Effects of fireworks on air quality in the main urban area of Nanchong City during the spring festival of 2014-2019

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Abstract

The discharge of fireworks will cause a sharp deterioration of the urban environmental air quality in the short term, and the duration of the pollution was prolonged.

Keywords: Fireworks, Fine particle (PM₂.₅), Spring Festival, Water-solubility ions, Nanchong City

1. Introduction

The Spring Festival, one of the four traditional festivals in China, has a history of more than 4,000 years. Since ancient times, people have the custom of setting off fireworks and firecrackers on New Year’s Eve. Setting off fireworks and firecrackers can bring people colorful visual experience and add a festive atmosphere for the festival. Fireworks are known to be displayed at national celebrations such as Independence Day in the United States, Deepawali in India, Bonfire Night in the UK, Bastille Day in France, Australia Day in Australia, and New Year’s Eve celebrations around the world [1-3]. However, in the process of setting off fireworks, there will be noise pollution [3], light pollution and a large amount of garbage, as well as a large amount of environmental air pollutants. They include gaseous pollutants (CO, CO₂, SO₂, NOₓ, etc.) [2, 4-7], water-solubility ions such as K⁺, Cl⁻, SO₄²⁻, and granular metal pollutants such as Mg, Al, Ba, Cu, K [1, 8-12]. These environmental air pollutants can float in the air for a long time, causing a sharp deterioration of air quality [5, 13], affecting atmospheric visibility [14], and even harming human health [15-18].

At present, some experts and scholars at home and abroad have carried out a lot of research work about the fireworks on the impact of urban environmental air quality, fireworks setting off release of pollutant concentration change trend and particle state pollutant components (mainly for PM₁₀ and PM₂.₅), physical and chemical characteristics and impact on the human health [1, 2, 4-12, 19-31]. The discharge of fireworks will cause a sharp deterioration of the urban environmental air quality in the short term, and the concom-
tation of PM$_{10}$, PM$_{2.5}$, NO$_2$ and SO$_2$ will rise sharply, especially for PM$_{10}$ and PM$_{2.5}$. Firstly, the hourly concentration of PM$_{10}$ and PM$_{2.5}$ during the discharge period can be several times or even ten times higher than that during the non-discharge period [8, 31]. Secondly, a large amount of dust containing K$^+$, Mg$^{2+}$, Cl$^-$, and other water-soluble ions and metal elements such as Mg, Al, K and Ba will be released in the process of fireworks discharge, which affects the composition and content of PM$_{10}$ and PM$_{2.5}$. Therefore, some scholars suggest that metallic elements should be used as tracers for fireworks such as Mg, Al, K and Ba [14, 26-31].

Located in East Asia, China is the largest monsoon region in the world, and the regional climate change is greatly affected by the monsoon [21]. China’s terrain is high in the west and low in the east, with mountains, plateaus and hills accounting for 67% of the land area, and basins and plains for 33% [23, 27]. Similar to many countries with complex topography, the changing trends and characteristics of ambient air quality in various cities are also fairly different. The huge difference of topography changes the microphysical and meteorological conditions of air pollution, which may affect the key meteorological parameters in the diffusion process of pollutants. The adverse meteorological conditions, such as high temperature, weak wind, stable atmospheric condensation for a long time, temperature inversion and low mixing layer, are the main causes of large-scale air pollution [21, 23]. Pollutants tend to diffuse because of the low temperature, dry air, low relative humidity and high wind speed in northern Chinese cities in winter. Scholars such as Han et al. [22] and Zhang et al. [23] analyzed the impact of fireworks on urban ambient air quality from the perspective of meteorological diffusion conditions for contamination. Their result shows that unfavorable pollution and meteorological diffusion conditions will aggravate urban ambient air pollution and even extend the duration of pollution such as breeze winds or inversions. In comparison with northern cities, southern cities in China, especially basin cities, have higher temperatures, insufficient light, and higher relative humidity in winter, so foggy weather and secondary conversion of particulate pollutants prone to occur. At the same time, with low wind speed, high quiet wind frequency, and frequent temperature inversion, pollutants are easy to accumulate and not easy to spread, which trigger long-term pollution.

Nanchong is located in the northeastern part of the Sichuan Basin. The topography of main urban area is relatively low. The conditions for the diffusion of pollutants in winter are extremely poor, and the rainfall is low, which is not conducive to the diffusion, transfer and sedimentation of pollution. Based on the automatic monitoring data of ambient air in Nanchong from 2014 to 2019, combined with the meteorological data and ambient air PM$_{2.5}$ source analysis data in the corresponding period, the following research was carried out: (1) The impact of fireworks on ambient air quality on New Year’s Eve were analyzed in detail. (2) Analyzed the causes of ambient air pollution during the Spring Festival in Nanchong. (3) Studied the trend of pollutant concentration changes. (4) Focused on the research of the conditions for the removal process of ambient air pollution in Nanchong during the Spring Festival so as to provide a theoretical basis for the prevention and control of ambient air pollution and the early warning and forecasting of ambient air quality in Nanchong. The research results can be used to predict the ambient air quality and have a certain guiding significance for the prevention and control of air pollution in basin cities.

2. Study Area and Data Source

2.1. Study Area and Climate

2.1.1. Study area

Nanchong City (30°35′–31°51′ N, 105°27′–106°58′ E, 256–889 masl) is located in the northeast of Sichuan Basin and the midstream of Jialing River. It is the city with the second biggest population in Sichuan Province. The main urban area of Nanchong City is in the south, which includes the districts of Shunqing, Gaoping, and Jialing. It is high in the northwest and low in the southeast. The study area is shown in Fig. 1.

