

# Numerical simulation of the effect of construction dust emission on air quality in Jinan, a Central City in the North China Plain

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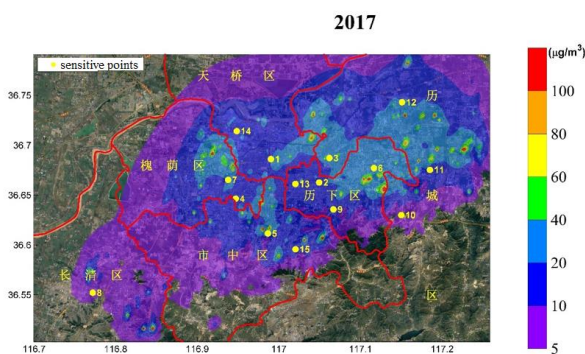
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## Graphical abstract



## Abstract

Numerical simulation was conducted to assess the impact of dust emission on typical environmental sites in Jinan City. The CALPUFF model was applied to five simulation scenarios. The results showed that dust emission had a significant impact on air quality in Jinan. The impact of dust emission on the average concentration of PM<sub>10</sub> at 15 monitoring sites was 19.8 µg/m<sup>3</sup>, accounting for 14.9% of the annual total. The impact of dust emission on the average concentration of PM<sub>2.5</sub> was 5.2 µg/m<sup>3</sup>, accounting for 8.1% of the annual total. Adoption of yellow warning measures in the emission reduction scenarios had insignificant environmental effects due to unfavorable meteorological conditions. Compared with the baseline scenario, the average concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> decreased by 13.6% and 1.9%, respectively. After adoption of orange and red warning measures, the impact of site dust emission on air quality at the monitoring site was reduced significantly. Significant environmental effects were achieved after all construction sites within a 2-km radius of the monitoring site were closed. Compared with the baseline scenario, the average concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> were reduced by 45.5% and 42.3%, respectively. The results showed that under adverse meteorological conditions, higher-level warning measures should be undertaken to reduce the impact of site emissions on environmental quality. Considering the

economic and social effects of emission reduction, temporary construction stoppage within 2 km of the monitoring site is a feasible plan that is in accordance with the goals of comprehensive environmental management.

**Keywords:** Jinan, Construction dust, Air quality, CALPUFF, Numerical simulation.

## 1. Introduction

With rapid urbanization in China, dust pollution from urban construction has become one of the main factors affecting air quality. Prevention of urban construction dust is essential for prevention and control of air pollution in various locations. According to a source analysis conducted in the City of Jinan, regional transmission accounts for 20–32% of atmospheric particulate matter (PM<sub>2.5</sub>), while emissions from local pollution sources contribute 68–80% of air pollution. Coal, dust, industrial activities, and motor vehicles are four major sources of air pollution, accounting for 27%, 24%, 18% and 15% of air pollution, respectively. Emissions from other sources such as restaurants, car repair shops, livestock and poultry farming, and building coatings account for approximately 16% of PM<sub>2.5</sub>. Dust is one of the main factors causing air pollution, and construction sites are a major source of urban dust (Chung *et al.*, 2014; Hye *et al.*, 2009; Junpen *et al.*, 2013; Liang *et al.*, 2018; Liu *et al.*, 2019; Niu *et al.*, 2010). Thus, effective control of dust pollution generated from urban construction sites is essential.

Numerical simulation is an effective tool for assessing the impacts of dust emission on air quality (Chang *et al.*, 2020; Don *et al.*, 2018; Kirthiga and Patel, 2018; Lai *et al.*, 2017; Latinopoulos *et al.*, 2012; Maity *et al.*, 2017; Misra *et al.*, 2014). Zhang *et al.* (2010) employed the CALPUFF model to simulate the impact of construction dust emission on environmental quality in the City of Guiyang. The results showed that construction dust accounted for nearly 12% of the annual average concentration of PM<sub>10</sub> across the entire urban area, with monthly contributions of up to 40% to PM<sub>10</sub> and annual contributions exceeding 25% in some areas. Driven by the intensity of construction and meteorological conditions, seasonal trends in the impact

of construction dust emission on air quality are clear. Xue *et al.* (2017) used the WRF/CMAQ model to simulate the impact of construction dust emission on air quality in Beijing. Their results showed that construction dust emission in Beijing has increased in a regularly fluctuating pattern over the years. Although the area covered by construction sites has decreased in recent years, the amount of construction remains high, resulting in high particulate matter emissions. Temporally, construction dust emission is greatest during summer and autumn. Spatially, construction dust is concentrated mainly in urban expansion areas and suburbs, where it is associated with the extension of human activities and the gradual outward progression of urbanization. Dust from construction contributed up to  $31.3 \mu\text{g}\cdot\text{m}^{-3}$   $\text{PM}_{10}$  and  $9.6 \mu\text{g}\cdot\text{m}^{-3}$   $\text{PM}_{2.5}$  in the air of Beijing. Zhao *et al.* (2009) simulated the impact of dust emission from construction sites on  $\text{PM}_{10}$  concentrations in Tianjin using the ISC3 model. The results revealed that the average concentration of  $\text{PM}_{10}$  produced from construction sites was  $20.3 \mu\text{g}\cdot\text{m}^{-3}$ , accounting for 13.3% of the atmospheric  $\text{PM}_{10}$  concentration.

The aim of this study was to analyze typical construction sites in Jinan and use the CALPUFF model to simulate their environmental impacts. The results will provide a scientific basis for the prevention and control of air pollution in Jinan.

