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Original Research

Characteristics and Sources Analysis of Carbonaceous Aerosols in Urban and Rural Areas of Nanchong City

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Abstract

To identify the characteristics and sources of carbonaceous aerosols in an urban area (UA) and rural area (Guihua Township, GH) of Nanchong City, organic carbon (OC) and elemental carbon (EC) were measured in fine particulate matter ($PM_{2.5}$) samples collected from December 2014 to April 2016. The results showed that the average concentrations of $PM_{2.5}$, OC, EC, and secondary organic carbon (SOC) in UA were 66.23±3.68 μg/m^3, 13.34±0.93 μg/m^3, 3.80±0.29 μg/m^3 and 10.05±0.83 μg/m^3, respectively, and those in GH were 60.13±4.28 μg/m^3, 13.82±1.03 μg/m^3, 3.92±0.44 μg/m^3 and 10.23±0.90 μg/m^3, respectively. The seasonal variations in $PM_{2.5}$, OC, EC, and SOC in UA and GH were similar, with the order summer<spring<autumn<winter. The average OC/EC ratio in UA was 4.72±0.31, and that in GH was 5.14±0.38. In addition, K^+, Pb, Zn, and As were positively correlated with OC and EC. This result indicated that biomass burning, fossil combustion, and motor vehicle exhaust within the Sichuan Basin were the main sources of $PM_{2.5}$ in Nanchong City. The poor meteorological diffusion conditions prevalent for pollutants were the main reason for the high concentration of carbonaceous aerosols in Nanchong City.

Keywords: organic carbon, elemental carbon, secondary organic carbon, fine particulate matter, backwards trajectories, Nanchong City

Introduction

Fine particulate matter ($PM_{2.5}$) refers to particulate matter with an aerodynamic equivalent diameter less than or equal to 2.5 μm in ambient air [1], which is mainly composed of carbonaceous components (sometimes called carbonaceous aerosols), water-soluble ions and chemical elements [2-7]. Carbonaceous aerosols are the main constituents of $PM_{2.5}$, accounting for approximately 20%~50% of the mass concentration of $PM_{2.5}$ in urban atmosphere [8-12]. It is generally classified into organic carbon (OC) and elemental carbon (EC, sometimes called black carbon). OC originates from primary anthropogenic production activities, such

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as biomass burning, fossil combustion, vehicle emission, and industrial production, as well as secondary organic carbon (SOC) formed by chemical reactions in the atmosphere [9, 13]. EC is a product of the incomplete combustion of residential coal, motor vehicle fuel, and biomass burning.

In recent years, a large number of studies have been carried out on carbonaceous aerosols (including mass concentration and sources, temporal and spatial characteristics, size distributions, impacts on visibility, analysis of sources, influence with meteorological conditions, and transformation mechanisms) in the Beijing-Tianjin-Hebei region [12, 14-18], the Yangtze River Delta [6, 10, 14-15, 18-20], the Pearl River Delta [15, 18, 21-23], Chengdu-Chongqing [11, 13-15, 18, 24-25] and other regions [26]. Due to the unevenness in economic development in China, most existing research on carbonaceous aerosols has focused on large cities with developed economies, and little attention is currently given to small cities and less developed areas. In addition, China has vast territories with different landforms, and there are larger differences in climatic conditions and energy consumption between the northern and the southern regions. Therefore, different cities have the different mass concentrations, sources, characteristics, and influencing factors for carbonaceous aerosols.

The Sichuan Basin is located in the southwest China and is surrounded by the 1000~3000 m Qinghai-Tibet Plateau, Daba Mountain, Huaying Mountain, and Yunnan-Guizhou Plateau. As the area is affected by a humid subtropical monsoon climate and high mountains, the Sichuan Basin has a mild climate with foggy and humid conditions, high levels of precipitation, low wind speeds, and frequent calm winds.

Nanchong City is a typical agricultural city in northeastern Sichuan Basin that was rapidly urbanized and shows low levels of industrialization. The topography of the main urban area is low-lying, and the diffusion conditions for pollutants are poor. The primary aims of the present study were to explore the characteristics, sources and levels of fine particulate matter and carbonaceous aerosols in Nanchong City. The results of our study could provide insights and a scientific basis for the prevention and control of air pollution in Nanchong City in the future. The main objectives of this study were as follows: (1) to determine the characteristics and sources of $PM_{2.5}$ and

