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Particulate matter assessment of a wetland in Beijing

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ABSTRACT

To increase the knowledge on the particulate matter of a wetland in Beijing, an experimental study on the concentration and composition of PM₁₀ and PM_{2.5} was implemented in Beijing Olympic Forest Park from 2013 to 2014. This study analyzed the meteorological factors and deposition fluxes at different heights and in different periods in the wetlands. The results showed that the mean mass concentrations of PM₁₀ and PM_{2.5} were the highest at 06:00–09:00 and the lowest at 15:00–18:00. And the annual concentration of PM₁₀ and PM_{2.5} in the wetland followed the order of dry period (winter) > normal water period (spring and autumn) > wet period (summer), with the concentration in the dry period significantly higher than that in the normal water and wet periods. The chemical composition of PM_{2.5} in the wetlands included NH₄⁺, K⁺, Na⁺, Mg²⁺, SO₄²⁻, NO₃⁻, and Cl⁻, which respectively accounted for 12.7%, 1.0%, 0.8%, 0.7%, 46.6%, 33.2%, and 5.1% of the average annual composition. The concentration of PM₁₀ and PM_{2.5} in the wetlands had a significant positive correlation with relative humidity, a negative correlation with wind speed, and an insignificant negative correlation with temperature and radiation. The daily average dry deposition amount of PM₁₀ in the different periods followed the order of dry period > normal water period > wet period, and the daily average dry deposition amount of PM_{2.5} in the different periods was dry period > wet period > normal water period.

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Introduction

In recent years, because of the acceleration of urbanization, urban air quality has decreased, and the dust formed by solid particles is becoming the major urban air pollutant (Guo et al., 2010). PM₁₀ and PM_{2.5} refer to particulate matter classes whose aerodynamic equivalent diameters are less than 10 and 2.5 μm, respectively (Yang et al., 2000). In the last two years, particulate matter pollution in Beijing and other metropolitan cities has gotten worse, which has led to the persistence of fog and haze that severely impairs travel. Many studies (Yang et al., 2000; Zhu et al., 2013; Dockery et al., 1993; An et al., 2000) have found that

increasing concentrations of particulate matter in the atmosphere have a close relationship with the incidence of coughing and other respiratory symptoms, lung function reduction, and asthma. The number of premature deaths caused by particulate matter has been increasing every year, and research on reduction of particulate matter has become crucial. There are many reports on the influence of forests in regulating and intercepting PM₁₀ and PM_{2.5} (Matsuda et al., 2015; Wu et al., 2012; Becker et al., 2000; Nguyen et al., 2015). Many studies (Yang et al., 2005; Nowak et al., 2006; Escobedo and Nowak, 2009; Sharma and Roy, 1997) have found that forests have a significant effect in absorbing atmospheric pollutants and in improving air quality.

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The influence of wetlands, which are also referred to as the “kidneys of the earth,” in regulating and intercepting PM_{10} and $PM_{2.5}$ is becoming an important topic. Many studies (Liu et al., 2003; Hao et al., 2008; Sun et al., 2010; Loïc and Luc, 1998) have led to the conclusion that wetlands can reduce particulate matter to some extent, by increasing atmospheric relative humidity within a certain range, thus promoting particulate matter settling. By analyzing collected soil, sediment, and air samples, Liu et al. (2003) performed a preliminary study of polycyclic aromatic hydrocarbon (PAH) pollution and its sources in the Lalu wetland in suburban Lhasa and found that PAHs in the wetland soil mainly came from the atmosphere. Sun et al. (2010) analyzed the vertical and horizontal distribution of atmospheric aerosols in the Hengshui Lake wetland by an aerial survey and found that the aerosol concentration over Hengshui Lake was lower than that of the surrounding land; furthermore, the range of the concentration of particles became smaller in the horizontal direction with height and the arithmetic average diameter of aerosol particles over the land was greater than those over Hengshui Lake.

The Beijing Olympic Forest Park has an intact wetland environment that plays a vital role in conservation and ecologically beneficial environmental construction in Beijing (Li et al., 2014; He et al., 2010). Therefore, it is a suitable model for wetland regulation and interception of particulate matter. We selected the Beijing Olympic Forest Park wetland for this study and investigated the concentration variations, influencing factors, and amounts of dry deposition of PM_{10} and $PM_{2.5}$ in the wetland in different periods within a year. Information about the wetland's influence on regulating and intercepting PM_{10} and $PM_{2.5}$ was obtained. The results of this study may provide theoretical and technical support for construction and protection of urban wetland parks.

