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Research Article

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Posted Date: July 8th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-431378/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on January 10th, 2022. See the published version at https://doi.org/10.1007/s11356-021-17690-1.

Fine Particulate Matter Pollution Characteristics and Source Apportionment of Changchun Atmosphere

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Abstract

In order to study the pollution characteristics and main sources of fine particulate matter in the atmosphere of the city of Changchun, $PM_{2.5}$ samples were collected during the four seasons in 2014, and representative months for each season are January, April, July, and October. Sample collection was carried out on 10 auto-monitoring stations in Changchun, and $PM_{2.5}$ mass concentration, and its chemical components (including inorganic elements, organic carbon, elemental carbon, and water-soluble ions) were measured. The results show that the annual average mass concentration of $PM_{2.5}$ in Changchun in 2014 was about 66.77 μg/m^3. Organic matter was the highest component in $PM_{2.5}$, followed by secondary inorganic ions (SNA), mineral dust (MIN), elemental carbon (EC), and trace elements (TE). Positive Matrix Factorization (PMF) results gave seven factors, namely, industrial, biomass- and coal-burning, industrial and soil dust, motor-vehicle, soil and secondary-ion, light-industrial, and hybrid-automotive and -industrial sources in $PM_{2.5}$, with contributing values of 18.9%, 24.2%, 5.7%, 23.0%, 11.5%, 13.0%, and 3.6%, respectively.

Keywords $PM_{2.5}$· source apportionment· PMF· water-soluble ions· organic carbon· elemental carbon· inorganic element.

Introduction

Fine particulate matter, or $PM_{2.5}$ (particle size 2.5 microns or less), is defined as a major global urban air pollutant and a major health risk factor (Lelieveld et al., 2015; Mukherjee and Agrawal, 2017). In December 2012, more than 300 international research institutions, including the World Health Organization, jointly released the Global Burden of Disease 2012 (GBD2010). Results showed that $PM_{2.5}$ could globally cause the premature deaths of approximately 3.2 million people, including China's death toll of 1.23 million (Zhao Yang et al. 2017). Therefore, the problem of fine-particulate-matter pollution has attracted wide attention at home and abroad.

$PM_{2.5}$ sources are a complex mixture of natural and anthropogenic sources. Chemical components mainly include water-soluble ions, carbon components (OC, EC), and inorganic elements (Wu Bobo et al. 2016). Primary sources include vehicle exhaust pipes, coal, and biomass combustion. Secondary sources include secondary sulfate, nitrate, and organic matter (Sun Tianle et al. 2019). In order to effectively control $PM_{2.5}$ concentrations in the urban atmosphere, scientific methods must be used for $PM_{2.5}$ source analysis.

As the core city of Jilin Province's Economic Zone, Changchun is fast-developing. In recent years, due to a series of reasons such as city-scale expansion, and population and vehicle increase, the pollution level of $PM_{2.5}$ has been increasing, and the outlook on air quality is not optimistic. Many observational $PM_{2.5}$ studies have been extensively carried out in China to understand the characteristics and sources of different chemical components in $PM_{2.5}$. Many scholars have used the Positive Matrix Factorization (PMF) model to analyze the main pollution sources of $PM_{2.5}$ in Tai'an, Beijing, Tianjin, and Shenzhen, but currently research on $PM_{2.5}$ is mainly concentrated in the Beijing–Tianjin–Hebei and the Pearl River Delta regions (Hong Ye et al. 2010). Previous studies on atmospheric particulate matter in Changchun have focused on PM_{10} and TSP. There are few studies on $PM_{2.5}$ sources in Changchun, and there is a lack of long-term systematic-observation data. So, this paper selected 10 sampling sites in Changchun, sampled during the four seasons, obtained $PM_{2.5}$ concentrations and its components in the representative sites in Changchun, and analyzed the sources with the PMF model in order to provide technical support for improving the air quality of Changchun. This paper fills the gap in the research of $PM_{2.5}$ in Changchun, as it is of great significance to control the concentration of $PM_{2.5}$ and reduce the risk of urban residents there.

Material and methods

Sampling Sites

Changchun is located at 43°05′N–45°15′N and 124°18′E–127°05E′, with a total area of 20,565 km^2. It has a temperate continental humid climate and is the central city of northeastern Asia's economic circle. Ten auto-monitoring stations were set up in Changchun, all of which are national controlling stations.

Among the 10 sites in Changchun, nine are located in the built-up area of Changchun: Daishan Park(DP), High-Tech Zone Management Committee(HZMC), Economic Exploitation Zone Sanitation Office(EEZCO), Jingyuetan(JYT), Bus Factory(BF), Labor Park(LP), Food Plant(FP), Institute of Post and Telecommunications(IPT), and Garden Department (GD), a clean control site is located in the Shuangyang District of Changchun, namely, Shuaiwanzi (SWZ). The corresponding setup is shown in Table 1.

