

Original Paper

Research on the Characteristics and Influencing Factors of Dust Diffusion from Highway Construction Sites in Guanzhong Region

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Abstract

To reveal the diffusion patterns of dust generated by vehicles during highway construction in the Guanzhong region, this paper, based on a highway construction project in the Guanzhong region, systematically studied the spatiotemporal distribution characteristics of line-source dust under different vehicle speeds using on-site monitoring methods. The results show that the dust concentration generated by construction vehicles increases significantly with increasing vehicle speed, and the peak concentrations of PM_{2.5} and PM₁₀ are positively correlated with vehicle speed. Dust diffusion exhibits obvious spatiotemporal attenuation characteristics, with high peak concentrations and rapid attenuation at nearby monitoring points. Due to the influence of meteorological conditions in the Guanzhong region, dust is mainly concentrated within a 50m downwind radius. This research can provide a scientific basis for the precise control of dust during highway construction.

Keywords

Highway construction, dust from line source, on-site monitoring, diffusion pattern, Guanzhong region

1. Introduction

Construction dust from highways is a significant source of fugitive emissions, accounting for 34%-45% of total urban dust emissions (2020; Chen et al., 2024; Li et al., 2022). Among these, line-source dust generated by transport vehicles (Xie, 2018) exhibits mobility, intermittency, and strong disturbance characteristics, making its diffusion pattern more complex than that of point and area sources. Due to the high emission intensity and low-altitude emission of this type of dust, it significantly impacts the health of construction workers and surrounding residents (Tao et al., 2022; Kaluarachchi et al., 2021;

Zhang et al., 2023). Therefore, controlling construction dust is crucial for protecting the health of workers and alleviating urban air pollution (Zhang et al., 2023; Yan et al., 2022). Existing research mainly focuses on plain areas such as the Beijing-Tianjin-Hebei region and the Yangtze River Delta, while research on the diffusion mechanism of construction dust in the Guanzhong region, with its unique “two mountains and one river” topography, remains insufficient. This region is hindered by the Qinling Mountains and the Loess Plateau, resulting in an average annual wind speed of only 1.2 m/s, a winter mixing layer height as low as 400 m, and atmospheric stability primarily at level F (stable), leading to pollutants that are “easy to accumulate and difficult to diffuse” (Lin, 2018; Cao, 2019).

Current research on construction dust mainly relies on CFD numerical simulation (Chen, 2023) (such as Realizable k- ϵ model and SST k- ω model), but the simulation results often deviate from the actual measurements due to the simplification of boundary conditions and insufficient localization of turbulence parameters. Chen Jian et al. pointed out that there is a lack of measured verification data on construction dust in the Guanzhong region, which restricts the regional applicability of the model. Although the “Construction Site Boundary Dust Emission Limit” (DB61/1078-2017) specifies the emission limit for PM₁₀, it does not consider the diffusion differences under different meteorological conditions.

In view of this, this paper relies on a highway construction project in the Guanzhong region to carry out on-site monitoring experiments of line source dust, focusing on solving the following problems: first, the quantitative relationship of dust diffusion under the coupling effect of different vehicle speeds and meteorological conditions; second, the determination of dust pollution control distance based on measured data. The research aims to establish a construction dust diffusion prediction model applicable to the Guanzhong region, and provide technical support for regional precise pollution control.

2. Materials and Methods

2.1 Overview of the Monitoring Area

The monitoring area is located on a highway construction section in the Guanzhong region (107°40′~109°49′E, 33°39′~34°45′N), which belongs to the warm temperate continental monsoon climate with four distinct seasons and an average annual precipitation of 500-700 mm. During the monitoring period (summer of 2021), the prevailing wind direction was northeasterly, with an average wind speed of 2.0 m/s, which meets the requirements of the “Technical Guidelines for Monitoring Unorganized Emissions of Air Pollutants” (HJ/T55-2000).

Through on-site investigation, it was found that most of the linear dust generated during the construction of the highway project was caused by vehicles at the construction site. This group of linear dust generation field monitoring tests took the transportation of materials by transport vehicles as an example, and the test section was an unpaved roadbed surface in the north-south direction. On the day of the test, the wind was due south, with an average wind speed of 2.017 m/s, a temperature of 35°C, and a humidity of 50.1%.