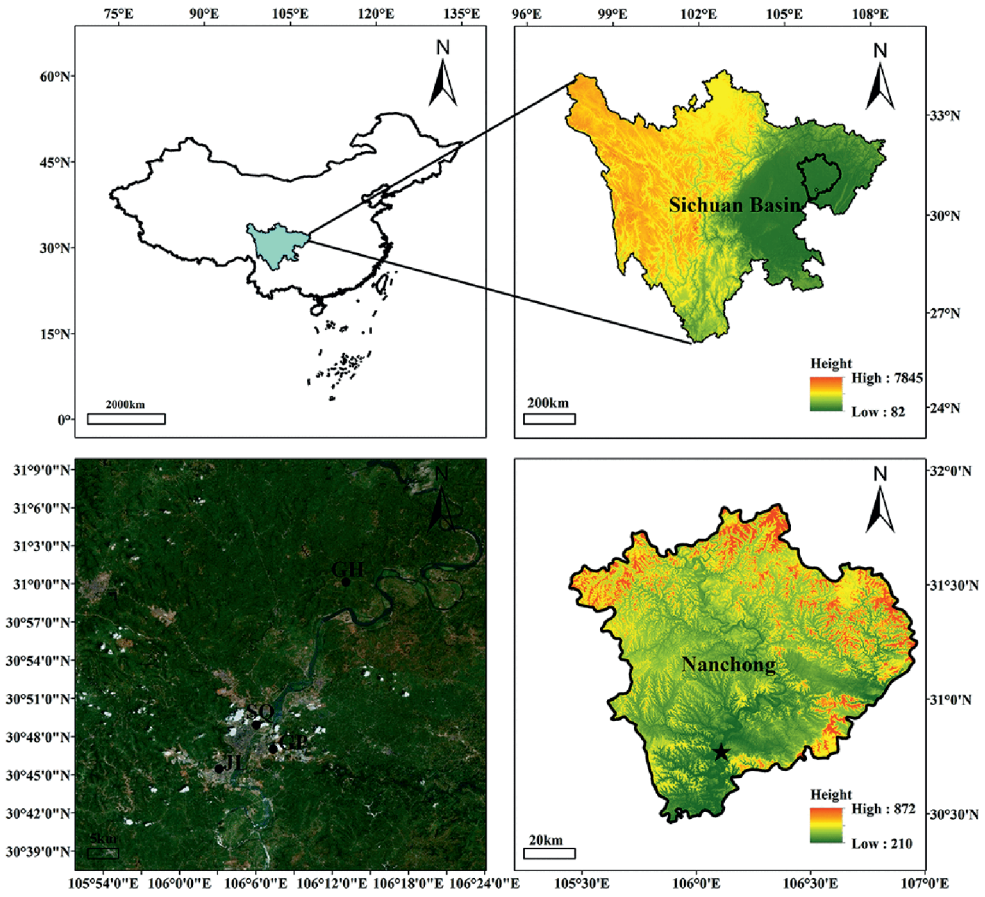

Fig. 1. a) The location of Sichuan Province in southwest of China. b) The topography of Sichuan Basin and the location of Nanchong in northeastern Sichuan Basin. c) The topography of Nanchong. d) The Shunqing (SQ), Gaoping (GP), Jialing (JL), and Guihua (GH) sampling sites in Nanchong.

carbonaceous aerosols in Nanchong; (2) to estimate the SOC levels in urban areas and rural areas; (3) to explore the OC and EC relationship; and (4) to analyse the seasonal variations in $PM_{2.5}$ and carbonaceous aerosols in urban areas and rural areas.

Materials and Methods

Study Area

Nanchong City (30°35′~31°51′N, 105°27′~106°58′E, 256~889 m a.s.l.) is located in the northeast region of the Sichuan Basin and near the midstream of Jialing River, and the terrain slopes from north to south (Fig. 1c). It has a mid-subtropical humid monsoon climate with four distinct seasons and is famous throughout the country for its breezy, damp, rainy, and foggy climate. It has the second largest population in Sichuan Province. The urban area of Nanchong City is located in the southern part of the city and includes the districts of Shunqing (SQ), Gaoping (GP), and Jialing (JL), with a population of over 1.7 million and an area of approximately 170 km^2. In this study, one site was selected for $PM_{2.5}$ sample collection in each of the three districts and in a rural area (the rural site is located in Guihua Township (GH), which is located upwind of the dominant wind direction of the city and approximately 25 kilometres away from the urban area) of Nanchong City. The concentrations of $PM_{2.5}$, OC, EC, and elements reported in the urban area (UA) of Nanchong City were the average of the data at SQ, GP, and JL. The $PM_{2.5}$ sampling sites are shown in Fig. 1d).

Sampling and Analysis

The $PM_{2.5}$ samples were collected synchronously at four sampling sites from December 2014 to April 2016. During the sampling period, samples were collected for 24 hours (from 10:00 a.m. to 10:00 a.m. of the next day) once every 6 days with a four-channel sampler made by Tianhong Instrument Co., Ltd. of China (model: TH-16A, flow rate: 16.7 L/min for each channel). The $PM_{2.5}$ samples were collected on Teflon filters and quartz filters. The procedures for membrane replacement and sample storage followed the Technical Guidelines for Source Analysis and Monitoring of Atmospheric Particulates (Trial) (MEE, Ministry of Ecology and Environment of China).

The Teflon filters were weighed at least three times with an electronic balance (AX105 Delta Range; Mettler Toledo, OH, USA) after being left for 24 h in a superclean environment at a constant temperature (20±1ºC) and relative humidity (40±3%). The $PM_{2.5}$ mass concentration was obtained by dividing the mass difference in the Teflon filter before and after sampling by the sampled air volume. Inductively coupled plasma-mass spectrometry (Agilent 7500c; Agilent Technologies Co., Ltd., CA, USA) was used to determine the elemental concentrations (Pb, Zn, As, Ca and Al) in particles collected on Teflon filters. A thermal-optical transmittance analyser (Sunset Laboratory Inc., USA) was used to analyse the concentrations of OC and EC. The analysis method was based on the National Institute of Occupational Safety and Health (NIOSH) 5040 protocol for ten carbon factions (four OC fractions, one pyrolyzed carbon (PC) fraction, and five EC fractions) [27]. OC was defined as the sum of the OC and PC fractions, while EC was defined as the fractions minus PC. The samples on the Teflon filters were first extracted ultrasonically using 10 mL ultrapure water, then the aqueous extract was passed through a 47 μm water filter and the concentrations of water-soluble ions were determined by ion chromatography (Dionex, ICS 2000).