2.1.2. Climate

Nanchong City belongs to the mid-subtropical humid monsoon climate with four distinct seasons. It is famous throughout the country for its breeze, damp, rainy, and foggy environment. The annual average temperature is 17.1°C and the average annual total sunshine hour is 1,369.1. The distribution of total solar radiation is more in spring and summer than in autumn and winter. The annual average raining days is as high as 183 days, and the average annual total precipitation is about 1,100 mm. There exists a significant seasonal variability in precipitation. The maximum rainfall appears in summer, followed by autumn and spring, and the least in winter. Meanwhile, the relative humidity of the air was relatively high, with an average annual relative humidity of 77%. The prevailing wind is from the northwest. The wind speed is small and the average wind speed for many years is between 1.2–1.7 m/s.

2.2. Data Source and Analysis Method

2.2.1. Data source

Air quality data in this study were collected from automatic monitoring data in the Environmental Monitoring Center of Nanchong City from 2014 to 2019, including standard air pollutants (SO$_2$, CO, NO$_2$, PM$_{10}$, PM$_{2.5}$, and O$_3$). Meteorological data were collected from the website (https://rp5.ru/). The ambient air fine particulate matter (PM$_{2.5}$) source analysis data originated from the project data (project number: 2015FZ0035) of “Nanchong Atmospheric Fine Particulate Matter (PM$_{2.5}$) Pollution Status and Sources Research” research.

Ambient air pollutant automatic monitoring instruments were all produced by Anhui Landun Photoelectron Co. Ltd. Among them, the automatic monitoring instruments of SO$_2$, NO$_2$, and O$_3$ were LHG-01A, automatic monitoring instruments of CO were T300, and the automatic monitoring instruments of PM$_{10}$ and PM$_{2.5}$ were LGH-01B and LGH-01E respectively. The Ambient Air Fine Particulate Matter (PM$_{2.5}$) Source Analysis Project of Nanchong had set up 3 sampling points in the urban area of Nanchong, which were located at the Nanchong Environmental Monitoring Station, Gaoping Monitoring Station and Jialing Environmental Protection Station.
Bureau. PM$_{2.5}$ samples were collected over 24 h (from 10:00 am to the next day 10:00 am) every 6 days with a four-channel sampler (TH-16A, Tianhong Instrument Co., Ltd., China) from December 20th, 2014 to April 30th, 2016. The PM$_{2.5}$ samples were collected on Teflon filters, which were determined the concentrations of ions and elements in PM$_{2.5}$. The Ion Chromatography (IC) (Dionex, IC-2000) for the analysis of anions and cations (including SO$_2^-$, NO$_3^-$, NH$_4^+$, K$^+$, Mg$^{2+}$, and Ca$^{2+}$), and the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent, 7500c) was used to determine the main elements (including P, Ca, Ti, V, Cr, Co, Ni, Cu, Zn, As, Se, Mo, Cd, Tl, Pb, Th, U, Na, Mg, Al, K, Mn, Fe and Ba).

2.3. The Calculation of PM$_{2.5}$ or PM$_{10}$ Contribution Rate

The formula is used to calculate the average concentrations of PM$_{2.5}$ or PM$_{10}$ during the fireworks burning contribution to the Spring Festival’s average concentrations. The calculation of PM$_{2.5}$ or PM$_{10}$ contribution rate is as follows:

$$CR = \frac{(FWC_{PMi}-FTC_{PM}) \times HOUR_{fw}}{FTC_{PM} \times HOUR_{total}}$$ (1)

Where CR is the contribution rate of PM$_{2.5}$ or PM$_{10}$ during the fireworks burning period, FWC$_{PMi}$ is the average concentrations of PM$_{2.5}$ or PM$_{10}$ during the fireworks burning period, FTC$_{PM}$ is the average concentrations of PM$_{2.5}$ or PM$_{10}$ during the Spring Festival, except for the effect of fireworks, HOUR$_{fw}$ is the hours of ambient air pollution for fireworks burning period, HOUR$_{total}$ is the hours of ambient air pollution during the Spring Festival.

2.4. Data Processing and Analysis

All data were analyzed using the statistical software IBM SPSS Statistics 23.0. Specifically, the normality and homoscedasticity of variables were checked by means of the Shapiro-Wilk and Levene tests, respectively. Normal and normalizable data were compared using one-way ANOVAs. The non-parametric tests (with the Kruskal-Wallis test) were used when the variables were unnormalizable. P < 0.05 was considered to be of statistical significance, and P < 0.01 was considered to be significantly correlated. Relationships between chemical components of PM$_{2.5}$ were tested using the Spearman correlation.

Origin-pro 9.0 software were used for data processing and graph drawing.