1. Materials and methods

1.1. Experimental size

The Beijing Olympic Forest Park is located in the North Olympic Park, Chaoyang District, Beijing. It covers an area of 680 ha and is the largest city park in Beijing. Its geographic coordinates are $40^{\circ}01'03.73''N$ and $116^{\circ}23'09.81''E$ (Fig. 1). The study area has a warm temperate semi-humid continental monsoon climate with an annual average temperature of $12.9^{\circ}C$ and an average annual rainfall of about 600 mm (Hu et

al., 2006). Rainfall is concentrated in summer, while in other seasons the air is dry.

The Beijing Olympic Forest Park has a rich variety of vegetation types. The tree configuration in the park is mainly mixed forest, including 530,000 trees and shrubs of more than 180 species that present different features across the four seasons (Dong et al., 2006). One of the most attractive areas in the park is the artificial wetland, which has many functions, including protecting water quality, esthetic appreciation, research and education, and ecological maintenance (He et al., 2010). With a large body of clear water and many species of aquatic plants, including reeds (*Phragmites australis*), cattails (*Typha angustifolia* L.), and canna (*Canna indica* Linn.), the wetland presents a pristine natural wetland landscape.

Because most of the human population is concentrated south of Olympic Forest Park, the sampling apparatus was placed on the central island in the northern part of the park. This minimizes the influence of local anthropogenic emissions and makes the island an ideal observation site to assess the particulate matter. Sample plots were 60 m long from north-to-south and 50 m in width from west-to-east, with two vertical gradient sampling points at 0.5 and 1.5 m. There is no significant local source of air pollutants near the monitoring station. In order to quantify the relationship between relative humidity and concentration of PM, we also monitored PM concentration over the bare land surrounding the wetlands as a reference. Climates were similar for the two sites.

1.2. Sampling procedure

A DustMate particulate matter sampler (DUSTMATE, Turnkey Instruments Ltd., UK), a suspended particulate pollutant sampler (TH-150C, Westernization instrument Technology Co., Ltd., China), and a small weather station (Kestrel 4000 Pocket Weather Meter, Nielsen-Kellerman, Boothwyn, PA, USA) were installed at each sampling point to collect particulate concentration and composition and meteorological data (Fig. 2). The meteorological data included temperature, wind speed, relative humidity, and

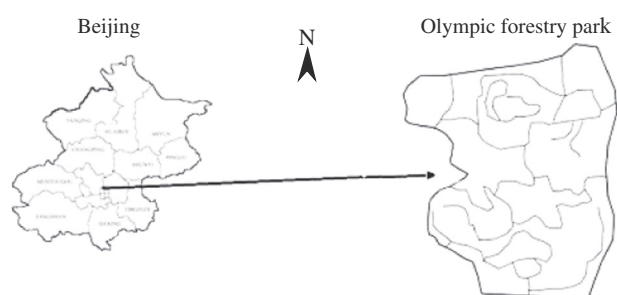


Fig. 1 – Study area and the locations of the sampling sites.

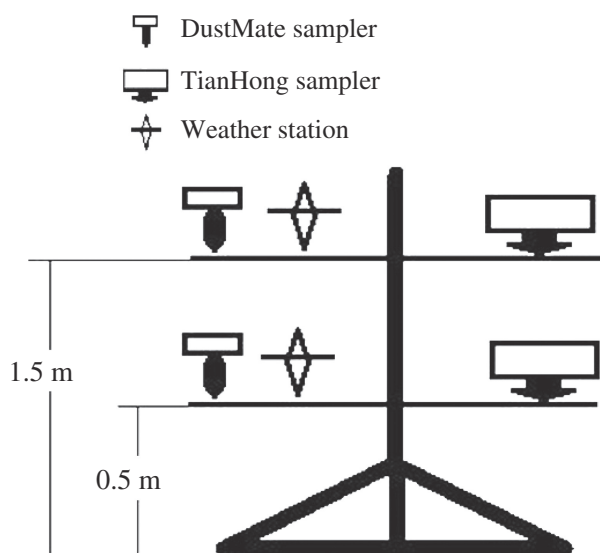


Fig. 2 – Schematic of instrument placement.

radiation. The particulate matter were measured from 06:00 to 18:00 at each sampling point, ensuring that the duration time for a sample was about 12 hr from April 2013 to April 2014. A total of 15 PM_{2.5} samples were collected in three different periods.

1.3. Analytical methods

1.3.1. Study period divisions

Based on the changes in water amount in the Olympic Forest Park wetland, the year was divided into three different periods: the dry period (mainly winter), normal water period (mainly spring and autumn), and wet period (mainly summer).

1.3.2. Analysis of concentration variation

Concentrations of PM_{2.5} and PM₁₀ were averaged by time point to establish their diurnal variation, and for different periods to establish their variation in different periods of the year.

1.3.3. Analysis of chemical composition and variation

Water-soluble ion analysis of the particulate matter was performed by clipping off one-fourth of a sampling filter membrane, dissolving it in 50 ml of deionized water, and performing ICS-2000 ion chromatography (ICS-2000, Dionex China Limited, China) to determine the anions and cations. The main chemical components of PM_{2.5} were determined from the concentration analysis data.

