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# Temporal and Spatial Distribution Characteristics of Atmospheric $PM_{2.5}$ Concentrations in Guiyang, China

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## ABSTRACT

The temporal and spatial variations of ambient particulate matter ($PM_{2.5}$) concentrations, effects of meteorological parameters and air mass trajectories in Guiyang were studied. The results showed that the overall average atmospheric $PM_{2.5}$ concentrations in Guiyang were calculated to be 33 µg.m$^{-3}$ in 2017, and were comparatively lower in northeast region and relatively higher in other regions among the four seasons. Monthly atmospheric $PM_{2.5}$ concentrations decreased in the first half of 2017 and increased in the second half as a whole. The frequencies of occurrence of atmospheric $PM_{2.5}$ concentrations exceeding the World Health Organization (WHO) guideline value, China's Ambient Air Quality Standard grade I, and grade II were 53%-67%, 33%-46%, and 7%-9%, respectively. These results suggested that a significant difference of temporal and spatial distribution characteristics of atmospheric $PM_{2.5}$ concentrations presented in Guiyang, and the situation of atmospheric $PM_{2.5}$ pollution in Guiyang according to WHO guideline value is still grim. Atmospheric $PM_{2.5}$ concentrations had a significant positive relation to other air quality indexes and were involved by atmospheric temperature, relative humidity, wind velocity, and surface temperature, demonstrating that atmospheric $PM_{2.5}$ pollution is the result of joint action of various factors. The 72 h backward trajectories pointed out that there were no long distance sources for Guiyang dust events. The results of potential source contribution function, concentration-weighted trajectory, and clustering analysis of air mass trajectories showed that endogenesis source was the major source for air pollution in Guiyang.

## INTRODUCTION

Particles with an aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$), which originate from both anthropogenic emission sources and natural processes, can substantially decrease the atmospheric visibility and influence the atmospheric environmental quality (Zhang et al. 2006, Hyslop 2009, Wang & Fang 2016, Ye et al.2018). But the far more serious problem is that $PM_{2.5}$ can enter the human respiratory system, even penetrate through lung cells into the blood circulation, thus posing a detrimental threat to human health as it can adsorb a large amount of heavy metal, organic matter, bacteria, and viruses (Pope & Dockery 2006, COMEAP 2009, 2010). China is experiencing severe $PM_{2.5}$ pollution problem at present, especially in the developed areas (Van et al. 2015, Zhang et al. 2017). There were about more than 80% people lived in the region where air quality did not reach the air quality standard (Apte et al. 2015). Therefore, the characteristics of ambient $PM_{2.5}$ pollution in some cities of China were strongly considered (Wang & Fang 2016, Li et al. 2017).

Atmospheric $PM_{2.5}$ pollution is a very complicated process because many factors (wind direction and speed, atmospheric humidity, surface temperature, pollution source, air mass trajectories, etc.) are involved (Amodio et al. 2012, Abderrahim et al. 2016). Usually elevated atmospheric $PM_{2.5}$ concentrations are the results of unfavourable meteorological conditions, such as high atmospheric humidity, low surface temperature, air mass across atmospheric contaminated areas and so on (Abderrahim et al. 2016, Biancofiore et al. 2017). In addition, these factors are of great importance for forecasting $PM_{2.5}$ concentration. Therefore, the influence of these factors on atmospheric $PM_{2.5}$ concentration must be clarified in the process of government's atmospheric environmental management.

Guiyang, a typical provincial capital in southwest China, has 4.9 million people and 1.2 million vehicles. It is located in the Yunnan-Guizhou Plateau, at an average elevation of 1,100 m above sea level. Also, Guiyang is in the watershed area for the Yangtze River and the Pearl River, and has a subtropical humid mild climate. The circulation pattern is ferrel cell. The economic development of Guiyang lags behind the coastal cities in China. It is also staring urban atmospheric environmental pollution with the economic development. However, the temporal and spatial variation of atmospheric $PM_{2.5}$ concentrations and the current