3. Results

3.1. The Overall Impact of Fireworks on Ambient Air Quality during the Spring Festival

According to the secondary standard of “Ambient Air Quality Standard” (GB3095-2012) [32] and “Technical Regulations on Ambient Air Quality Index (AQI)” (HJ633-2012) [33], during the Spring Festival from 2014 to 2019, the ambient air had been polluted to different degrees in the urban area of Nanchong (Table 1), including New Year’s Eve (NYE), the first day of the first month (NYFD), the second day of the first month (NYSD), the third day of the first month (NYTD), the fourth day of the first month (NYFOD), the fifth day of the first month (NYFID) and the sixth day of the first month (NYSID). During the pollution period, the primary pollutants of ambient air were PM$_{2.5}$. Among them, during the Spring Festival in Nanchong in 2014 and 2016, the degree of ambient air pollution was the heaviest and lasted the longest. In 2014, there were 6 days of serious polluted weather, while there were 3 days of serious polluted weather, 1 day of moderate polluted weather, and 1 day of mildly polluted weather in 2016. 2018 and 2019 are next, with 3 days of polluted weather. In 2015 and 2017, the pollution was lighter and lasted the shortest, with only two days of pollution. In 2015, 2016, 2018, and 2019, the level of ambient air pollution in NYFD was more serious than that of NYE, and the level of ambient air pollution increased. However, the opposite trend (the decrease of pollution) was mainly due to rainfall on NYFD in 2014 and 2017.
3.2.1. The impact on PM$_{2.5}$

3.2.1.1. The impact on the overall concentration of PM$_{2.5}$

Each year, during the Spring Festival, the display of fireworks in Nanchong was concentrated on NYE nights. The discharge caused a significant growth in the daily concentration of PM$_{2.5}$ in the ambient air in the urban area of Nanchong on NYFD. In last six years, NYFD’s daily PM$_{2.5}$ concentration was as high as 176.0, 146.0, 209.0, 80.0, 160.0 and 150.0 µg/m$^3$, which were all higher than the daily concentration limit value of the secondary standard of China (75.0 µg/m$^3$) (Fig. 2(a)). Compared with the...
day of NYE, the daily PM$_{2.5}$ concentration on NYFD during the four-year Spring Festival in 2015, 2016, 2018 and 2019 increased significantly, which increased by 37.7, 80.2, 48.1 and 114.3%, respectively. Due to rain on NYFD in 2014 and 2017, the concentration of PM$_{2.5}$ dropped slightly. And due to the different duration of pollution each year, the average concentration of PM$_{2.5}$ during the Spring Festival of each year varied greatly. During the six-year Spring Festival, the average concentration of PM$_{2.5}$ was 160.0, 71.2, 125.9, 66.7, 75.7 and 72.0 μg/m$^3$, respectively, all higher than the national Grade II standard of annual average concentration (35 μg/m$^3$). In terms of the pollution period during the Spring Festival of each year, the average concentration of PM$_{2.5}$ was relatively high (Table 2), exceeding the national secondary standard (35.0 μg/m$^3$) by 3.91, 2.65, 3.26, 3.39, 2.57 and 2.64 times, respectively.

3.2.1.2. Impact on hourly PM$_{2.5}$ concentration
During the Spring Festival, the concentration of PM$_{2.5}$ and PM$_{10}$ in the ambient air was most affected by fireworks. It was divided into three stages (Fig. S1) according to the changing law of PM$_{2.5}$ and PM$_{10}$ concentration and the source of pollution. The first stage: The pre-discharge stage of fireworks (NYE 01:00 to 20:00); The second stage: the impact stage of the discharge of fireworks (around NYE 20:00 to NYFD 05:00, and the duration of different years was slightly different); The third stage: the rest of the Spring Festival (NYFD 05:00 to NYSID).

In the first stage, the change of the degree of PM$_{2.5}$ concentration each year was generally small (Fig. S1), and its change trend was basically consistent with the annual average daily change trend of PM$_{2.5}$ (Fig. 3(a)).

During the Spring Festival, fireworks in Nanchong City were set off at the night of NYE (the second stage). The hourly PM$_{2.5}$ concentration change trend during this period was significantly different from the annual average PM$_{2.5}$ change trend (Fig. S1 and Fig. 3(a)). After NYE 20:00, the hourly PM$_{2.5}$ concentration increased significantly with the soar of fireworks. NYE 24:00 to NYFD 01:00 was the time for fireworks to be set off intensively. During this period, the PM$_{2.5}$ concentration in the ambient air rose sharply and there was an obvious peak at 02:00 on NYFD; There was no significant peak in 2017 and 2019, due to rainfall after 20:00 on NYE in 2017 and the increased control efforts of government to prohibit setting off fireworks in urban areas in 2019. Compared to last hour of the second phase, the hourly PM$_{2.5}$ concentration in 2014, 2015, 2016 and 2018 increased by 51.9, 101.3, 107.1 and 63.2%, respectively. After 02:00 on NYFD, as the phenomenon of fireworks was gradually reduced, the pollutants released by fireworks were reduced accordingly. At the same time, under the effects of diffusion, migration, and sedimentation, the concentration of PM$_{2.5}$ gradually decreased. After NYFD 05:00 in the morning (some years were slightly extended), the daily variation rule gradually returned to normal, which was consistent with the annual average variation of PM$_{2.5}$ (Fig. 3(a)). In the second stage, the average concentration of PM$_{2.5}$ generally was higher than 150.0 μg/m$^3$ when fireworks were set off on NYE during the 6 years (Table 2), which was more than twice the daily average concentration of ambient air quality in the secondary standard. The PM$_{2.5}$ concentration during the pollution period contributed a lot, with the contribution rates of 2.1, 16.3, 7.8, 0.2, 17.2, and 14.3% in the last 6 years.

Fig. 2. Changes of average daily concentration of environmental air pollutants in Nanchong City during the Spring Festival from 2014 to 2019.
In the third stage, although fireworks were set off sporadically, the impact on the transform trend of PM$_{2.5}$ concentration was minimal. Therefore, the daily variation of PM$_{2.5}$ during this period was consistent with the annual average variation of PM$_{2.5}$ (Fig. 3(a)).

