Variation in Urban Forest Regulation of Air Particulate Matter Concentration

Fengfeng Ma [1], Xiang Zhou [2,*], Nan Deng [1], Xiqun Li [1]

[1] Hunan Academy of Forestry, Changsha Hunan, China
[2] Hunan Center of Natural Resources Affairs, Changsha Hunan, China

Abstract: Urban forest was vital to adjusting Air Particulate Matter Concentration (APMC). The purpose of this study was designed to provide a more detailed analysis of the urban forest long-time scales effect on APMC. The paper assessed effect of forests (urban greening) on APMC in an urban environment, where an urban green center (nearly 2 km2) and a nearby (5 km away) bare-ground site (at a road intersection) in Yuhua District of Changsha, China, were chosen to delve into daily, seasonal, and annual variation of APMC in an urban forest and a non-forested site respectively. It was found that: (1) on a daily basis, APMC in both the urban forest and the non-forested site was high in the morning and evening, but low at noon, demonstrating a "two-peak-one-trough" or V-shaped pattern. Additionally, APMC in the morning was higher than evening. (2) in terms of season, APMC was high in spring and winter, but low in summer and fall. (3) the annual change of the APMC showed a "bimodal" annual trend in urban forest and non-forested site, with a peak concentration in the urban forest coming later than the non-forested site. (4) temperature and average wind speed composed main factors affecting APMC in Changsha's ecotope. The paper characterized the change pattern in APMC in urban environment (forested and non-forested), suggested appropriate recreational periods in the urban forest, and gave insight in planning and construction of urban greening projects.

Keywords: Air Particulate Matter Concentration; urban forests; bare ground site.

1. Introduction

Smoke and fog ("smog") can cause air pollutant, suspended Particulate Matter (PM). PM2.5 refers to particles with aerodynamic equivalent diameter (AED)≦ 2.5 microns, which considered to be main cause of "smog" [1, 2]. At present, air PM is still the primary pollutant reducing urban air quality, which can cause or exacerbate diseases once directly inhaled [3-6]. In recent years, highly concentrated smoke PM frequently appears in many regions of China in winter and spring, giving rise to concerns to the country's air quality. As a result, great emphasis has been placed on studying characteristics of air particulate matter concentration (APMC) in geographical areas [6-9].

Urban forests play an essential role in improving the quality of the urban environment [10-12]. Researches show that certain species in urban forests for urban greening are available in holding and setting dust, therefore effectively reducing urban air pollution [4, 13-17]. Urban forest can help improve air quality for many different air pollutants in cities, which has a potential to reduce the air pollutants from the atmosphere, and consequently can help improve human health [18-20]. Trees can reduce air pollutants in two ways: by direct reduction from the air, and by indirect reduction to avoiding the emission of air pollutants [18]. The study of the first way were focused on the PM retention capacities of leaf surfaces in different species [10, 12, 21-23]. Indirectly, trees can reduce the air pollutants by adjust the temperature or humidity or other factors in the forest, which focus on the study of time-related changing patterns in APMC [24-25]. Recent researches on daily changing patterns in APMC in urban green spaces focus on northern areas [13, 15, 24] and coastal cities [25] of China, with urban forest parks frequently selected as research sites. However, very few studies analyze changing patterns based on overall features or long-time scales in Chinese regions.

Changsha is a high-rainfall, southern city in Hunan province of China, which is located at evergreen broad-leaved forest and secondary forest, Pinus massoniana forest area in the hills of the Yangtze River, the floristic region of Central China.

The study was designed to provide a more detailed analysis of the urban forest long-time scales effect on APMC in Changsha. The main objectives of the paper are: (1) to describe time-related changes of APMC; (2) to analyze the control effect of urban forest on PM; (3) to make sure the relationship of Air PM and Meteorological Factors.