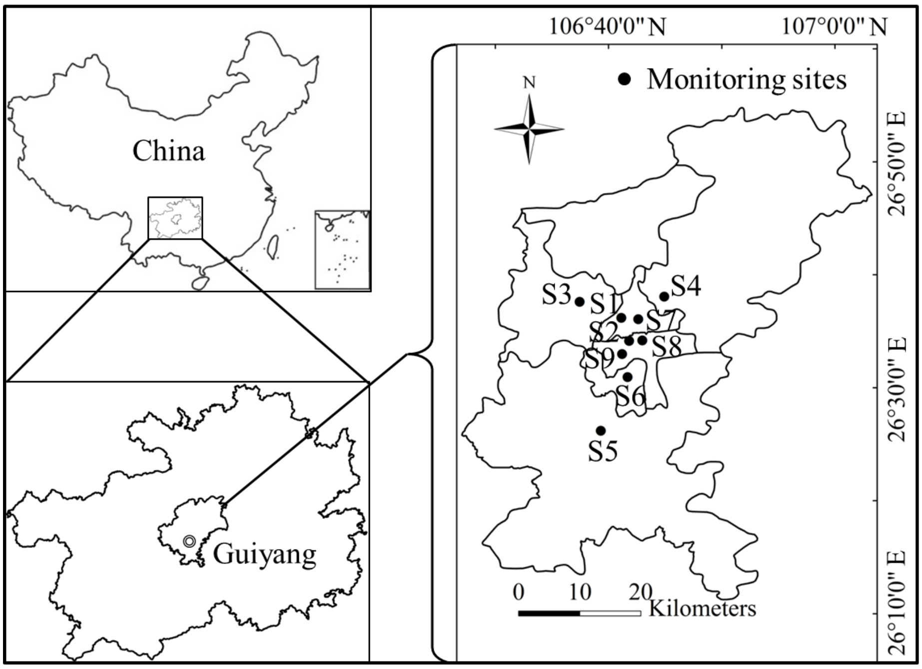


Fig. 1: Locations of monitoring stations in Guiyang.

meteorological factors involved are not clear in Guiyang.

From the knowledge gaps outlined above, our objectives were to (1) identify the characteristics of temporal and spatial variations of atmospheric $PM_{2.5}$ concentrations in Guiyang, (2) investigate the effects of meteorological parameters on atmospheric $PM_{2.5}$ concentrations, and (3) discuss the role and potential source of air mass trajectories in atmospheric $PM_{2.5}$ pollution of Guiyang.

## MATERIALS AND METHODS

### Study Area

Ma'anshan (S1, 106.6856° E, 26.6029° N), Environmental protection site (S2, 106.6971° E, 26.5689° N), Jianhu Road (S3, 106.6243° E, 26.6266° N), Yanzichong (S4, 106.7487° E, 26.6343° N), Biyunwo (S5, 106.6554° E, 26.4364° N), Zhongyuan Country (S6, 106.6948° E, 26.5155° N), Hongbianmen (S7, 106.7105° E, 26.6009° N), Xinhua Road (S8, 106.7164° E, 26.5697° N), and Taiciqiao (S9,106.6867° E, 26.5495° N) were selected as monitoring sites for Guiyang by Chinese Ministry of Environmental Protection (Fig. 1). We have also choosen the same sites for analysing in this study.

### Data Sources

The hourly concentrations of $PM_{2.5}$, $PM_{10}$, $SO_2$, $NO_2$, $O_3$ and CO were derived from the urban air quality real-time publishing platform of the China National Environmental Monitoring Centre (http://106.37.208.233: 20035/). Monitoring method has been described by Hu et al. (2014). The annual mean, quarterly average, and monthly averages were all calculated based on arithmetic mean value of 24-hour average within a year, quarter and month, respectively. Meteorological data were obtained from China Meteorological Data Service Center (http://data.cma.cn/). All data presented in this study were in the period from January 1, 2017 to December 31, 2017. Generally, March, April, and May are considered as spring months, June, July, and August are considered as summer months, September, October, and November are considered as autumn months and December, January and February are considered as winter months.