### 3.2.2. Impact on PM$_{10}$

#### 3.2.2.1. Impact on overall PM$_{10}$ concentration

During the Spring Festival from 2014 to 2019, the change trend of PM$_{10}$ concentration in Nanchong was basically the same as PM$_{2.5}$. Affected by the concentrated display of fireworks on NYE, the PM$_{10}$ concentration on NYFD increased significantly in the four years of 2015, 2016, 2018, and 2019, reaching 203.0, 282.0, 220.0, and 192.0 $\mu$g/m$^3$, respectively (Fig. S2(b)). Compared to NYE, it increased 30.1, 73.0, 37.5 and 61.3%, respectively. The daily concentration of PM$_{10}$ on NYFD was as high as 242.0 and 111.0 $\mu$g/m$^3$ in 2014 and 2017, although it was slightly lower than that on NYE due to rainfall. During the Spring Festival of each year, the average concentration of PM$_{10}$ in the pollution period exceeded the national Grade II standard of annual average concentration (70.0 $\mu$g/m$^3$) 2.34, 1.61, 1.94, 1.51 and 1.37 times, respectively (Table 2). As far as the entire Spring Festival period was concerned, the average concentration of PM$_{10}$ during the Spring Festival of each year was also quite different. The average concentration of PM$_{10}$ during the six-year Spring Festival was 219.4, 100.8, 174.9, 100.1, 106.7 and 100.7 $\mu$g/m$^3$, and all of them higher than the national Grade II standard of annual average concentration (70.0 $\mu$g/m$^3$).

#### 3.2.2.2. Impact on hourly PM$_{10}$ concentration

During the Spring Festival from 2014 to 2019, the trend and change pattern of ambient air hourly PM$_{10}$ concentration in Nanchong (Fig. S2) was similar to the trend and change pattern of PM$_{2.5}$. During the non-fireworks intensive discharge period (the first and third phases), the change trend of PM$_{10}$ hourly concentration was basically consistent with the annual average daily change trend.
of PM₁₀ (Fig. 3(b)). During the intensive setting off period of fireworks on NYE (the second stage), the hourly PM₁₀ concentration change trend was consistent with the PM₂.₅ change trend during the same period. After NYE 2000, the concentration of PM₁₀ increased with the increase of fireworks discharge. And the hourly PM₁₀ concentration peaked at around NYFD 02:00 (except in 2017 and 2019). The maximum hourly concentrations of PM₁₀ in 2014, 2015, 2016 and 2018 were as high as 400, 665, 794 and 533 µg/m³, which increased by 33.9, 101.1, 66.5 and 62.0%, respectively, as compared with the previous hour. During the period of concentrated discharge of fireworks, the average concentration of PM₁₀ in the six years was relatively high, exceeding 200 µg/m³ (Table 2), and the contribution rates to the pollution period during the Spring Festival were 2.0, 16.5, 7.9, 0.2, 17.3 and 12.8%, respectively.

3.3. The Impact of Fireworks on Ambient Air Gaseous Pollutants

During the Spring Festival from 2014 to 2019, the average concentration of ambient air gaseous pollutants (SO₂, NO₂, CO, O₃) in Nanchong urban area met the national Grade II standard of annual average concentration [32], and the average concentration of SO₂, NO₂, and CO indicated an overall downward trend, and the average concentration of O₃ showed an upward trend (Table 3). From the perspective of the hourly SO₂ concentration changes, the SO₂ hourly concentration changes were not large during the non-fireworks display period (Fig. 2(c)). During the fireworks display period on NYE, the change trend of the hourly SO₂ concentration each year was basically the same. After 2000 on NYE, the hourly SO₂ concentration gradually increased with the increase of fireworks, reaching a peak at 01:00 in the morning of NYFD. Compared with the previous hour (Fig. S3), the hourly SO₂ concentration increased by 1.91, 1.98, 1.67, 3.31, 5.57, and 1.29 times. Since then, with the reduction of fireworks, the hourly SO₂ concentration gradually decreased and gradually returned to normal levels at around 05:00 on NYFD. During the period of NYE fireworks discharge from 2015 to 2019, the average concentration of SO₂ was significantly higher than the average concentration of SO₂ during the Spring Festival (p < 0.05). From the perspective of the changes in the hourly concentration of NO₂, its trend (Fig. S4) was basically the same as the annual average daily change of NO₂ in each year (Fig. 2(d)). The maximum daily hourly concentration occurred at around 21:00 pm or 9:00 am, and the low value appeared around 6:00 am or 16:00 pm.

With the increase of fireworks on NYE, there was no significant change in the hourly NO₂ concentration, and only a small fluctuation occurred at 01:00 on NYFD. From the perspective of the changes in the hourly concentration of CO, the change trend of CO in each year was different. The overall change trend (Fig. S5) was basically the same as the annual average daily change of CO in each year (Fig. 2(e)). The maximum daily hourly concentration of CO appeared around 10:00 am or 22:00 pm, and the lowest hourly concentration of CO appeared in the early morning or around 5:00 in the afternoon. However, the display of fireworks on NYE has no significant effect on the hourly concentration of CO, and it only appeared slight fluctuations at NYFD 01:00. From the perspective of the changes in O₃, hourly concentration, the change trend of O₃ was basically the same during the Spring Festival of each year and had a trend of increasing year by year. In the non-fireworks stage, the variation trend of O₃ hourly concentration (Fig. S6) is basically consistent with the annual average daily variation trend of O₃. During fireworks display stage of NYE, the hourly concentration of O₃ increased slightly at around 21:00 on NYE with the increase in the number of firecrackers set off, and then decreased slightly at around 2:00 on NYFD.