1.3.4. Analysis of the amount of dry deposition

Model of the amount of deposition:

$$D = S_s \times t \quad (1)$$

$$S_s = C_c \times g \times P_p \times D_p \times 2 / (18 \times \eta) \quad (2)$$

where, D ($\mu\text{g}/\text{m}^2$) is the amount of deposition, S_s ($\mu\text{g}/(\text{m}^2\cdot\text{sec})$) is the cumulative deposition speed, g is the gravitational acceleration, P_p is the concentration of particulate matter, D_p is the particulate matter diameter, and η is the dynamic viscosity of air, which may be expressed as

$$\eta = \eta_0 \times T / T_0 \quad (3)$$

where, η_0 is the reference coefficient of viscosity, T (K) is the temperature, and T_0 (K) is the reference temperature. Under normal circumstances, the air coefficient of viscosity at 0°C is 17.1 and can be calculated according to the reference coefficients and the measured temperature. In Eqs. (1)–(2), C_c is the correction factor, which may be expressed as

$$C_c = 1 + (\lambda / D_p) \times (2.514 + 0.8 \exp(-0.55 D_p / \lambda)) \quad (4)$$

In Eqs. (1)–(4), λ is the molecular mean free path, generally taken as 65 nm (Mammarella et al., 2011).

2. Results

2.1. Concentration variation of PM₁₀ and PM_{2.5} in the wetland

2.1.1. Diurnal variation

The mean mass concentration of the entire sampling period was divided into four time periods: 06:00–09:00, 09:00–12:00, 12:00–15:00, and 15:00–18:00. As shown in Fig. 3, the diurnal

variations of PM₁₀ and PM_{2.5} concentrations in the wetland were largely identical and showed a downward trend overall. PM₁₀ and PM_{2.5} both showed the highest average concentration at 06:00–09:00, and in this period, the average concentration of PM₁₀ was approximately 148 $\mu\text{g}/\text{m}^3$ and that of PM_{2.5} was approximately 39 $\mu\text{g}/\text{m}^3$. They both showed the highest instantaneous concentrations at 06:00, with the highest concentration of PM₁₀ approximately 193 $\mu\text{g}/\text{m}^3$ and that of PM_{2.5} approximately 58 $\mu\text{g}/\text{m}^3$. In the 09:00–12:00 and 12:00–15:00 periods, the concentrations of PM₁₀ and PM_{2.5} in the wetland stabilized and showed nonsignificant change. In these two periods, the average concentration of PM₁₀ was approximately 110 $\mu\text{g}/\text{m}^3$ and that of PM_{2.5} approximately 33 $\mu\text{g}/\text{m}^3$. In the 15:00–18:00 period, the average concentrations of PM₁₀ and PM_{2.5} in the wetland reached the lowest point of the day, with that of PM₁₀ approximately 80 $\mu\text{g}/\text{m}^3$ and that of PM_{2.5} approximately 22 $\mu\text{g}/\text{m}^3$.

2.1.2. Variation between periods

According to the changes of water amount in the Olympic Forest Park wetland, the year was divided into three periods: dry, normal water, and wet periods. As shown in Fig. 4, the variation in PM₁₀ and PM_{2.5} concentrations in the wetland was similar in each period. The concentrations of PM₁₀ and PM_{2.5} in wetland were the highest in the dry period, much higher than those in the normal water and wet periods, at 183 and 69 $\mu\text{g}/\text{m}^3$, respectively. In the normal water period, the concentrations of PM₁₀ and PM_{2.5} in the wetland were lower at 92 and 21 $\mu\text{g}/\text{m}^3$, respectively. In the wet period, the concentrations of PM₁₀ and PM_{2.5} in the wetland reached their minimum values of 88 and 18 $\mu\text{g}/\text{m}^3$, respectively, and showed little difference from those in the normal water period.

2.2. Chemical composition of PM_{2.5} in the wetland

Average concentrations ($\mu\text{g}/\text{m}^3$) of seven ions detected in this study included Na⁺ (0.19 ± 0.19), NH₄⁺ (2.97 ± 2.97), K⁺ (0.23 ± 0.22), Mg²⁺ (0.16 ± 0.15), Cl[−] (1.19 ± 1.09), NO₃[−] (7.79 ± 6.95) and SO₄^{2−} (10.94 ± 9.25). The cation with the highest concentration was NH₄⁺ at 12.7%, followed by K⁺ at 1.0%, Na⁺ at 0.8% and Mg²⁺ at 0.7%. The anion with the highest concentration was SO₄^{2−} at 46.6%, followed by NO₃[−] at 33.2% and Cl[−] at only 5.1%.