Receptor Sample Collection

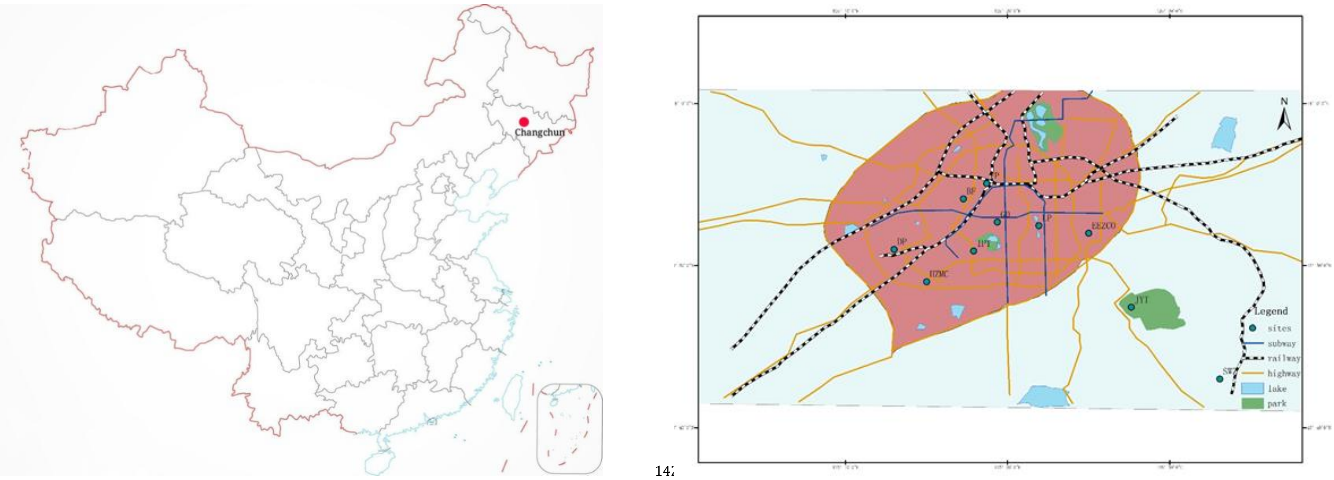
In 2014, $PM_{2.5}$ samples were collected in Changchun. In each season, representative months were selected to be January, April, July, and October. Chemical components (inorganic elements, carbonaceous components, and water-soluble ions) were measured. A medium-volume air sampler (KC-120 Particulate Sampler, China) at a flow rate of 100 L/min was used to collect $PM_{2.5}$ samples for 22 h daily. In order to evaluate the error of the sampling process, a blank filter membrane was arranged during the sampling process. The blank filter membrane was weighed alone and with the sampling membrane, underwent the whole process of sampling, and was then shipped back to the laboratory with the sampling membrane. The difference between blank filter mass before and after sampling should have been much smaller than the particle mass on the sampling filter; otherwise, batch-sampling monitoring data were invalid.

Samples were collected on a quartz fiber filter (90 mm diameter) or a cellulose filter (Teflon, 90 mm diameter). The filter was weighed before and after the sampling progress with a microbalance MX5 Metter Toledo. We weighed the filter in the weighing chamber for 48 hours. Balance conditions were temperature, which was controlled at 15–30 °C; accuracy, controlled at 1 °C; humidity, controlled at 50% ± 5% RH; and balanced room-temperature humidity that was consistent with the constant temperature and humidity equipment.

To assess the effects of unstable conditions, blank filters were periodically used during each sampling process, and their values were used to correct the measurements of other filters. The hourly $PM_{2.5}$ concentrations of used in this paper were monitored by the Changchun central monitoring station.

Table 1. Sampling-site coordinates and functional area.

Sampling sites	Coordinates	Sites situation
(IPT)	125°17′02″E，43°50′49″N	Educational and cultural area
(LP)	125°21′56″E，43°52′28″N	An area of business and residence
(GD)	125°19′22″E，43°52′41″N	Located in the area of business culture and education
(FP)	125°18′42″E，43°55′04″N	Industrial zone
(BF)	125°17′16″E，43°54′07″N	Industrial zone
(EEZCO)	125°25′00″E，43°52′00″N	Industrial zone
(HZMC)	125°15′00″E，43°49′00″N	In the direction of the wind of the city
(DP)	125°13′00″E，43°51′00″N	Industrial zone
(JYT)	125°27′38″E，43°47′26″N	Park
(SWZ)	125°43′10″E，43°30′55″N	Blank control



a)

b)

Figure 1. Map (a) is the location of the study area (Changchun) in China. Map (b) is the sampling sites in Changchun.

Figure 2. $PM_{2.5}$ Sampler

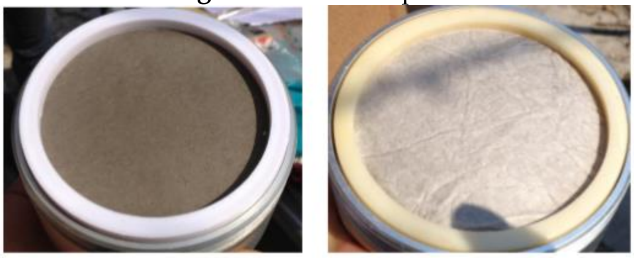


Figure 3. Filter after sampling. Quartz filter on the left and Teflon filter on the right

Component Analysis Test

Analysis of water-soluble ions

One-fourth of the filter membrane was cut and put into a sample tube. Then, 10 mL of ultrapure water was added, the sample was placed in an ultrasonic cleaner, sonicated for 20–25 min to dissolve the ions, and then placed in centrifuge for 5 min; the extract was filtered through a filter (0.45 μm). Mass concentrations of Na^+, K^+, Mg^{2+}, and cations were analyzed with an ion chromatograph (DIONEX ICS-2000, USA), and the anion mass concentrations, such as Cl^-, NO_3^-, SO_4^{2-} were analyzed with an ion chromatograph (DIONEX ICS-3000, USA). Use the standard sample to calibrate the standard curve, and add a standard sample for every 10 samples for calibration. The measurement timing of water-soluble ions, each sample is measured> 2 times, and the same product has a continuous measurement error <5%.