3.4. Influence of Fireworks on the Chemical Composition of PM₂⁵

Based on the analysis of the results of fine particulate matter (PM₂.₅) in the urban area of Nanchong City from 2014 to 2016, the results showed that the average concentration of PM₂.₅ was about 130.50 µg/m³ during the Spring Festival, which was 98.10% higher than that in the non-Spring Festival period (65.86 µg/m³), and the increase was extremely significant (p < 0.01).

During the Spring Festival, the total concentration of eight water-soluble ions (Na⁺, NH₄⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻, SO₄²⁻ and NO₃⁻) was about 50.70 µg/m³ in the ambient air PM₂.₅. Compared with the non-Spring Festival period (25.09 µg/m³), the total concentration was significantly increased by 102.99% (p < 0.01). Meanwhile, the concentrations of Mg²⁺, K⁺, Cl⁻, NO₃⁻, Na⁺, Ca²⁺ and SO₄²⁻ 7 ions were 0.85, 9.44, 5.42, 12.58, 0.22, 0.46 and 16.25 µg/m³, respectively during the Spring Festival (Fig. 4). Compared with non-Spring Festival period, they were increased by 26.04, 9.25,

| Year | During the Spring Festival | Pollution period during the Spring Festival | Fireworks and firecrackers on New Year’s Eve affect the time of day |
|------|-----------------------------|---------------------------------|--------------------------------------------------|
|      | SO₂ (µg/m³) | NO₂ (µg/m³) | CO (mg/m³) | O₃ (µg/m³) | SO₂ (µg/m³) | NO₂ (µg/m³) | CO (mg/m³) | O₃ (µg/m³) |
| 2014 | 32.9         | 39.6         | 1.5        | 27.0       | 32.7       | 40.5       | 1.5        | 27.2       | 32.0       | 33.9       | 1.3        | 33.3       |
| 2015 | 7.1          | 21.1         | 1.4        | 27.4       | 10.4       | 18.8       | 1.5        | 26.3       | 19.6       | 20.7       | 1.7        | 22.3       |
| 2016 | 8.0          | 31.9         | 1.1        | 29.3       | 8.8        | 35.7       | 1.3        | 27.5       | 21.9       | 49.2       | 1.4        | 21.1       |
| 2017 | 10.1         | 26.1         | 1.0        | 48.4       | 11.0       | 29.9       | 1.3        | 51.4       | 17.1       | 23.9       | 1.1        | 49.5       |
| 2018 | 11.6         | 29.6         | 1.0        | 81.4       | 11.3       | 36.1       | 1.3        | 73.8       | 13.8       | 39.8       | 1.4        | 60.7       |
| 2019 | 5.1          | 17.1         | 0.9        | 56.6       | 5.5        | 20.9       | 1.0        | 61.5       | 7.9        | 27.8       | 1.1        | 40.3       |
6.41, 0.93, 0.78, 0.64 and 0.51 times, in which Mg$$^{2+}$$, K$$^{+}$$ and Cl$$^{-}$$ ions were significantly increased ($p < 0.01$), and Na$$^{+}$$ was significantly increased ($p < 0.05$). The concentration of NH$$^{4+}$$ was still as high as 5.47 $\mu$g/m$^3$, although it was lower than that during non-Spring Festival. In terms of the proportions of various ions, the proportions of Mg$$^{2+}$$, K$$^{+}$$ and Cl$$^{-}$$ in PM$_{2.5}$ increased from 0.06, 1.55 and 1.09% during the non-Spring Festival to 0.62, 7.06 and 3.67% during the Spring Festival, and the increasing rates reached a very significant level ($p < 0.01$). But the proportion of the remaining 5 ions in PM$_{2.5}$ showed a decreasing trend.

The concentrations of 24 inorganic elements were measured in the ambient air PM$_{2.5}$ of Nanchong City, including P, Ca, Ti, V, Cr, Co, Ni, Cu, Zn, As, Se, Mo, Cd, Tl, Pb, Th, U, Na, Mg, Al, K, Mn, Fe and Ba (Fig. 5). During the Spring Festival, the
total concentration of the 24 inorganic elements was 25.10 μg/m², which was 8.33 times higher than that of 2.69 μg/m² during the non-Spring Festival. Except for Ni, Se, Ti and Th, the concentrations of the other 20 inorganic elements all increased to different degrees. Among them, the concentrations of Cr, Co, Cu, Pb, Mg, Al, K, Mn and Ba were significantly increased compared with those in non-Spring Festival period ($p < 0.05$). In terms of the proportions of various metal elements, the proportions of 7 metal elements (Co, Cu, Pb, Mg, Al, K and Ba) in PM$_{2.5}$ showed an increasing trend during the non-Spring Festival period, while the proportions of 6 metal elements (Cu, Pb, Mg, Al, K and Ba) increased significantly ($p < 0.05$).

### 4. Discussion

The raw material of fireworks is black powder, which will release a large number of pollutants in the process of setting off and cause pollution to the ambient air. Influenced by the setting off of fireworks, the ambient air in the urban area of Nanchong had been polluted to varying degrees during the Spring Festival from 2014 to 2019. The economic activities of Nanchong are mainly agricultural production, with few industrial enterprises, and during the Spring Festival, factories are in a state of shutdown as it is in holidays. Therefore, during the whole Spring Festival, the sources of urban ambient air pollutants are mainly from the living and travel activities of urban residents and the setting off of fireworks. The phenomenon of fireworks setting off during the Spring Festival is mainly concentrated at the night of NYE. Under the influence of fireworks setting off, the ambient air quality of NYE and NYFD has seriously deteriorated. In 2018 and 2019, the ambient air quality of Nanchong urban area had changed from good to moderate or heavy pollution on NYFD. Researches like Pan Benfeng et al. [5] made a statistical analysis of the ambient air pollution in major cities of China during the Spring Festival: influenced by the setting off of fireworks, 48 of the 74 cities in China experienced pollution on NYFD in 2013, and the exceeding rate was 64.9%; 149 cities out of 161 major cities in China were polluted on NYFD in 2014, with the over-standard rate as high as 92.5%. In foreign countries, examples and research report showing that, during important festivals like Deepawali in India [2, 4, 9], Bonfire Night in England [34, 35], Bastille Day in France [9, 18], Australia Day in Australia [9, 18], Independence day in the United [36, 37], and “New Year’s Eve” in various countries, fireworks had been set off and caused ambient air pollution in related local cities.

