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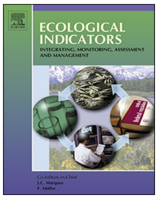

Trend analysis and forecast of $PM_{2.5}$ in Fuzhou, China using the ARIMA model

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ABSTRACT

Atmospheric haze from particulate matter has become a major health concern in many large and medium-sized cities of China. Fine airborne particles, $PM_{2.5}$, are a major component of haze, and the reasons for their fluctuating concentrations need to be better understood to improve air quality. While much of the air quality data from the China National Environmental Monitoring Centre (CNEMC) has already been analyzed for larger Chinese cities such as Beijing and Shanghai, the data from Fuzhou is the topic of this study. Time series data of pollutant concentrations and meteorological parameters were accessed for Fuzhou from August 2014 to July 2016, covering two cold periods (November through February) and two warm periods (May through July). $PM_{2.5}$ concentrations were compared with those of other pollutants and with meteorological parameters, and the AutoRegressive Integrated Moving Average (ARIMA) model was applied to forecast $PM_{2.5}$ concentrations. The correlation analysis of Spearman's rho showed that $PM_{2.5}$ concentrations had significant positive correlations with PM_{10}, SO_2 and NO_2 concentrations, while they had negative correlations with meteorological parameters. The ARIMA results showed that $PM_{2.5}$ concentrations experienced seasonal fluctuations over the two years, which were higher in the cold periods and lower in the corresponding warm periods, ranging from 23 to 52 $\mu g/m^3$ and from 19 to 31 $\mu g/m^3$, respectively. Average $PM_{2.5}$ concentrations during these same cold periods and warm periods were 35 $\mu g/m^3$ over the two cold periods, which was 52% higher than the 23 $\mu g/m^3$ averaged over the two warm periods. Compared to the two observed years, 2014–15 and 2015–16, the forecast of $PM_{2.5}$ concentrations for 2016–17, ranging from about 15 to 30 $\mu g/m^3$, exhibited similar seasonal fluctuations but also reduced in the same period, ranging from 19 to 52 $\mu g/m^3$. It is speculated that the Fuzhou Government's macro-policy on air quality may be one of the reasons for the decrease in $PM_{2.5}$ concentration during the cold periods. Possible causes were given for the discrepancies between actual and fit values.

1. Introduction

China's reform and opening-up policy, socio-economic development, and the acceleration of industrialization have led to a sustained increase in total energy consumption (Li et al., 2014; Lardy, 2016; Yuan et al., 2016a,b). The increased energy consumption has resulted in serious air pollution (Guo et al., 2017; Peng et al., 2017; Zhang and Li, 2017), with airborne particulate matter attracting special attention in recent years (Zhou and Zhou, 2017).

Particulate matter, floating in the air, comes in a wide range of sizes (Katheeri et al., 2012). Fine particles, also called $PM_{2.5}$, are one of the most complex and harmful chemical components of particulate matter (Dieme et al., 2012; Kelly and Fussell, 2012; Zhang et al., 2012). $PM_{2.5}$ is the particulate matter of 2.5 μm in diameter or smaller. This can not only easily get into the human body and be dissolved and absorbed at an accelerated rate, causing respiratory and cardiovascular diseases (He et al., 2001; Zhu and Zhao, 2014), as well as severe environmental problems such as haze (Xue et al., 2014; Yuan et al., 2016a,b; Ropkins et al., 2017). Haze pollutants are mainly caused by human factors such as industrial emissions, coal combustion, and automobile exhaust. Haze occurs when pollutants from human activities are beyond the environment's purifying capacity and is mainly formed by atmospheric pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NOx), $PM_{2.5}$, and PM_{10} (Jiang, 2016; Wang et al., 2017). The former two pollutants

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are gaseous and the latter two are inhalable particulate matter. Moreover, Davis and Guo showed that most of the ambient particulate matter is below $PM_{2.5}$, in the submicron size range (Davis and Guo, 2000), therefore, the particulate matter is the chief culprit in aggravating air pollution (Cuspiliciet al., 2017; Zhou and Zhou, 2017).