2.3. Influence of meteorological factors on PM₁₀ and PM_{2.5} in the wetland

Meteorological factors, including temperature, relative humidity, wind speed, and radiation, were recorded in each time period during the day by the small weather stations, and the influence of these meteorological factors on PM₁₀ and PM_{2.5} in the wetland was investigated. Temperature, relative humidity, wind speed, and radiation were all correlated with the concentrations of PM₁₀ and PM_{2.5} (Table 1). These concentrations were positively correlated with relative humidity but negatively correlated with temperature, wind speed, and radiation. The correlation of the concentrations of particulate matter with temperature and radiation was not significant (Fig. 5). However, the concentrations of PM₁₀ and PM_{2.5} had significant positive correlations with relative humidity and

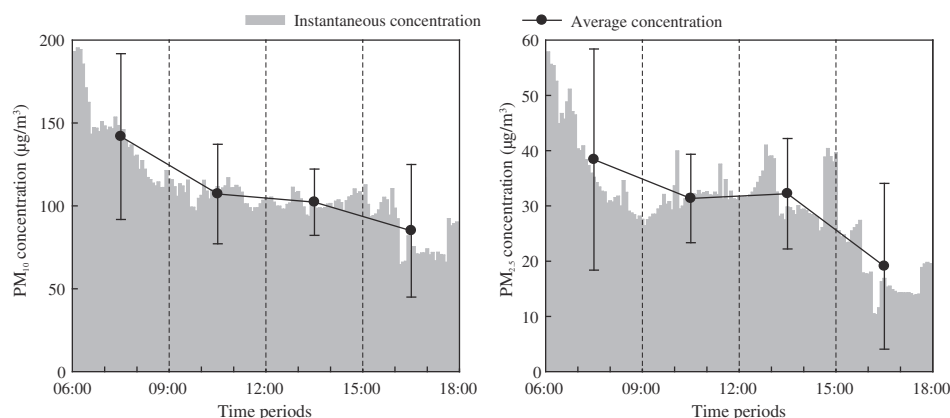


Fig. 3 – Concentration changes of PM_{10} and $PM_{2.5}$ in the wetland during daytime.

significant negative correlations with wind speed, showing that the concentrations of PM_{10} and $PM_{2.5}$ in the wetland had strong relationships with relative humidity and wind speed.

2.4. Amount of dry deposition of PM_{10} and $PM_{2.5}$ in the wetland

2.4.1. Amount of dry deposition of PM_{10}

The amount of dry deposition of PM_{10} at different heights in different periods was calculated according to the model of the amount of deposition. The results derived from the model of the amount of deposition are within the permissible error range of <30%. The period distribution of dry deposition of PM_{10} at different heights was similar (Fig. 6). The average daily amount of dry deposition of PM_{10} at 0.5 m height in the wetland followed the order dry period ($4517 \mu\text{g}/\text{m}^2$) > normal water period ($3174 \mu\text{g}/\text{m}^2$) > wet period ($2304 \mu\text{g}/\text{m}^2$). The average daily amount of dry deposition of PM_{10} at 1.5 m height in the wetland was dry period ($3543 \mu\text{g}/\text{m}^2$) > normal water period ($2486 \mu\text{g}/\text{m}^2$) > wet period ($2332 \mu\text{g}/\text{m}^2$). The amount of dry deposition in the dry and normal water periods at 0.5 m height was significantly higher in both cases than those at 1.5 m height, with the amount of dry deposition in the wet period at 0.5 m height similar to that at 1.5 m height.

2.4.2. Amount of dry deposition of $PM_{2.5}$

Amounts of dry deposition of $PM_{2.5}$ at different heights in different periods were calculated according to the model of the

amount of deposition (the results derived from the model are within the permissible error range of <30%). The period distribution of dry deposition of $PM_{2.5}$ at different heights was basically the same (Fig. 6). The average daily amount of dry deposition of $PM_{2.5}$ at 0.5 m height in the wetland followed the order of dry period ($1688 \mu\text{g}/\text{m}^2$) > wet period ($825 \mu\text{g}/\text{m}^2$) > normal water period ($298 \mu\text{g}/\text{m}^2$). The average daily amount of dry deposition of $PM_{2.5}$ at 1.5 m height in the wetland was dry period ($1647 \mu\text{g}/\text{m}^2$) > wet period ($821 \mu\text{g}/\text{m}^2$) > normal water period ($292 \mu\text{g}/\text{m}^2$). The amount of dry deposition in different periods at 1.5 m height was similar to that at 0.5 m height.