## RESULTS

### Overview of Atmospheric $PM_{2.5}$ Mass Concentration

The overall average atmospheric $PM_{2.5}$ concentrations for all sites were calculated to be 33 $\mu g.m^{-3}$. The value was lower than China's Ambient Air Quality Standard (AAQS) (BG3095-2012)(MEP2012) grade II (35 $\mu g.m^{-3}$), but exceeding both AAQS grade I (15 $\mu g.m^{-3}$) and the World Health Organization (WHO) guideline value of 10 $\mu g.m^{-3}$. Sum of the days when 24-hour mean of $PM_{2.5}$ lower than WHO guideline value of 25 $\mu g.m^{-3}$ ranged from 121-172 d. However, those values were much higher when AAQS grade I and grade II were

Table1: The sum of 24-hour mean of atmospheric $PM_{2.5}$ in various ranges at different sites in 2017.

| Range ($\mu g.m^{-3}$) | Days | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | average |
| < 25 | 143 | 172 | 123 | 170 | 121 | 166 | 134 | 125 | 135 | 143 |
| < 35 | 208 | 246 | 197 | 237 | 203 | 228 | 197 | 204 | 203 | 214 |
| < 75 | 331 | 337 | 342 | 341 | 337 | 334 | 335 | 335 | 338 | 337 |

selected as standard concentration limits (Table 1). The frequencies of occurrence of atmospheric $PM_{2.5}$ concentrations exceeding WHO guideline value, AAQS grade I, and grade II were 53%-67%, 33%-46%, and 7%-9%, respectively. Those results suggested that the situation of atmospheric $PM_{2.5}$ pollution in Guiyang according to WHO guideline value is still grim.

### Seasonal Variation

The characteristics of spatial distribution of atmospheric $PM_{2.5}$ concentrations in Guiyang, which were calculated based on Kriging spatial interpolation algorithm (Goovaerts 2000), were significantly different among four seasons (Fig. 2). Atmospheric $PM_{2.5}$ concentrations ranged from 26.32 $\mu g.m^{-3}$ to 39.26 $\mu g.m^{-3}$, and were relatively higher in western and southwest areas in spring. In summer and autumn, atmospheric $PM_{2.5}$ concentrations were calculated to be 14.18-28.38 $\mu g.m^{-3}$ and 26.27-34.75 $\mu g.m^{-3}$, respectively. Atmospheric $PM_{2.5}$ concentrations in all the areas except northeast region were relatively higher in the two seasons. In winter, atmospheric $PM_{2.5}$ concentrations ranged from 44.78 $\mu g.m^{-3}$ to 49.96 $\mu g.m^{-3}$, and were relatively higher in southeast and northwest areas. Overall, atmospheric $PM_{2.5}$ concentrations were comparatively lower in northeast region and relatively higher in the other regions among the four seasons. This showed a significant difference in temporal and spatial distribution characteristics of atmospheric $PM_{2.5}$ concentrations in Guiyang.

### Monthly Variation

Monthly atmospheric $PM_{2.5}$ concentrations decreased in the first half of 2017 and increased in the second half as a whole, but there was no significant regularity in atmospheric $PM_{2.5}$ concentrations of different sites within any month. Higher monthly atmospheric $PM_{2.5}$ concentrations were observed in January (46.8±3.8 $\mu g.m^{-3}$), February (42.8±4.6 $\mu g.m^{-3}$), November (46.6±5.2 $\mu g.m^{-3}$), and December (53.2±5.4 $\mu g.m^{-3}$), and lower values were observed in June (21.4±6.2 $\mu g.m^{-3}$), July (19.5±4.3 $\mu g.m^{-3}$), August (20.0±4.6 $\mu g.m^{-3}$), September (21.7±4.4 $\mu g.m^{-3}$), and October (22.5±4.7 $\mu g.m^{-3}$). These results were lower than atmospheric $PM_{2.5}$ concentrations in 2013 by 56%-60% (Liang 2015). Atmospheric $PM_{2.5}$ concentrations of all and five months can be up to standard according to AAQS grade II and grade I, respectively. However, every month's atmospheric $PM_{2.5}$ concentrations were above WHO annual mean, and only four month's atmospheric $PM_{2.5}$ concentrations were under WHO 24-hour mean (Fig. 3).