## 2. Methods and study region

### 2.1. Methods

The CALPUFF model was selected for use in this study. CALPUFF is a guideline model recommended by the United States Environmental Protection Agency. It is a multi-layered, multi-species, non-steady-state Lagrangian Gaussian smoke puff dispersion model. The model tracks the movement of a discrete smoke puff after release, simulating its diffusion, transformation, and clearance along its path until the puff leaves the simulation area. Spatiotemporal variations in meteorological conditions are explicitly considered during analysis of smoke puff diffusion. An important characteristic of non-steady-state diffusion is that the smoke puff can alter its path as the wind direction changes. During movement, smoke puffs follow the spatiotemporal variations in surface characteristics such as surface roughness and soil moisture content. The guideline on air quality models from the United States Environmental Protection Agency states that the purpose of the CALPUFF model is to assess the impacts of spatiotemporal changes in meteorological conditions on transport and diffusion. CALPUFF is a relatively mature model with a long history of development, which has been tested and evaluated by many users. CALPUFF can simulate moderate scales from dozens of meters to hundreds of kilometers, as well as some non-steady-state conditions (such as calm wind, fumigation, recirculation, complex terrain, and coastal conditions). Its meteorological modules include land and water boundary layer models that use the predicted wind field or station data as the initial estimated field to analyze the initial estimated wind field from

morphodynamics and overland flow parameters, and it is suitable for simulation of complex terrain.

The CALPUFF model system includes three main modules, CALMET, CALPUFF, and CALPOST, as well as pre-processing programs for geographic and meteorological data (Atabi *et al.*, 2016; Shekarzifard *et al.*, 2017). Briefly, CALMET is a meteorological model that establishes three-dimensional gridded wind and temperature fields in the simulation area and simultaneously generates two-dimensional mixing height, surface characteristics, and diffusion characteristics. CALPUFF is a transport and diffusion model. The puff released from the emission source is transported via advection, and its diffusion and transformation processes along the transport path are simulated. The meteorological field with spatiotemporal variations generated by CALMET is used to steer CALPUFF. The main output files of CALPUFF include the concentration field and deposition flux. CALPOST is a post-processing module used to process these output files, generate time-series files, calculate the maximum concentration, and identify points exceeding a certain threshold concentration.

### 2.2. Study region

Jinan, the capital of Shandong Province, is a typical polluted city on the North China Plain, hosting the highest  $\text{SO}_2$ ,  $\text{NO}_x$ , and  $\text{PM}_{2.5}$  emissions in China (Zhang *et al.*, 2009) (Figure 1). Jinan is bordered by Tai Mountain to the south and the Yellow River to the north, with greater topographic variations in the south than in the north. The altitude of the area ranges from 23 m to 975 m above sea level, with high contrast relief. Hilly areas and alluvial plains lie across the city from south to north (Yang *et al.*, 2012). The city has experienced dramatic population and spatial growth during the last 50 years, as the population has increased from 3.19 million in 1952 to 8.83 million in 2018, and the developed area increased from  $24.6 \text{ km}^2$  in 1949 to over  $500 \text{ km}^2$  in 2018. The semi-humid continental monsoon climate is characterized by cold, dry winters and hot, wet summers. The average annual precipitation is 636 mm, with 75% occurring during the wet season.

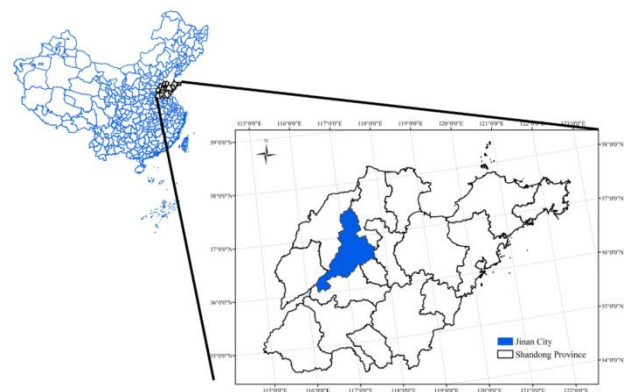


Figure 1. Location of the study area.

## 3. Data sources

### 3.1. Geographic and meteorological data sources

The use of CALMET to generate 3D diagnostic wind fields and 2D micrometeorological parameter fields requires the

input of geographic data, including terrain height, land use, surface parameters (surface roughness, surface albedo, Bowen ratio, soil heat flux, and leaf area index) and anthropogenic heat flux. A common terrain database is provided in the CALMET user manual. This study used SRTM3 terrain elevation data with a resolution of 90 m, provided by the United States Geological Survey, as the input for the terrain pre-processing module TERREL to obtain gridded terrain in the study area with a 100-m resolution. Global land cover data from the United States Geological Survey, with a resolution of 1 km, were used to assign land use and were input into the land-use pre-processing module CTGPROC. Due to the low resolution of global land-use data, in cases where the simulation mesh resolution was finer than the data resolution, the original land-use data with low resolution were divided into finer grids by increasing the sampling density of each grid. Gridded terrain and land-use data at the same resolution were input into the pre-processing module MAKEGEO, and the surface parameters of each grid were calculated using geographic parameters for various land-use types with the CALMET default settings to obtain geographic data (GEO.DAT) for the use of CALMET.