* Corresponding author: Xiang Zhou, zhouxiang_@126.com

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2. Material and Methods

2.1 Study area

The research site chosen in the paper locates in a nearly 2 km2 urban forest in the suburban area of Changsha, while measured data are compared with a bare-ground (non-forested) site approximately 5 km away in the same city.

Dujiachong experimental forest farm was located at Lituo town and Dongjing town of Yuhua District of Changsha, Hunan province of China, with latitudes 28°06′N, longitudes 113°03′E at an altitude of 110 m. The soil in the forest farm was 50 cm thick, with moderately fertile quaternary red clay of pH 5.6–6.0. The farm was characterized with a subtropical monsoon climate, with an annual average temperature of 17.1°C and an extreme low temperature of -11.3°C. The average annual rainfall was between 1400–1900 mm and the frost-free period is 264 d. It covered an area of 2.67 km2 and had a vegetation coverage (i.e. ratio of the total area covered by trees, shrubs, and herbage to the whole sample area) greater than 95%. Its forest type consisted of broadleaved forests dominated by Liquidambar formosana, Cinnamomum camphora, Sassafras tsumu. and Schima superba, and mixed coniferous-broadleaf forests of Pinus massoniana and Cunninghamia lanceolata, or L. formosana and C. camphora.

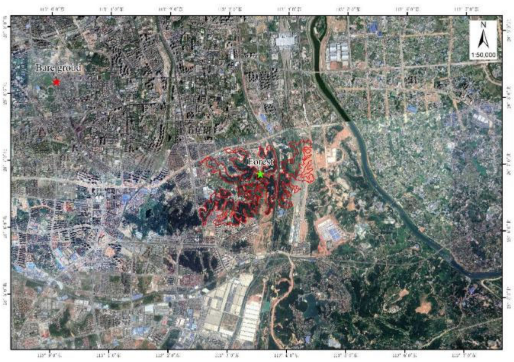

Figure 1. Geographical position of research

2.2 Sample Sites

A mixed coniferous and broadleaf forest, with the largest area in the forest farm, was selected as the observation site (Fig. 1). The study plot was dominated by P. massoniana and L. formosana, including species such as C. camphora, S. tsumu, Castanopsis sclerophylla. The forest was approximately 35 years old with a canopy density of 0.9 and positioned on a west-facing slope. The average diameter of trees at breast height was 22.4 cm, and the average tree height was 15.6 m. The shrub coverage percentage was 85%, made up of Ilex bioritsensis, Symplocos sumuntia, Quercus fabri, Cyclobalanopsis glauca, Gardenia jasminoides, and other species. The herbaceous coverage percentage was 70%, dominated by Dryopteridaceae, Osmanthusheterophyllus, Lophatherumgracile, etc.

A 1 km2 area of bare-ground site at the intersection of Xiangzhang Road and Shaoshan South Road was chosen as the control (Fig. 1). Shaoshan South Road, a main road in Changsha, featured a large number of inhale together with Xiangzhang Road. With a big supermarket located at the northeast of the intersection of the two roads, there tended to be traffic jams almost every day in the intersection during rush hour. Samples were collected from the center of the sample areas.

2.3 Experimental unit and design

The air quality sample of urban forest was in the middle position of 400m2 sample sites, and the bare-ground sampling was the southwest corner of Xiangzhang Road and Shaoshan South Road. Sunny and cloudy days were selected for sampling every month between September 2014 and August 2015. 2 or 3 days were observed in each month. On sampling days, observations were carried out once per hour from 08:00 to 18:00, while urban forest and bare-ground site were observed simultaneously. The same positions were observed every time. A Dustmate fume and particle detector (Turnkey Instruments Company, England) were employed to measure air PM at a breathing height of 1.5 m, and each measurement was repeated three times by observer. 25 days were observed in my study. In addition, four particles were measured, with particle size ordering as total suspended particles (TSP)> PM10> PM2.5> PM1.0. In general, TSP and PM10 were categorized as large-sized PM, while PM2.5 and PM1.0 were categorized as small-sized PM. Based on a handheld weather station: TRM-GPS1, China, time, air temperature, relative humidity, wind speed and incident of sunlight were recorded in sampling times.