## DISCUSSION

### Relationship Among Air Quality Indexes

Sulphate radicals and nitrate radicals, the key chemical composition of atmospheric $PM_{2.5}$, can be respectively generated by photochemical reactions of sulphur dioxide and nitrogen dioxide (Angelino et al. 2001, Proemse et al. 2012). The presence of $O_3$ can facilitate these reactions because it is a strong oxidizing chemical. Therefore, atmospheric $PM_{2.5}$ concentrations had a significant positive relation to the concentrations of $SO_2$, $NO_2$, and suggested that secondary reactions were of great importance for the formation of aerosol particles (Table 2) (Angelino et al. 2001). In addition, atmospheric $PM_{2.5}$ concentrations were positively associated with CO, which had a significant positive relation to the concentrations of $SO_2$ and $NO_2$ (Table 2), showing that emissions from fossil fuels were the import pollution source for $PM_{2.5}$ (Weber et al. 2007). The results were consistent with pollution sources apportionment by positive matrix factor model and showed that the coal-fired, biomass combustion and transportation emissions were the predominant sources for $PM_{2.5}$ in Guiyang (Liang 2015).

### Relationship Between Atmospheric $PM_{2.5}$ Concentration and Meteorological Parameters

As surface and atmospheric temperature rise, and thermal motion speed of gas molecules increase simultaneously. Diffusion rate of atmospheric pollutants from surface to high altitude thus elevate and make the atmospheric $PM_{2.5}$ concentrations to decrease (Hien et al. 2002). Generally, atmospheric $PM_{2.5}$ concentrations decrease with raising wind velocity because of turbulent diffusivity (Degaetano & Doherty 2004). The contrary phenomenon often occurs during sandstorms (Claiborn et al. 2000). Atmospheric stability becomes more stable when the atmospheric pressure