2.2 Monitoring Scheme Design

An M5S laser dust monitor (measuring range: PM2.5 0-1000 $\mu\text{g}/\text{m}^3$, PM10 0-3000 $\mu\text{g}/\text{m}^3$, resolution 1 $\mu\text{g}/\text{m}^3$, accuracy $\pm 10\%$) was used, equipped with a six-channel particle size distribution (0.3, 0.5, 1.0, 2.5, 5.0, 10.0 μm). Zero-point and span calibrations were performed before sampling, and the relative error was controlled within $\pm 5\%$.

Table 1. Specifications of M5S Dust Monitor

Name	Specification	Name	Specification
Product Size	8.2*6.1*4cm	PM2.5 Monitoring Range	0-1000 $\mu\text{g}/\text{m}^3$
Product Weight	140g	PM10 Monitoring Range	0-3000 $\mu\text{g}/\text{m}^3$
Monitoring Particle Size Range	0.3-10 μm	Power Supply	5V/1A
		Specifications	



Figure 1. M5S Type Dust Monitoring Instrument

According to HJ/T 55-2000, five monitoring points (A-1 to A-5) were set up downwind, at distances of 10m, 20m, 30m, 40m, and 50m from the roadbed centerline, respectively, at a sampling height of 1.5m (human breathing zone). A control point (C-1) was also set up upwind for background concentration subtraction (background values: PM2.5 35 $\pm 8\mu\text{g}/\text{m}^3$, PM10 78 $\pm 12\mu\text{g}/\text{m}^3$).

An unpaved roadbed section (loess soil, 8% moisture content) was selected, and standard dump trucks (rated load 20t, tire pressure 0.8MPa) were used. Three speed gradients were set: 40, 50, and 60 km/h. Each gradient was repeated twice ($n=2$), with an interval of at least 5 minutes between each test to ensure complete particulate matter settling. Meteorological parameters (wind speed, wind direction, temperature, and humidity) were monitored simultaneously at a sampling frequency of 1Hz, with recording times of 5 minutes before and after the vehicle passed.

The instruments were arranged downwind from south to north according to their labels, with a monitoring point every 10 meters. The first monitoring point was at least 50 meters from the end of the test section, and the last monitoring point was about 50 meters from the end of the test section. The

vehicle stopped about 40 meters away from the first monitoring point and waited for the dust to have fully dispersed in the monitored section (about 1 minute) before slowly returning to the starting point.



Figure 2. Linear Source Dust Test Site



Figure 3. On-site Instrument Layout

3. Results and Analysis

3.1 Characteristics of Dust Concentration Variation at Different Vehicle Speeds

Figure 4 shows the PM_{2.5} concentration over time at monitoring point A-1 (closest to the vehicle's starting point) under different vehicle speeds (40, 50, and 60 km/h). The vehicle's passage time is $t=0$, and the results are the average of two repeated experiments. Overall, the concentration at the monitoring point rapidly rises to its peak after the vehicle passes, and then exhibits a biexponential decay trend. The peak time coincides closely with the time the vehicle passes the monitoring point, indicating that dust dispersion is mainly caused by mechanical disturbance and is significantly influenced by background airflow transport.

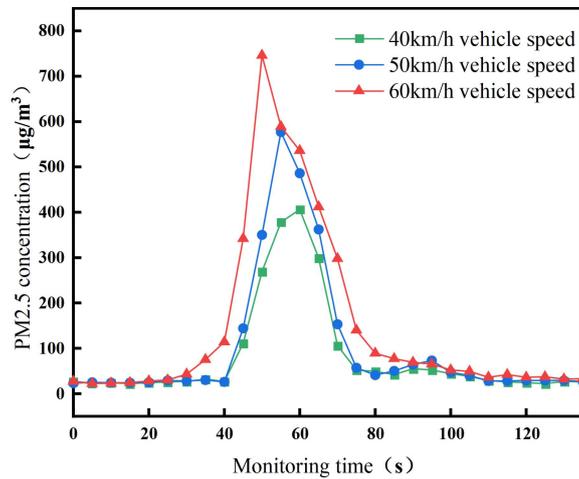


Figure 4. Comparison of PM2.5 Concentration Changes at Monitoring Point A-1 under Different Vehicle Speeds

