Variation Characteristics of PM\textsubscript{10} and Its Interaction with Meteorological Effects during 2014-2016, Fuzhou, China

Junyi Li\textsuperscript{a}, Danmei Sun\textsuperscript{b}, Yulin Huang\textsuperscript{c}, Ye Chen\textsuperscript{d}, Yuxiang Lan\textsuperscript{e} and Jianwen Dong\textsuperscript{*}

Fujian Agriculture and Forestry University, Fuzhou, China

*Corresponding author e-mail: fjdjw@fafu.edu.cn, \textsuperscript{a}529596435@qq.com, \textsuperscript{b}474789475@qq.com, \textsuperscript{c}649197199@qq.com, \textsuperscript{d}349358108@qq.com, \textsuperscript{e}719220079@qq.com

Abstract. Air pollution has become worldwide environmental issue in present day. In this study, the concentrations of PM\textsubscript{10} was analyzed with hourly datasets, and the data of meteorological conditions were measured per 3 hours from 1\textsuperscript{st} Sep 2014 to 30\textsuperscript{th} Sep 2016 at Fuzhou city in the southeastern China. The mean value of mass concentration of PM\textsubscript{10} is 54.65±24.07μg m\textsuperscript{-3} in the study period. The correlation coefficient between mass concentrations of PM\textsubscript{10} and meteorological factors were analyzed, it shows that there existed a negative correlation between PM\textsubscript{10} and T (−0.03), RU (-0.27), WS (−0.10), HCC (−0.04), VIS (−0.31), DPT (-0.15) and RF (-0.14). Subsequently, the impacts of typhoons on the mass concentrations of PM\textsubscript{10} during September 10\textsuperscript{th} 2016 to September 16\textsuperscript{th} 2016 were analyzed during which the mass concentration of PM\textsubscript{10} decreased at a large extent and the particulates have more prominent changes during the typhoon period compared with coarse particulates.

1. Introduction

For the past decades, along with the rapid process of urbanization, economic development and industrialization, the atmospheric concentration of particulate matter increased significantly. The concentration of PM\textsubscript{10} acts as an important indicator of visibility, precipitation, and air quality. In light of the extensive impacts of PM\textsubscript{10} on health, environment, visibility and climate, many researchers and scholars have conducted relevant studies recently\cite{1, 2}. As mentioned above, those particulates with diameter ≤10μm can be directly absorbed by human body together with toxic gas and rise various respiratory and cardiovascular diseases \cite{3-5}. Due to their significance to solar and atmospheric radiation, these particulates have direct impacts on the climate. The cooling or warming effects of particulates depend on the specific operation process - either light absorption process or scattering process \cite{6}. Besides the direct influences over the climate, particulates also generate indirect impacts on the cloud and rainfall through changing the physical and radiation characteristics of clouds. Whereas, human beings still lack in-depth understanding about the concrete impacts of particulates on climate \cite{7}. For precisely perceiving the impacts of particulates on the climate, it becomes increasingly important to figure out the local dynamics of particulates \cite{8}.

Along with the rapid development of urbanization, industrialization and social economy, air pollution problems become increasingly deteriorated. For example, the frequency of hazy days at...
present is much higher than previous ten years [9]. As for Fuzhou, the deterioration of air quality may mainly attribute to the increase of vehicles (the amount of car totaled 1.09 million in 2015). Many researches on Physico-chemical characteristic analysis choose cities in the northern part of China for the higher urbanization and industrialization [10-12]. However, it is worth noticing that, the case study of Fuzhou can be illustrated as the representative of ecosystem service research which can offer preferential value for other major cities confronted by air quality problems in the humid subtropical region.

According to CAAQS (China Ambient Air Quality Standards No: GB3095-2012), this study elaborately explored the hourly average mass concentration of PM10 in Fuzhou during September 1st 2014 to September 30th 2016. At the same time, this study also analyzes the correlation between PM10 and meteorological in the study period to conduct a comprehensive air quality evaluation. The main contributions of this paper can be summarized as follows. 1), we analyze the variation of PM10 concentration on the daily, monthly, seasonal and spatial basis. 2), it aims to conclude the influences of meteorology on atmospheric environment in the research region.