3. Discussion

3.1. Concentration and dry deposition of particulate matter in different periods

This results show that the highest concentrations of PM_{10} and $PM_{2.5}$ in the wetland were observed in the morning. At this time, the wetland still had a high relative humidity. By noon, the air quality gradually improved. By dusk, the water vapor gradually descended to the lake or condensed, and the air humidity gradually decreased. The particulate matter in the air settled following the water vapor, and became dust. Thus, at this time, the concentration of PM_{10} and $PM_{2.5}$ in the wetland was the lowest, and the air quality reached its highest point of the day.

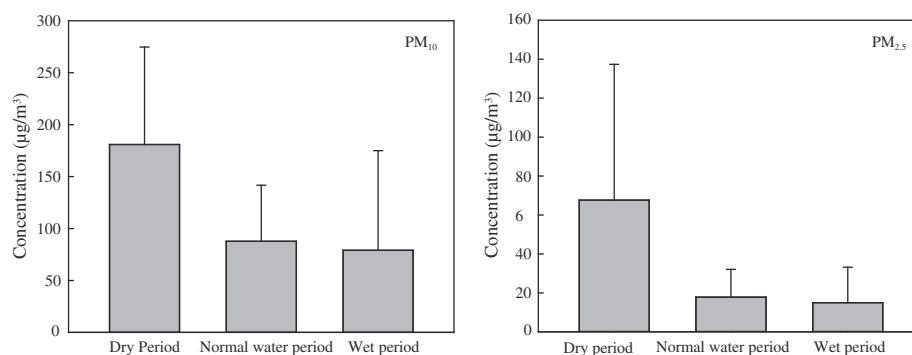


Fig. 4 – Concentrations of PM_{10} and $PM_{2.5}$ in the wetland during different periods.

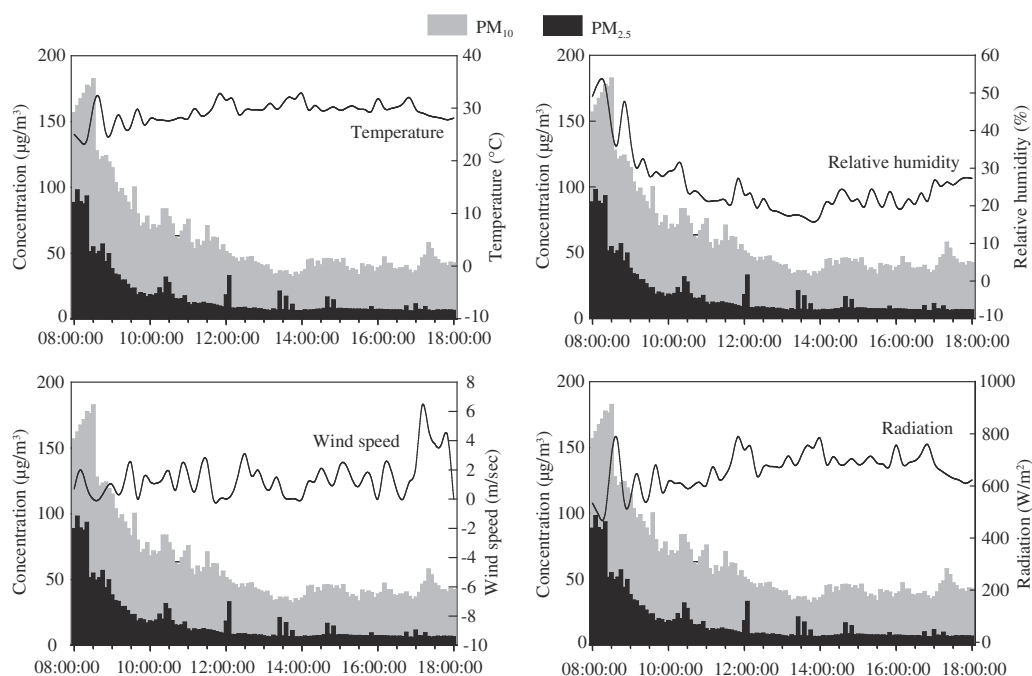
Table 1 – Regression analysis relating meteorological factors and concentrations of PM_{2.5} and PM₁₀ in the wetland.

Particulate matter	Parameter	Meteorological factors			
		Temperature	Relative humidity	Wind speed	Radiation
PM ₁₀	R ²	0.079	0.366	0.017	0.028
	p-Value	<0.001	<0.001	0.025	0.006
PM _{2.5}	R ²	0.033	0.576	0.003	0.061
	p-Value	0.003	<0.001	0.420	<0.001