The daily concentrations of ambient air pollutants ($PM_{2.5}$ and PM_{10}) during the sampling period were collected from automatic monitoring data in the Nanchong Ecological and Environmental Monitoring Central Station of Sichuan Province. The meteorological data (such as air temperature (AT), air pressure (AP), relative humidity (RH), wind speed (WS), precipitation (P), and days of precipitation (DP)) during the sampling period were collected from https://rp5.ru/. The tracked aerological data for air masses (such as pressure and wind speed) for backwards trajectory analysis were obtained from the Air Resource Laboratory, National Oceanic and Atmospheric Administration (http://www.arl.noaa.gov/).

Data Processing and Statistical Analysis

Backwards Trajectory Analysis

In this study, Meteoinfo software (download website: http://www.meteothinker.com) was used to analyse the 24-h backwards trajectories of 500 m-high air masses in the urban area of Nanchong (30.80 N, 106.08 E, 500 m AGL) [28]. Then, cluster analysis was used in Meteoinfo software to classify the 24-h backwards trajectories of the air masses during the sampling period.

SOC Estimation

In this study, the EC-tracer method was used to estimate the SOC level in UA and GH [29]. The formula for SOC is as follow :

$$SOC = OC - EC \times (OC/EC)_{Primary} \quad (1)$$

where the $(OC/EC)_{Primary}$ ratio indicates the contribution of primary sources to the sample. In this study, we selected the minimum OC/EC ratio as the primary OC/EC ratio in each season. The $(OC/EC)_{primary}$ ratios of spring, summer, autumn and winter in UA were 0.89, 2.60, 1.65, and 1.34 respectively, and those in GH were 0.94, 2.30, 1.40, and 0.97, respectively.

Enrichment factor (EF)

EF was used to analyse the relative contributions of anthropogenic sources and natural sources to the metals in $PM_{2.5}$ [30]. The formula of EF is as follow:

$$EF_i = \frac{(C_i/C_{ref})_{PM2.5}}{(C_i/C_{ref})_{soil}} \quad (2)$$

where EF_i denotes the enrichment factor for element i, $(C_i/C_{ref})_{PM2.5}$ denotes the ratio of the concentrations of element i to the reference element ref in $PM_{2.5}$, and $(C_i/C_{ref})_{soil}$ denotes the ratio of the concentrations of element i to the reference element ref in topsoil.

The evaluation criterion for the element EF in $PM_{2.5}$ is based on ref [31]. When the *EFi* of element *i* is greater than 10, it indicates that an element is mainly contributed by the anthropogenic sources; when *EFi* is less than 10, an element is mainly contributed by the natural sources. The concentrations of the elements in the topsoil were derived from the background values of topsoil elements in Sichuan Province [32]. During the sampling period, the average concentrations of ferrum (Fe) and aluminium (Al) in $PM_{2.5}$ were low in UA and GH. However, there was a large difference in the concentration of Fe in $PM_{2.5}$ between UA and GH (χ^2 = 37.300, P<0.001) and a small difference in the concentration of Al (χ^2 = 1.861, P = 0.173). Therefore, Al was selected as the reference element.

Data Processing and Analysis

All the data (including the concentrations of $PM_{2.5}$, OC, EC, and elemental and the OC/EC ratio) were analysed using the statistical software SPSS 22.0. 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 ANOVA (with the Duncan's multiple range test). Nonparametric tests (with the Kruskal–Wallis H test) were used when the variables were not unnormalizable. The values are expressed as the mean±SE. To investigate the relationships between the elemental, OC, and EC concentrations in $PM_{2.5}$, Spearman's correlation analysis was applied.

Origin-Pro 9.0 and ArcGIS 10.8 software were used for data processing and graph construction.

Results and Discussion

Characteristic of $PM_{2.5}$

During the sampling period, the daily concentrations of $PM_{2.5}$ ranged from 8.87 to 204.31 μg/m^3 in UA, which exceeded the standard daily $PM_{2.5}$ concentration by 35.40% and from 8.23 to 210.22 μg/m^3 in GH, which exceeded the standard daily $PM_{2.5}$ concentration by 32.97%, respectively (the upper limit of the daily average of $PM_{2.5}$ concentration is 75 μg/m^3 for Class II areas based on the Standard of China's National Air Quality Standard for areas, such as urban residential, commercial and traffic, cultural, industrial, and rural areas) [1]. The annual average concentration of $PM_{2.5}$ was 66.23±3.68 μg/m^3 in UA and 60.13±4.28 μg/m^3 in GH (Table 1), which significantly exceeded the Grade II Standard of China's National Air Quality Standard for $PM_{2.5}$ (one-sample t-test, UA: t = 8.478, P<0.001; GH: t = 6.154, P<0.001) (the upper limit of the annual average is 35 μg/m^3 for Class II areas) [1], at 0.89-fold and 0.72-fold, respectively. It can be concluded that $PM_{2.5}$ pollution in Nanchong was relatively severe during the study period. Lei et al. [33] found that $PM_{2.5}$ was the main non-attainment pollutant in the urban areas of Nanchong City from 2015 to 2018, and the annual average concentrations of $PM_{2.5}$ exceeded 35 μg /m^3 for four consecutive years. Similarly, the other cities in the Sichuan Basin also showed severe $PM_{2.5}$ pollution between 2009 and 2016 [14, 34-35].