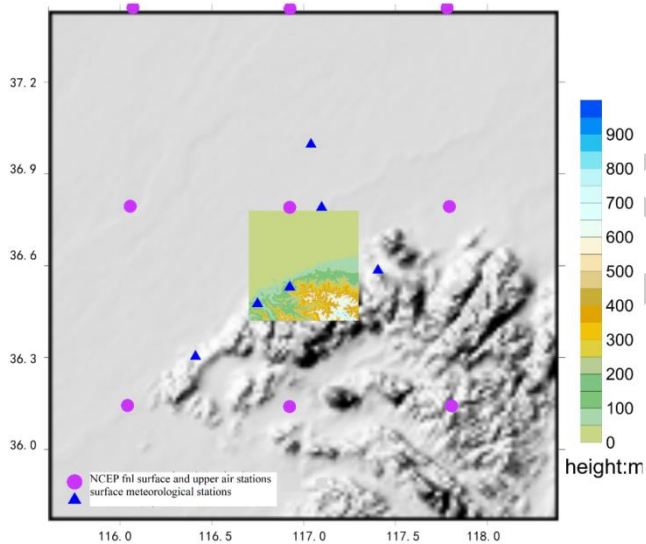


Figure 2. Locations of meteorological observation sites.

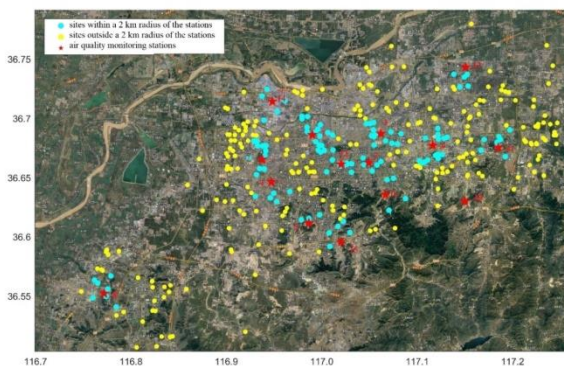


Figure 3. Locations of pollution sources and sensitive points.

Surface meteorological data include conventional surface meteorological observations from nine stations obtained from the meteorological element analysis field of the National Weather Service National Centers for Environmental Prediction (NCEP), including hourly wind direction, wind

speed, temperature, relative humidity, precipitation, total cloud cover, and barometric pressure from six surface meteorological stations. Upper atmospheric data include sounding observations (pressure, altitude, temperature, wind direction, and wind speed in 13 layers from 1000 to 500 hPa) collected four times per day (0000, 0600, 1200, and 1800 UTC) at nine stations of the meteorological element analysis field of the National Weather Service National Centers for Environmental Prediction. Figure 2 shows the locations of the meteorological stations.

### 3.2. Emission sources and sensitive points

A total of 15 air quality monitoring stations in Jinan were selected as sensitive points (see Table 1). The simulation area includes these 15 points, and the boundary of the simulation area is 5 km from the nearest sensitive point. There were 724 construction sites within the simulation area. Simulations were performed for these sites, 220 of which were within a 2-km radius of a sensitive point, as shown in Figure 3. The emissions from construction sites in 2017 and simulated emissions under five scenarios were provided by the Jinan Environmental Research Institute.

## 4. Analysis of simulation results

Five emission scenarios were analyzed in this study, as shown in Table 2. Emissions under scenarios with alerts issued were calculated based on the *Emergency Plan for Heavy Air Pollution Weather in Jinan*. The meteorological conditions were based on the 3 days from December 29 to December 31, 2017, when typical meteorological conditions unfavorable to diffusion occurred. Spatial distribution graphs of PM<sub>10</sub> and PM<sub>2.5</sub> were drawn for each scenario, and the concentrations at 15 sensitive points were extracted for analysis.

### 4.1. Scenario 1 analysis

Table 3 lists the concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> at each sensitive point under this scenario and their contributions to the environmental concentration at the monitoring point. The monitoring values are annual average concentrations of particulate matter at each station. Figures 4 and 5 display the average concentration distributions of PM<sub>10</sub> and PM<sub>2.5</sub>, respectively, under this scenario. The figures reveal that dust emission had the greatest impact on the average concentration of PM<sub>10</sub> at sites located in the development zone, reaching 31.0 μg/m<sup>3</sup>. The impact of dust emission on the average PM<sub>10</sub> concentration across all 15 monitoring stations was 19.8 μg/m<sup>3</sup>, accounting for 14.9% of the average monitoring value. Similarly, dust emission had the greatest impact on the average concentration of PM<sub>2.5</sub> at stations within the development zone, reaching 7.8 μg/m<sup>3</sup>. Its impact on the average PM<sub>2.5</sub> concentration at the 15 monitoring points was 5.2 μg/m<sup>3</sup>, accounting for 8.1% of the average monitoring values. The spatial distribution based on all construction sites in the simulation area showed the diffusion trajectories of PM<sub>2.5</sub> and PM<sub>10</sub> generally covering the entire simulation area, and areas with high concentrations were generally concentrated in the northern part of Lixia District and the western part of Licheng District.

**Table 1.** Information about the 15 sensitive points

| No. | Name                           | Longitude | Latitude |
|-----|--------------------------------|-----------|----------|
| 1   | Jinan chemical plant           | 116.9903  | 36.6861  |
| 2   | Air quality monitoring station | 117.0494  | 36.6627  |
| 3   | Seed warehouse                 | 117.0619  | 36.6872  |
| 4   | Second machine tool plant      | 116.9472  | 36.6464  |
| 5   | Kegansuo site                  | 116.9866  | 36.6116  |
| 6   | Development zone               | 117.1164  | 36.6772  |
| 7   | Nongkesuo site                 | 116.9378  | 36.6653  |
| 8   | Changing Party School          | 116.772   | 36.5522  |
| 9   | School of Economics            | 117.0669  | 36.6357  |
| 10  | High and New School            | 117.15    | 36.63    |
| 11  | Construction College           | 117.1851  | 36.6753  |
| 12  | Jinan Baosheng site            | 117.1509  | 36.7431  |
| 13  | Quancheng Square               | 117.0203  | 36.6612  |
| 14  | Lanxiang Vocational School     | 116.9483  | 36.7142  |
| 15  | Shandong Luneng site           | 117.0204  | 36.5957  |