The pollutants released during fireworks discharge are mainly particulate pollutants, which increase the concentration of PM$_{2.5}$ and PM$_{10}$ in the ambient air. During the Spring Festival, fireworks are mainly set off in the night of NYE, during which the hourly variation trend of PM$_{2.5}$ and PM$_{10}$ concentrations is completely different from the annual average diurnal variation trend. The trend of the changes of PM$_{2.5}$ and PM$_{10}$ hourly concentration during this period is completely different from the annual average daily trend. The annual average daily variation curve of PM$_{2.5}$ and PM$_{10}$ is “double peaks and double valleys”, the peak at night appears at around 22:00. And after NYE 20:00, the concentration of PM$_{2.5}$ and PM$_{10}$ increased significantly with the increase of fireworks, and the period between NYE 24:00 to NYFD 01:00 was the period with the highest frequency of fireworks, with its concentration peaked at NYFD 02:00. The hourly PM$_{2.5}$ concentration of Nanchong in 2014, 2015, 2016 and 2018 was as high as 352, 451, 678 and 382 μg/m², respectively, an increase of 51.9, 101.3, and 107.1% from the previous hour. At the same time, the PM$_{10}$ hourly concentration in the same hour was as high as 400, 665, 794 and 533 μg/m², respectively, which increased by 33.9, 101.1, 66.5 and 62.0% from the previous hour. This phenomenon also existed on NYE in many cities and regions such as Beijing [23], Tianjin [39], Beijing-Tianjin-Hebei [8, 40] and the Pearl River Delta [6]. The setting off of fireworks caused a sharp rise in the concentration of PM$_{2.5}$, with an obvious peak. In a large scale of holiday celebrations in abroad, there was also a custom of setting off fireworks. After a large number of fireworks were set off, the PM$_{2.5}$ and PM$_{10}$ hourly concentrations in the ambient air had risen sharply for a short period of time [9, 18, 41, 42].

