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Original Research Paper

Factor Analysis of Mass Concentration Characterization of PM2.5 and its Impact Factors in a Suburban Roadside: Taking a National Road of Zhengzhou, China as an Example

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ABSTRACT

During the winter season from November 4, 2014 to November 16, 2014, one-hour average fine samples (PM2.5) of airborne particulate matter were collected at a busy roadside of the No. 107 national road located in a suburb of Zhengzhou City, China. For a convenient comparative analysis, two sets of data were tested in two different locations (No. 1 and No. 2) at a distance of 200m beside the road. Following previous research results, we considered traffic flow, ambient air temperature, relative humidity, wind speed, wind direction, atmospheric pressure and haze condition as factors to analyse their potential influence on the mass concentration of PM2.5. Same day data from the China National Environmental Monitoring Centre were also compared with the data of the study. Results showed that the average ambient PM2.5 concentrations were significantly higher at the tested suburban roadside than in the city region. However, the *t*-test result disclosed that the two sets of data had no significant difference (p = 0.001). The difference between the roadside data and the background concentration could be attributed to certain factors that were only sampled at the suburban roadside. Pearson correlation analysis was performed to identify the source contribution of the ambient PM2.5 concentration at the study locations. The correlation values indicated that the major factors with relatively significant influence on the PM2.5 data during the events under study were temperature (0.310 at the No. 1 site and 0.268 at the No. 2 site), relative humidity (0.532 at the No. 1 site and 0.303 at the No. 2 site), traffic flow (0.393 at the No. 1 site and 0.379 at the No. 2 site), wind speed (“0.264 at the No. 1 site and “0.187 at the No. 2 site), and wind direction (0.262 at the No. 2 site). Among all the impact parameters considered in the study, traffic flow contributed most to the PM2.5 mass concentration (correlation values were 0.393 and 0.379 for the No. 1 and No. 2 sites, respectively). Relative humidity (correlation value = 0.532 for the No. 1 site and correlation value = 0.303 for the No. 2 site) and wind speed contributed to the reduction of the PM2.5 mass concentration.

INTRODUCTION

Anthropogenic aerosol, especially PM2.5, in areas with high economic growth is gradually becoming a major environmental pollution problem. High mass concentrations of PM2.5 can adversely affect human health (Sun & Cui 2013, Li et al. 2013, Tang et al. 2015). Many previous studies have verified that vehicle engine exhausts are important contributors to PM2.5 pollution (Khan et al. 2010, Ofelia et al. 2014), especially in China (Bao et al. 2010, Zhao et al. 2013, An et al. 2014, Feng et al. 2012, Huang et al. 2014). Some studies have confirmed the association between roadside PM2.5 pollution levels and traffic (Nguyen et al. 2014, Song et al. 2012, Zhao et al. 2014). Meteorological parameters (Fang et al. 2007), such as wind speed and wind direction (Peter et al. 2002, Yin 2014), have also been found to be important factors for fine particle concentrations in urban roadsides. However, few studies have been conducted on the effect of traffic and meteorological parameters at suburban roadsides on PM2.5 mass concentrations.

The present study collected and analysed PM2.5 samples from two different suburban roadside locations in Zhengzhou City, China, that could represent the typical national road traffic condition outside the city. We then investigated the relationship between traffic conditions and some environmental observations, as well as the corresponding impact of such relationship on suburban roadside PM2.5 pollution.