Organic- and Elemental-Carbon Analysis

Organic carbon and elemental carbon in this study was performed using a semi-continuous OCEC carbon aerosol analyzer (Sunset Laboratory Inc.).

Inorganic-Element Analysis

Cut Teflon filter into small pieces with ceramic scissors and put it in the digestion tank/Teflon beaker.10ml of nitric acid-hydrochloric acid mixture was added to immerse the filter membrane, and heat and reflux at 100±5℃ for 2.0 hours, then cool. Rinse the inner wall of the beaker with reagent water, and leave it for half an hour for leaching. Bring the volume to 50.0ml. Then inorganic elements were determined by inductively coupled plasma mass spectrometry (ICP-MS, Agilent, America).

PMF Source-Apportionment Model

In this study, a PMF receptor model was used to analyze the main sources of $PM_{2.5}$ in Changchun. The receptor model is a mathematical model for analyzing the chemical composition and physical properties of atmospheric particulate matter. It can quantitatively identify the contribution ratios of every kinds of pollution sources on the basis of factor eigenvalues or source profiles. The PMF model is a commonly used model for the source apportionment of atmospheric particulate matters. Compared with other source-analytical methods, it need not to measure the source composition profile, does not require to input the pollutant discharge inventory and photochemical reaction mechanism equations, and it can simultaneously determine the source composition profiles and source contribution ratios. The PMF model decomposes observed component-concentration matrix X_{ij} into source-concentration-profile matrix F_{kj} and factor-contribution-ratio matrix G_{ik} (Formula 1), where E_{ij} is the residual matrix, the difference between model-simulation and actual-observation values. The sum of the squares of the residuals of the observation data and its error estimation ratio was defined as Q, and the solution process of the PMF model is the process of minimizing the value of Q.

$$\mathrm{E}_{ij} = X_{ij} - \sum_1^p G_{ik}F_{kj} \qquad (1)$$

The basic input to the PMF model is the mass concentration and uncertainty of the chemical components of the sample. Basic output was (a) the share and uncertainty of each chemical component in the source spectrum, (b) the contribution of each factor (source) to the overall concentration of the particulate matter, and (c) the time series of the contribution of each factor (source).

Uncertainty detection method:

concentration below detection limit Unc =

$$\frac{5}{6} * \mathrm{MDL} \qquad (2)$$

concentration above detection limit Unc =

$$\sqrt{(Error\ Fraction \times concentration)^2 + (MDL)^2} \qquad (3)$$

This study used EPA PMF 5.0 model software released by the US Environmental Protection Agency in the calculations.

Sample-Mass Closure

Atmospheric particulate-matter mass closure can estimate the impact of aerosols from different sources on ambient air quality on the basis of the proportion of different constituent compounds. Mineral dust (MIN), elemental carbon (EC), trace elements (TE), organic matter (OM), secondary inorganic ions (SNA; SO_4^{2-}, NO_3^-, NH_4^+) and the rest are the mass reconstitution of $PM_{2.5}$. Three kinds of water-soluble ions, EC, and TE were directly measured, and OM and MIN were calculated with many of the measured components, as follows.

It was generally assumed that there was 0.2–0.4 g of other elements (e.g., O, H, and N) per gram of carbon in the OM in atmospheric particulate matters, so 1.2–1.4 represents the times of the weight of OM to OC (Fumo Yang, et al. 2004). Turpin and Lim recently tested the rationality of this approach and considered that it is appropriate to assume 1.4 for aerosols in urban areas, but it is more suitable for nonurban areas with more bio aerosols or secondary oxidized aerosols with 1.9–2.3 (Fumo Yang, et al. 2004). In this paper, we took 1.4 as the OC multiplier.

Soil dust in atmospheric particulate matter is usually estimated by the sum of the oxide concentrations of specific elements. It is generally assumed that soil dust is composed of the oxides of six elements (i.e., SiO_2, Al_2O_3, TiO_2, CaO, FeO, Fe_2O_3, and K_2O). It includes six of the eight most important compounds that construct the continental crust. The two other oxides, Na_2O and MgO, account for about 3% of the mass of Earth's crust. Since Ti concentration was lower than the detection limit, MIN calculation was MIN=2.20[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] +1.93[Mg].

Results and Discussion

Descriptive Statistics

The long-term average temperature of Changchun in 2018 was 7 °C, the highest temperature was 36 °C, and the lowest temperature was –32 °C. Annual precipitation was 1480.5 mm, average daily precipitation is 4.1 mm, and annual average humidity is 62%. The main wind direction is southwestern, western, and southern (meteorological data from meteorological-data network). The average concentration of $PM_{2.5}$ in Changchun in 2014 was 66.77 μg/m^3, which was 1.9 times the annual average limit value (35 μg/m^3) in the Ambient Air Quality Standard (GB 3095-2012). Monthly mean values of $PM_{2.5}$ in Changchun in 2014 are shown in Figure 4. The $PM_{2.5}$ data peaked in October, and the monthly average concentration was as high as 143.76 μg/m^3. The reason is that the gas pollutant emissions are high during the start-up and commissioning of the heating boiler at the end of October, and it is easy to form inversion weather in autumn, meteorological conditions which is unfavorable for the spread of gas pollutants are frequent.