2. Sampling site and meteorological conditions

Fuzhou located in the East Sea (25°15′-26°39′N and 118°08′E -120°31′E) [13]. Under the influence of East Asian Monsoon and changeable meteorological conditions, Fuzhou is in a humid subtropical region. Pursuant to previous research data, annual average relative humidity (RH), rain fall (RF), and wind speed (WS) in Fuzhou is respectively 77%, 1342.5mm, and 2.8m/s. Predominant wind direction is southwesterly wind in summer and northeasterly wind in other three seasons during the whole year [14]. The long summer is very hot and humid while the short winter is relatively mild and dry. It is very common to see heavy rain in the hot summer in Fuzhou. Later on, Fuzhou is also frequently hit by typhoons from the late summer to the early winter. In terms of the monthly average temperature, the maximal value falls on July as 28.9°C and the minimum value falls on January as 10.9°C. As for the monthly sunshine, the maximal value falls on July as 54% and the minimum value falls on March as 24%. Accordingly, it can be derived that Fuzhou city receives 1,607-hour sunshine in every year on average [13, 15].

Figure 1. Location of study area. (a: Location of Fuzhou City in China; b: Study area).

3. Data

The meteorological data adopted in this study offered by the Chinese Meteorological Department (CMD, http://data.cma.cn/). The weather monitoring station (26°5′ N, 119°16.98′ E) locates at the busy commercial and residential area of Gulou District of Fuzhou city. The data of PM10 concentration were got from the statistics in 6 sites stored by the Ministry of Environment Protection of the People’s Republic of China (MEPRC, http://www.mep.gov.cn/hjzl/), including Gulou, Cangshan, Taijiang and Jinan District. Available data is collected once every three hours for
4. Results and discussion

4.1. PM10 mass concentrations overview

Daily variation of PM$_{10}$ concentration is shown in Fig.2. The mean values of mass concentration of PM$_{10}$ within the research period is 54.65±24.07μg m$^{-3}$. According to the information released by CAAQS, the mass concentration of PM$_{10}$ were in the secondary level (40<PM$_{10}$<70μg m$^{-3}$). The mass concentration of PM$_{10}$ (6~304μg m$^{-3}$) in this study was similar as shown in previous studies took in the southern China [9, 16]. Compare with other cities in China, the concentration of PM in Fuzhou is relatively low. For PM$_{10}$, the percentage of hourly mass concentration is 47.6% in the primary level (<50μg m$^{-3}$) and 99.9% in the secondary level (<150μg m$^{-3}$). The maximal hourly value of PM$_{10}$ (304 μg m$^{-3}$) occurred in January 2016 while the minimum value occurred in September. Liu et al. 2017 found that the mass concentration of PM$_{10}$ (82.79μg m$^{-3}$) in Xiamen, a city nearly 200 km away from Fuzhou city, is similar to this study [17].

![Figure 2](image_url) Daily variations of PM10 and PM2.5 from 1st Sept 2014 to 30th Sep 2016 over Fuzhou.

When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper.

Table 1 lists a comprehensive summary for the mass concentration of particulates from existing studies, including this study. To conduct a comparative study, this research specifically calculates the data in the same period of different years in Fuzhou. In the past twenty years, China has enacted a series of laws and regulations to make control on air pollution [18]. The result of this study well proves that Fuzhou city has achieved favorable performance in terms of atmospheric environment governance. For the same reason, the mass concentration of PM$_{10}$ nowadays respectively decreases by 14.2% (from 66 to 56.65μg/m$^3$) compared with that in 2013 and 2014 [9].
Table 1. Comparison of mass concentration of PM$_{10}$ between Fuzhou and other cities in the world.

| Places               | PM$_{10}$ (μg m$^{-3}$) | References                        | Places               | PM$_{10}$ (μg m$^{-3}$) | References                        |
|----------------------|--------------------------|-----------------------------------|----------------------|--------------------------|-----------------------------------|
| Fuzhou city, China   | 54.65±24.07              | Present study                     | Erzurum, Turkey      | 31                       | Hanefi Bayraktar et al. (2016) [19]|
| Fuzhou city, China   | 66±29                    | Yungang Wang et al. (2014) [9]    | Delhi, India         | 208±14                   | Guttikunda and Calori (2013) [20]  |
| Patna, India         | 192.0±132.8              | Tiwari S et al. (2016) [21]       | Dhaka, Bangladesh    | 97.7                     | Begum et al. (2013) [22]           |