This article analyzed the concentration differences of particulate matter in different periods of the year and showed that over a year, concentrations of PM₁₀ and PM_{2.5} in the wetland were the highest in the dry period and the lowest in the wet period, and that the concentration in the dry period was significantly higher than that in the normal water and wet periods. This result shows that the highest concentration of PM₁₀ and PM_{2.5} in the wetland was in the dry period, which had the worst air quality. It is unlikely that the fact that human-related pollution is the most severe in winter was the only reason for the poor air quality measured. Another important reason is the function of the wetland. In the dry period, the water in the wetland was frozen, and the air humidity was low, so that the dustfall effect of the wetland on the particulate matter was not observed. Furthermore, plants in the wetland withered, and their adsorption of particulate matter was low. In contrast, in the wet period, there was a lot of water in the wetland and the air humidity was high, so that the dustfall effect of the wetland on the particulate matter was prominent. The concentration of PM₁₀ and PM_{2.5} in the wetland was the lowest, and the air quality was at its highest point of the year during this period. This result reflected the wetland's influence on regulating and intercepting PM₁₀ and PM_{2.5} during the year. This conclusion is consistent with those

of many other studies. Yang et al. (2002b) studied the variation in PM_{2.5} concentration and its correlation with PM₁₀ and total suspended particulates (TSP) in Beijing in 2002 and found that the concentration of PM_{2.5} has clear seasonal variation, with the highest concentration in winter and the lowest in summer. Many other studies (Escobedo et al., 2008; Balestrini et al., 2007; Prajapati and Tripathi, 2008) have shown similar trends.

Table 2 shows mean deposition velocities for different periods and heights. Deposition velocities of PM₁₀ and PM_{2.5} in the dry period were the higher than in the normal water and wet periods. The high deposition velocity in the dry period observed in this study was associated with larger friction velocity and unstable conditions in this period (Wesely and Hicks, 2000). The uncertainty in the data is possibly associated with the fact that the parameterization did not consider the processes of upward flux or rain, and/or the measurement uncertainties. In addition, by analysis of the daily average dry deposition amount of particulate matter in different periods of the year, it was seen that the daily average dry deposition amount of PM₁₀ in different periods followed the order of dry period > normal water period > wet period and that the daily average dry deposition amount of PM_{2.5} in different periods was dry period > wet period > normal water period. These

**Fig. 5 – Real-time changes of meteorological factors and concentration of PM_{2.5} and PM₁₀ in the wetland.**

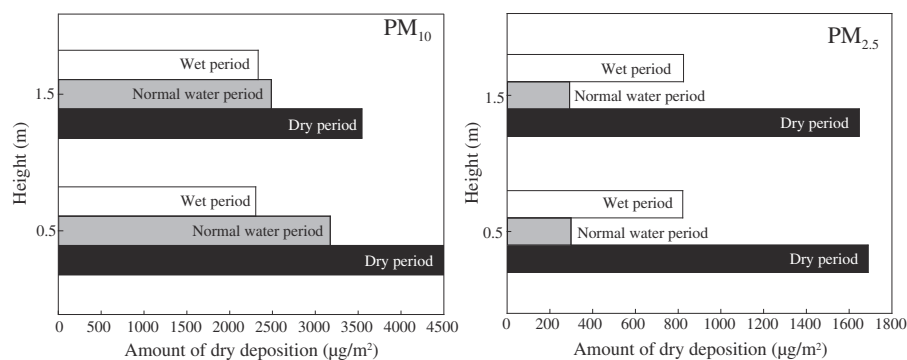


Fig. 6 – Dry deposition of PM₁₀ and PM_{2.5} in the wetland.

results all show that the wetland had both the highest concentration and the highest dry deposition amount of particulate matter in the dry period (winter), and had relatively high air quality in the wet period (summer).

3.2. Chemical composition of PM_{2.5} in the wetland

The chemical composition of PM_{2.5} has also received considerable attention. Xu et al. (2007) studied the composition and sources of PM_{2.5} by positive matrix factorization (PMF) in Beijing in 2007 and found that SO₄²⁻, NO₃⁻, and NH₄⁺ are the major ions of PM_{2.5} in Beijing. Yang et al. (2002a) studied lower-atmospheric aerosols in winter in a northern suburb of Beijing and found that the order of aerosol ion concentrations at three different study heights was the same as found in this study, which is SO₄²⁻ > NO₃⁻ > Cl⁻ and NH₄⁺ > Ca²⁺ > K⁺ > Na⁺. SO₄²⁻ and NO₃⁻ accounted for the largest proportions of anions and NH₄⁺ the largest proportion of cations. Our study showed that the chemical composition of PM_{2.5} in the wetland mainly consisted of NH₄⁺, K⁺, Na⁺, Mg²⁺, SO₄²⁻, NO₃⁻ and Cl⁻, which respectively accounted for 12.7%, 1.0%, 0.8%, 0.7%, 46.6%, 33.2%, and 5.1%. This result is also consistent with the previous findings. A comparison with data obtained on other sites in Beijing shows that our result is consistent with the combined proportion of NH₄⁺, SO₄²⁻ and NO₃⁻ greater than 85% (Table 3 and Fig. 7).