SAMPLING AND METHODS

Sampling: PM2.5 aerosol samples and some meteorologi-

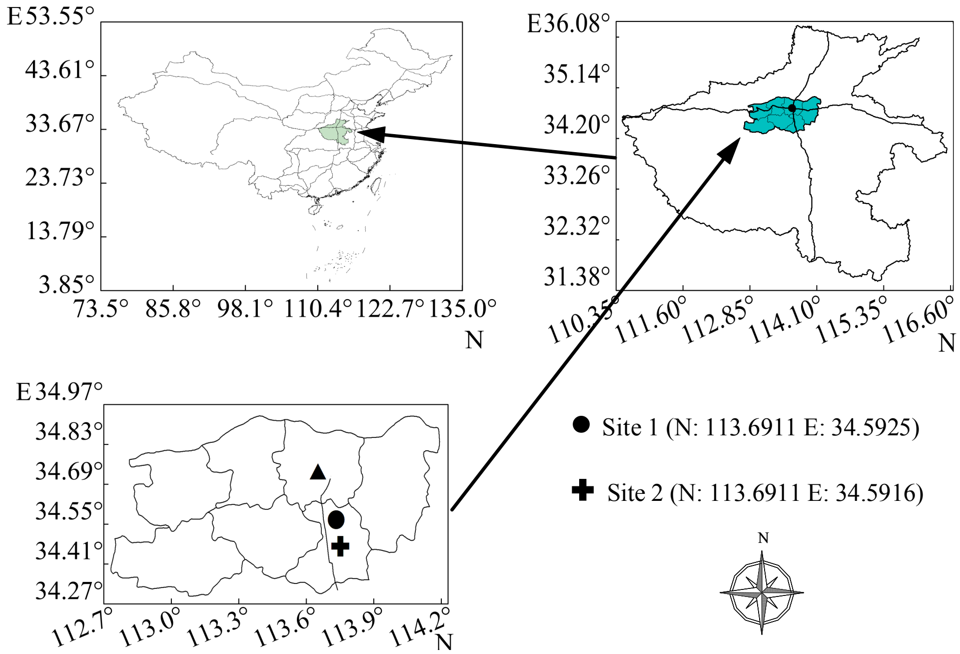

Fig. 1: Monitoring sites at No. 107 national road in Zhengzhou City, China.

cal parameters were tested in November 2014. The sampling locations were set up to represent the typical suburban road traffic condition. The road is a straight six-lane road with a speed limit of 60 km/h. The road passing the site is flat with no elevations; vehicles traversing this road run on a steady workload with constant speed. As shown in Fig. 1, the monitoring sites were located close to the No. 107 national road, which is approximately 16 km away from the urban region of Zhengzhou city. The sampling was performed at two points (No. 1 and No. 2) on the east sides of one road. The sampling locations were close to the road (within 2.5 m from the curb) and had a distance of 500 m (No. 1 site was located north of the No. 2 site). Average traffic flow, simultaneous meteorological data, and vehicle flows were recorded.

Samples of PM2.5 mass concentrations were collected by DUSTTRAK TSI (Model 8520, TSI Company, U.S.). We also measured the meteorological parameters using TSI Model 7525 (TSI Company, U.S.), TSI Model 9535 (TSI Company, U.S.) and other instruments.

The sampling events were conducted during the morning rush hour (8:30-11:30 a.m.) and during the afternoon rush hour (2:00-4:00 p.m.) from November 4, 2014 to November 16, 2014.

Traffic flow, ambient air temperature, relative humidity, wind speed, wind direction, atmospheric pressure and haze condition was also tested as factors to analyse their potential influence on the mass concentration of PM2.5. Fig. 2 shows the wind rose for Zhengzhou city, which was considered because wind speed and wind direction might serve important functions in the investigation.

Method: The data of this study and the same-day data from the China National Environmental Monitoring Centre (CNEMC) were compared through a *t*-test. Pearson correlation analysis was performed to identify the source contribution of the ambient PM2.5 concentration in the tested area.

RESULTS AND ANALYSIS

PM2.5 mass concentration sampling: The PM2.5 mass con-

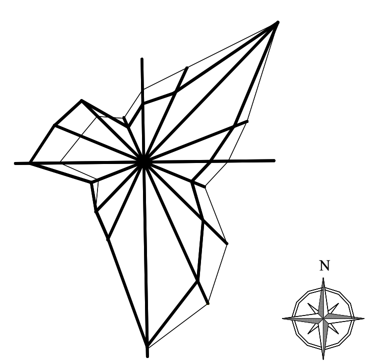

Fig. 2: Schematic map of wind rose of Zhengzhou City.

Table 1: PM2.5 mass concentration (mg/m^3) collected in November 2014 at the No. 107 national road in a southern suburb in Zhengzhou.

	November 4, 2014	November 5, 2014	November 10, 2014	November 11, 2014	November 13, 2014	November 14, 2014	November 16, 2014
No. 1 site	0.291±0.125 (N* = 118)	0.449±0.136 (N* = 90)	0.234±0.068 (N* = 60)	0.322±0.147 (N* = 150)	0.080±0.034 (N* = 120)	0.264±0.020 (N* = 60)	0.359±0.144 (N* = 131)
No. 2 site	0.207±0.080 (N* = 120)	0.357±0.083 (N* = 90)	0.210±0.099 (N* = 60)	0.364±0.118 (N* = 150)	0.142±0.077 (N* = 120)	0.259±0.019 (N* = 60)	0.403±0.252 (N* = 136)

* Samples

Table 2: Meteorological parameters of test days.