There had studies shown that the value of PM$_{2.5}$/PM$_{10}$ can be used to identify the sources of PM$_{2.5}$ and PM$_{10}$ [43, 44]. The large ratio of PM$_{2.5}$ to PM$_{10}$ indicated that the impact of local pollution sources was greater such as industrial production, fossil fuel combustion, biomass combustion, motor vehicle exhaust, and human life. The lower value of PM$_{2.5}$/PM$_{10}$ was mainly caused by sand or dust transported from a long distance [45], and the differences between different regions and seasons were also obvious. In winter, the Sichuan Basin has low wind speed, high relative humidity, low rainfall, mostly local pollution and low probability of dust pollution, with high PM$_{2.5}$/PM$_{10}$ averages [44]. For example, the average value of PM$_{2.5}$/PM$_{10}$ in Chengdu can be as high as 0.85 in winter [46]. The sand and dust weather in the basin cities are all transmitted from long distances. The high mountains in the western and northern parts of the basin block the intrusion of sand and dust. At the same time, the concentration of PM$_{2.5}$ and PM$_{10}$ rises rapidly, but the increase rate of the two is different. The value of PM$_{2.5}$/PM$_{10}$ is significantly reduced, and the average value is about 0.50 [48]. The particulate matter in the ambient air is still dominated by larger particles, but the PM$_{2.5}$/PM$_{10}$ value in the ambient air is still higher than the PM$_{2.5}$/PM$_{10}$ value in the cities of northwest China when dust weather occurs [47]. During the Spring Festival from 2014 to 2019, the mean value of PM$_{2.5}$/PM$_{10}$ was higher than 0.70 (Table 2), which was slightly higher than the mean value of PM$_{2.5}$/PM$_{10}$ in each year (Table 1), indicating that fine particulate matter (PM$_{2.5}$) was the main pollutant during the Spring Festival in each year. However, this phenomenon exists in the basin city of Chengdu. The PM$_{2.5}$/PM$_{10}$ value in the urban area of Chengdu was as high as 0.89 before and after the Spring Festival in 2014, and the primary pollutant during the pollution period was fine particulate matter [20]. However, from 0:00 to 20:00 on NYE, the PM$_{2.5}$/PM$_{10}$ hourly value from 2014 to 2018 was generally above 0.60, indicating that the main source of particulate pollutants was local pollution sources. However, the PM$_{2.5}$/PM$_{10}$ hourly value on the day before NYE in 2019 (February 3) was about 0.50, which was basically the same as the PM$_{2.5}$/PM$_{10}$ value when dust weather occurred in Nanchong in the past, indicating the occurrence of long-distance dust weather.
Compared with the average value of PM$_{2.5}$/PM$_{10}$ during the entire pollution period during the Spring Festival, there was no significant difference in the average value of PM$_{2.5}$/PM$_{10}$ during the concentrated discharge of fireworks on NYE in each year. However, the value of PM$_{2.5}$/PM$_{10}$ in the period concentrated discharge of fireworks on NYE was not fixed in each year. During the concentrated discharge of fireworks from 2014 to 2018, the hourly value of PM$_{2.5}$/PM$_{10}$ increased with the rapid increase of PM$_{2.5}$ and PM$_{10}$ hourly concentration. After the hourly concentration of PM$_{2.5}$ and PM$_{10}$ decreased, PM$_{2.5}$/PM$_{10}$ hourly value increased. The PM$_{10}$ value also dropped sharply and then gradually returned to the average level. The reason for this phenomenon is that Nanchong is located in the northeastern part of the Sichuan Basin, with low wind speed in winter, high frequency of quiet wind, low rainfall, high relative humidity, and low boundary layer. Therefore, a large amount of dry particulate matter can be released during the discharge of fireworks, causing a sharp increase in the hourly concentration of PM$_{2.5}$ and PM$_{10}$ in the ambient air. The larger particles (such as PM$_{10}$) can quickly settle to the ground by gravity, and the smaller particles (such as PM$_{2.5}$) can float in the air for a long time, causing the PM$_{2.5}$/PM$_{10}$ hour raise briefly. At the same time, the dry particles with smaller particle diameters floating in the air condense into larger particles through moisture absorption and transformation, resulting in a temporary drop in the hourly value of PM$_{2.5}$/PM$_{10}$. When the particles with larger particle diameters are affected by gravity, the hourly value of PM$_{2.5}$/PM$_{10}$ gradually returns to the average level. This is basically consistent with the results of Xu et al. [49] and others on the impact of fireworks on ambient air in Beijing's urban areas. However, Zhao et al. [6] and others believed that the release of fireworks will cause the value of urban ambient air PM$_{2.5}$ and PM$_{10}$ in the Pearl River Delta gradually increased after falling and returned to normal levels. Zhao et al [6] and others neglected that after the phenomenon of fireworks, the PM$_{2.5}$/PM$_{10}$ values rose for a short time before they began to decrease. The reason may be related to the time, location, intensity of discharge and local meteorological when setting off fireworks. Larger wind speeds can effectively promote the migration and diffusion of particulate matter. And particles with smaller diameters will spread evenly in the air to farther places under the push of airflow [50-53]. During the Spring Festival in 2019, the action of Nanchong's Government to ban on fireworks has been implemented well. So there are fewer fireworks in urban areas. In addition, there was a long-distance dust weather on the Stage of concentrated discharge of fireworks was about 0.65. This difference may be caused by the different meteorological conditions in the two places. The low wind speed in winter in the urban area of Nanchong City is conducive to the long-term floating of PM$_{2.5}$ in the air, while particles with large particle size are easy to settle to the ground through dry deposition. In addition, compared with the northern cities, the relative humidity of the basin cities in winter is higher, which is conducive to the growth of PM$_{2.5}$ moisture absorption, and the higher relative humidity can promote the conversion of gaseous pollutants into PM$_{2.5}$.

Compared with PM$_{2.5}$ and PM$_{10}$, the impact of fireworks on gaseous pollutants was relatively small such as SO$_2$, CO, NO$_x$ and O$_3$. SO$_2$ released by fireworks on NYE caused an increase in the concentration of SO$_2$ in the ambient air of Nanchong City. The change trend of SO$_2$ was basically the same as that of PM$_{2.5}$ and PM$_{10}$, and there was a clear peak at NYFD 01:00. During 2014 to 2019, the peak concentration of SO$_2$ in the year increased by 1.91, 1.98, 1.67, 3.31, 5.57, and 1.29 times compared with the previous hour, while in the Pearl River Delta, Beijing-Tianjin-Hebei region, Chengdu, Xi'an, Hong Kong, and other cities and regions in India and abroad. There was also a phenomenon that the hourly SO$_2$ concentration was temporarily increased due to the setting off of fireworks [6, 8, 54, 41, 42]. During NYE fireworks display stage, the CO and NO$_2$ in the ambient air of Nanchong presented a small increase around 01:00 on NYFD and then quickly decreased and returned to normal levels. Other domestic cities also had the same trend of change such as Beijing, Tianjin, Guangzhou and Shenzhen [6, 17, 41, 55]. At the same time, the hourly O$_3$ concentration fluctuated slightly, indicating that the firing process of fireworks could promote the production of O$_3$. The reason may be that a large amount of radiant energy was released during the discharge of fireworks, which could promote the conversion of O$_3$ precursors into O$_3$ [54, 56, 57]. It showed that the impact of fireworks on CO, NO$_2$ and O$_3$ was relatively small.