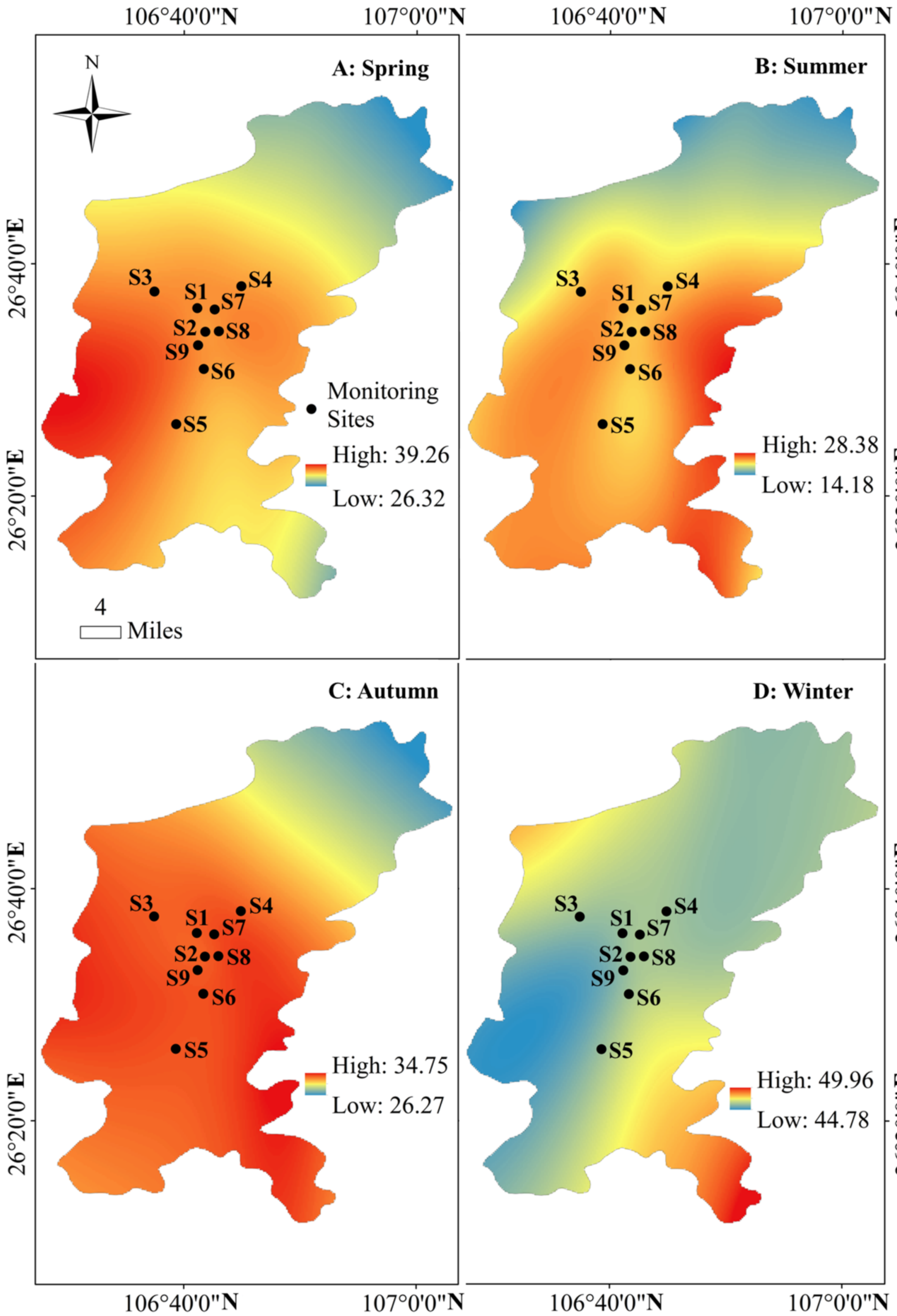


Fig. 2: Spatial distribution characteristics of atmospheric $PM_{2.5}$ concentrations in different seasons.

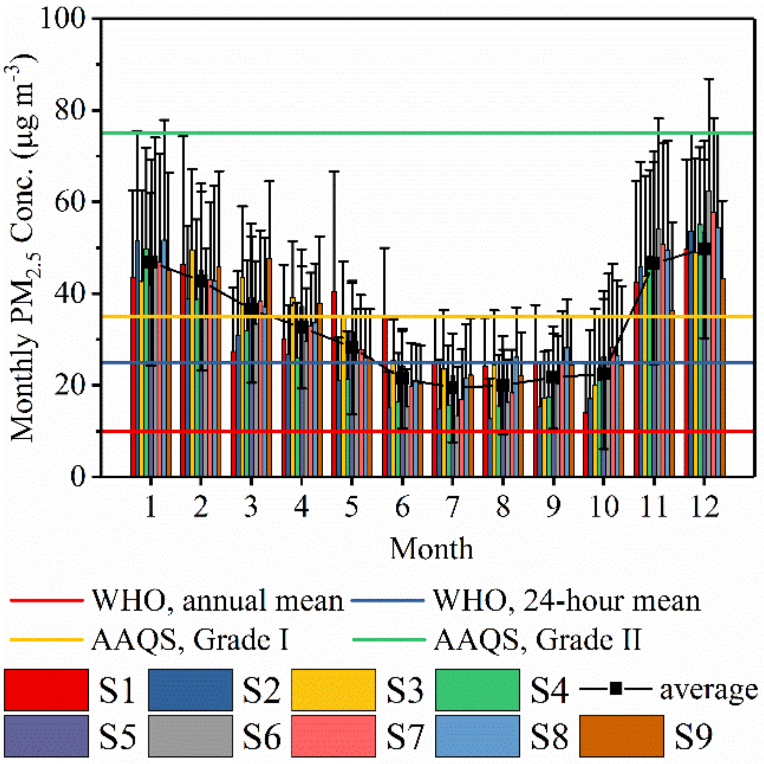


Fig. 3: Monthly atmospheric $PM_{2.5}$ concentrations for monitoring sites.