4.2. Relationships between PM10 and other pollutants

Other co-pollutants such as SO$_2$, CO, NO$_2$, and O$_3$ are also analyzed during the same period and their hourly means (for two years) are 6.17±2.35μg m$^{-3}$, 0.72±0.18mg m$^{-3}$, 30.10±12.22μg m$^{-3}$ and 92.90±37.38μg m$^{-3}$, respectively. Correlation analysis among the mass concentrations of PM$_{10}$ between SO$_2$, NO$_2$ and O$_3$ is calculated (Table 2). SO$_2$ concentrations show a strong increase during the winter time in Fuzhou, but not significant as the findings in years ago [9]. The correlation coefficient (r) between mass concentrations of PM$_{10}$ and SO$_2$ is 0.67 for the entire study period. When the data is analyzed for various seasons, the correlation between PM$_{10}$ and SO$_2$ is 0.68, 0.65, 0.69 and 0.63 for spring, summer, autumn and winter, respectively. What’s more, the correlation for NO$_2$ and O$_3$ is observed to be 0.50 and 0.44 with PM$_{10}$ during the entire study period. In general, there is a greater exposure risk as pollutants often get trapped in the lower layers of the atmosphere thereby resulting in high concentrations of PM$_{10}$ at the surface.

Table 2. Correlation analysis among PM and gaseous pollutants during the study period.

| PM$_{10}$ | SO2  | CO  | NO2  | O3  |
|-----------|------|-----|------|-----|
| Over all  | 0.67 | 0.36| 0.50 | 0.44|
| Spring    | 0.68 | 0.34| 0.52 | 0.34|
| Summer    | 0.65 | 0.42| 0.45 | 0.76|
| Autumn    | 0.69 | 0.28| 0.36 | 0.53|
| Winner    | 0.63 | 0.22| 0.40 | 0.47|

4.3. Relationships among PM and meteorological parameters

To understand the influences of meteorology on aerosols, this study analyzes the correlation between the PM$_{10}$ concentration and meteorological including temperature (T), atmospheric pressure (AP), relative humidity (RH), wind speed (WS), cloudiness (CN), height of cloud ceiling (HCC), visibility (VIS), dew point temperature (DT) and rainfall (RF). During the research period, the variation of meteorological parameters is observed as follows. The value of T varies from -1.9 to 38.7°C (21.03±7.35°C), AP varies from731.8 to 771.4 mmHg (753.78±11.35mmHg); RH varies from19.0 to 99.0% (with mean value: 74.72±15.61%); WS varies from0 to 12m/s (with mean value: 2.30±1.31m/s) and CN varies from0 to 100% (with mean value: 31.11±11.84%); HCC varies from 200 to 5000m (2743.77±1955.88m), VIS varies from 0.1 to 30 km (14.97±9.67km); DT varies from-15.2 to 27.3°C (16.00±7.65°C) and RF varies from 0 to 155km (14.97±9.67km). The maximal value of T, RF and WS occurs in summer while that of VIS, RH and AP respectively occurs in autumn, spring and winter. The value of RH is much higher in spring and much lower in winter.

There exists a negative correlation between PM$_{10}$ and T (−0.03), RU (-0.27), WS (−0.10), HCC (−0.04), VIS (−0.31), DPT (-0.15) and RF (−0.14). WS and PM$_{10}$ are largely negatively correlated in autumn (-0.17), while such tendency is less prominent in summer (−0.10). This rule of law is found roughly universal in other cities of the world [23, 24]. Results of this study conform to the conclusions
of relevant researches conducted in any other regions in the world. As for RF, it regularly occurs in each month throughout the research period. The data of RF and PM$_{10}$ is monitored and calculated at fixed intervals. There has a negative correlation (−0.14) between RF and PM$_{10}$ for the reason that most of the PMs are absorbed by RF in the end. Through conducting the correlation study, Galindo et al. (2011) [25], Vassilakos et al. (2007) [26] and Seungmin et al. (2011) [27] found a similar negative correlation between PM$_{10}$ and RF.

Next, this study continues to explore the impacts of WD (wind direction) on atmospheric aerosols in Fuzhou city. Fig.3 presents the correlation between PM$_{10}$ mass concentration and seasonal WD (a: spring; b: summer; c: autumn; d: winter). We find a tremendous variation on the mass concentration of PM$_{10}$ along with the variation of WD. For example, in spring and summer, the mass concentration of PM$_{10}$ varies together with the direction of WD from NNE to ENE. Throughout the whole research period, the mass concentration of PM is much higher in cold seasons. It has been found that people tend to burn the crops in winter which increase the accumulation of biomass aerosols. As for PM$_{10}$, the mass concentration achieved the maximal value in winter (60.32μg m$^{-3}$), followed by spring (59.92μg m$^{-3}$), autumn (58.91μg m$^{-3}$) and summer (41.92μg m$^{-3}$). This study also analyzes the concentration of PM$_{10}$ in variable conditions, finding that the mass concentration of PM$_{10}$ will reach the maximum in winter (60.36μg m$^{-3}$), followed by autumn (52.15μg m$^{-3}$), spring (50.09μg m$^{-3}$) and summer (41.92μg m$^{-3}$).