**Table 2.** Simulation scenario descriptions

| No. | Scenario description              | Pollution source emission  | Meteorological conditions |
|-----|-----------------------------------|--|---------------------------|
| 1   | Basic scenario                    | Normal emissions from all construction sites                                   | Year 2017                 |
| 2   | Yellow alert                      | Emissions reduced by 35%   | December 29–31, 2017      |
| 3   | Orange alert                      | Emissions reduced by 70%   | December 29–31, 2017      |
| 4   | Red alert                         | Emissions reduced by 90%   | December 29–31, 2017      |
| 5   | Other emission reduction scenario | Closing all construction sites within a 2-km radius of meteorological stations | Year 2017                 |

**Table 3.** Concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> under scenario 1 and their ratios to monitoring data

| No.                     | Name                           | PM <sub>10</sub> concentration (μg/m <sup>3</sup> ) |                        |        | PM <sub>2.5</sub> concentration (μg/m <sup>3</sup> ) |                        |        |
|-------------------------|--------------------------------|---|------------------------|--------|--|------------------------|--------|
|                         |                                | Simulated mean value                                | Monitored annual value | Ratio  | Simulated mean value                                 | Monitored annual value | Ratio  |
| 1                       | Jinan chemical plant           | 21.2  | 124                    | 17.09% | 5.6  | 59                     | 9.54%  |
| 2                       | Air quality monitoring station | 17.4  | 132                    | 13.19% | 4.8  | 70                     | 6.91%  |
| 3                       | Seed warehouse                 | 23.9  | 133                    | 17.95% | 6.3  | 68                     | 9.23%  |
| 4                       | Second machine tool plant      | 16.1  | 145                    | 11.11% | 4.4  | 76                     | 5.78%  |
| 5                       | Kegansuo site                  | 24.7  | 121                    | 20.40% | 6.3  | 59                     | 10.74% |
| 6                       | Development zone               | 31.0  | 116                    | 26.74% | 7.8  | 58                     | 13.42% |
| 7                       | Nongkesuo site                 | 22.8  | 148                    | 15.42% | 5.8  | 62                     | 9.42%  |
| 8                       | Changing Party School          | 7.4   | 122                    | 6.08%  | 2.0  | 64                     | 3.16%  |
| 9                       | School of Economics            | 15.9  | 114                    | 13.97% | 4.4  | 60                     | 7.36%  |
| 10                      | High and New School            | 8.8   | 134                    | 6.59%  | 2.6  | 60                     | 4.41%  |
| 11                      | Construction College           | 19.1  | 127                    | 15.06% | 4.9  | 57                     | 8.65%  |
| 12                      | Jinan Baosheng site            | 24.6  | 202                    | 12.20% | 6.2  | 79                     | 7.81%  |
| 13                      | Quancheng Square               | 30.6  | 131                    | 23.33% | 7.7  | 63                     | 12.22% |
| 14                      | Lanxiang Vocational School     | 18.3  | 151                    | 12.11% | 4.8  | 77                     | 6.28%  |
| 15                      | Shandong Luneng site           | 14.7  | 122                    | 12.05% | 4.0  | 56                     | 7.21%  |
| Average of the 15 sites |                                | 19.8  | 134.8                  | 14.89% | 5.2  | 64.5                   | 8.14%  |

#### 4.2. Scenario 2 analysis

Table 4 lists the concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> at each sensitive point under this scenario and their contributions to the environmental concentrations at the monitoring points. Figures 6 and 7 display the distributions of the average concentration of PM<sub>10</sub> and PM<sub>2.5</sub>, respectively, under this scenario.

In the yellow alert scenario, dust emission had the greatest impact on the average concentration of PM<sub>10</sub> at Kegansuo station, reaching 35.7 μg/m<sup>3</sup>. Its impact on the

average PM<sub>10</sub> concentration across all 15 monitoring stations was 17.1 μg/m<sup>3</sup>, accounting for 13.1% of the average observed value. Dust emission had the greatest impact on the average concentration of PM<sub>2.5</sub> at Kegansuo station, reaching 9.6 μg/m<sup>3</sup>. Its impact on the average PM<sub>10</sub> concentration across all 15 monitoring stations was 5.1 μg/m<sup>3</sup>, accounting for 8.2% of the average observed value. The simulation results revealed that when extremely adverse meteorological conditions occur, dust continues to have a substantial impact on air quality at the monitoring stations, despite a 35% reduction in

emissions. Compared with the baseline scenario, the average concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> across the 15 stations decreased by 13.6% and 1.9%, respectively.

PM<sub>2.5</sub> concentration across all 15 monitoring stations was 2.4 μg/m<sup>3</sup>, accounting for 3.77% of the average monitoring value. Spatially, the area influenced by the diffusion trajectories of PM<sub>10</sub> and PM<sub>2.5</sub>, based on their average concentrations, was reduced. However, under adverse weather conditions, impacts on air quality at the monitoring stations were still observed. Compared with the baseline scenario, the average concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> at the 15 stations were reduced by 60.1% and 53.8%, respectively.