2.4 Data Analysis

Data analysis was conducted via SPSS Version 16.0 (SPSS, Chicago, IL, USA) and R language 3.3.0 for Windows. Comparison of the research sites were performed using one-way analysis of variance (ANOVA) followed by Turkey HSD tests and T-test. Correlation of air PM and meteorological factors were carried out based on bivariate correlation and analysis of variance. All figures and tables were drafted through R language 3.3.0, and significance levels were set at p= 0.05 in all statistical analyses.

3. Results

3.1 Change in APMC

The change in APMC in the mixed urban forest and the bare ground research site were illustrated in Fig. 2, both showed a law of TSP>PM10>PM2.5>PM1.0. Monthly curves of APMC in the forest and in the bare-ground sites were essentially bimodal (Fig. 3). Monthly peak concentration of PM (PM10, PM2.5, and PM1.0) in the forest and bare-ground site in February and January respectively. The lowest APMC of all particles occurred in June at both sites. APMC in both sites were high in winter and spring, while low in summer and fall (Tab. 1). Additionally, TSP concentration was higher in the urban forest in spring and winter, while lower in the bare-ground site in summer and fall. The lowest concentrations of PM10, PM2.5, and PM1.0 in the urban forest and the bare-

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ground sites were recorded in summer and fall respectively.

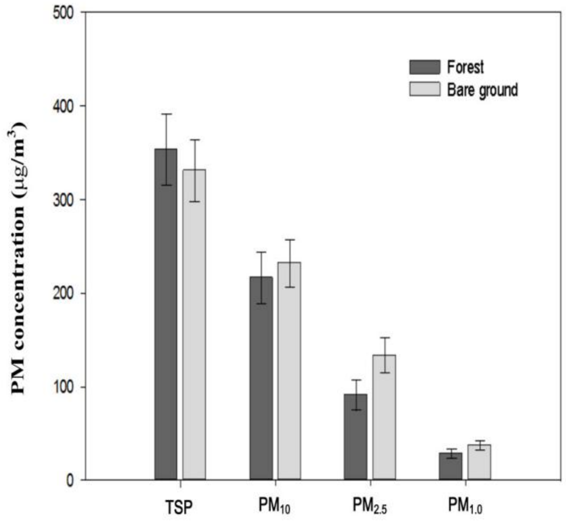

Figure 2. Variations in air particulate matter concentrations between an urban forest and bare-ground site. Four particle sizes are measuredsite

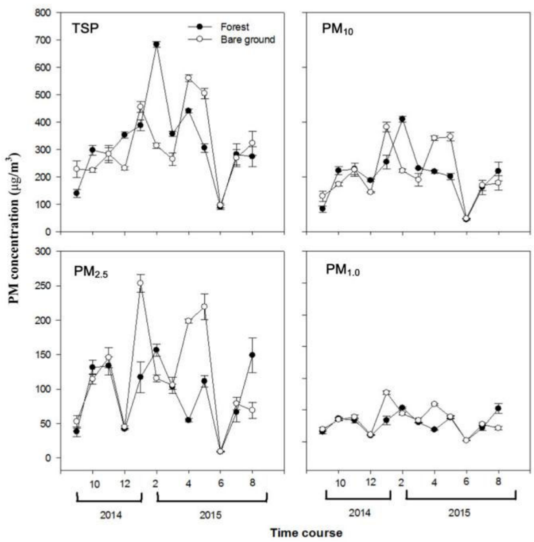

Figure 3. Monthly variations in air particulate matter concentrations between an urban forest and bare-ground site.

