support, China's new energy vehicles are developing rapidly. By June 2019, the number of new energy vehicles in China had reached 3440000, more than 15 times that at the end of 2014 [64].

The policies issued by the state are the vane to guide air pollution control, and many scholars are working hard for these standards. For example, the road surface with air photocatalytic purification based on ZnO nanostructures has been developed for large-scale purification of real automobile exhaust pollutants [65]. The potential of photocatalytic coatings to reduce air pollution in urban environments has been demonstrated through CFD simulations and field monitoring. In confined areas close to walls, the application of photocatalytic coatings can reduce pollutants by 50% [66]. Ming *et al.* [67] verified through CFD simulation that installing wind traps in street canyons can reduce the flow and diffusion of pollutants in street canyons. Gulia *et al.* [68] conducted a performance assessment study of Delhi traffic intersections in 2021 with an air pollution control device called Wind Augmentation and purifYing Unit (WAYU). The average removal rates of PM_{10} and $PM_{2.5}$ were 42% and 22%, respectively. Huang *et al.* [69] studied the mitigation effect of air purification street lamps on automobile exhaust pollution in street canyons. Through simulation and wind tunnel test verification, it was concluded that the PM concentration, NOx concentration and CO concentration of purified street lamps in high pollution areas under different wind directions were reduced by 13.28%, 25.09% and 11.76% respectively. Correa *et al.*[70] have described a portable and easy-to-operate system that helps eliminate droplets or aerosols present in the environment by circulating air through a UV-

C reactor. Lin *et al*.[71] used two separate chargers to process ultrafine rice and submicron particles, achieving a agglomeration efficiency of 40.2%. Wang [72] *et al.* proposed a new idea to combine air pollutants with energy storage devices, and also proposed the principle of recycling air pollutants into energy storage materials, including directly used as active materials, converted into active materials and modified electrodes as dopants.

5. Prospect and challenge of air pollution prevention and control in China

China has made remarkable achievements in the prevention and control of air pollution since the release of “Atmosphere Ten Articles". Now Chinacontinues to strengthen the prevention and control of air pollution. First, the problem of particulate matter in major cities has not been completely solved. In 2017, nearly 75% of 74 major cities in China still failed to meet the annual average value of $PM_{2.5}$ standard GB 3095. If $PM_{2.5}$ standards are further tightened in the future, only Zhoushan, Haikou and Lhasa will be able to meet the requirement of WHO's second transitional phase target (annual limit of 25 $\mu g/m^3$). The regional problem of $PM_{2.5}$ pollution is still prominent in China. In 2018, $PM_{2.5}$ in Beijing-Tianjin-Hebei and its surrounding areas and in the Fenhe River Plain were 60 and 58 $\mu g/m^3$ respectively, exceeding 71% and 66% of GB 3095 standard limits respectively [73]. Further strengthen the control of mobile pollution sources, with diesel truck pollution control as a priority task, promote the promotion of new energy vehicles, improve regional transport structure, and strengthen non-road mobile source pollution control. Research [74] points out that the electrification of traffic in key areas can effectively reduce the emission of $PM_{2.5}$ and O_3 major pollutants, improve regional and urban air quality, and realize the synergy of environmental benefits and climate benefits.

In addition to the prevention and control of air pollution, China is also faced with the task of coping with climate change. In 2015, China submitted intensified Actions to Address Climate Change -- China's Nationally Determined Contribution [75], promising that CO_2 emissions would peak around 2030 and strive to peak as soon as possible. After 2005, China's energy intensity and carbon emission per unit GDP declined significantly, while carbon emission per unit energy consumption did not improve significantly [76]. In view of the fact that energy consumption will continue to rise in the future, it is inevitable to further promote the transformation of energy structure and develop low-carbon energy technologies [60].

To sum up, China's air pollution control is still a long way to go. In The Beijing-Tianjin-Hebei region and the Fenhe-Weihe Plain, $PM_{2.5}$ still exceeds the standard and the O_3 pollution problem is prominent. In the next period of time, we should focus on non-electric coal-fired pollution and diesel truck pollution and other key areas, through the energy structure, transport structure and industrial structure of the system adjustment to achieve the root cause of pollution control, strengthen NO_x and VOCs emission control, to achieve further improvement of air quality in China [60]. While carrying out in-depth air pollution control, China is also actively fulfilling the responsibility of greenhouse gas emission reduction under the Paris Agreement. In the future, we should actively improve energy efficiency and optimize energy structure, vigorously develop clean energy technologies such as new energy vehicles and wind power, and promote environmental air quality management to enter a positive interactive stage between air pollution prevention and climate change, so as to achieve synergistic progress in environmental governance and climate change response.

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