arises, and the vertical migration rate of pollutants decrease at the same time (Green et al. 2015). Thus, atmospheric $PM_{2.5}$ concentration can elevate in the condition with high atmospheric pressure. The water vapour condensation can form secondary aerosol particles when atmospheric humidity increases (Weber et al. 2007). Sulphate and nitrate, an important component in these particles, will congeal into larger particles through collides (Proemse et al. 2012). The generation rate of atmospheric $PM_{2.5}$ is thus enhanced. Therefore, correlation analysis indicates that atmospheric $PM_{2.5}$ concentrations had significant positive relation to atmospheric pressure, and negative relation to surface temperature, atmospheric temperature, wind velocity and relative humidity (Table 3). The rain and snow will capture particulates in the air through the pathways, including collision and adsorption in the precipitation process (Hien et al. 2002). Photochemical reactions of sulphur oxides and nitrogen oxides can facilitate the formation rate of aerosol particles (Anastasio 2012). The atmospheric $PM_{2.5}$ concentrations should be high on a sunny day and low on a rainy day based on these theories. In fact, we found that atmospheric $PM_{2.5}$ concentrations had nothing to do with amount of precipitation and sunshine duration (Table 3). These results demonstrate that the atmospheric $PM_{2.5}$ concentrations cannot be affected by a single factor. Air pollution is the result of joint action of various factors.

Stepwise regression analysis (Sun et al. 2015) was used to find influencing meteorological factors among these parameters involved in atmospheric $PM_{2.5}$ concentrations. Atmospheric $PM_{2.5}$ concentrations were apportioned to the four principal components (atmospheric temperature, relative humidity, wind velocity and surface temperature) by stepwise regression. The proportion of the variance for atmospheric $PM_{2.5}$ concentrations explained by this model was 0.459 (Table 4), which was much lower than 1.0, suggesting that there were some other factors, such as atmospheric chemistry reaction, involved in atmospheric $PM_{2.5}$ concentrations (Anastasio 2012). The relationship among air quality indexes and between atmospheric $PM_{2.5}$ concentrations and meteorological parameters confirmed this hypothesis. Atmospheric temperature was responsible for 0.203 of atmospheric $PM_{2.5}$ concentrations, which indicated that atmospheric temperature was the most important variable of atmospheric $PM_{2.5}$ concentrations in Guiyang.

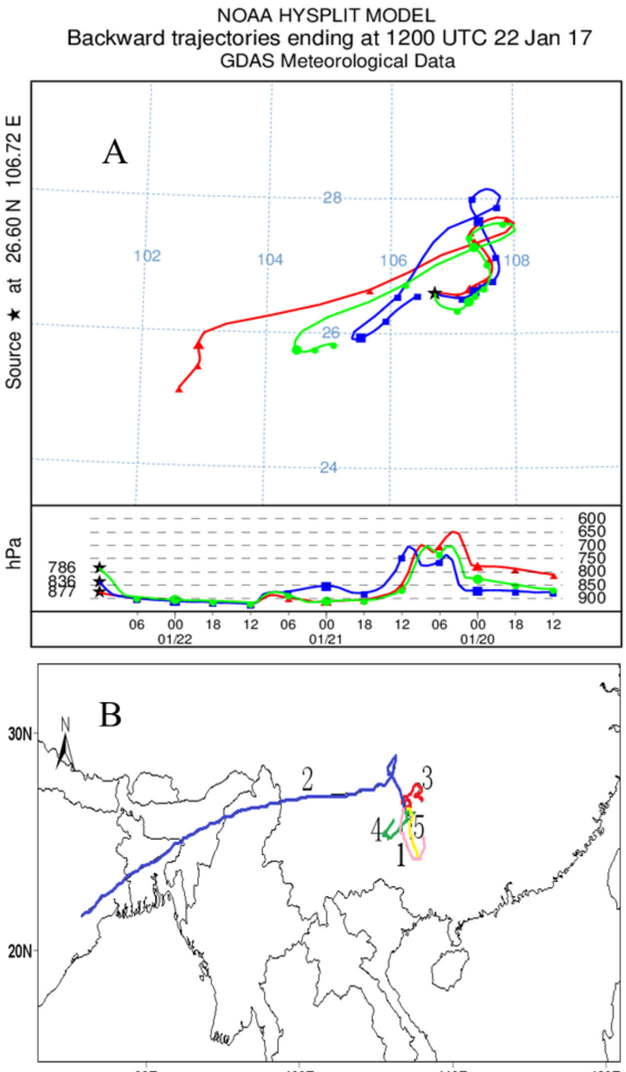


Fig. 4: Back-trajectories in 72 h of aatmospheric $PM_{2.5}$ episode day (A) and airflow back-trajectories clusters in January (B).