Daily APMC of both the forest and bare-ground sites were found to be high in the morning and evening, while low at noon. The concentrations of all four sized PM were higher in the morning than in the evening (Fig. 4). The result showed a not well absorption in concentrations of TSP in the urban forest on cloudy days. Daily averaged concentrations of TSP, PM10, PM2.5 and PM1.0 in urban forest and bare-ground site all peaking at 09:00, but varying between 14:00 and 16:00 when APMC reached lowest points, which the levels increased to evening levels. The changes may be related with commuter rush hours, particularly for the PM2.5 and PM1.0.

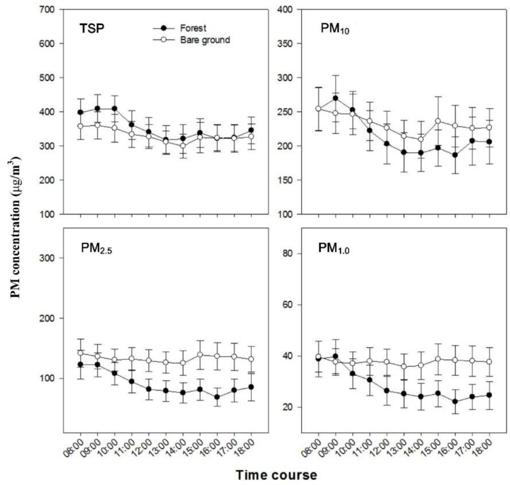

Figure 4. Daily variations in air particulate matter (PM) concentrations between an urban forest and bare-ground site.

Table 1. Seasonal variations in air particulate matter (PM) concentrations between an urban forest and bare-ground site in Yuhua District, Changsha, Hunan Province, China. Four particle sizes are measured [size ordering: total suspended particles (TSP) > PM10> PM2.5> PM1.0]. E.g., PM2.5: particles with an aerodynamic equivalent diameter of less than or equal to 2.5 microns.

Season	Forest				Bare ground			
	TSP	PM10	PM2.5	PM1.0	TSP	PM10	PM2.5	PM1.0
Spring	555.96±77.16	308.31±69.33	101.49±40.04	34.57±13.28	418.16±62.31	285.91±39.72	166.01±31.43	48.32±8.56
Summer	226.10±45.96	136.13±31.65	62.21±24.84	20.75±8.72	290.03±84.49	187.98±58.93	102.53±39.42	23.03±7.15
Fall	229.29±43.14	166.73±43.62	97.64±34.53	31.42±8.95	241.05±38.08	156.89±26.22	81.91±24.90	26.51±6.41
Winter	348.19±34.62	227.95±39.13	100.45±31.75	26.93±8.52	342.67±59.95	269.69±56.15	163.10±43.07	47.46±12.44

Control effect of urban forest on PM

Generally, plants act as biological filters for PM (Robert et al., 2018). The levels of TSP in the urban forest was slightly higher than the bare-ground site, while the level of PM10, PM2.5 and PM1.0 in the forest were lower than the bare ground (Fig. 2). Except for TSP, T-test showed significant difference between the urban forest and bare-ground sites in other PM levels ($p<0.05$).

Monthly peak concentration of PM (PM10, PM2.5, and PM1.0) in the forest came later in the year (February) than in the bare-ground site (January) (Fig. 3). The highest concentration of large PM (TSP and PM10) came in the urban forest, while the highest concentrations of small PM (PM2.5 and PM1.0) occurred in the bare-ground site. The same trend was observed in the spring under highly "smoggy" condition (Tab. 1). Changes in seasonal variations in APMC in the urban forest and bare-ground sites were related to the particle size (Tab. 1). PM10, PM2.5, and PM1.0 concentrations of the urban forest were lower than the bare-ground site in summer. In all seasons except fall, the concentrations of PM2.5 and PM1.0 in the urban forest were lower than the bare-ground site, indicating forest significantly reduced concentration of small-sized PM.

