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Original Research Paper

Effect of Roadside Forest Belts on Particles Including TSP, PM10, PM2.5, and PM1 under Different Seasons in Beijing, China

Shengzhuo Hua*, Xin Cai, Fengbin Sun*(***) and Xinxiao Yu*†**
*School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
**Beijing Water Conservation Ecological Engineering Consulting Co.,Ltd., Beijing, 100055, China
***Zachry Department of Civil Engineering, Texas A&M University, Texas, 77843, USA
†Corresponding author: Xinxiao Yu

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ABSTRACT

Analysing the rules of forests for PM2.5 is important given the serious damage caused by air pollution today. Differently sized particle concentrations were measured in the Poplar shelterbelt. The poplar shelterbelt along the Fifth Ring Road near the South Park of the Beijing Olympic Forest Park was selected as a research object, and six monitoring sites were set from the roadside through to the woodland centre. The particle concentrations were monitored from April to December 2013. A handheld DustMate dust monitor (Turnkey Instruments, UK) was used to measure the concentrations. The differently sized particle concentrations were compared inside and outside the forest. The order of the average concentrations of total suspended particulate (TSP) and PM10 were as follows: outside the forest > within the forest > outside the forest. The average concentrations of PM2.5 and PM1 were as follows: outside the forest > outside the forest > within the forest. The concentrations of TSP and PM10 decreased, then increased, and finally declined all the way from the edge on the side of the road to the edge on the side of the park. The trough of the concentration curve was detected near the monitoring site 3F, and the concentrations of TSP and PM10 declined outside the forest on the park side. The concentrations of PM2.5 and PM1 decreased, then increased, and then further decreased. The trough was first recorded around the monitoring site 18F, and the concentration increased outside the forest on the park side.

INTRODUCTION

Air particulate pollution caused by nature or human activities is a serious atmospheric problem, and it is associated to health hazards for animals, plants, and people (Almeida et al. 2006). Atmospheric particles based on particle sizes can be further divided to subpopulations, including total suspended particulate (TSP) with an aerodynamical diameter < 100 μm, particle matter with an aerodynamical diameter < 10 μm (PM10), particle matter with an aerodynamical diameter < 2.5 μm (PM2.5), and particle matter with an aerodynamical diameter < 1.0 μm (PM1) (Bennett et al. 2012). The particulate matter that is deposited on the leaves may cause mechanical burn and reduce the photosynthetic intensity, which damages the plants (Cao et al. 2012).

Studies have indicated that forests significantly affect the absorption of air pollutants and improve air quality (Escobedo et al. 2009). Particulate matter can be effectively trapped by the rough surfaces of plants. Therefore, plants can be considered as city dust filters. Atmospheric particulate matter is retained and absorbed by trees in urban areas (Gehrig et al. 2003). The matter retained on the plant surface that later washed into the soil and became fixed, which reduces the concentrations of PM2.5 and other particles in the air (Mcdonald et al. 2007, Nanos et al. 2007). Therefore, increasing urban forest cover can control atmospheric particulate matter and reduce its damaging effects.

Urban green belts can influence particle concentrations in the atmosphere (Nowak 1994). Data on the particle concentrations around forest belts along major roads were analysed for subsequent research on forest construction for particle absorption. Planting trees in and around the city is useful.

MATERIALS AND METHODS

Setting of sample area: The *Populus tomentosa* (poplar) forest belt along the Fifth Ring Road near the Olympic Forest Park in the Haidian District in Beijing, China was selected as the sample area (Fig. 1). The *P. tomentosa* forest belt was 60-m wide. More details are found in Table 1. Six monitoring sites were established to monitor the particle concentrations as follows. No. 1 is at the roadside (ROS). No. 2 is located approximately 3 m from the road (3F). No. 3 is located approximately 18 m from the road (18F). No. 4 is

Fig. 1: Experimental sites for the research in Beijing.

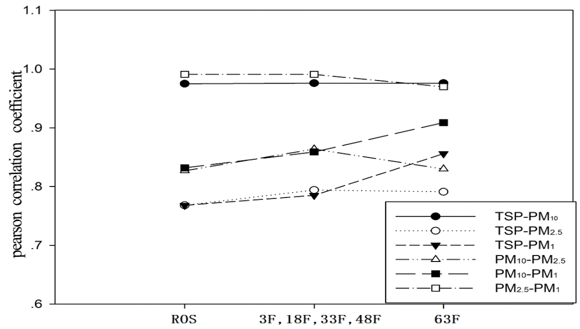

Fig. 2: Pearson correlation of different sizes of particles in and out of the forest belt.