## Effects of Air Mass Trajectories and Potential Source

The 72 h backward trajectories, which were calculated using the Hybrid Single Particle Lagrangian Integrated Trajectory Model developed by Air Resources Laboratory in the National Oceanic and Atmospheric Administration, starting at three altitudes of 100, 500 and 1000 m for a high concentration event (01/22/2017) to examine the histories of air mass that led to high atmospheric $PM_{2.5}$ concentration (Hu et al. 2014, Chen et al. 2015). The results pointed out that there was no long distance source for Guiyang dusts event. The longest trajectory was at an altitude of 1000 m and from the northeast of Yunnan Province, and the others were from Guizhou Province (Fig. 4A).

Clustering analysis by Draxler et al. (2009) and Draxler & Hess (1998), which was used to classify the air flow backward trajectories of Guiyang in January, also found the same phenomenon. The longest trajectory passed over India, Bangladesh, Burma and the northern Yunnan Province, and had the minimum atmospheric $PM_{2.5}$ concentration. The shorter trajectories were mainly from the province of Guizhou (Fig. 4B and Table 5). This elucidated that the distance of trajectories was negatively correlated to atmospheric $PM_{2.5}$ concentrations in air masses. Also, clustering analysis indicated that wind velocity was very low, regional meteorological condition was stable, and diffusion capacity was weak in January. The meteorological parameters proved this conclusion. For example, the surface temperature was very low (6.3°C), atmospheric pressure was relatively high (88740 pa), and wind velocity was slow (1.8 $ms^{-1}$) on 22 January 2017. Therefore, the atmospheric $PM_{2.5}$ concentrations in these time phases were relatively high, and endogenesis pollution may be the major source for Guiyang.

Potential source contribution function (PSCF) (Han et al. 2007) and concentration-weighted trajectory (CWT) (Zhao et al. 2015) were applied to identify the potential

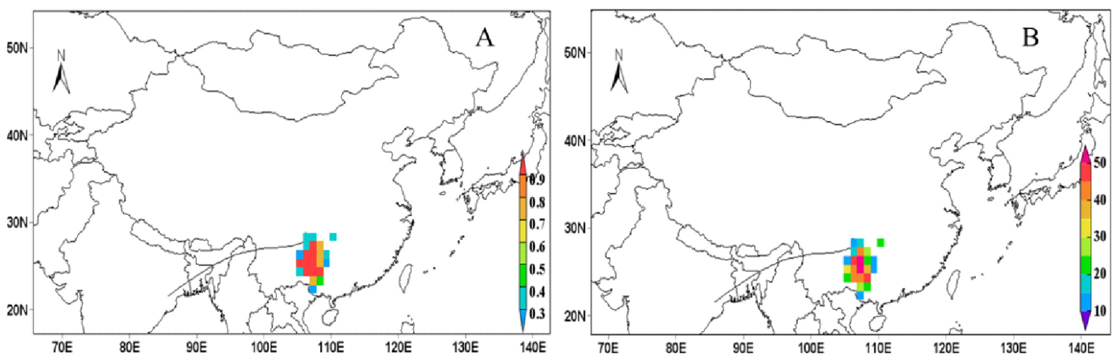


Fig. 5: Potential source zones (A) and weighted trajectory (B) of Guiyang $PM_{2.5}$.

Table 2: Correlation coefficient among air quality indexes.

| Index | $PM_{2.5}$ | CO | $NO_2$ | $O_3$ | $PM_{10}$ | $SO_2$ |
|---|---|---|---|---|---|---|
| $PM_{2.5}$ | 1 | | | | | |
| CO | 0.665** | 1 | | | | |
| $NO_2$ | 0.734** | 0.613** | 1 | | | |
| $O_3$ | 0.210** | -0.161** | 0.218** | 1 | | |
| $PM_{10}$ | 0.954** | 0.586** | 0.796** | 0.276** | 1 | |
| $SO_2$ | 0.740** | 0.682** | 0.748** | 0.017 | 0.739** | 1 |

** Correlation is significant at the 0.01 level (2-tailed).

Table 3: The results of correlation analysis between atmospheric $PM_{2.5}$ concentrations and meteorological parameters.