Since 2009, haze has appeared frequently in various parts of China (Yuan et al., 2016a,b) and the Chinese government has begun to respond. The measurement of $PM_{2.5}$ was first clearly defined by the "Measurement of Gravity of PM_{10} and $PM_{2.5}$ in Ambient Air," issued by the Ministry of Environmental Protection of the People's Republic of China (MEP), and was implemented on January 1st, 2011 (the MEP has recently been renamed as the Ministry of Ecology and Environment as of 2018, but we retain the older acronym MEP for our 2014–2016 period). MEP also issued the "First-stage Monitoring Implementation Plan for New Air Quality Standards" (FMIPNAQS) on May 24th, 2012, which requires 24-hour monitoring of $PM_{2.5}$ concentrations to be implemented immediately in 74 major cities of China. The China National Environmental Monitoring Centre (CNEMC) has released on-line Urban Air Quality Report of 74 cities of China, which includes monthly mean concentrations of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3 since July 2014 (CNEMC, 2014).

Many studies of $PM_{2.5}$ in China have been carried out. These included the spatial distributions of $PM_{2.5}$ concentrations (Zhang and Cao, 2015), the chemical composition of PM_{10} and $PM_{2.5}$ (Hagler et al., 2006), the characteristics of $PM_{2.5}$ and health impacts (Venners et al., 2003; Cheng et al., 2013), the relationship between visual range and the concentrations of PM_{10} and $PM_{2.5}$ (Yang et al., 2007), and the size distribution of PM (Wu et al., 2002). However, most of these studies focused merely on the physical and chemical ingredients of $PM_{2.5}$, while the analysis of the overall effects of $PM_{2.5}$ failed to include the other pollutants and meteorological parameters, as well as forecast of $PM_{2.5}$, that need to be recognized. In addition, the existing studies of PM-related atmospheric haze have given priority to large tier-1 metropolises such as Beijing, Guangzhou, and Shanghai (Wu et al., 2007; Chang et al., 2009; Wu et al., 2011). But it also needs to be recognized that PM air pollution is a problem not only in metropolises, but also in 2-tier and 3-tier cities, whose air pollution data was gathered as part of the 74-city survey mentioned above (CNEMC, 2014) but was not fully analyzed.

The case study for this investigation into $PM_{2.5}$ forecasting is the city of Fuzhou, one of the cities whose CNEMC data has not yet been analyzed. Fuzhou, a 2-tier city, the capital of Fujian Province, is the central city of Western Taiwan Straits Economic Zone. As one of the starting cities of the Maritime Silk Road, Fuzhou covers an area of 12 000 square kilometers, with a population over 7.5 million. Fig. 1 below displays four factors — GDP, permanent population, per capita salary, and vehicle ownership in Fuzhou from 2014 to 2016. (Note that CNEMC, 2014 is dated from the *start*, not the end, of the two-year survey period.) Fig. 1 shows that each of these four parameters in Fuzhou have been increasing year by year from 2014 to 2016 (Fuzhou Bureau of Statistics, 2016). Assuming other factors were constant, one might predict that the observed increase in vehicle ownership and in GDP from 2014 to 2016, shown below in Fig. 1, could cause an increase in average $PM_{2.5}$ concentrations from one year to the next.

Although the haze episodes in Fuzhou are not the most serious in China, they were sufficient to motivate the Fuzhou government to tackle the air quality problems by undertaking a "Blue Sky of Fuzhou" campaign to improve air quality. Policies such as "Vehicles without green environmental test window stickers cannot enter the Second Ring Road of Fuzhou," "Accelerate elimination of vehicles with yellow license plates (signifying environmental noncompliance)," "Introduce moderate regulations as a response to adverse meteorological changes in Fuzhou air quality," and "Implementation plan for enhancing the environmental air quality plan in Fuzhou" were progressively instituted by the Fuzhou government from 2009 to 2017 to control the pollutants (http://www.fuzhou.gov.cn/zgfzzt/shbj/).