Fig.4 presents the sites of main gas emission sources in Fuzhou city and corresponding explanations. Within the research region in Fuzhou, there are considerable factories intersecting with residential regions, including both power plants and chemical industries. As a consequence, southeasterly wind would blow the air pollutants from these sources to other places. Whereas, the wind would not blow the pollutants from local regions back to the source regions.

Table 3. Correlation analysis among PM$_{10}$ and meteorological factors during different seasons.

|        | PM$_{10}$ | T  | AP | RU  | WS  | CC  | HCC | VIS | DPT | RF  |
|--------|-----------|----|----|-----|-----|-----|-----|-----|-----|-----|
| Over all study | -0.0301 | 0.060 | -0.273 | -0.0102 | 0.021 | -0.035 | -0.306 | -0.148 | -0.138 |
| Spring | -0.276 | -0.054 | -0.276 | -0.045 | 0.011 | -0.018 | -0.203 | 0.098 | -0.167 |
| Summer | -0.342 | 0.193 | -0.282 | -0.059* | -0.002 | -0.113 | -0.265 | 0.237 | -0.140 |
| Autumn | -0.001 | 0.215 | -0.267 | -0.165 | 0.060* | -0.106 | -0.337 | -0.173 | -0.164 |
| Winner | 0.110 | 0.061* | -0.296 | -0.068* | 0.002 | 0.016 | -0.255 | -0.140 | -0.176 |

**Figure 3.** Mean mass concentrations of PM10 with respect to wind directions during spring, summer, autumn and winter seasons for calm condition (C) and variable condition (V) during the study period.
5. Conclusion
This study analyzes the correlation between mass concentration of PM$_{10}$ and meteorological parameters including T, AP, RH, WS, CN, HCC, VIS, DT and RF. There exists negative correlations between PM$_{10}$ and T ($-0.03$), RU ($-0.27$), WS ($-0.10$), HCC ($-0.04$), VIS ($-0.31$), DPT ($-0.15$) and RF ($-0.14$). This study continues to explore the impacts of WD on atmospheric aerosols in Fuzhou city. As a consequence, southeasterly wind would blow the air pollutants from the sources to the city area. Subsequently, this study analyzed the impacts of typhoons in the research regions during September $10^{th}$ 2016 - September $16^{th}$ 2016. During this period of typhoon, the mass concentration of PM$_{10}$ and PM$_{2.5}$ would decrease to a large extent. Furthermore, in comparison with coarse particulates, the fine particulates would have more prominent changes in typhoon period.

References
[1] Rokjin J. Park A, D.J.J.A. Regional visibility statistics in the UnitedStates: natural and transboundary pollution in uences, and implications for theregional haze rule. Atmos Environ 2006, 40.
[2] Molnar. Trends in visibility over Hungarybetween 1996-2002. Atmos Environ 2008, 42, 2621-2629.
[3] Mannucci PM, H.S.M.I. Effects on health of air pollution: a narrative review. Internal and Emergency Medicin 2015, 10, 657-662.
[4] Massimo Stafoggia, G.C. Long-term exposure to ambient air pollution and incidence of acute coronary events-analysis of eleven European cohorts from the ESCAPE Project. Environ Health Perspect 2014, 122, 919-925.
[5] Richard Atkinson, I.M.C.A. Long-term exposure to outdoor air pollution and incidence of cardiovascular diseases. Epidemiology 2013, 24, 44-53.
[6] Myhre, G. Consistency between satellite-derived and modeled estimates of the direct aerosol effect. Science 2009, 325, 187-190.
[7] Peter A. Alpert, P.A.A.W. The influence of marine microbial activities on aerosol production: A laboratory mesocosm study. Journal of Geophysical Research (Atmospheres) 2015.
[8] Marco Natali, A.Z.A. Assessment of trace metal air pollution in Paris using slurry-TXRF analysis on cemetery mosses. Environ Sci Pollut R 2016, 23, 23496-23510.
[9] Wang, Y.C.; Ying, Q.; Hu, J.; Zhang, L. Spatial and temporal variations of six criteria air pollutants in 31provincial capital cities in China during 2013–2014. Environ Int 2014, 73, 413-422.
[10] Filonchyk, M.; Yan, H.; Yang, S.; Hurynovich, V. A study of PM2.5 and PM10 concentrations in the atmosphere of large cities in Gansu Province, China, in summer period. J Earth Syst Sci 2016, 125, 1175-1187, doi:10.1007/s12040-016-0722-x.
[11] Tian, Y.; Shi, G.; Huangfu, Y. Seasonal and regional variations of source contributions for
PM10 and PM2.5 in urban environment. Sci Total Environ 2016, 557-558, 697-704.