During the sampling period, there was no significant difference in the $PM_{2.5}$ concentration between UA and GH (χ^2 = 46.615, P = 0.127), and the seasonal trends in which were similar (Rs = 0.827, P<0.001). The seasons were categorized as spring (March to May), summer (June to August), fall (September to November), and winter (December to February). The average concentrations of $PM_{2.5}$ in UA and GH were highest in winter, with the mean values of 95.70±5.99 μg/m^3 and 87.85±6.05 μg/m^3, respectively (Table 1), which were significantly higher than those in other seasons (UA: χ^2 = 46.615, P<0.001; GH: χ^2 = 43.429, P<0.001), followed by spring and autumn, and lowest in summer (Table 1). This indicates that the $PM_{2.5}$ pollution was at the same level in UA and GH during the sampling period. Moreover, the same trends in $PM_{2.5}$ observed in Nanchong City were found in most cities in China [36-38].

Previous studies have indicated that atmospheric particulate pollution is influenced by the source emission intensity, atmospheric processes, and meteorological conditions [39-44]. When the sources of particles in the atmosphere are relatively stable, the PM concentration is principally affected by atmospheric processes [45] and meteorological conditions [39-44, 46]. Fig. 2 shows the cluster analysis results of 24-h backwards trajectories of 500 m-high aerosol sources in the urban area of Nanchong. During the study period, the mass concentration of aerosols was primarily influenced by sources within the Sichuan Basin, and the contributions were 79.45% in spring, 85.42% in summer, 83.89% in autumn, and 81.12% in winter. However, unlike in northern cities in China, there was no extensive coal combustion or wood burning in winter because of the warm temperatures (approximately 10ºC on average) in the Sichuan Basin [45-46]. Therefore, the PM concentrations of the cities in the Sichuan Basin during winter were more affected by atmospheric processes and meteorological conditions [33, 40, 47].

Table 1. The seasonal concentrations of PM2.5 in UA and GH of Nanchong City.

	Total (μg/m³)	Spring (μg/m³)	Summer (μg/m³)	Autumn (μg/m³)	Winter (μg/m³)
UA	66.2±3.7	57.3±4.1	35.2±3.4	37.0±6.1	95.7±6.0
GH	60.1±4.3	45.7±7.2	30.3±3.4	31.4±4.8	87.9±6.0

In the sampling period, there was a negative correlation between $PM_{2.5}$ and air pressure (Rs = -0.137, P = 0.065), wind speed (Rs = -0.310, P<0.001), and precipitation (Rs = -0.300, P<0.001) in winter and a positive correlation between $PM_{2.5}$ and air temperature (Rs = 0.010, P = 0.897), and relative humidity (Rs = 0.225, P = 0.002). In particular, $PM_{2.5}$ was significantly affected by relative humidity, wind speed, and precipitation. Similar to other cities in the Sichuan Basin, poor meteorological diffusion conditions exist for pollutants (such as low wind speed, high frequency of calmer winds, low levels of rainfall, and low boundary layer) during winter in Nanchong (Fig. 3), which is not conducive to the diffusion and transport of $PM_{2.5}$ and readily cause the accumulation of $PM_{2.5}$ [44]. In addition, the higher temperatures and relative humidity prevalent in winter are conducive to the conversion of other pollutants into $PM_{2.5}$ [40, 42, 48]. In contrast, the more intensive convective air currents and greater amounts of rainfall in summer are conducive to the diffusion and transport of $PM_{2.5}$, and the higher temperature and more intense illumination intensity are conducive to the removal of particulate matter via secondary reactions with other substances in the air [33, 42]. In spring, northerly sand and dust storms entered the Sichuan Basin and affected the PM concentration of Nanchong at times [33]. Because dust particles are mainly composed of larger particles, the concentrations of PM_{10} and $PM_{2.5}$ in the air rise simultaneously in dusty weather, but the increase in the range of PM_{10} is much higher than that of $PM_{2.5}$, resulting in a significant decline in the $PM_{2.5}/PM_{10}$ ratio. In the sampling period, the $PM_{2.5}/PM_{10}$ ratio in spring was 64.53%, which was lower than that in other seasons (summer: 66.09%; autumn: 72.43%; winter: 70.92%). In autumn, atmospheric relative humidity (RH) was relatively higher and the hygroscopic growth of particles was greater, leading to an increase in the mass concentrations of $PM_{2.5}$ and PM_{10}. In Nanchong during the autumn, the conditions are moister and foggier, and lager particles formed due to hygroscopic growth are more easily removed by gravity deposition, resulting in an increase in the $PM_{2.5}/PM_{10}$ ratio. During the sampling period, the $PM_{2.5}/PM_{10}$ ratio in autumn was highest.