The component content of aerosol particles in the ambient air can reflect the influence of local pollution sources to a certain extent, while the component concentration of aerosol particles can reflect the degree of pollution of the local ambient air [58]. The raw materials of fireworks are black powder, and their main components are sulfur, charcoal powder, nitrate, potassium chlorate or potassium nitrate, etc. Metal powders such as Cu, Mg, Al, K, and Ba are often added in the production process of fireworks so as to add the color rendering effect. Therefore, the particulate pollutants released by fireworks contained ions like K$^+$, Mg$^{2+}$, Cl$^-$, SO$_4^{2-}$ [14, 26-31] and metal elements such as Mg, Al, Ba, Cu, K, etc [1, 8-12]. During the Spring Festival from 2014 to 2016, the concentrations of K$^+$, Mg$^{2+}$ and Cl$^-$ in PM$_{2.5}$ and their proportion in PM$_{2.5}$ all increased significantly ($p < 0.01$) during the non-Spring Festival period. The concentration of six metals(Cu, Pb, Mg, Al, K, and Ba) and the content of those metals in PM$_{2.5}$ are also significantly higher than those during the non-Spring Festival period ($p < 0.05$), which is in line with the consistent results of Beijing [24]. Shanghai
the Spring Festival. In PM2.5 samples, there was an obvious correla-
tion between SO4$^{2-}$, NO2, CO and O3 concentrations, while Mg$^{2+}$ comes from crustal mineral dust. However, there were a large number of fireworks set off during the Spring Festival. K$^+$ took the form of potassium nitrate and potassium perchlorate as the main oxidant of fireworks, and Mg$^{2+}$ took the form of aluminum magnesium alloy as the main reducing agent and colorant. Thus, K$^+$ and Mg$^{2+}$ showed a high correlation ($r = 0.917$). There was a strong linear correlation among K$^+$, Cl$^-$, Mg$^{2+}$ and SO4$^{2-}$, and the correlation coefficients were all above 0.7, indicating that the four had a common source. Therefore, K$^+$, Cl$^-$, Mg$^{2+}$ and SO4$^{2-}$ may mainly from the centralized discharge of fireworks during the Spring Festival. In PM2.5 samples, there was an obvious correlation between SO4$^{2-}$ and NO3$^-$. Cl$^-$, Mg$^{2+}$, K$^+$, Na$^+$ and NH4$^+$, with correlation coefficients of 0.867, 0.933, 0.717, 0.667, 0.850 and 0.733, respectively. The results indicated that there were similar sources or formation pathways among the ions, which may mainly come from fireworks. The concentrations of Ti, V, Cr, Co, Ni, Cu, Zn, Cd, Pb, U, Mg, Al, K, Mn, Fe, Ba and other metal elements in fine particles were highly correlated during the Spring Festival, with the correlation coefficient ranging from 0.667 to 1.000. In particular, the correlation coefficients of Cr, Co, Ni, Zn, Cd, U, Mg, Al, K and Mn were all greater than 0.817, reaching a significant correlation. The correlations of these elements were poor during non-Spring Festival. Therefore, the contents of water-soluble ions and metal elements in PM2.5 particles increased rapidly during the Spring Festival, which further indicated that the obvious increase of PM2.5 concentration during fireworks discharge was mainly caused by fireworks discharge. Through comparison, it is found that the duration of the ambient air pollution process in Nanchong City was different during the last six-year Spring Festival. There are 6, 2, 5, 2, 3 and 3 days of continuous pollution from 2014 to 2019 respectively. Cities located in the basin were affected by complex and variable meteorological conditions. Small wind, temperature inversion and high humidity are not conducive to the diffusion of pollutants, which aggravate the degree of environmental air pollution and prolong the duration of pollution in the urban area of Nanchong City. However, the passage of cold air and rainfall in the north have obvious effects on the diffusion and removal of pollutants.

5. Conclusions

(1) The ambient air quality of Nanchong was significantly affected by the fireworks on NYE, triggering the deterioration of the ambient air quality in the urban area. Affected by the topography of the basin, the display of fireworks will aggravate the degree of environmental air pollution and prolong the duration of pollution in the urban area. When the cold air from the north passes through, bringing strong winds and rainfall processes, the concentration of pollutants was significantly reduced through diffusion and wet deposition. Therefore, setting off fireworks should be reduced and pollution should be eliminated by developing alternatives to existing fireworks.

(2) PM2.5 and PM10 concentrations increased significantly after fireworks were set off, and the peak value appeared at about 02:00 on NYE, but the value of PM2.5/PM10 did not change significantly. The significant increase in the concentrations and percentages of water-soluble ions and metal elements in PM2.5 indicated that fireworks were the main sources of chemical components in PM2.5 during the Spring Festival. The concentration of SO2 in gaseous pollutants was slightly affected by fireworks, while NO2, CO and O3 were not affected basically. Fine particulate pollutants need more attention in future studies and should be included in national health guidelines.

(3) The research results can be used to predict the ambient air quality and have a certain guiding significance for the prevention and control of air pollution in basin cities. The study still has some limitations. Due to the limitation of instruments, the analysis of PM2.5 components in this study mainly adopted off-line analysis after membrane sampling. However, the long period of membrane cumulative sampling and analysis made it impossible to accurately measure some volatile components and obtain the time-by-time variation trend. In the follow-up study, the chemical characteristics, diurnal variation characteristics and formation mechanism of secondary aerosol of particulate matter will be studied by using the on-line continuous monitoring system of water-soluble components of atmospheric fine particles. Future studies will also focus on characterization of health effects associated with acute exposure to air pollutants.

Acknowledgments

The authors sincerely thank Nanchong Ecological and Environmental Monitoring Central Station of Sichuan Province for the permission to access their data. This study was supported by the Science and Technology Plan Project of Nanchong City (No. 19YFZJ0032). The opinions in this study do not reflect the views or policies of the station.

Conflict-of-Interest

The authors declare that they have no conflict of interest.

Author Contributions

Y.F.Q. (M.D) wrote and revised the manuscript. X.Y. (Postgraduate Student) wrote and revised the manuscript. W.D. (M.D), J.H. (SN ENGR) and J.X. (M.D) made significant contributions to data acquisition, analysis, and interpretation. D.Y.L. (M.D), Q.Z. (Postgraduate Student), and P.Z. (Postgraduate Student) helped organize the manuscript data. Q.M.Q. (Professor) and Y.X.L. (Professor) made key changes to important academic content and were responsible for the final revision.
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