The previous studies demonstrated that the ratio of NO₃⁻/SO₄²⁻ could be reasonably used to evaluate the contribution of mobile and stationary sources to sulfur and nitrogen in the atmosphere in China (Wang et al., 2005; Cao et al., 2009). The mass ratio of NO₃⁻/SO₄²⁻ during the sampling periods was 0.71. Compared with other studies, it was similar to those of Guangzhou (0.79) (Tan et al., 2009), Beijing (0.83–0.87) (Zhang et al., 2013), Beijing (0.67) (Wang et al., 2005), and Shanghai (0.64) (Wang et al., 2006), where the traffic densities were heavy. This implies that the impact of vehicle exhaust should

not be neglected against the background of the rapid increase of motor vehicles in the urban area.

3.3. Influence of meteorological factors on particulate matter in the wetland

Recent studies have suggested that concentrations of particulate matter could be affected by relative humidity. Luo et al. (2013) studied the influence of meteorological factors on PM₁₀ and PM_{2.5} in Beijing and found that the concentrations of PM₁₀ and PM_{2.5} were most affected by humidity and temperature, followed by wind speed. Bi et al. (2013) performed a correlation analysis of meteorological factors and PM_{2.5} in Kunming city and found that the order of influence of meteorological factors on PM₁₀ was wind speed > atmospheric pressure > relative humidity > temperature, and that the corresponding order for PM_{2.5} was relative humidity > wind speed > atmospheric pressure > temperature. Our study also analyzed the correlation between the wetland meteorological factors and particulate matter. However, we found that the meteorological factor in the wetland most relevant to the concentration variation in PM₁₀ and PM_{2.5} was relative humidity, followed by wind speed, and that temperature and radiation had little influence on this variation. This finding is somewhat different from those of previous studies. The following reasons may account for the different results. First, there may be differences in the influence of meteorological factors on particulate matter in different land zones; our study area was a wetland and the other study areas were cities. Second, the analyzed meteorological factors may have been different. Third, the statistical analyses may be different. These factors may have led to differences among the research findings.

In this study, concentrations of particulate matter were monitored to analyze the influence of humidity on the particulate matter, where bare land was used as a comparison to the wetland (Fig. 8). In general, the variations of the PM concentration coincided with that of relative humidity. Moreover, generally higher PM concentration was found under higher humidity conditions. When the relative humidity was less than 20%, the concentration of PM_{2.5} in the wetland and bare land increased slowly. The average concentration of PM_{2.5} in the wetland was 18% less than over the bare land. The concentration of PM_{2.5} increased steadily in the wetland and bare land when relative humidity was 20%–40%. The average concentration of PM_{2.5} in the wetland was 3%

Table 2 – Mean deposition velocities (µg/(m²·sec)) in different periods and heights.

	Heights	Dry period	Normal water period	Wet period
PM _{2.5}	1.5 m	0.0293 ± 0.0252	0.0052 ± 0.0050	0.0143 ± 0.0142
	0.5 m	0.0286 ± 0.0255	0.0051 ± 0.0050	0.0143 ± 0.0141
PM ₁₀	1.5 m	0.0615 ± 0.0606	0.0432 ± 0.0421	0.0405 ± 0.0404
	0.5 m	0.0784 ± 0.0743	0.0551 ± 0.0550	0.0400 ± 0.0398

Table 3 – Statistical summary of the measured species concentrations of PM_{2.5} (μg/m³).