Table 1: Parameters of forest structural characteristics.

Vegetation type	Wide (m)	LAI	High (m)	DBH (cm)
Populus tomentosa	60	3.26	12.40	16.36

Note:Diameter at breast height for tree (DBH)

located approximately 33 m from the road (33F). No. 5 is located approximately 48 m from the road (48F). No. 6 is located approximately 63 m from the road (63F). The meteorograph was set at monitoring site Nos. 2, 4, and 6. The experimental period was from January 1 to December 31, 2013.

Instrument and data acquisition: A handheld DustMate dust monitor (Turnkey Instruments, UK) was used to measure the concentrations. The instrument was fixed on a tripod during monitoring with its air inlet 1.5 m above the ground. A Kestrel 4500 handheld portable weather station (Kestrel Weather, Mt. Eliza, Victoria, Australia) was fixed 1.4 m above the ground. Both instruments were set to automatically record data every 5 min.

Data processing: Descriptions of the particle concentration change within the forests with the average concentration may be affected by certain particles with high concentrations given that differently sized particles may vary in concentrations on different days. Therefore, the particle concentration should be standardized, and the standardized concentrations should be used to describe the pattern of concentration variation within the shelterbelt.

The standardization formula for particle concentrations at monitoring sites is expressed as Formula (1).

$$\chi^* = \frac{\chi - \chi_{min}}{\chi_{max} - \chi_{min}} \quad ...(1)$$

where,

χ^* = the standardized average concentration of certain particle,

χ = the measured concentration within a certain period of time at the monitoring site,

χ_{min} = the minimum concentration of a certain particle within a given monitoring period,

χ_{max} = the maximum concentration of a certain particle within a given monitoring period.

RESULT ANALYSIS AND DISCUSSION

Meteorological factors and effects: Table 2 shows the different meteorological parameters at the monitoring sites. The wind speed at the studied sites was relatively low. Different sites within the forest usually showed inconsistent wind directions, and there was no wind most of the time. For different monitoring sites, average wind speed, temperature, and atmospheric pressure indicated the following trend: monitoring site 33F < monitoring site 3F < monitoring site 63F. Forest belts can form microclimates, within which wind speed, temperature, and atmospheric pressure are lower, and relative humidity is higher than the surrounding area (Nowak et al. 2000). Moisture enhances particle absorption with high humidity, making it difficult for the particles present in moist air and suspended in low altitude to spread, which causes high particulate matter concentrations (Odum 1983). Affected by the microclimate within the park, the overall humidity in the park was high, and the moisture does not easily dissipate. The humidity within the park was higher than the monitoring site located nearer to the North Fifth Ring Road, which causes the humidity detected at 63 F to be higher than that at 3F.

Particle concentration changes inside and outside the forest: The concentration data of four types of particles from January to December 2013 inside and outside of the forest are presented in Table 3. The average data of particle con-

Table 2: Meteorological factor statistics at different monitoring points (μg/m³).

Site	Meteorological factor	Mean	Standard value	Min value	Max value
3F	Wind direction (°)	244.80	79.00	0.00	359.0
	Wind speed (m/s)	0.31	0.40	0.00	3.20
	Temperature (°C)	25.50	3.00	1.90	39.60
	Relative humidity (%)	60.60	17.00	18.50	91.8
	Barometric pressure (KPa)	100.10	0.40	99.00	102.00
33F	Wind direction (°)	199.50	121.00	0.00	359.00
	Wind speed (m/s)	0.26	0.40	0.00	3.200
	Temperature (°C)	25.20	2.80	1.70	35.10
	Relative humidity (%)	61.70	18.30	17.10	91.70
	Barometric pressure (KPa)	100.10	0.40	99.00	102.20
63F	Wind direction (°)	149.70	65.60	0.00	359.00
	Wind speed (m/s)	0.30	0.40	0.00	3.00
	Temperature (°C)	26.00	3.60	1.80	44.30
	Relative humidity (%)	60.70	18.80	16.80	92.90
	Barometric pressure (KPa)	100.10	0.40	99.00	102.00

Table 3: Particle concentration inside and outside the forest belts (μg/m³).