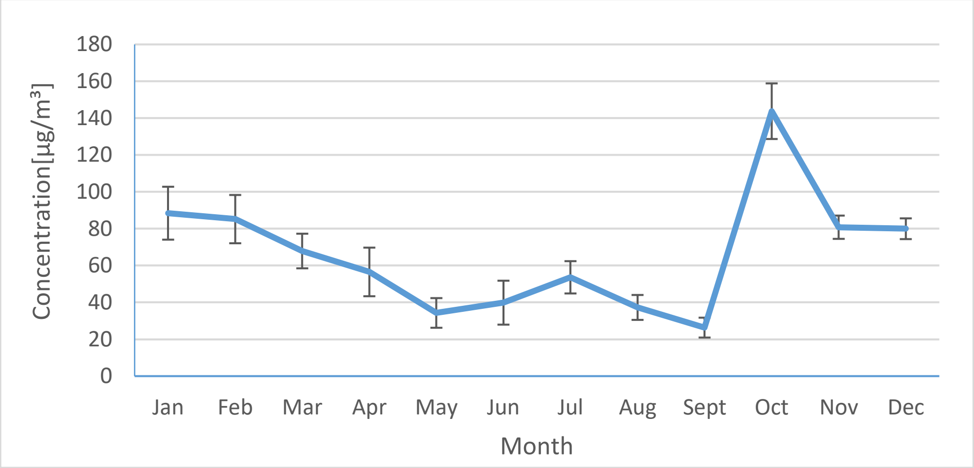


Figure 4. Monthly mean concentration changes of $PM_{2.5}$ in Changchun. The error bars are represented by standard deviation.

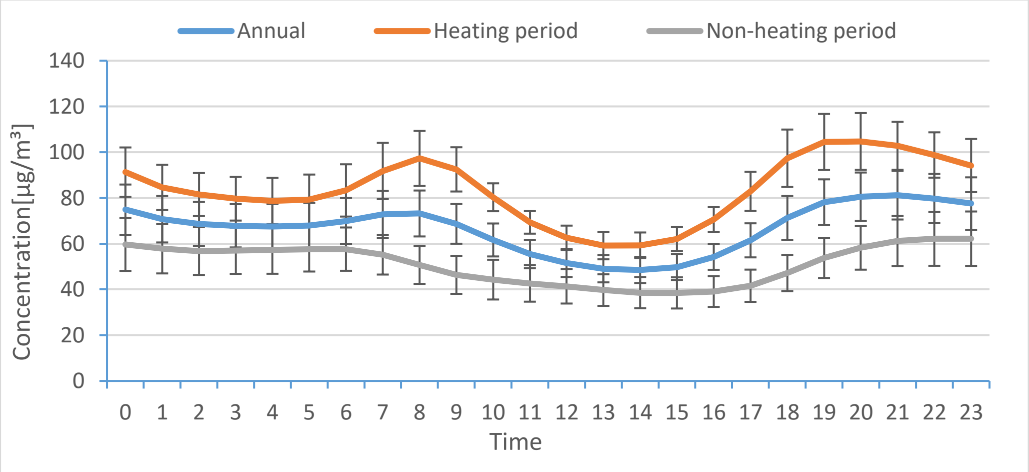


Figure 5. Comparison of Changchun's hourly $PM_{2.5}$ concentration changes in heating and non-heating periods, and for the whole year. The error bars are represented by standard deviation.

The heating period in Changchun is from mid to late October to early April of the following year. It can be seen from Figure 5 that hourly $PM_{2.5}$ concentrations in Changchun basically showed a bimodal change, and the heating period was significantly higher than the non-heating period. The first peak appeared in the morning from 6:00 to 9:00, during early traffic peak. The number of road vehicles increased gradually, and emitted pollutants increased. The second peak appeared at 19:00 to 21:00. The reason may be the outdoor human activities. Barbecues are a common dietary feature in the Northeast. During this period, residents like to have a barbecue, and grilled fumes increase $PM_{2.5}$ concentrations. Due to the large amount of coal used during the heating period, $PM_{2.5}$

concentrations significantly increased compared to the non-heating period.

Mass closure

From the perspective of the whole year, OM was the highest proportion of Changchun $PM_{2.5}$, accounting for 38.2%. From the four seasons, the seasonal variation trend for OM was winter > summer > autumn > spring, and OM proportion was the highest in winter contributed 60%. The reason is that heating in Changchun begins in winter, and the amount of burnt coal increases, resulting in an increase in discharged pollutants. The reason why summer OM proportion is higher than that in spring and autumn is that the increasing of barbecues in the summer night, and the emission of a large amount of oil smoke. The seasonal trend for MIN is spring > summer > winter > autumn. Wind speed in spring and summer was higher than that in autumn and winter, which rolls up surface dust. The trend of EC in $PM_{2.5}$ is autumn > spring > summer > winter, and EC proportion in autumn is significantly higher than that of the other seasons, which is due to large-scale straw burning in autumn and a relatively high motor flow. EC produced by biomass burning in the autumn and motor-vehicle exhausts have great impact on $PM_{2.5}$. The seasonal change of SNA is spring > autumn > winter > summer, and the formation of secondary particulate matter is not only related to pollutant discharge, but also wind speed, temperature, humidity, and other meteorological conditions that have related impact on the formation of secondary particulate matter. During the winter–spring transition, the increase in the number of activated molecules which is due to the gradual increase in temperature makes it easier for SO_2 to be converted into sulfate ions (Zheng Y J et al. 2015). Straw burning in autumn has great influence on NO_X, resulting in an increase in nitrate ion content, so SNA proportion in spring and autumn is higher.