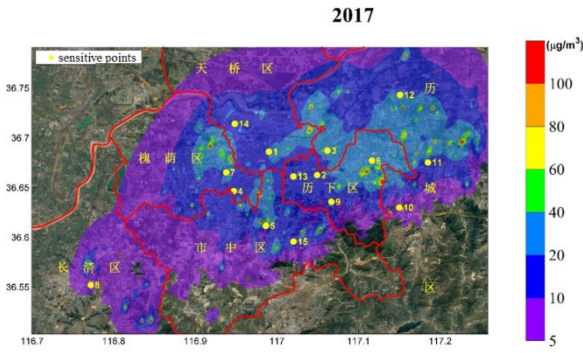


Figure 4. Average concentration of PM<sub>10</sub> under scenario 1.

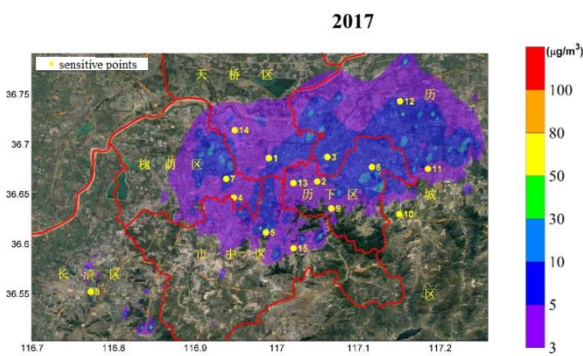


Figure 5. Average concentration of PM<sub>2.5</sub> under scenario 1.

4.3. Scenario 3 analysis

Table 5 lists the concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> at each sensitive point under this scenario and their contributions to the environmental concentrations at the monitoring points. Figures 8 and 9 display the average concentration distributions of PM<sub>10</sub> and PM<sub>2.5</sub>, respectively, under this scenario.

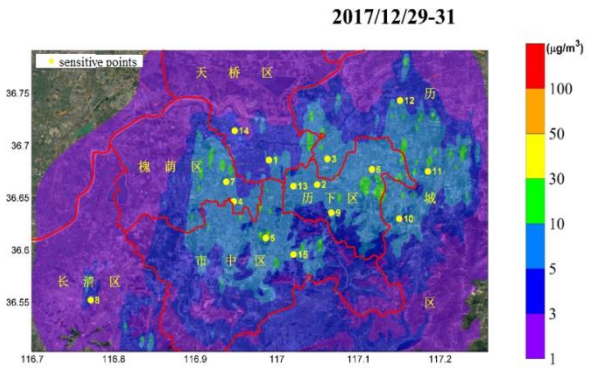


Figure 7. Average concentration of PM<sub>2.5</sub> under scenario 2.

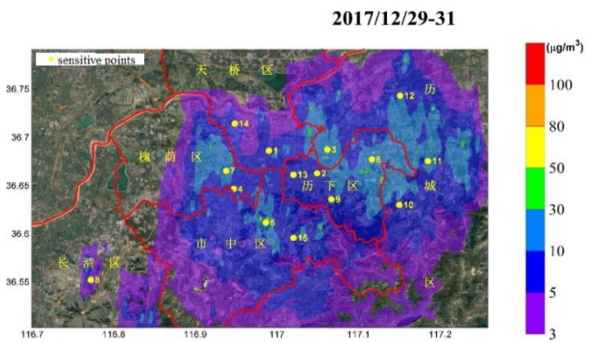


Figure 8. Average concentration of PM<sub>10</sub> under scenario 3.

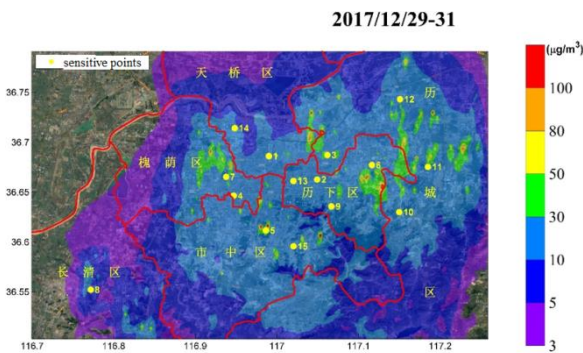


Figure 6. Average concentration of PM<sub>10</sub> under scenario 2.

Under orange alert conditions, dust emission had the greatest impact on the average PM<sub>10</sub> concentration at Kegansuo station, reaching 16.5 μg/m<sup>3</sup>, and its impact on the average PM<sub>10</sub> concentration across all 15 monitoring stations was 7.9 μg/m<sup>3</sup>, accounting for 6.02% of the average monitoring value. Dust emission had the greatest impact on the average PM<sub>2.5</sub> concentration at Kegansuo station, reaching 4.5 μg/m<sup>3</sup>, and its impact on the average

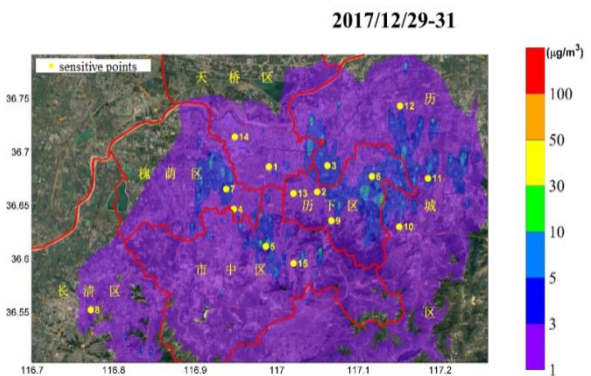


Figure 9. Average concentration of PM<sub>2.5</sub> under scenario 3.

4.4. Scenario 4 analysis

Table 6 lists the concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> at each sensitive point under this scenario and their contributions to the environmental concentrations at the monitoring points. Figures 10 and 11 display the average concentration distributions of PM<sub>10</sub> and PM<sub>2.5</sub>, respectively, under this scenario.