Characteristics of OC and EC

During the sampling period, the average concentrations of OC and EC in UA were 13.34±0.93 μg/m³ and 3.80±0.29 μg/m³, and those in GH were 13.82±1.03 μg/m³ and 3.92±0.44 μg/m³, respectively.

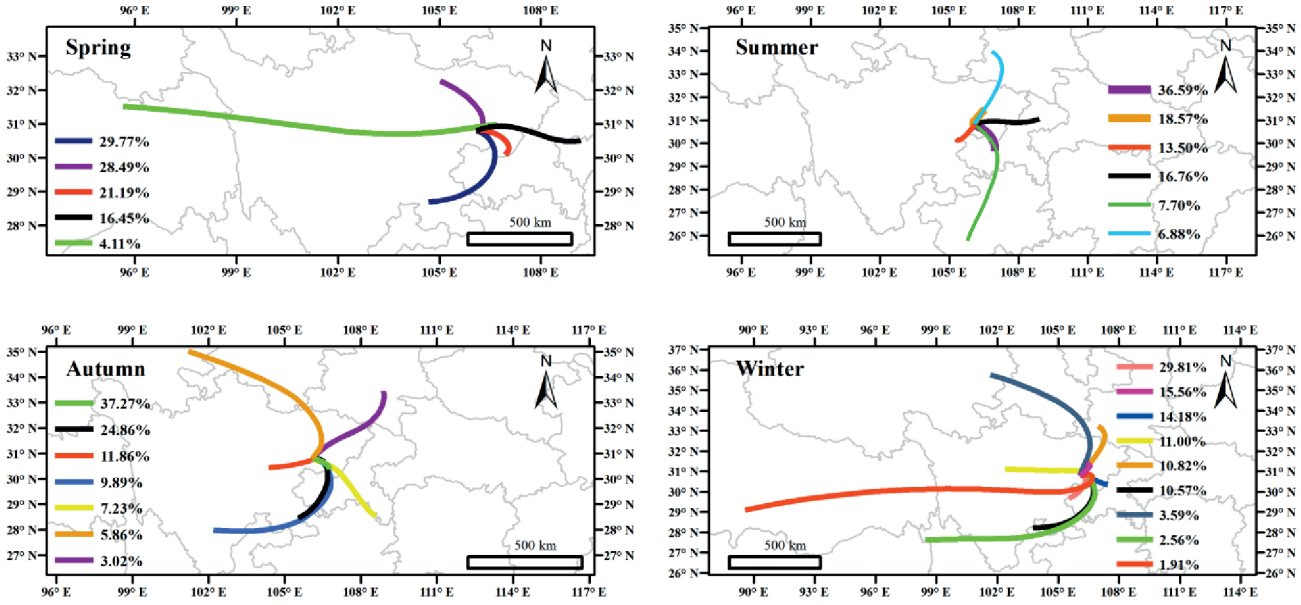

Fig. 2. The 24-h backward trajectories of 500m-high air mass in the urban area of Nanchong (30.80 N, 106.08 E, 500m AGL) during the study period. The colored lines represent the direction of the air mass in figure, the numbers in the legend represent the proportion of sources of air mass in this direction in four seasons.

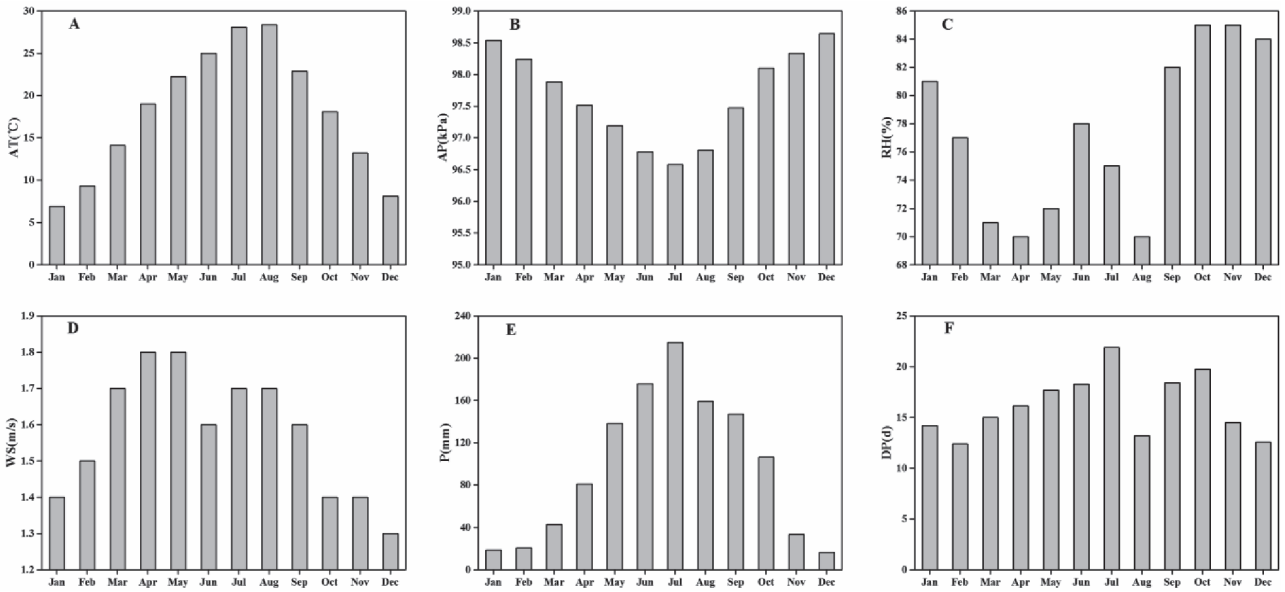

Fig. 3. Monthly variations of air temperature (AT), air pressure (AP), relative humidity (RH), wind speed (WS), precipitation (P), and days of precipitation (DP) in the Main Urban Area of Nanchong City.