	November 4, 2014	November 5, 2014	November 10, 2014	November 11, 2014	November 13, 2014	November 14, 2014	November 16, 2014
Sun condition	Sunny	Sunny	Cloudy	Cloudy	Sunny	Sunny	Sunny
Haze condition	Haze	Haze	Haze	Haze	Haze	No haze	Haze
Atmospheric pressure (kPa)	100.2	100.2	100.5	100.3	101	100.7	101
Temperature (°C)	16.4±3.6	18.8±3.7	16.1±0.5	18.2±1.9	15.0±4.1	18.7±0.9	15.0±2.8
Relative humidity (RH%)	38.9±8.6	46.7±15.1	53.5±1.7	41.2±10.1	18.2±5.5	23.8±1.6	44.2±16.6
Wind speed (m/s)	0.7±0.3	0.4±0.4	1.0±0.1	1.0±0.3	0.6±0.3	0.3±0.1	0.5±0.3
Wind direction	North	North	North	North to northeast	Northeast	East	Northeast
Traffic flow (vehicles/min)	29±7	30±9	29±5	28±4	27±3	27±3	26±5

Table 3: Data from China national environmental monitoring centre (CNEMC)**

	November 4, 2014	November 5, 2014	November 10, 2014	November 11, 2014	November 13, 2014	November 14, 2014	November 16, 2014
24 h average mass concentration of PM2.5 (mg/m^3)	0.068	0.115	0.122	0.103	0.037	0.104	0.117

**Data from http://www.cnemc.cn

Table 4: The *t*-test results of the CNEMC data and the data of all the tested locations.

No. 1 site		No. 2 site	
t-value	Significane	*t*-value	Significane
4.241	0.001	4.683	0.001

centration sampling yielded 1465 samples of 2 min PM2.5 and samples of 50 h PM2.5. The results are given in Table 1. The mean mass concentrations of PM2.5 at the No. 1 site ranged from 0.080 mg/m^3 (SD = 0.034) to 0.449 mg/m^3 (SD = 0.136). By contrast, the mean mass concentrations of PM2.5 at the No. 2 site ranged from 0.142 mg/m^3 (SD = 0.077) to 0.403 mg/m^3 (SD = 0.252). As shown in Figs. 3 and 4, all the sampling days for all the testing sites revealed similar variation trends with significant decreases in the afternoon, except in November 16 for the No. 2 site. Most of the PM2.5 mass concentration data exceeded the limit of the national standard of China (0.075 mg/m^3) (MEPPRC 2012). We deduced that poor vehicle emission controls, poor vehicle maintenance, and high moving traffic condition with swirling dust were the major causes of the high mass concentration levels at the study location. Considering that the No. 107 national road was still under construction during the study period, re-suspended road dust from the traffic and construction activities became a major source of pollution aerosols (Han et al. 2007).

Meteorological parameter sampling: The results of the meteorological parameter sampling are illustrated in Table 2. Sun condition results showed that most sampling days had sun, except for two days, which were cloudy. Unfortunately, only one sampling day had no haze. Atmospheric pressure and traffic flow varied in tiny fluctuations during the sampling days. However, temperature, relative humidity, wind speed and wind direction varied greatly. Temperature samplings ranged from 15.0°C (SD = 2.8) to 18.8°C (SD = 3.7). The variation ranges of relative humidity and wind speed were 188% (from 18.2% to 53.3%) and 233% (from 0.3 m/s to 1.0 m/s), respectively. As an important factor in the mass concentration of roadside PM2.5, the wind directions during the sampling days were north or northeast and were consistent with the high-frequency wind directions in the wind rose of Zhengzhou (Fig. 2).