Particle type	Site	Mean	Minimum value	Maximum value
TSP	ROS	318.10	25.80	3164.10
	3F, 18F, 33F, 48F	304.00	15.90	3517.20
	63F	276.44	25.30	3639.40
PM10	ROS	204.19	13.00	2084.50
	3F, 18F, 33F, 48F	203.50	9.90	3018.60
	63F	191.56	12.40	3606.30
PM2.5	ROS	83.56	2.92	453.46
	3F, 18F, 33F, 48F	91.49	2.85	550.12
	63F	92.09	3.08	635.29
PM1.0	ROS	26.58	0.63	186.20
	3F, 18F, 33F, 48F	28.76	0.64	194.15
	63F	29.91	0.63	285.16

centrations from monitoring sites 3F to 48F inside the forest were compared with the data from monitoring sites ROS and 63F outside the forest. The concentration of coarse particulate matter (TSP and PM10) declined gradually when passing through the forest, and the observed concentrations showed the following pattern: outside the forest by the road > inside the forest > outside the forest in the park. The concentrations of fine particulate matter (PM2.5 and PM1) changed as follows: outside the forest by the road > outside the forest in the park > inside the forest. The standard deviation for the four tested particle sizes all showed the following pattern: outside the forest in the park > inside the forest > outside the forest by the road. This suggests that the particulate matter concentrations were most variable outside the forest areas during the monitoring period.

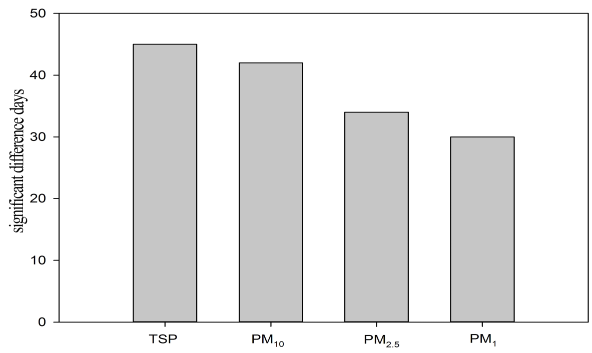

Fig. 3: Days with significant difference of particle concentration in and out the forest belt.

Correlation analysis of particle concentrations with different particle sizes: Pearson correlation analysis was used to evaluate the concentration of differently sized particles inside and outside the forest belt (Fig. 2). Significant positive correlations were detected among all particle sizes with correlation coefficients of over 0.75. The correlation coefficient between PM2.5 and PM1 was the most significant, followed by the coefficient between TSP and PM10. The smallest coefficient was between TSP and PM2.5, followed by the coefficient between TSP and PM1, the second smallest among all measured coefficients. Across all monitored

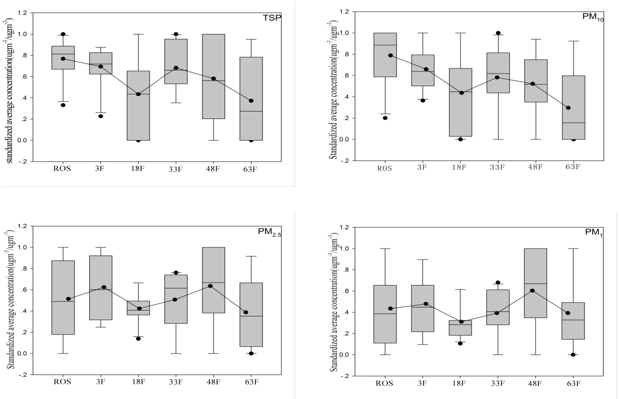

Fig. 4: Particle standard average concentration in spring.

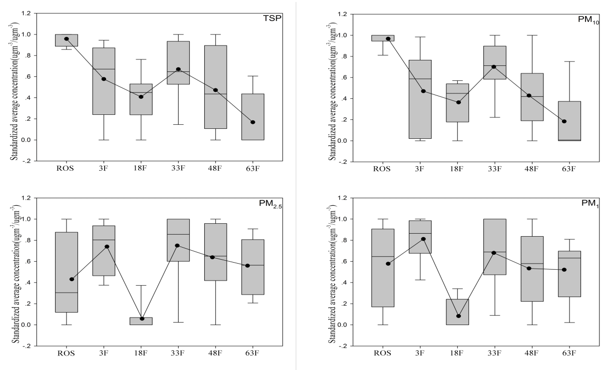

Fig. 6: Particle standard average concentration in autumn.