Compared with other cities in the Sichuan Basin, the OC and EC levels in Nanchong were lower than in Chengdu (the 19.0±13.3 μg/m^3 OC, 4.6±2.6 μg/m^3 EC in May 2012 to April 2013 [49]), in Chongqing (the 20.66 μg/m^3 OC, 6.16 μg/m^3 EC in October 2015 to August 2016 [50]), in Meishan (the 15.8±9.6 μg/m^3 OC, 6.6±5.36 μg/m^3 EC in August 2012 to August 2013 [51]), and in Neijiang (the 18.3±8.4 μg/m^3 OC, 4.1±1.8 μg/m^3 EC from May 2012 to April 2013 [49]), and were slightly higher than in Deyang (the 9.6±6.1 μg/m^3 OC, 3.4±2.6 μg/m^3 EC in August 2012 to August 2013 [51]).

However, there were slight differences in OC (χ^2 = 0.017, P = 0.897) and EC (χ^2 = 0.877, P = 0.349) between UA and GH during the sampling period. The seasonal variation trends in EC and OC concentrations in the two regions were consistent, with the highest in winter, followed by autumn or spring, and the lowest in summer (Fig. 4), and the differences in OC and EC between seasons reached a significant level in UA (OC: χ^2 = 55.381, P<0.001; EC: χ^2 = 47.481, P<0.001) and GH (OC: χ^2 = 43.406, P<0.001; EC: χ^2 = 43.163, P<0.001). The seasonal trends were similar to those in other cities in the Sichuan Basin, such as Chengdu, Meishan, Deyang, and Neijiang [49, 51]. In addition, the seasonal trends in OC and EC in UA and GH were consistent with $PM_{2.5}$ and showed a high correlation (P<0.001) during the sampling period. OC and EC in UA and GH were similar to $PM_{2.5}$, which was greatly affected by meteorological conditions.

The Relationship between OC and EC

Previous studies have indicated that the OC/EC ratio can be used to identify the source of carbonaceous aerosols [52]. An OC/EC ratio >5, indicates that the

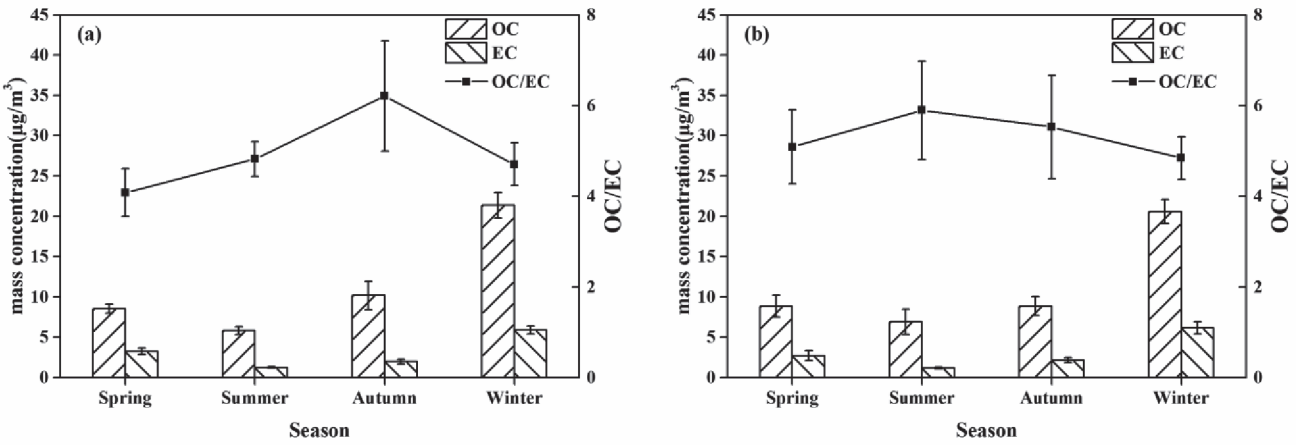

Fig. 4. Seasonal variation trends of OC and EC concentration, and OC/EC ratio in UA a), and in GH b).

carbonaceous aerosols mainly come from biomass burning, whereas an OC/EC ratio <2, indicates that the carbonaceous aerosols mainly come from fossil fuel combustion [53]. During the sampling period, the daily OC/EC ratios ranged from 0.89 to 17.52 in UA and from 0.94 to 15.93 in GH. The concentrations of OC (*R*s = 0.746, *P*<0.001) and EC (*R*s = 0.675, *P* 0.001), the OC/EC ratio (*R*s = 0.349, *P* = 0.001) were significantly positively correlated between UA and GH, indicating that the sources of carbonaceous aerosols in UA and GH were the same. During the sample period, the number of days with OC/EC ratios greater than 5 accounted for 38.05% and 42.86% of the total days, and the number of days with OC/EC ratios less than 2 accounted for 19.47% and 18.68% of the total days in UA and GH, respectively, reflecting the important contribution of biomass burning and fossil fuel combustion. Nanchong is an agricultural city with low levels of industrialization. Due to a lack of technology for processing straw and the high cost of staw-processing, most straw has been open burning in the past [33]. Previous studies have indicated that OC and EC were mainly derived from biomass burning, fossil combustion, and motor vehicle exhaust in the Sichuan Basin [13, 49, 54-55].