The daily variations in APMC, except TSP, were lower in the urban forest than in the bare-ground site (Fig. 4). Daily averaged concentrations of TSP, PM10, PM2.5 and PM1.0 in urban forest were 1.07, 0.93, 0.68 and 0.76 times in the bare-ground site respectively. However, in the 9:00 am, except for PM2.5, APMC in the urban forest were higher than in the bare-ground.

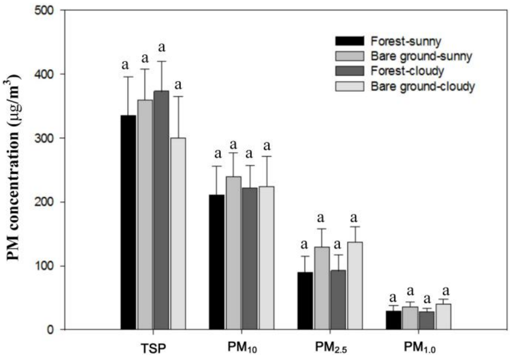

Figure 5. Variations in air particulate matter concentrations between an urban forest and bare-ground site under different weather conditions.

3.2 Weather Effect on APMC

APMC in the urban forest and the bare-ground site were compared and analyzed in sunny and cloudy days. As a result, no significant differences were found between the sites in terms of concentrations of the four types of PM in both sunny and cloudy conditions ($p>0.05$) (Fig. 5). Urban forest concentrations of small-sized air PM (PM2.5 and PM1.0) were lower than those from the bare-ground site. The highest TSP concentrations were found in the urban forest on cloudy days, which may be due to canopy density and reduced air permeability of the forest affecting the dispersibility of the particles.

Highest PM10/TSP and PM2.5/PM10 ratios were observed in the bare-ground site on cloudy days, while highest PM1.0/PM2.5 was found in the urban forest on sunny days (Tab. 2). The finding suggested that the chance for inhalation of respirable PM (PM2.5 and PM10) was higher on cloudy days, which may pose a potential risk to human health. In the same weather, ratios of small-sized PM in the forest and the bare-ground sites were also compared and analyzed. Both in sunny days and cloudy days, the PM10/TSP and PM2.5/PM10 values in the urban forest were lower than in the bare-ground site, with PM1.0/PM2.5 value in the urban forest higher than that of bare ground. The result may come from differences in settling rates of particles in different vegetation, as particles smaller than 2 μm required longer settling times than larger particles (Fu et al., 2014). T-test indicated no significant difference in proportion of small-sized PM between the two sites ($p>0.05$).

Table 2. Ratios of small size air particulate matter (PM) in an urban forest and bare-ground site in different weather. The letter "a" means no significant ($p<0.05$) difference between urban forest and bare ground site in different weather.

Weather	Type	PM_{10}/TSP	$PM_{2.5}/PM_{10}$	$PM_{1.0}/PM_{2.5}$
Sunny	Forest	62.91a	42.62a	32.67a
	Bare ground	66.49a	54.21a	27.58a
Cloudy	Forest	59.52a	41.56a	29.86a
	Bare ground	74.88a	61.02a	28.99a

The daily variations of the APMC in both research sites were significantly affected by weather (Fig. 6). On sunny days, concentrations of TSP, PM10, PM2.5, and PM1.0 were higher in the bare-ground site than in the urban forest. On cloudy days, concentrations of TSP and PM10 in the urban forest surpassed the bare-ground site, while the PM2.5 and PM1.0 concentrations in the urban forest tended to be lower than the bare-ground site. The findings indicated that there might be a difference in adsorption and settling of different-sized PM particles in the forest.