Mass closure results in Changchun are similar to those in Beijing (Yang Fumo et al. 2004) and Shenzhen (Huang Xiaofei et al. 2013), but OM proportion in Changchun $PM_{2.5}$ was higher and SNA proportion was lower; the main components of $PM_{2.5}$ in Shenyang are SNA, OM, and MIN (Tian Shasha, Zhang Xian, et al. 2019). This may be related to the industrial structure and meteorological conditions in Shenyang. Changchun's MIN accounts for 12%, which is twice as high as that of downtown Los Angeles (Yang Fumo, He Kebin, et al. 2004). This is where characteristics of fine particulate matter pollution in Changchun and cities of the United States are different.

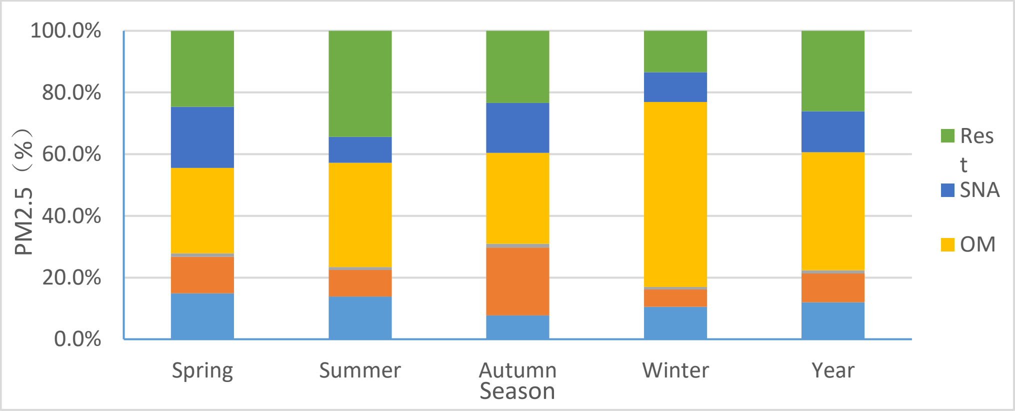


Figure 6. $PM_{2.5}$ mass closure calculated on basis of analytical results for Changchun.

Enrichment Factors

The enrichment factor (EF) was used to determine the natural or believed sources of the 21 elements. The enrichment factor for element X is defined as

$$EF_x=\frac{(C_x/C_{ref})_{PM}}{(C_x/C_{ref})_{crust}}, \quad (2)$$

where C_x is the concentration of element X, Cref is the concentration of the reference element, $(C_x/C_{ref})_{PM}$ is the ratio of the two in $PM_{2.5}$, and $(C_x/C_{ref})_{crust}$ is the concentration ratio of the two in the crust. This paper chose Al as the reference element = 1. The background value of soil elements was taken from background and reference values of soil chemical elements in Chinese cities. Results are shown in Figure 4.

Studies have shown that an EF < 1 indicates that elements are not enriched mainly from natural sources such as the crust, and EF > 10 indicates that elements are enriched mainly from anthropogenic sources. According to the results, Co (<1) was mainly from crust source, while Mg, K, Ca, Mn, Fe, Si (1-10) were from both anthropogenic and crustal sources. For B, V, Cr, Ni, Cu, Zn, As, Se, Mo, Cd, Sn, Pb and Si (>10), they were mainly from anthropogenic source. The higher the EF, the stronger the enrichment degree. The EF of B, Cr, Zn, As, Se, Mo, Cd, Sn, Pb, and Hg was greater than 100, indicating strong enrichment.

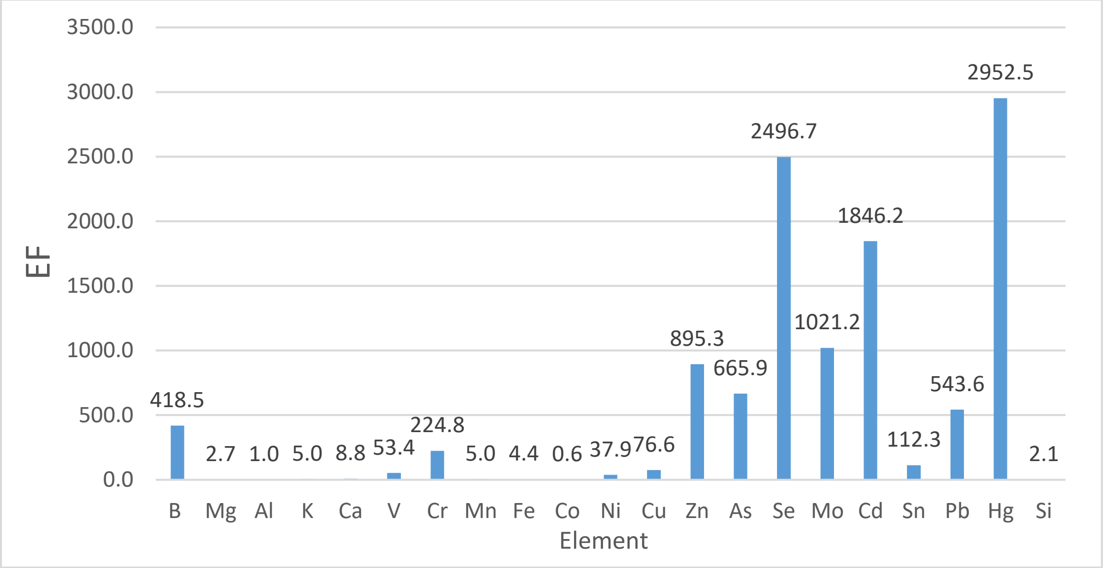


Figure 7. Enrichment-factor results of about 21 elements.