[12] Haijun Zhou, J.H.B.Z.; Tao Liu, Y.Y. The distribution of PM10 and PM2.5 carbonaceous aerosol in Baotou, China. Atmos Res 2016, 178, 102-113.

[13] Hu, X.; Hong, W.; Qiu, R. Geographic variations of ecosystem service intensity in Fuzhou City, China. Sci Total Environ 2015, 512-513, 215-226.

[14] Lingling Xu A, C.X.C.J. Seasonal variations and chemical compositions of PM2.5 aerosol in the urban area of Fuzhou, China. Atmos Res 2012, 104, 264-272.

[15] Cai, Y.; Zhang, H.; Zheng, P.; Pan, W. Quantifying the Impact of Land use/Land Cover Changes on the Urban Heat Island: A Case Study of the Natural Wetlands Distribution Area of Fuzhou City, China. Wetlands 2016, 36, 285-298, doi:10.1007/s13157-016-0738-7.

[16] Wang, J.; Zhang, Y.; Feng, Y.; Zheng, X.; Jiao, L.; Hong, S. Characterization and source apportionment of aerosol light extinction with a coupled model of CMB-IMPROVE in Hangzhou, Yangtze River Delta of China. Atmos Res 2016.

[17] Liu, B.; Yang, J.; Yuan, J.; et al. Source apportionment of atmospheric pollutants based on the online data by using PMF and ME2 models at a megacity, China. Atmos Res 2017, 185, 22-31.

[18] Ma, X.; Jia, H. Particulate matter and gaseous pollutions in three megacities over China: Situation and implication. Atmos Environ 2016, 140, 476-494.

[19] Bayraktar, H.; Turalioğlu, F.S.; Tuncel, G. Average mass concentrations of TSP, PM10 and PM2.5 in Erzurum urban atmosphere, Turkey. Stoch Env Res Risk a 2008, 24, 57-65.

[20] Guttikunda, S.K.; Calori, G. A GIS based emissions inventory at 1 km × 1 km spatial resolution for air pollution analysis in Delhi, India. Atmospheric Environment 2013, 67, 101-111.

[21] Tiwari, S.; Tunved, P.; Hopke, P.K.; Srivastava, A.K.; Bisht, D.S.; Pandey, A.K. Observations of ambient trace gas and PM10 concentrations at Patna, Central Ganga Basin during 2013-2014: The influence of meteorological variables on atmospheric pollutants. Atmos Res 2016, 180, 310.

[22] Begum, B.A.; Hopke, P.K.; Andreas. Air pollution by fine particulate matter in Bangladesh. 2013.

[23] Mukesh Sharma, S.M. Assessment of ambient air PM10 and PM2.5 and characterization of PM10 in the city of Kanpur, India. Atmos Environ 2005, 39, 6015-6026.

[24] Cao, J.; Zhu, C.; Chow, J.C.; et al. Black carbon relationships with emissions and meteorology in Xi'an, China. Atmospheric Research 2014, 194-202.

[25] Galindo, N.; Varea, M.; Gil-Moltó, J. The Influence of Meteorology on Particulate Matter Concentrations at an Urban Mediterranean Location. Water Air Soil Poll 2011, 215, 365-372.

[26] Vasilakos; Veros, et al. Estimation of selected heavy metals and arsenic in PM10 aerosols in the ambient air of the Greater Athens Area, Greece. Journal of Hazardous Materials 2007, 140, 389-398.

[27] Lee, S.; Ho, C.; Choi, Y. High-PM10 concentration episodes in Seoul, Korea: Background sources and related meteorological conditions. Atmos Environ 2011, 45, 7240-7247.