Characteristics of SOC

The OC/EC ratio is often used to identify the transformation of carbonaceous aerosols. A high OC/EC ratio coupled with a poor correlation indicates an influx of urban pollutants from other locations or the formation of SOC from photochemical reactions. On the other hand, a high correlation indicates primary emissions and a secondary formation derived from the primary carbon [29, 56-57]. When the OC/EC ratio >2, SOC formation occurs [58]. During the sampling period, the average OC/EC ratio in UA was 4.72±0.31, that in GH was 5.14±0.38, and there was a significant positive correlation between OC and EC (UA: *R*s = 0.611, *P*<0.001; GH: *R*s = 0.645, *P*<0.001). The average concentrations of SOC estimated by the EC-tracer method [29] were 10.05±0.83 μg/m^3 and 10.23±0.90 μg/m^3, accounting for 71.78% and 71.81% of the OC in UA and GH, respectively. The SOC concentration and SOC/OC ratio in Nanchong were higher than those in other cities in the Sichuan Basin, such as Chengdu (SOC: 5.1 μg/m^3; SOC/OC: 26.7%), Chongqing (SOC: 3.9 μg/m^3; SOC/OC: 25.7%), and Neijiang (SOC: 4.5 μg/m^3; SOC/OC: 24.6%) [49]. The OC in $PM_{2.5}$ was seriously polluted by secondary pollution in Nanchong City.

However, SOC pollution in Nanchong was severe overall, and there was a significant difference in SOC concentration between seasons (UA: χ^2 = 26.990, *P*<0.001; GH: χ^2 = 27.579 *P*<0.001). The concentrations of SOC in UA and GH were highest in winter, followed by spring and autumn, and lowest in summer (Fig. 5). In winter, there were high temperatures, high relative humidity, and low precipitation, which was conducive to the formation of SOC. In addition, the lower wind speed was not conducive to the diffusion and migration of SOC. In winter, there were significant positive correlations between OC and EC in UA (*P* = 0.018) and GH (*P* = 0.018) (Table 2), indicating that SOC mainly came from local emission sources and secondary formation.

The Relationship between OC, and EC and K^+, Pb, Zn, and As

Previous studies have shown that K^+ can be used as a marker for biomass burning [59-60], Pb and Zn can be used as markers of motor vehicle exhaust [61-63], and As can be used as a marker of fossil fuel combustion [64-65]. The concentrations of K^+, Pb, Zn, and As in $PM_{2.5}$ during the sampling period at UA and GH are shown in Table 3. The average concentrations of K^+ in UA and in GH were 1.15±0.14 μg/m^3 and 1.11±0.18 μg/m^3, respectively. Compared with other cities in the Sichuan Basin, the K^+ level in Nanchong was higher than that in megacities such as Chengdu (the 0.7±0.5 μg/m^3 K^+ from October 2014 to July 2015

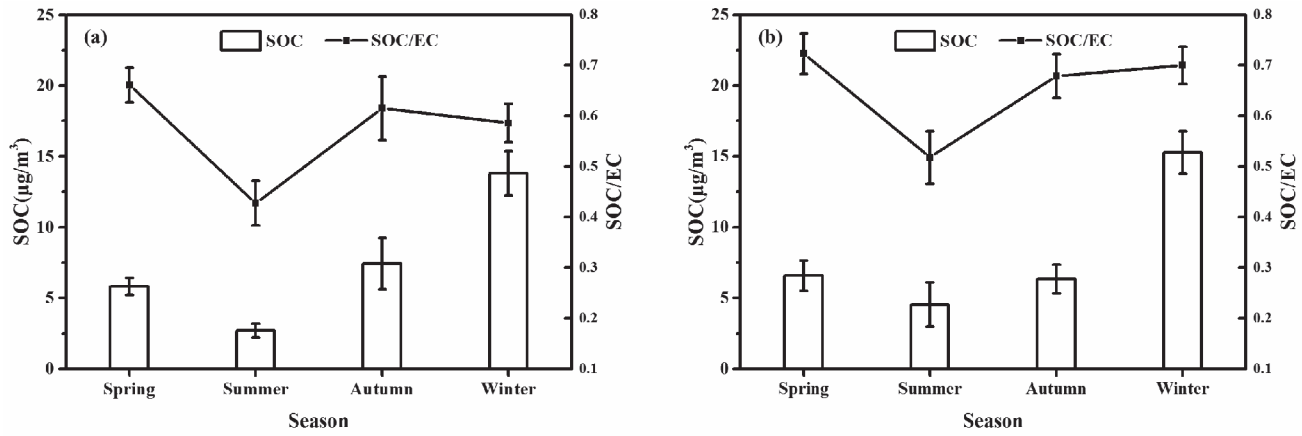

Fig. 5. Seasonal variation trends of SOC concentration and SOC/OC ratio in UA a), and in GH b).