Source apportionment

The model ran in a factor of 3–9 to find the best results. The most stable solution was found when the factor number was 7. Seven factors were industrial, biomass- and coal-burning, industrial and soil dust, motor-vehicle, soil and secondary-ion, light-industrial, and hybrid-automotive and industrial sources. The contribution rate of each factor must be greater than 0.05%, otherwise it will not be included in the determined factor.

The contribution rate of the first factor was 18.9%, from which the specific gravity of Zn, Cd, Cu, and Mn was large. Zn is often derived from rolling mills, Cu and Mn are related to metal smelting, and Changchun is used as a hub for automobile manufacturing, which has great demand for steel smelting. Hence, judgment factor 1 is industrial sources.

The contribution rate of the second factor was 24.2%. From this, Cl^- and K^+ had large specific gravity. Cl^- can be used as a characteristic component of coal-fired emissions; and K^+ is a characteristic component of biomass combustion, and it is converted from NO_x. Straw burning has a great influence on NO_x. Winter heating in Changchun and straw burning in autumn have great influence on $PM_{2.5}$. Judgment factor 2 is biomass-and coal-burning sources.

The contribution rate of the third factor was 5.7%, in which Mn, Ni, and Al were relatively large. Mn and Ni are mainly from artificial sources and related to metal smelting; they belong to industrial dust, and Al mainly comes from Earth's crust. Hence, judgment factor 3 is industrial and soil dust.

The contribution rate of the fourth factor was 23.0%, in which the contributions of EC, Pb, and Se were more prominent. EC is the main emission of motor fuel. Pb production is related to the wear of the brake components of motor vehicles. Hence, judgment factor 4 is motor-vehicle sources. In Changchun, the number of motor vehicles is high, and traffic is prone to congestion. The motor-vehicle exhausts have great impact on the atmosphere.

The contribution rate of the fifth factor was 11.5%, in which Co, Mg^{2+}, SO_4^{2-} had a high load. Co is a soil element, Mg^{2+} may be derived from road dust, and SO_4^{2-} is secondary ion; so, judgment factor 5 is a soil and secondary-ion sources.

The sixth factor contributed 13.0%, in which F^- and Na^+ had large specific gravity, while atmospheric perfluorinated and polyfluoro-organic compounds (PFCs) are usually used as surfactants in nonstick coatings, paper, textiles, and other coatings. In this production, judgment factor 6 is light industrial sources.

The seventh factor contributed 3.6%, of which Hg, V, and Cr had higher load rates. Studies showed that oil and gas used in motor vehicles contain Hg. After combustion in motor-vehicle engines, exhaust gas containing Hg is discharged into the atmosphere. In addition, V is often added as an auxiliary material to oil products. Cr mainly comes from industrial production such as electroplating, battery manufacturing, and stainless-steel production. Hence, judgment factor 7 is hybrid-automotive and -industrial sources.

This study compared the results of $PM_{2.5}$ source apportionment in Changchun with other important cities, and found that the contribution rate of coal-fired sources in Changchun is similar to that of Zhengzhou (Geng Ningbo, Wang Jia, et al. 2013), and slightly higher than that of Beijing (Wang Hailin, Zhuang Yahui, et al. 2008) and Tianjin (Kong Shaofei, Han Bin, et al. 2010), which may be related to coal-firing demands in the Beijing–Tianjin region. Compared with Hangzhou (Wang Jiao, Zhang Yufen, et al. 2016), the contribution rate of coal-fired sources in Changchun is much higher than that in Hangzhou, which is mainly related to the non-heating season in Hangzhou, resulting in less contribution from coal-fired sources. The secondary-ion contribution rate of Changchun is significantly lower than that of Beijing, Tianjin, Shenzhen (Huang Xiaofei, Yun Hui, et al. 2013), Hangzhou, and other cities. This may be related to the relatively stable meteorological conditions in Changchun during the sampling period, which is not conducive to the formation of secondary ions. From the perspective of the contribution rate of motor vehicles, Changchun is similar to Shenzhen and Hangzhou, higher than that of Beijing, which may be related to the motor-vehicle limit policy in various regions. Due to energy-structure differences of each region, industrial structure, economic-development status, and natural conditions, the results of each study are uncertain. Therefore, the source-apportionment results need further examination in the future.