Against this background, it is necessary to analyze the trend of $PM_{2.5}$ in Fuzhou, and correlation analysis of pollutants concentrations and meteorological parameters need to be studied. The paper will illustrate the features of the changes in pollutant concentrations, differences and dependencies, as well as possible causes. In addition, to account for the seasonal fluctuations, the ARIMA model, a time series model which was proposed by Box and Jenkins (Box and Jenkins, 1976), will be employed in this study to forecast $PM_{2.5}$ concentrations. The ARIMA model is accepted as a powerful and widely used statistical tool for analyzing and predicting time series data and recognized as an important statistical prediction model (Romilly, 2005). The merits of the ARIMA model are that it can identify seasonal changes and consider serial correlation within the same time series (Yurekli et al., 2007). The prediction of $PM_{2.5}$ concentrations using the ARIMA model can provide guidance for the control of air pollution.

Therefore, the trend analysis and forecast of $PM_{2.5}$ in Fuzhou can not only provide an understanding of the correlation between concentrations of various pollutants and meteorological parameters in Fuzhou, but may also provide essential guidelines for environmental regulation (Li et al., 2017) to the Fuzhou government.

2. Materials and methods

2.1. Study sites

Fuzhou city is located in the eastern part of Fujian Province, at 25°15′N latitude, 120°31′E longitude and an altitude of 84 m above mean sea level. Its landform is a typical estuary basin (roughly comparable to Los Angeles), and the hilly area accounts for 72.68% of the total area, which is surrounded by mountains. Fuzhou lies on the north bank of the estuary of Fujian's largest river and is an important commercial and government center on the southeast coast of China.

Due to the East Asian Monsoon, Fuzhou has a humid subtropical climate. The sunshine are long, and the rainfalls are sufficient, with very hot and humid in the months from May through July and mild and dry in the months from November through February. The annual mean temperature varies from 20 °C to 25 °C, the annual relative humidity is about 77%, and the annual mean rainfall varies from 900 mm to 2100 mm. Fuzhou often suffers torrential rains during the monsoon from March to May and usually suffers typhoons from July to October. The prevailing winds in the city are commonly a northerly wind during the period from September to May and a southeasterly or southwesterly wind during the period from June to August.

According to the requirements of FMIPNAQS, six national air quality auto-monitoring stations were built in Fuzhou (identified by red in Fig. 2). The station located in Gu Mountain provides the background concentrations of air pollutants as a baseline, while the other 5 stations located in Wusi North road, Ziyang Road, Fujian Normal University, Yangqiao West Road, and Kuai'an are intentionally placed very near major thoroughfares. Those location of the stations were set in accordance with the Ambient Air Quality Monitoring Standards of China and were recognized by China's MEP.

A series of instruments are deployed at each station for auto-monitoring and collecting data. Levels of nitrogen oxide (NO-NO_2-NOx) emissions in ambient air are measured using chemiluminescent technology with the Thermo Scientific™ Model 42i NO-NO_2-NOx Analyzer; levels of SO_2 are measured in ambient air up to 100 ppm with the Thermo Scientific™ Model 43i SO_2 Analyzer; ambient air monitoring instruments are calibrated with the Thermo Scientific™ Model 146i Multi-Gas Calibrator, which can generate gas standards; and $PM_{2.5}$ and PM_{10} airborne particulates are monitored by the Thermo Scientific™ 1405 TEOM™ Continuous Ambient Particulate Monitor. All the pollutants mentioned above are auto-monitored once every 5 min, thus the total number of samples taken from August 2014 through July 2016 were about 1,260,000, and the monthly mean concentrations of these pollutants were announced by CNEMC (CNEMC, 2014).