Table 2. The correlation between OC and EC in UA and GH of Nanchong City.

Stations	Spring	Summer	Autumn	Winter
UA	0.400*	0.353	0.225	0.358*
GH	0.120	0.471	-0.104	0.368*

Note: * means correlation was significant at the 0.05 level.

Table 3. The concentrations of K^+, Pb, Zn, and As in $PM_{2.5}$ in UA and GH of Nanchong City.

	K^+ (μg/m^3)	Pb (μg/m^3 • 10^{-2})	Zn (μg/m^3 • 10^{-2})	As (μg/m^3 • 10^{-3})
UA	1.15±0.14	4.56±0.57	6.30±0.28	1.89±0.12
GH	1.11±0.18	3.20±0.30	4.15±0.31	2.80±0.30

Table 4. The correlation between OC, EC, and K^+, Pb, Zn, As in UA and GH of Nanchong City.

Stations	Species	K^+	Pb	Zn	As
UA	OC	0.803**	0.840**	0.669**	0.197*
	EC	0.603**	0.715**	0.578**	0.239*
GH	OC	0.723**	0.785**	0.571**	0.422**
	EC	0.466**	0.679**	0.425**	0.353**

Note: * and ** mean correlations were significant at the 0.05 and 0.01 level, respectively.

[45]) and Chongqing (the 0.80 μg/m^3 K^+ from May 2012 to May 2013 [66], the 0.6±0.5 μg/m^3 K^+ from October 2014 to July 2015 [45]), and was at the same level as that in Deyang (the average seasonal concentrations of K^+ ranged from 0.6 to 1.5 μg/m^3 from August 2013 to August 2014 [51]) and Meishan (the average seasonal concentrations of K^+ ranged from 0.8 to 1.7 μg/m^3 from August 2013 to August 2014 [51]). In addition, the contributions of K^+ to $PM_{2.5}$ in UA and GH were as high as 1.74% and 1.85%, respectively. In contrast, the concentrations of Pb, Zn, and As were lower, and accounted for relatively small proportions of $PM_{2.5}$. However, the EFs of Pb, Zn, and As in UA were 23615.502,11664.808 and 2907.349, respectively, and those in GH were 16562.347, 76763.948 and 4313.372, respectively, which were much higher than 10. During the sampling period, K^+, Pb, Zn and As were significantly positively correlated with OC and EC in UA and GH (P<0.05) (Table 4), indicating that K^+, Pb, Zn, and As in Nanchong were mainly emitted by anthropogenic sources, such as biomass burning, fossil combustion, and motor vehicle exhaust.

Conclusions

During the sampling period, the average concentrations of $PM_{2.5}$ in UA and GH were 66.23±3.68 μg/m^3 and 60.13±4.28 μg/m^3, respectively. This result shows that $PM_{2.5}$ pollution in Nanchong was relatively severe during the study period. The seasonal variation trends of $PM_{2.5}$ in UA and GH were similar, with the order of summer<spring<autumn<winter.

The mass concentration of aerosols was primarily influenced by sources within the Sichuan Basin, and the contributions were 79.45% in spring, 85.42% in summer, 83.89% in autumn, and 81.12% in winter. The poor meteorological diffusion conditions for pollutants (such as low wind speed, frequent calm winds, low rainfall, and low boundary layer) and the higher temperature and relative humidity conditions were the main reasons for the high concentration of aerosols in UA and GH.

The average concentrations of OC and EC in UA were 13.34±0.93 μg/m^3 and 3.80±0.29 μg/m^3, and those in GH were 13.82±1.03 μg/m^3 and 3.92±0.44 μg/m^3, respectively. The differences in OC and EC concentrations were small between UA and GH, and the seasonal trends were consistent, with the highest in winter, followed by spring or autumn, and the lowest in summer.

During the sampling period, the daily OC/EC ratios in UA ranged from 0.89 to 17.52 with an average of 4.72±0.31, and those in GH ranged from 0.94 to 15.93 with an average of 5.14±0.38. The number of days with the OC/EC ratios greater than 5 in UA and GH accounted for 38.05% and 42.86% of the total days, respectively, and the number of days with the OC/EC ratios less than 2 accounted for 19.47% and 18.68% of the total days, respectively, reflecting the important contributions of biomass burning, fossil fuel combustion and motor vehicle exhaust. The average concentrations of SOC were 10.05±0.83 μg/m^3 and 10.23±0.90 μg/m^3,

and accounting for 71.78% and 71.81% of the OC in UA and GH, respectively, indicating that the OC in $PM_{2.5}$ contained large amounts of secondary pollutants in Nanchong City.

During the sampling period, K^+, Pb, Zn, and As were significantly positively correlated with OC and EC in UA and GH, and the EFs of Pb, Zn, and As in UA were 23615.502,11664.808 and 2907.349, and in GH were 16562.347, 76763.948 and 4313.372, respectively. This result indicated that biomass burning, fossil combustion, and motor vehicle exhaust were the main sources of $PM_{2.5}$ in UA and GH.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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