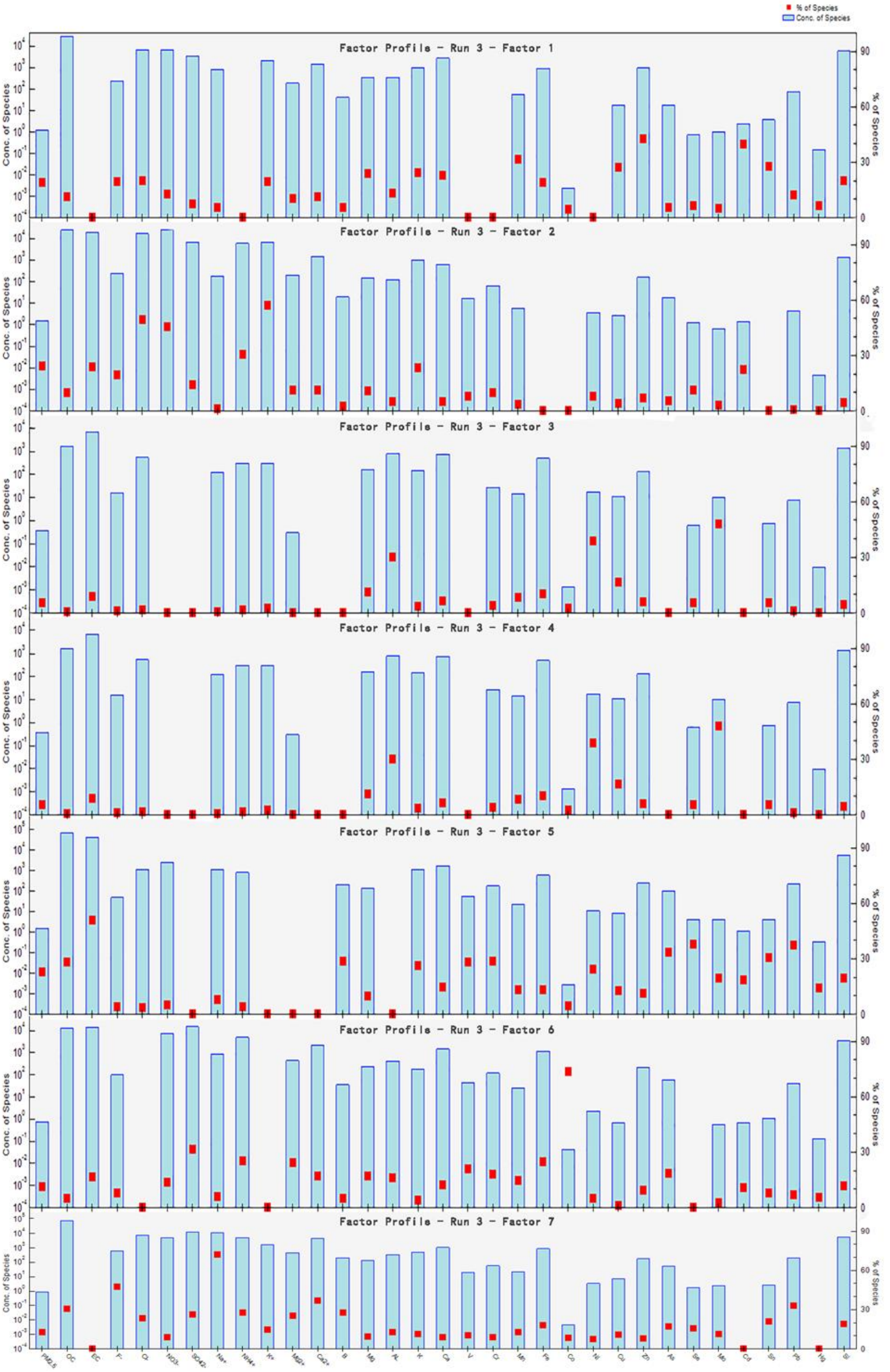


Figure 8. Factor profiles for $PM_{2.5}$ resolved by Positive Matrix Factorization (PMF). The red dot represents the element's contribution to that source. Blue bars represent the concentration of elements in the source

Table 2. Background information of the sources

Source Name	Feature elements	Related Literature
industrial sources.	Zn Cu Mn As	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019； Sun T.L.; Zou B.B.; Xiaofeng Huang Source Apportionment of atmospheric PM2.5 in Shenzhen，2019; Schwarz J., Petra P.; Štěpán R. Assessment of air pollution origin based on year-long parallel measurement of PM2.5 and PM10 at two suburban sites in Prague, Czech Republic.2019； Liu B S, Song N, Dai Q L, et al. Chemical composition and source apportionment of ambient PM2.5 during the non-heating period in Taian, China，2016；

		Tan J H, Zhang L M, Zhou X M, et al. Chemical characteristics and source apportionment of PM2.5 in Lanzhou, China，2017
Biomass burning	K$^+$	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019； Sun T.L.;Zou B.B.; Xiaofeng Huang Source Apportionment of atmospheric PM2.5 in Shenzhen，2019;
coal-burning sources	Cl$^-$ As Se	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019； Schwarz J., Petra P.; Štěpán R. Assessment of air pollution origin based on year-long parallel measurement of PM2.5 and PM10 at two suburban sites in Prague, Czech Republic.2019； Feng J.L; Yu H., et al, Chemical composition and source apportionment of PM2.5, during Chinese Spring Festival at Xinxiang, a heavily polluted city in North China: Fireworks and health risks,2016; Shih-Chieh Hsu,Shaw Chen Liu et al,Long-range south-eastward transport of Asian biosmoke pollution: Signature detected by aerosol potassium in Northern Taiwan,2009
motor-vehicle sources.	EC Pb	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019； Liu S.Ma T.et al, Chemical Composition Characteristics and Source Apportionment of PM2.5 During Winter in Taiyuan,2019
secondary-ion sources.	SO_4^{2-} NO_3^- NH_4^+	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019； Schwarz J., Petra P.; Štěpán R. Assessment of air pollution origin based on year-long parallel measurement of PM2.5 and PM10 at two suburban sites in Prague, Czech Republic.2019； Jia X H, Xie J F, Ma X, et al. Analysis of water-soluble constituents in winter of PM2.5 in Taiyuan City,2013
light industrial sources.	F$^-$	HE PF，WANG H，et al，Residue characteristics of per fluorinated compounds in the atmosphere of Shenzhen,2016
soil dust	Mg Al Si Ti Te	Tian S.S.; Zhang X.; Yan S.S. Characteristics and sources of PM2.5 pollution components in Shenyang City，2019 Liu J, Wu D, Fan S J, et al. A one-year, on-line, multi-site observational study on water-soluble inorganic ions in PM2.5 over the Pearl River Delta region, China,2017