| Meteorological parameters | Analysis results | | |
|---|---|---|---|
| | Pearson Correlation | Sig. (2-tailed) | Std. Error |
| Surface temperature | -0.449** | 0.00 | 0.036 |
| Atmospheric temperature | -0.453** | 0.000 | 0.036 |
| Amount of precipitation | 0.022 | 0.682 | 0.059 |
| Wind velocity | -0.209** | 0.000 | 0.049 |
| Atmospheric pressure | 0.429** | 0.000 | 0.039 |
| Sunshine duration | 0.009 | 0.859 | 0.051 |
| Relative humidity | -0.321** | 0.000 | 0.047 |

**Correlation is significant at the 0.01 level (2-tailed)

Table 4: Results of stepwise procedure analysis.

| Step | Variables entered | R | R Square | Adjusted R Square | Std. Error of the Estimate | Coefficient Of regression | t | Sig. |
|---|---|---|---|---|---|---|---|---|
| 1 | Wedu | 0.453 | 0.205 | 0.203 | 16.72926 | -0.453 | -9.583 | 0.00 |
| 2 | Wedu | 0.613 | 0.376 | 0.372 | 14.84315 | -0.532 | -12.455 | 0.00 |
| | Sidu | | | | | -0.421 | -9.86 | |
| 3 | Wedu | 0.664 | 0.441 | 0.436 | 14.07094 | -0.549 | -13.544 | 0.00 |
| | Sidu | | | | | -0.432 | -10.659 | |
| | Fengshu | | | | | -0.255 | -6.406 | |
| 4 | Wedu | 0.682 | 0.465 | 0.459 | 13.78158 | 0.246 | 1.214 | 0.00 |
| | Sidu | | | | | -0.478 | -11.567 | |
| | Fengshu | | | | | -0.261 | -6.687 | |
| | Dibiaowendu | | | | | -0.821 | -4.003 | |

Table 5: Statistical results of atmospheric $PM_{2.5}$ concentrations in January.

| Cluster | Number | Pathways | Mean value ($\mu g.m^{-3}$) | Ration |
|---|---|---|---|---|
| 1 | 7 | Southern GuizhouNorthern Guangxi | 41.86 | 22.58% |
| 2 | 1 | India, Bangladesh, Burma, Northern Yunnan | 41.28 | 3.23% |
| 3 | 6 | Northeast Guizhou | 50.37 | 19.35% |
| 4 | 5 | Southwest of Guizhou | 44.42 | 16.13% |
| 5 | 12 | Southeastern Guizhou | 49.47 | 38.71% |
| Sum | 31 | | 46.85 | |

source zones and its contribution for ambient $PM_{2.5}$ in Guiyang in January. Both PSCF (Fig. 5A) and CWT (Fig. 5B) showed that the southern of Guizhou Province and the northern of Guangxi Province were the main dust sources of Guiyang. However, these regions were underdeveloped areas in China and the ambient air qualities in these regions were excellent in general (Zhou et al. 2018). The results of PSCF and CWT were calculated based on air mass trajectories which could help to analyse the potential sources and their contribution to air contaminant. Thus, they could not be used to determine the exact source of air dust because $PM_{2.5}$ was not only from anthropogenic emissions, but also can be generated through complicated atmospheric chemistry reaction (Anastasio 2012). The discussion presented above also confirmed this view. This elucidated that endogenesis source was the major source for air pollution in Guiyang. Therefore, the implementation of air environment quality management in Guiyang should focus on decreasing endogenous anthropogenic emissions.

## CONCLUSIONS

The overall, seasonal monthly atmospheric $PM_{2.5}$ concentrations analysed in this study suggested that there was a significant difference in the temporal and spatial distribution characteristics of atmospheric $PM_{2.5}$ concentrations in Guiyang. Also, the results showed that the situation of $PM_{2.5}$ pollution in Guiyang according to WHO guideline value was still grim at present.

Atmospheric temperature, relative humidity, wind velocity and surface temperature were the most important meteorological parameters involved in ambient $PM_{2.5}$ concentrations in Guiyang. External pollutant sources from other provinces in China had no effect on $PM_{2.5}$ pollution in Guiyang, and endogenesis source was the major source for air pollution.

## ACKNOWLEDGMENTS

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