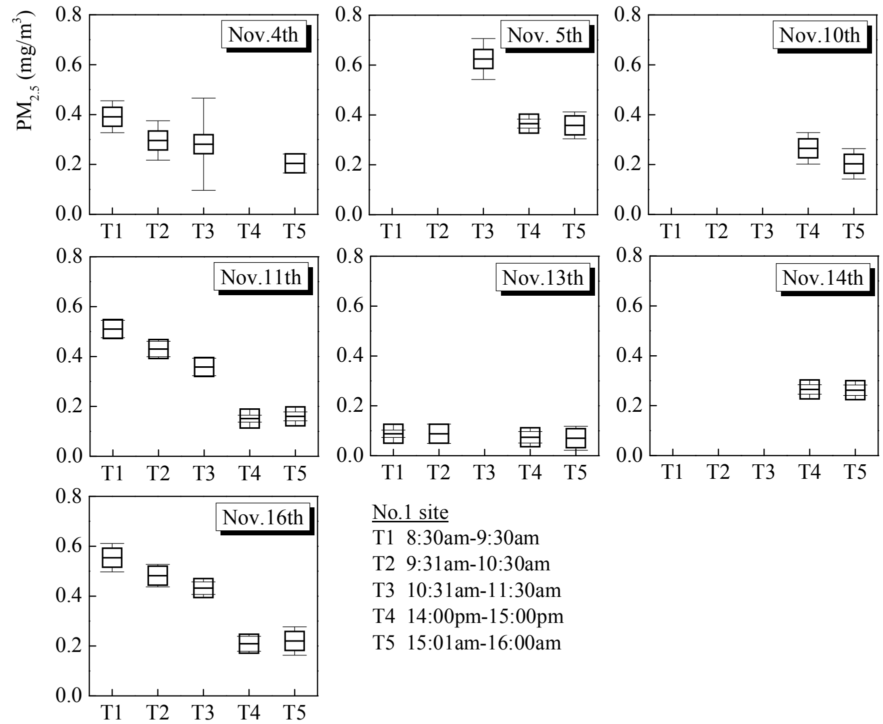

Fig. 3: Sampling results of the No. 1 site.

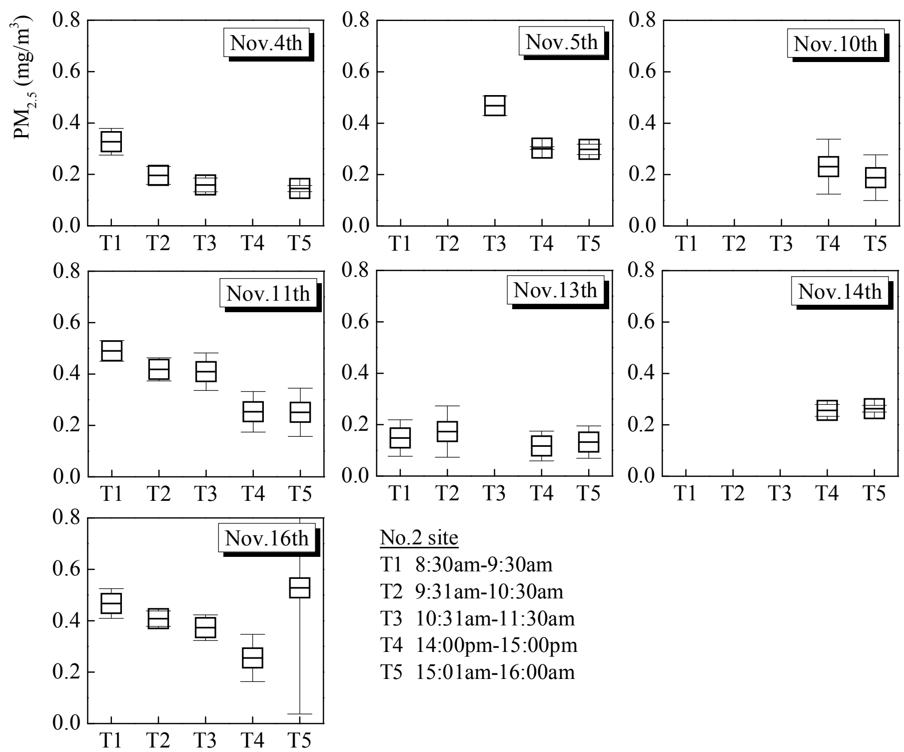

Fig. 4: Sampling results of the No. 2 site.

Table 5: Pearson results for $PM_{2.5}$ data and traffic flow and meteorological parameters.