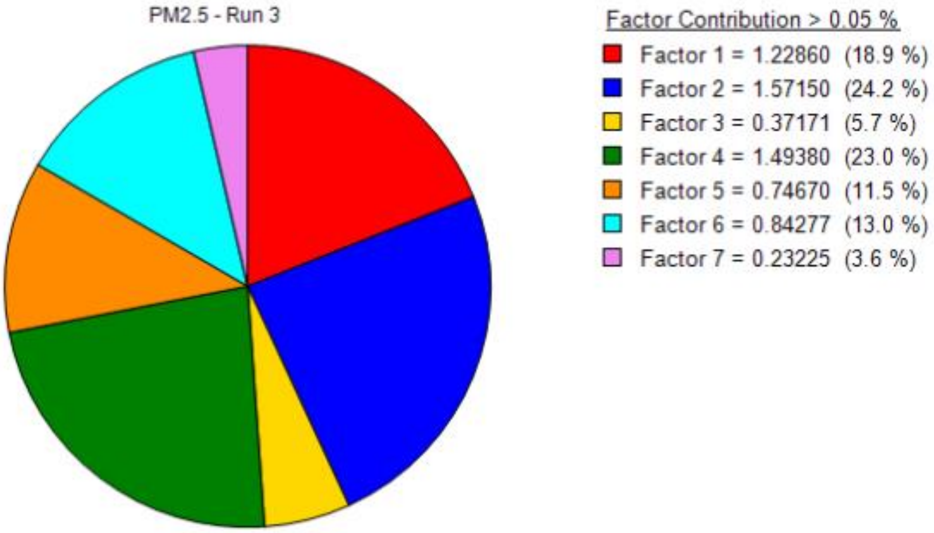


Figure 9. Average factor contribution to $PM_{2.5}$ for Changchun.

Conclusion

1. In 2014, the average mass concentration of $PM_{2.5}$ in Changchun was 66.77 μg/m^3, exceeding the standard by 1.9 times. The $PM_{2.5}$ concentrations in the heating period was significantly higher than that in the non-heating period. For the hourly concentration, the hourly $PM_{2.5}$ concentrations in Changchun basically showed double peak changes that have certain regional characteristics. Changchun should pay attention to controlling the impact of coal burning during winter heating.

2. From the perspective of the mass closure of Changchun $PM_{2.5}$, OM had the largest proportion of $PM_{2.5}$, accounting for 38.2%. Changchun should make efforts to control the emission of organic pollutants in the air. SNA in $PM_{2.5}$ should not be ignored, accounting for 13.3%. MIN accounted for 12%, which is twice the city center of Los Angeles. This is the difference between characteristics of fine particulate pollution in Changchun and big cities in the United States, which may be related to the degree of urban greening. $PM_{2.5}$ quality reconstruction in various regions has certain regional characteristics.

3. Results of PMF analysis showed that $PM_{2.5}$ sources in Changchun are divided into industrial, biomass- and coal-burning, industrial and soil dust, motor-vehicle, soil and secondary-ion, light-industrial, and hybrid-automotive and -industrial sources, accounting for 18.9%, 24.2%, 5.7%, 23.0%, 11.5%, 13.0%, 3.6%, respectively. Compared with other cities' source-apportionment results, it was found that winter heating in northern regions has increased the proportion

of coal-burning sources. Due to the low winter temperature and stable meteorological conditions in Changchun, the proportion of secondary-ion sources is relatively low compared to other cities. Motor-vehicle limit policy is implemented in the Beijing-Tianjin-Hebei region, so the vehicle sources in Changchun are relatively high.

Therefore, Changchun should: improve the utilization efficiency of coal combustion and vigorously develop clean energy; actively promote green travel, encouraging citizens to use public transport to reduce vehicle emissions; strengthen environmental management and straw remediation actions while encouraging comprehensive straw utilization; increase urban greening areas and regularly carry out ground-sprinkling work, reducing the impact of ground dust on the atmosphere; and increase the management of street barbecue merchants, strictly prohibit open-air barbecue, and impose corresponding punishments on violators.

Declarations

Abbreviations

Not applicable

Ethical Approval and Consent to participate

Not applicable

Consent for publication

All authors have read and agreed to the published this version of the manuscript.

Availablity of supporting data

Not applicable

Competing interests

Not applicable

Funding

This study was supported by Ecology and Environment Department of Jilin Province (NO. 2018-19 and 2019-08).

Authors' contributions

Z.Y. worked for the conceptualization, original draft writing, review and editing of the article. Y.T. worked for field sampling and filter analysis. J.W. and J.T. worked on the data curation and methodology and also worked as supervisors and directors of this study.

Acknowledgements

The authors thank the Jilin environmental monitoring station for assistance regarding data sources and sampling.

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