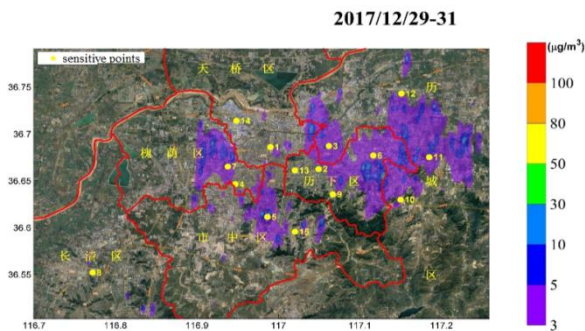


Figure 10. Average concentration of PM<sub>10</sub> under scenario 4.

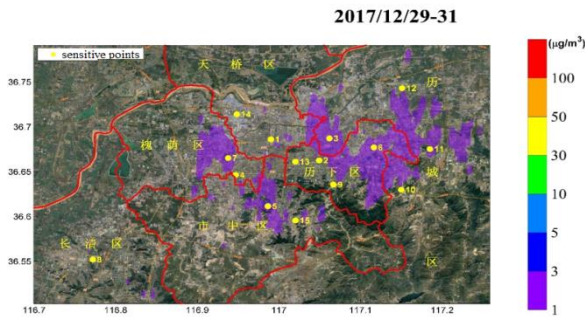


Figure 11. Average concentration of PM<sub>2.5</sub> under scenario 4.

Table 4. Concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> under scenario 2 and their ratios to monitoring data

| No.                     | Name                           | PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) |                        |        | PM <sub>2.5</sub> concentration (µg/m <sup>3</sup> ) |                        |        |
|-------------------------|--------------------------------|---|------------------------|--------|--|------------------------|--------|
|                         |                                | Simulated mean value                                | Monitored annual value | Ratio  | Simulated mean value                                 | Monitored annual value | Ratio  |
| 1                       | Jinan chemical plant           | 10.3  | 124                    | 8.35%  | 3.5  | 59                     | 6.02%  |
| 2                       | Air quality monitoring station | 14.0  | 132                    | 10.57% | 4.7  | 70                     | 6.74%  |
| 3                       | Seed warehouse                 | 17.7  | 133                    | 13.31% | 5.3  | 68                     | 7.83%  |
| 4                       | Second machine tool plant      | 12.3  | 145                    | 8.45%  | 4.2  | 76                     | 5.51%  |
| 5                       | Kegansuo site                  | 35.7  | 121                    | 29.53% | 9.6  | 59                     | 16.35% |
| 6                       | Development zone               | 20.5  | 116                    | 17.70% | 5.8  | 58                     | 10.02% |
| 7                       | Nongkesuo site                 | 18.5  | 148                    | 12.52% | 5.4  | 62                     | 8.65%  |
| 8                       | Changing Party School          | 6.3   | 122                    | 5.14%  | 2.3  | 64                     | 3.56%  |
| 9                       | School of Economics            | 14.1  | 114                    | 12.33% | 4.9  | 60                     | 8.14%  |
| 10                      | High and New School            | 16.8  | 134                    | 12.52% | 5.4  | 60                     | 9.04%  |
| 11                      | Construction College           | 25.2  | 127                    | 19.88% | 6.6  | 57                     | 11.50% |
| 12                      | Jinan Baosheng site            | 14.5  | 202                    | 7.19%  | 3.8  | 79                     | 4.79%  |
| 13                      | Quancheng Square               | 31.1  | 131                    | 23.77% | 8.4  | 63                     | 13.28% |
| 14                      | Lanxiang Vocational School     | 7.9   | 151                    | 5.23%  | 2.6  | 77                     | 3.43%  |
| 15                      | Shandong Luneng site           | 11.4  | 122                    | 9.31%  | 4.4  | 56                     | 7.79%  |
| Average of the 15 sites |                                | 17.1  | 134.8                  | 13.05% | 5.1  | 64.5                   | 8.18%  |

Table 5. Concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> under scenario 3 and their ratios to monitoring data

| No. | Name                           | PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) |                        |        | PM <sub>2.5</sub> concentration (µg/m <sup>3</sup> ) |                        |       |
|-----|--------------------------------|---|------------------------|--------|--|------------------------|-------|
|     |                                | Simulated mean value                                | Monitored annual value | Ratio  | Simulated mean value                                 | Monitored annual value | Ratio |
| 1   | Jinan chemical plant           | 4.8   | 124                    | 3.85%  | 1.6  | 59                     | 2.78% |
| 2   | Air quality monitoring station | 6.4   | 132                    | 4.88%  | 2.2  | 70                     | 3.11% |
| 3   | Seed warehouse                 | 8.2   | 133                    | 6.15%  | 2.5  | 68                     | 3.61% |
| 4   | Second machine tool plant      | 5.7   | 145                    | 3.90%  | 1.9  | 76                     | 2.54% |
| 5   | Kegansuo site                  | 16.5  | 121                    | 13.63% | 4.5  | 59                     | 7.55% |
| 6   | Development zone               | 9.5   | 116                    | 8.17%  | 2.7  | 58                     | 4.63% |
| 7   | Nongkesuo site                 | 8.5   | 148                    | 5.77%  | 2.5  | 62                     | 3.99% |
| 8   | Changing Party School          | 2.9   | 122                    | 2.37%  | 1.1  | 64                     | 1.64% |
| 9   | School of Economics            | 6.5   | 114                    | 5.69%  | 2.3  | 60                     | 3.76% |
| 10  | High and New School            | 7.7   | 134                    | 5.78%  | 2.5  | 60                     | 4.17% |