	Pearson correlation (Significance)						
	Temperature	Relative humidity	Traffic flow	Wind speed	Wind direction	Atmospheric pressure	Haze condition
No. 1 site	0.310 (0.242)	0.532 (0.219)	0.393 (0.384)	-0.264 (0.568)	0.097 (0.836)	-0.364 (0.187)	0.141 (0.762)
No. 2 site	0.268 (0.560)	0.303 (0.508)	0.379 (0.210)	-0.187 (0.688)	0.262 (0.570)	-0.007 (0.869)	0.151 (0.746)

Table 6: Correlation of PM_{10} data and meteorological parameters from previous studies.

	Correlation value (Level of significance)						
	Temperature	Relative humidity	Traffic flow	Wind speed	Wind direction	Atmospheric pressure	Haze condition
Li et al. (2010) (PM10)	0.308 (-)	0.095 (-)	0.381 (0.05)	-0.185 (-)		-0.378 (0.05)	
	-0.102 (-)	-0.348 (-)	0.358 (0.05)	-0.392 (0.05)		0.425 (0.05)	
Xi (2004) (PM10)		-0.33 (<0.01)		-0.58 (<0.01)		0.51 (<0.01)	

(-) Indicates that the significance level was not mentioned by the authors.

PM2.5 data from CNEMC: The PM2.5 data from the CNEMC are listed in Table 3. As shown in the table, the 24h average mass concentration of PM2.5 ranged from 0.037 mg/m^3 to 0.117 mg/m^3. The *t*-test was employed to identify the difference between the PM2.5 mass concentration at the No. 107 national roadside and that from the CNEMC data. The *t*-test results in Table 4 demonstrate that the CNEMC data and the sampling data for all the tested locations in the study had no significant difference ($p = 0.001$). We could further reveal that the difference between the roadside data and the background concentration might be attributed to certain factors, such as meteorological parameters at the suburban roadside.

Pearson correlation analysis of PM2.5 data and traffic flow and meteorological parameters: Considering the influence of the background concentration of PM2.5, data from this study were subtracted from the background concentration in the CNEMC data and then used in the following Pearson correlation analysis. Table 5 shows the results of the Pearson correlation analysis of PM2.5 and some meteorological parameters. The relative humidity at all the sampling sites had the most significant correlation (0.532 for the No. 1 site and 0.303 for the No. 2 site) with the PM2.5 mass concentration in this study. However, the wind speed at all the sampling sites had a negative correlation value (0.264 for the No. 1 site and 0.187 for the No. 2 site) with low significance. The traffic flow at all the sampling sites had the highest correlation value (0.393 for the No. 1 site and 0.379 for the No. 2 site) with a relatively high significance in the corresponding set. We found that traffic condition was the dominant impact factor for the mass concentration of PM2.5. Nevertheless, wind speed may serve a significant function in reducing the mass concentration of PM2.5 at the suburban roadside in Zhengzhou. Local topography may also be important because of its influence on the wind; it showed a potential impact on the PM2.5 mass concentration results because of certain limitations in the sampling strategy (Brandon et al. 2007).

Table 6 shows that some studies have investigated the correlation of PM10 and meteorological parameters and arrived at the same conclusions as this study, particularly with regard to the correlation between PM, meteorological parameters, and traffic flow. Li (2010) disclosed that wind speed has a negative effect and that traffic flow has a positive effect on PM concentration. Moreover, Xi (2004) and Zhao et al. (2014) proposed that wind speed can contribute to the decrease of PM concentrations.

CONCLUSIONS

This study employed a *t*-test to analyse the correlation between the sampled PM2.5 mass concentration at a suburban national road and the background concentration in Zhengzhou. The data for all the tested locations and the CNEMC data showed no significant difference ($p = 0.001$).

Pearson correlation analysis was also employed to analyse the correlation between the PM2.5 sampling data and meteorological parameters. Among all the meteorological parameters, the vehicles passing the sampling site contributed most to the PM2.5 mass concentration (correlation value = 0.393 at the No. 1 site). However, some correlation was found between the mass concentrations of PM2.5 and the meteorological parameters, namely, temperature, traffic flow, relative humidity, wind speed and wind direction. The relative humidity in the winter season of central China (correlation value = 0.532 for the

No. 1 site and correlation value = 0.303 for the No. 2 site) and the wind speed with special sampling topography contributed to the reduction of PM2.5 mass concentration. The results offer a scientific basis for controlling and governing air atmospheric pollution.

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