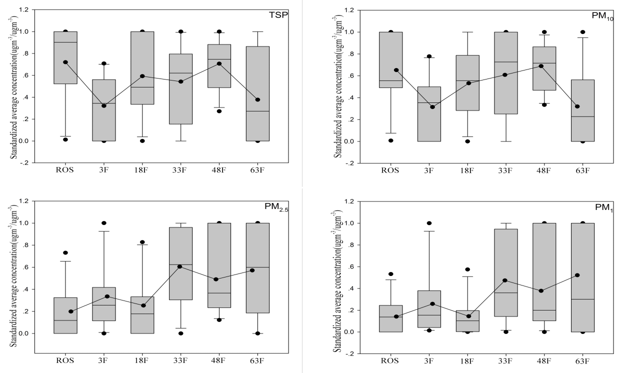

Fig. 5 Particle standard average concentration in summer.

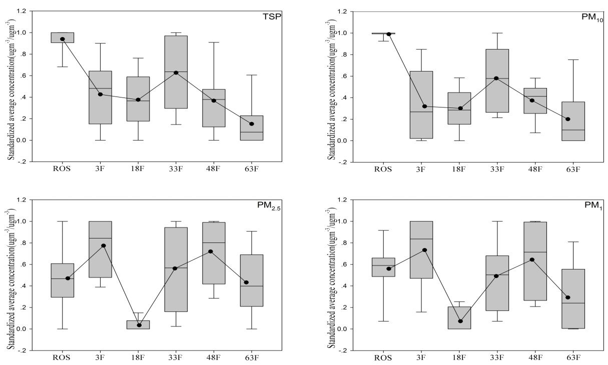

Fig. 7: Particle standard average concentration in winter.

locations, the correlation coefficients between TSP and PM1 and PM10 and PM2.5 indicated the following pattern: outside the forest in the park > inside the forest > outside the forest by the road. Minimal differences were observed for the correlation coefficient between TSP and PM10. The correlation coefficient between PM2.5 and PM1 showed the following pattern: outside the forest by the road = inside the forest > outside the forest in the park.

Remarkable correlation has been observed between the concentrations of PM10 and PM2.5 within an urban area in Beijing with a coefficient of 0.9155 (Pan et al. 2004). As a result of the impact of the forest belt and traffic pollution, the correlation coefficient between PM10 and PM2.5 observed in our study was only 0.827-0.864, which is lower than 0.9155. Qi Feiyan showed a higher linear correlation of particle concentration in forests than in areas with no forest, which was inconsistent with our results (Song et al. 2012). This difference may be explained by varied forest widths and structural parameters. Wide forest belts provide better absorption for particles, which affects the correlation between particles of different sizes.

Analysis of differences in particle concentration in and out of the forest: The analysis of differences in particle concentration is presented in Fig. 3. The variation in particle concentration in different monitoring sites was significant at a confidence level of 95%. A significant difference of TSP change was detected at 45 days, from May to December, at six monitoring sites in and out of the forest belts. This result was more than all the other three particles (for PM10, PM2.5, and PM1, in which the days with significant difference were 42, 34, and 30, respectively). As particles diffuse from monitoring site Nos. 1 to 6, the effect of forest belt on the particle concentration varied with the size of particles, which varied particle concentrations across the monitoring sites.

The different effect of forest belts on differently sized particles may be explained by the varied degrees of meteorological parameters surrounding the forest belts, such that, the retention capabilities of plants vary with particle size (Song et al. 2012). The number of large particles decreases with the increased distance from the road owing to particle retention by plants. The small particles are easily affected by the atmospheric diffusion processes and tend to spread along a long distance. During the transport from the edge of forest on the side of the Fifth Ring Road to the other side of the forest, which is on the side of the park, the particles with different sizes demonstrated distinct differences at various monitoring sites owing to the change of meteorological parameters and the retention by plants.

Concentration changes of particles inside the forest in different seasons

Particle concentration changes in spring**:** The particle concentrations of the four tested particles in spring are presented in Fig. 4. The standardized concentrations are provided, and the dotted line represents the average of standardized concentrations. Wave-like changes were observed for differently sized particles from the edge of the forest by the road to the edge of the forest in the park. The changing pattern of TSP was similar to PM10, and the trend of PM2.5 resembled that of PM1. The Pearson correlation test showed that the correlation coefficient between the standardized concentration of TSP and PM10 was 0.921 and that between PM2.5 and PM1 was 0.914, which indicated significant positive correlations. No significant correlation was detected between other combinations. The TSP and PM10 concentrations from the monitoring site ROS to 63F showed a decreasing tendency. This is followed by an increase before finally decreasing again. The pattern of variation in PM2.5 was similar to that of PM1. The variation showed an increase, a decrease, another increase, and finally a decrease. The results showed that the particle concentration did not steadily decrease when differently sized particles were transported through the forest belt. The concentration showed a wave-like fluctuation owing to the impact of meteorological parameters inside the forest and the influences of the trees themselves. All tested particles were measured with concentrations lower than the roadside of the Fifth Ring Road when passing the forest belt in spring.