3.3 Correlation between APMC and Meteorological Factors

Concentration of large-sized PM (TSP and PM10) in the forest was significantly negatively correlated with average temperature, maximum temperature and minimum temperature; TSP concentration of the bare ground at intersection was significantly and positively correlated with the maximum wind speed ($p<0.05$) (Tab. 3). In addition, concentration of large-sized PM (TSP and PM10) in the forest was most strongly correlated with the minimum temperature, and the concentration of small-sized PM (PM2.5 and PM1.0) was most highly linked with maximum wind speed. In contrast, in the bare-ground site, the concentration of large-sized PM (TSP and PM10) was most interconnected with maximum wind speed, while the concentration of small-sized PM2.5 was most strongly connected with the sunshine duration and the PM1.0 concentration was most closely linked with the minimum temperature ($p<0.05$).

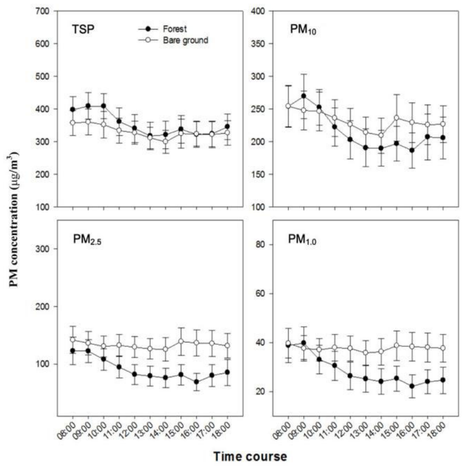

Figure 6. Daily variations in air particulate matter concentrations between an urban forest and bare-ground site under different weather.

Table 3. Correlation analysis of air particulate matter (PM) concentrations and meteorological factors between an urban forest and bare-ground site. The sample size is 600m2. Four particle sizes are measured.

Type	PM	Monthly mean temperature (°C)	Monthly Maximum temperature (°C)	Monthly Minimum temperature (°C)	Relative humidity (%)	Average wind speed (m/s)	Maximum wind speed (m/s)	Monthly precipitation (mm)	Sunshine duration (h)	Pressure (Pa)
Urban forest	TSP	-0.695*	-0.684*	-0.704*	-0.073	0.372	0.291	-0.337	-0.413	0.368
	PM_{10}	-0.645*	-0.644*	-0.646*	-0.078	0.260	0.290	-0.377	-0.376	0.394
	$PM_{2.5}$	-0.270	-0.283	-0.261	0.027	0.073	0.309	-0.285	-0.154	0.202
	$PM_{1.0}$	-0.156	-0.165	-0.151	0.171	0.211	0.450	-0.229	-0.094	0.028
Bare ground intersection	TSP	-0.258	-0.237	-0.275	0.236	0.566	0.669*	-0.054	-0.374	-0.038
	PM_{10}	-0.429	-0.416	-0.440	0.154	0.484	0.568	-0.116	-0.498	0.137
	$PM_{2.5}$	-0.412	-0.403	-0.420	0.147	0.410	0.490	-0.063	-0.497	0.161
	$PM_{1.0}$	-0.521	-0.512	-0.531	0.095	0.478	0.318	-0.293	-0.477	0.253

*indicates signifiant correlation ($p<0.05$)

4. Discussion

4.1 Time-related Changes of APMC

APMC in the urban forest shows time-related changes. On a daily basis, APMC is high in the morning and evening while low at noon, forming a V-shaped pattern which is consistent with previous findings [4, 25-26]. In contrast to an earlier study [9], APMC in the morning is found to be higher than evening.

In terms of Season, APMC tends to be high in spring and winter, while low in summer and fall, which is the result of seasonally changed air quality of Changsha, and the pollution is more serious in winter and spring, with better air quality in summer and fall [27]. And the annual change demonstrates a bimodal shape, as the first peak concentration of PM comes between January and February and the second peak concentration of PM between April and May. The result may be due to climate in Changsha. Because Changsha featured many foggy and dry days during winter (January) and spring (February) in 2014-2015, and heavy rainfall and slow wind speed between April and May hinder dispersion of PM, it was hard for polluted air to be dispersed. Furthermore, long-distance transport of dust from northern China increased the concentration of air PM. Besides, forest growth was in dormancy in winter, resulting in worse dust settling and higher APMC, especially on "smoggy" days. In the summer, however, Changsha experienced frequent rainfalls and humid days, promoting removal of air PM [12]. Besides, forests flourished in summer, reaching their most vigorous growth of the year, thus improving adsorption of air PM and reducing APMC in the forest.