Under red alert conditions, the impact of dust emission on the average PM<sub>10</sub> concentration at the Kegansuo station was greatest, at 5.5 µg/m<sup>3</sup>, and its impact on the average PM<sub>10</sub> concentration across all 15 monitoring stations was 2.6 µg/m<sup>3</sup>, accounting for 2.0% of the average monitoring value. Dust emission had the greatest impact on the average PM<sub>2.5</sub> concentration at the Kegansuo station, reaching 1.5 µg/m<sup>3</sup>. Its impact on the average PM<sub>2.5</sub> concentration across all 15 monitoring stations was 0.8 µg/m<sup>3</sup>, accounting for 1.26% of the average monitoring value. In terms of the spatial distributions of pollutants, Licheng District had the highest PM<sub>10</sub> and PM<sub>2.5</sub> concentrations. Additionally, the region of influence was significantly smaller than those in other alert scenarios and the baseline scenario. These results show that when red alert measures are adopted during the hot season, dust pollution at construction sites in Jinan is generally controlled. Compared with the baseline scenario, the average concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> across all 15 stations decreased by 86.9% and 84.6%, respectively.

|                         |                            |      |       |        |     |      |       |
|-------------------------|----------------------------|------|-------|--------|-----|------|-------|
| 11                      | Construction College       | 11.7 | 127   | 9.18%  | 3.0 | 57   | 5.31% |
| 12                      | Jinan Baosheng site        | 6.7  | 202   | 3.32%  | 1.7 | 79   | 2.21% |
| 13                      | Quancheng Square           | 14.4 | 131   | 10.97% | 3.9 | 63   | 6.13% |
| 14                      | Lanxiang Vocational School | 3.6  | 151   | 2.41%  | 1.2 | 77   | 1.58% |
| 15                      | Shandong Luneng site       | 5.2  | 122   | 4.30%  | 2.0 | 56   | 3.60% |
| Average of the 15 sites |                            | 7.9  | 134.8 | 6.02%  | 2.4 | 64.5 | 3.77% |

**Table 6** Concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> under scenario 4 and their ratios to monitoring data

| No.                     | Name                           | PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) |                        |       | PM <sub>2.5</sub> concentration (µg/m <sup>3</sup> ) |                        |       |
|-------------------------|--------------------------------|---|------------------------|-------|--|------------------------|-------|
|                         |                                | Simulated mean value                                | Monitored annual value | Ratio | Simulated mean value                                 | Monitored annual value | Ratio |
| 1                       | Jinan chemical plant           | 1.6   | 124                    | 1.28% | 0.5  | 59                     | 0.93% |
| 2                       | Air quality monitoring station | 2.1   | 132                    | 1.63% | 0.7  | 70                     | 1.04% |
| 3                       | Seed warehouse                 | 2.7   | 133                    | 2.05% | 0.8  | 68                     | 1.20% |
| 4                       | Second machine tool plant      | 1.9   | 145                    | 1.30% | 0.6  | 76                     | 0.85% |
| 5                       | Kegansuo site                  | 5.5   | 121                    | 4.54% | 1.5  | 59                     | 2.51% |
| 6                       | Development zone               | 3.2   | 116                    | 2.72% | 0.9  | 58                     | 1.54% |
| 7                       | Nongkesuo site                 | 2.8   | 148                    | 1.92% | 0.8  | 62                     | 1.33% |
| 8                       | Changing Party School          | 1.0   | 122                    | 0.79% | 0.4  | 64                     | 0.55% |
| 9                       | School of Economics            | 2.2   | 114                    | 1.90% | 0.8  | 60                     | 1.25% |
| 10                      | High and New School            | 2.6   | 134                    | 1.93% | 0.8  | 60                     | 1.39% |
| 11                      | Construction College           | 3.9   | 127                    | 3.06% | 1.0  | 57                     | 1.77% |
| 12                      | Jinan Baosheng site            | 2.2   | 202                    | 1.11% | 0.6  | 79                     | 0.74% |
| 13                      | Quancheng Square               | 4.8   | 131                    | 3.65% | 1.3  | 63                     | 2.04% |
| 14                      | Lanxiang Vocational School     | 1.2   | 151                    | 0.80% | 0.4  | 77                     | 0.53% |
| 15                      | Shandong Luneng site           | 1.7   | 122                    | 1.43% | 0.7  | 56                     | 1.20% |
| Average of the 15 sites |                                | 2.6   | 134.8                  | 2.01% | 0.8  | 64.5                   | 1.26% |

**Table 7.** Concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> under scenario 5 and their ratios to monitoring data