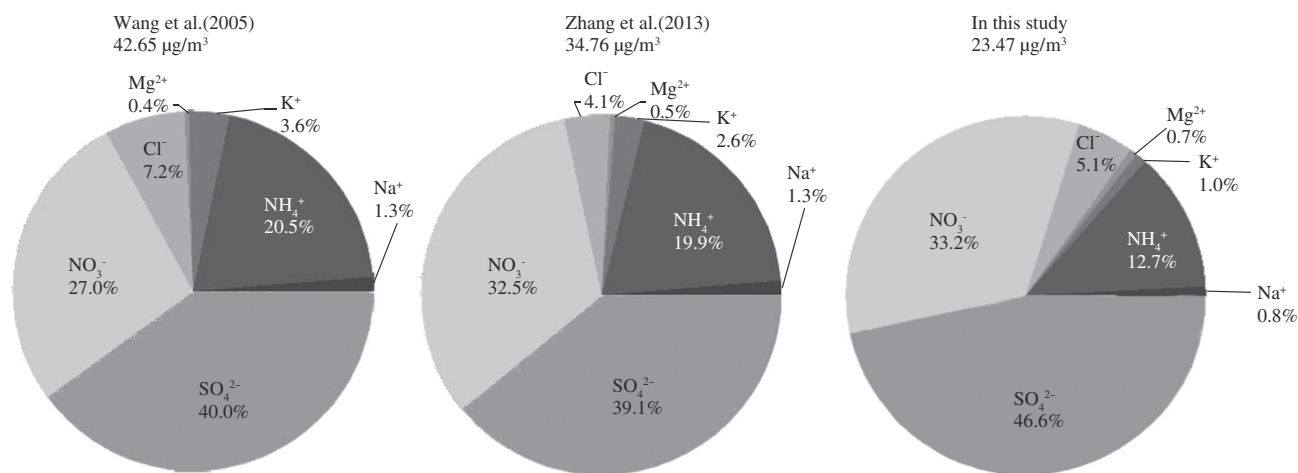
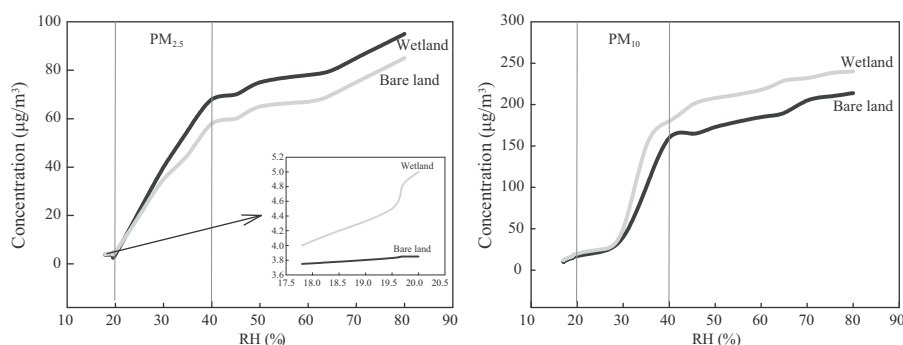
	Na ⁺	NH ₄ ⁺	K ⁺	Mg ²⁺	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻
In this study	0.19 ± 0.19	2.97 ± 2.97	0.23 ± 0.22	0.16 ± 0.15	1.19 ± 1.09	7.79 ± 6.95	10.94 ± 9.25
Beijing, Zhang et al. (2013)	0.46 ± 0.55	6.90 ± 7.10	0.92 ± 0.75	0.16 ± 0.13	1.42 ± 2.18	11.30 ± 10.80	13.60 ± 12.40
Beijing, Wang et al. (2005)	0.55 ± 0.54	8.72 ± 7.66	1.55 ± 1.63	0.17 ± 0.1	3.07 ± 3.13	11.52 ± 11.37	17.07 ± 16.52

greater than over the bare land. When relative humidity was greater than 40%, PM_{2.5} concentration increased at a slower rate, although the average concentration of PM_{2.5} in the wetland was still 14% greater than over the bare land. As can be seen from the relationship between relative humidity and PM₁₀, the PM₁₀ concentration of wetlands was 15% less than the bare land concentration. This may due to the different mechanisms of atmospheric deposition: coarse particles are captured easily on wet surfaces, and fine particles settle back to the ground when polymerization takes place (Pye, 1987).

4. Conclusions

In the daytime, PM₁₀ and PM_{2.5} in the Beijing Olympic Forest Park wetland both showed the highest average concentrations

at 06:00–09:00. At 09:00–12:00 and 12:00–15:00, they stabilized and changed only insignificantly. At 15:00–18:00, the average concentration of PM₁₀ and PM_{2.5} in the wetland reached the lowest level of the day. Over a year, the concentrations of PM₁₀ and PM_{2.5} in the wetland were the highest in the dry period and the lowest in the wet period. The concentration in the dry period was significantly higher than in the normal water and wet periods. The chemical composition of PM_{2.5} in the Beijing Olympic Forest Park wetland mainly included NH₄⁺, K⁺, Na⁺, Mg²⁺, SO₄²⁻, NO₃⁻ and Cl⁻. The proportions of these ions were 12.7% NH₄⁺, 1.0% K⁺, 0.8% Na⁺, 0.7% Mg²⁺, 46.6% SO₄²⁻, 33.2% NO₃⁻, and 5.1% Cl⁻, respectively. This finding may reflect the high solubility of the three anions and the wetland's purification function with respect to these three anions. The concentrations of PM₁₀ and PM_{2.5} had a significant positive correlation with relative humidity, significant negative

**Fig. 7 – Mass and major compositions of PM_{2.5}.****Fig. 8 – Relationship of particle matter and relative humidity (RH). Inset plot was magnification of the curve when RH was below 20%.**

correlation with wind speed, and nonsignificant negative correlation with temperature and radiation. The daily average dry deposition amount of PM₁₀ in different periods followed the order of dry period > normal water period > wet period, and the daily average dry deposition amount of PM_{2.5} in different periods was dry period > wet period > normal water period. This result shows that the highest daily average dry deposition amount of particulate matter occurred in the dry period of the year.

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