Therefore, to keep health, both physically and mentally health, residents are encouraged to visit urban green spaces on sunny or summer days (except for 08:00–10:00 in the morning) rather than smoky, foggy and cloudy days.

4.2 Control effect of Urban forest on PM

In contrast to previous studies [25], there is a difference in settlement and adsorption of PM by vegetation, and a significant removal effect on small PM (PM2.5 and PM1.0). It is also found the lowest forest concentrations of PM10, PM2.5, and PM1.0 come in summer, while the lowest concentrations in the bare-ground site occur in fall. In all seasons except fall, forest concentrations of small-sized PM (PM2.5and PM1.0) are lower than the bare-ground site. The result was also due to climate in fall of Changsha, 2014, when polluted days became increasingly frequent from early September and fog and smoke came nearly every day in second half of October, thus leading to high APMC. Additionally, there were neither strong wind nor heavy rainfall during that period, resulting in relatively steady air and making small-sized PM not easily be dispersed in the urban forest. As a result, concentration of PM became much higher in the forest than in the bare-ground site.

Forest concentrations of large-sized PM (TSP) are higher than the bare-ground site in spring and winter, a result of frequent smoke and fog. The observed pattern reverses in summer, which is likely to be related to the seasonal growth pattern of vegetation. In addition, it is found the maximum concentration of PM in the forest comes one month later than non-forested area, manifesting the forest function in retaining different sized PM [28-30]. Previous researches illustrated different vegetation types featured different adsorption capacities for PM [31]. Vegetation selection and structural configuration are, therefore, essential for road greening and planning urban green spaces [15, 32].

4.3 Relationship of Air PM and Meteorological Factors

The size of air PM is related not only to the nature of the PM itself, but also to environmental factors such as meteorology. Fu et al [25-26] and Che et al[33] believed within a certain range, concentration of all sized PM negatively correlated with temperature and wind speed, while positively correlated with relative humidity, which was consistent with the findings of the paper. However, the paper found a lowest correlation between concentration of different sized PM and relative humidity in both the urban forest and the bare-ground site, which in contrast to some earlier findings [24, 34-36]. It is also found a significant influence of temperature on concentration of TSP and PM10, as well as a significant effect of the maximum wind speed on TSP in the bare-ground site, while other meteorological factors are found to exert no significant effect on APMC, in further contrast to some prior publications [24-25, 36-37], suggesting a temperature rise could enhance vertical convection of atmosphere, conducive to atmospheric diffusion and thus negatively correlated with APMC.

Overall, the present study demonstrated daily, seasonal and annual variation of APMC in the forested and non-forested site (bare ground at a road intersection), finding APMC in both sites shows variations related to time and weather, and many factors are affecting APMC in the urban forest. In sunny days, all four types of APMC are lower in the urban forest than the bare-ground site, in contrast, concentrations of TSP are higher in the forest during cloudy days. It is suggested influence of different weather on APMC in the forest be further studied. Furthermore, the paper finds that vegetation has a significant effect on adjusting forestry climate in removing small-sized PM (PM2.5 and PM1.0). The paper focuses on a mixed coniferous broadleaf forest and further studies on APMC in other forest types such as coniferous pure forests or broadleaved pure forests, or forests in different stand structures, are planned to be implemented.

Acknowledgements

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Declarations

List of abbreviations

air particulate matter concentration (APMC); particulate matter (PM); aerodynamic equivalent diameter (AED); total suspended particles (TSP)

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