| No.                     | Name                           | PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) |                        |        | PM <sub>2.5</sub> concentration (µg/m <sup>3</sup> ) |                        |       |
|-------------------------|--------------------------------|---|------------------------|--------|--|------------------------|-------|
|                         |                                | Simulated mean value                                | Monitored annual value | Ratio  | Simulated mean value                                 | Monitored annual value | Ratio |
| 1                       | Jinan chemical plant           | 11.9  | 124                    | 9.56%  | 3.3  | 59                     | 5.55% |
| 2                       | Air quality monitoring station | 10.6  | 132                    | 8.00%  | 3.0  | 70                     | 4.32% |
| 3                       | Seed warehouse                 | 13.2  | 133                    | 9.96%  | 3.6  | 68                     | 5.36% |
| 4                       | Second machine tool plant      | 10.0  | 145                    | 6.91%  | 2.8  | 76                     | 3.69% |
| 5                       | Kegansuo site                  | 10.3  | 121                    | 8.51%  | 2.9  | 59                     | 4.86% |
| 6                       | Development zone               | 16.8  | 116                    | 14.45% | 4.4  | 58                     | 7.55% |
| 7                       | Nongkesuo site                 | 10.7  | 148                    | 7.22%  | 2.9  | 62                     | 4.73% |
| 8                       | Changing Party School          | 4.1   | 122                    | 3.38%  | 1.2  | 64                     | 1.87% |
| 9                       | School of Economics            | 9.8   | 114                    | 8.62%  | 2.8  | 60                     | 4.66% |
| 10                      | High and New School            | 6.8   | 134                    | 5.10%  | 2.0  | 60                     | 3.38% |
| 11                      | Construction College           | 12.5  | 127                    | 9.84%  | 3.3  | 57                     | 5.78% |
| 12                      | Jinan Baosheng site            | 13.8  | 202                    | 6.83%  | 3.6  | 79                     | 4.55% |
| 13                      | Quancheng Square               | 12.0  | 131                    | 9.15%  | 3.3  | 63                     | 5.28% |
| 14                      | Lanxiang Vocational School     | 11.1  | 151                    | 7.36%  | 3.0  | 77                     | 3.94% |
| 15                      | Shandong Luneng site           | 8.4   | 122                    | 6.88%  | 2.4  | 56                     | 4.28% |
| Average of the 15 sites |                                | 10.8  | 134.8                  | 8.12%  | 3.0  | 64.5                   | 4.65% |

#### 4.5. Scenario 5 analysis

Table 7 lists the PM<sub>10</sub> and PM<sub>2.5</sub> concentrations at each sensitive point under this scenario and their contributions to the environmental concentrations at the monitoring

points. Figures 12 and 13 show the average concentration distributions of PM<sub>10</sub> and PM<sub>2.5</sub>, respectively, under this scenario.

When all construction sites were shut down within a 2-km radius of the monitoring point, dust emission had the greatest impact on the average  $PM_{10}$  concentration at stations within the development zone, reaching  $16.7 \mu\text{g}/\text{m}^3$ . Its impact on the average  $PM_{10}$  concentration across all 15 monitoring stations was  $10.8 \mu\text{g}/\text{m}^3$ , accounting for 8.12% of the average monitoring value. Dust emission had the greatest impact on the average  $PM_{2.5}$  concentration at stations within the development zone, reaching  $4.3 \mu\text{g}/\text{m}^3$ . Its impact on the average  $PM_{2.5}$  concentration of the 15 monitoring stations was  $3.0 \mu\text{g}/\text{m}^3$ , accounting for 4.65% of the average monitoring value. Compared with the baseline scenario, the average concentrations of  $PM_{10}$  and  $PM_{2.5}$  across the 15 stations under this scenario decreased by 45.5% and 42.3%, respectively. Spatially, the diffusion trajectories of  $PM_{10}$  and  $PM_{2.5}$  were concentrated in Lixia, Huaiyin, the northern part of Shizhong District, the southern part of Tianqiao, and the western part of Licheng. The results of this study demonstrated that shutting down construction sites within 2 km of the sensitive points during the hot season significantly reduced particulate matter concentrations at individual monitoring stations, although short-term concentration peaks occurred. Compared with the baseline scenario, the average  $PM_{10}$  and  $PM_{2.5}$  concentrations at the 15 stations were reduced by 45.5% and 42.3%, respectively.

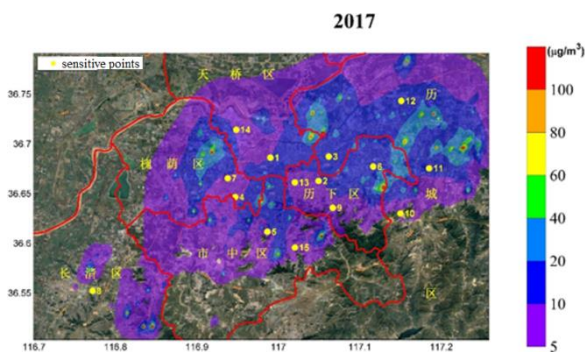


Figure 12. Average concentration of  $PM_{10}$  under scenario 5.

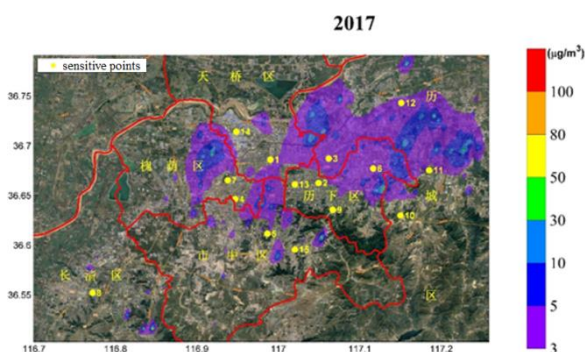


Figure 13. Average concentration of  $PM_{2.5}$  under scenario 5.

## 5. Conclusions and recommendations

Dust emission from construction sites has a significant impact on air quality in Jinan. The impacts of dust emission on the average concentrations of  $PM_{10}$  and  $PM_{2.5}$  were  $19.8$  and  $5.2 \mu\text{g}/\text{m}^3$ , respectively. Dust emission had

the greatest impact on the stations of Quancheng Square, Kegansuo and within the development zone. Under adverse weather conditions, high-level alert measures are required to reduce the impact of construction site emissions on environmental quality. Considering the economic and social effects of emission reduction, when temporary control measures are required, shutting down construction sites within a 2-km radius of monitoring stations is a feasible plan that aligns with the requirements of integrated environmental management.

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