Vehicle speed has a significant enhancing effect on dust generation. When the vehicle speed increases from 40 km/h to 60 km/h, the peak concentration of PM2.5 at monitoring point A-1 increases from 405 $\mu\text{g}/\text{m}^3$ to 746 $\mu\text{g}/\text{m}^3$, an increase of about 1.8 times; during the same period, the peak concentration of PM10 increases from 894 $\mu\text{g}/\text{m}^3$ to 1259 $\mu\text{g}/\text{m}^3$, an increase of about 1.4 times (Table 2). This indicates that under high-speed driving conditions, the shear friction between the tires and the road surface intensifies, resulting in a significantly higher proportion of fine particulate matter (PM2.5) lifted from the roadbed surface than coarse particulate matter. This phenomenon is consistent with the research conclusions of Chen Jian et al. (2023) in the Guanzhong region—fine particulate matter is more sensitive to mechanical disturbance energy.

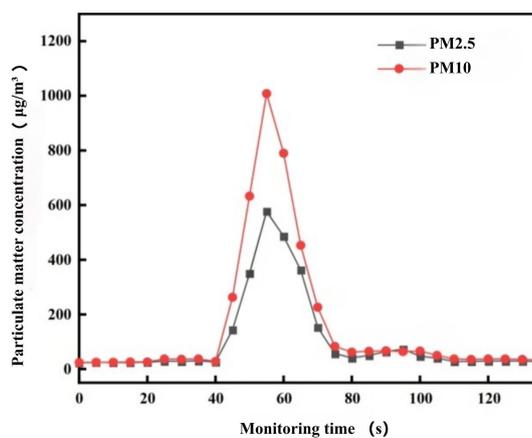


Figure 5. Comparison of PM2.5 and PM10 Concentrations at Monitoring Point A-1 at a Vehicle Speed of 50 km/h

As shown in Figure 5, the attenuation trend of PM_{2.5} at a vehicle speed of 50 km/h is basically the same as that of PM₁₀, but the attenuation is slightly slower in the later stage, reflecting the long-term suspension characteristics of fine particulate matter.

3.2 Space Diffusion Patterns of Dust

Table 2 shows the average PM₁₀ concentration at various monitoring points under different vehicle speeds. Spatially, dust concentration decreases with increasing distance in a power-law manner, with the fastest decrease occurring within 20m. The decrease slows significantly after 40m, and the concentration at 50m is close to the background level. This is related to the meteorological conditions in the Guanzhong region during summer, which have a relatively high mixing layer height (approximately 800-1000m) and atmospheric instability levels of B-C (unstable to weakly unstable), thus facilitating the vertical diffusion of dust.

Table 2. Average PM₁₀ Concentration at Various Monitoring Points under Different Vehicle Speeds

Vehicle Speed (km/h)	A-1($\mu\text{g}/\text{m}^3$)	A-2($\mu\text{g}/\text{m}^3$)	A-3($\mu\text{g}/\text{m}^3$)	A-4($\mu\text{g}/\text{m}^3$)	A-5($\mu\text{g}/\text{m}^3$)
40	894	280	135	74	47
50	1008	441	200	105	66
60	1259	657	293	154	85

Note. Data are the average of two repeated trials.

Comparing vehicle speeds, the concentrations at all monitoring points were significantly higher at 60 km/h than at 40 km/h, but the decay rates were basically the same, indicating that spatial diffusion patterns are mainly controlled by meteorological conditions, and vehicle speed primarily affects the amount of dust generated. Taking a distance of 20m as an example, the PM₁₀ concentration at 60 km/h was approximately 2.3 times that at 40 km/h, further confirming the enhancing effect of vehicle speed on dust generation.