Particle concentration changes in summer: The correlation coefficient of the standardized daily concentration between TSP and PM10 in summer was 0.912, and that between PM2.5 and PM1 was 0.936. Fig. 5 indicates that the standardized concentrations for TSP and PM10 were the lowest at monitoring site 3F, followed by 63F. The highest standardized concentrations were observed at monitoring site 48F. The lowest and highest standardized concentrations for PM2.5 and PM1 were observed at monitoring sites ROS and 63F, respectively.

The reduction of crude particle concentrations after passing the forest belt in summer was significantly lower than in spring, and an increasing trend was also observed with fine particle concentration. The meteorological data showed that the temperature was higher with increased humidity than in spring. The high temperature and humidity increased the particle concentrations within the forest, especially the fine particles. Related research reported that the PM2.5 concentration in *Platycladus orientalis* with relatively high canopy density under high temperature and high humidity was 2.53 times of the concentration under a continuously sunny weather. In the current study, days with high temperature and humidity occurred several times from June to August, which lead to significantly higher particle concentrations detected inside forest than those at the roadside (Pašková et al. 2012). Monitoring location 63F was located within the Olympic Forest Park. The road width within the park is limited, and the particle concentration was likely affected by the microclimate inside the park. This result may explain why the fine particle concentration measured at monitoring site 63F inside the park was significantly higher than those at other monitoring sites.

Particle concentration changes in autumn: The correlation coefficient of standardized daily particle concentration between TSP and PM10 in summer was 0.825 and 0.821 between PM2.5 and PM1. Fig. 6 shows that the minimum and maximum standardized concentrations of both TSP and PM10 were recorded at monitoring sites 63F and 33F, respectively. The lowest PM2.5 and PM1 concentrations were measured at monitoring site 18F, and the standardized concentration of PM2.5 at monitoring site 63F was higher than that at monitoring site ROS. The standardized concentration of PM1 at monitoring site 63F was lower than that at monitoring site ROS. On different monitoring days, the TSP and PM10 concentrations detected at monitoring site ROS were always higher than other monitoring sites. However, the PM2.5 and PM1 concentrations measured at monitoring site ROS were inconsistent with high variation; however, the concentration at monitoring site 18F remained at a relatively low level. Particle concentrations of TSP, PM10, and PM1 declined after passing through the forest; however, the PM2.5 concentration increased slightly (Pathak et al. 2009).

Particle concentration changes in winter: The particle concentration change from the edge of the forest by the road to the edge in the park in winter is presented in Fig.7. The Pearson correlation test showed that the coefficient of standardized daily concentration between TSP and PM10 in summer was 0.921 and that between PM2.5 and PM1 was 0.914; both are with significant positive correlation (Yao et al. 2002). The changing pattern of TSP concentration from monitoring site ROS to 63F resembled PM10 with an initial decrease. This is followed by an increase and then a decrease. The trough was detected around monitoring site 18F, and the peak around monitoring site 33F.

Monitoring site 63F had the minimum average standardized concentration of TSP. The variation in PM2.5 from monitoring site ROS to 63F was similar to PM1. Both increased first, then decreased, increased again, and finally decreased with the trough located around from monitoring site 18F and the peaks observed around monitoring sites 3F and 48F. The minimum average standardized concentration was reported from monitoring site 33F, with a minimal variation range.

CONCLUSIONS

This study selected six types of urban greenlands in the Beijing Olympic Park, which include grassland, shrub, conifer, broadleaf tree, mixed trees, and a control to study the relationship between urban greenland and PM. The field survey lasted from May to December 2013. TSP, PM10, PM2.5, PM1, and some meteorological factors were the main parameters monitored.

The PM concentrations significantly differed across the three seasons. The PM concentrations with the four particle sizes were lower in the summer than in other seasons. The concentrations for TSP and PM10 were significantly higher in September and November than in the other months. The difference between summer, autumn, and winter was insignificant. The concentrations for PM2.5 and PM1 in autumn were higher than in other seasons. The PM2.5 and PM1 concentrations were significantly lower during summer than in other seasons, especially in August and October.

The daily variation of particulate matter formed a "double-apex" curve. The PM concentrations were higher at dawn and dusk and lower at noon. In comparison with dusk, concentration was normally lower at dawn. PM usually has high levels because of the high air humidity.

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