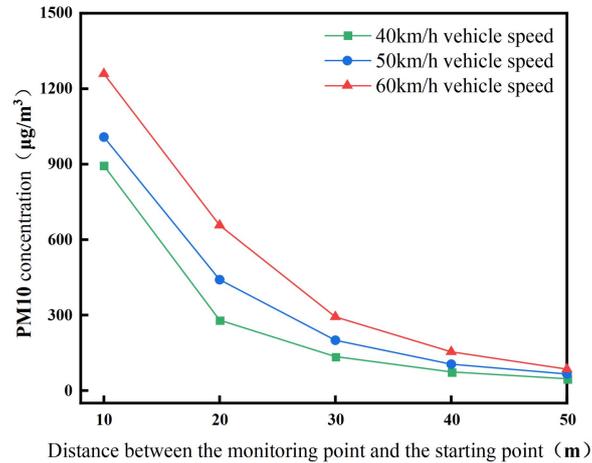


Figure 6. Spatial Decay of PM10 Peak Concentration at Different Vehicle Speeds

3.3 The Impact of Meteorological Conditions on Dust Dispersion

Meteorological parameters during the monitoring period showed that the Guanzhong region experienced low summer wind speeds (average 2.017 m/s) and southerly winds, which, when aligned with the direction of vehicle travel, facilitated dust transport along roads. Due to the obstructing topography of the Guanzhong region, the dust dispersion range was limited to within 50 meters.

The results of this study are consistent with the findings of Chen Jian et al. regarding dust from highway construction in the Guanzhong region. Linear source dust concentration is positively correlated with vehicle speed, and fine particulate matter (PM_{2.5}) is more sensitive to changes in vehicle speed.

Compared to the results from studies in North China, the Guanzhong region, due to its basin topography and lower average wind speed, exhibits a relatively shorter dust dispersion distance but a higher peak concentration. This suggests that closer attention should be paid to dust control within 20 meters during construction in this region.

4. Results Discussion

4.1 Analysis of Test Results

Data was collected through repeated experiments at different vehicle speeds and processed into concentration change graphs, leading to the following conclusions:

The timing of the dust concentration peaks obtained from various instruments indicates that dust travels with the airflow.

The closer the instrument is to the dust generation point, the larger the dust concentration peak it collects, suggesting that dust gradually settles or diffuses in other directions during its propagation. This is also related to the unstable wind speed and direction at the site.

Based on the trends of PM_{2.5} and PM₁₀ changes at different vehicle speeds, as vehicle speed increases, more dust is stirred up, resulting in larger concentration peaks shown in the graphs.

4.2 Control Recommendations

Based on the monitoring results, the following targeted measures are proposed:

- (1) Regarding speed limit management, the speed of vehicles on construction access roads should be controlled below 40 km/h, which can significantly reduce dust generation.
- (2) Regarding water spraying for dust suppression, for unpaved roads, water should be sprayed before vehicles pass to maintain the surface moisture content of the roadbed above 10%, which can effectively suppress dust generation. The surface soil moisture content of the roadbed in this test section is 8%, posing a certain risk of dust generation.
- (3) Regarding partial fencing, fencing of at least 2.5m should be set up downwind in sensitive areas (such as residential areas and office areas), which can block about 70% of dust diffusion.

5. Conclusions

- (1) The concentration of dust from highway construction sites increases significantly with vehicle speed, and PM_{2.5} is more sensitive to changes in vehicle speed. The peak PM_{2.5} concentration at 60 km/h is approximately 1.8 times that at 40 km/h.
- (2) Dust dispersion exhibits a clear spatiotemporal decay characteristic, with the concentration peak occurring after vehicles pass, and the fastest decay occurring within 20m.
- (3) Due to the influence of meteorological conditions in the Guanzhong region, dust in the Guanzhong region during summer under low wind speed conditions is mainly concentrated within 50m downwind, requiring strengthened seasonal control.
- (4) This reveals the regulatory role of local meteorological conditions: low wind speeds lead to rapid near-field settling of coarse particulate matter, but fine particulate matter (PM_{2.5}) still exhibits long-term suspended characteristics in the far field, requiring differentiated dust suppression strategies—primarily water spraying for near-field dust suppression, and supplemented by fencing filtration in the far field.

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