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Seasonal Variations in $PM_{2.5}$ Carbon Components: A Case Study

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Abstract: This study conducted a comprehensive analysis of the carbon components in $PM_{2.5}$ particulate matter in Linfen City for the year 2020. Utilizing the thermal-optical transmittance (TOT) method, the mass concentrations of organic carbon (OC) and elemental carbon (EC) in $PM_{2.5}$ were quantitatively assessed. Findings revealed seasonal variations in the concentrations of OC and EC. Specifically, concentrations in spring were registered at $4.45\mu g/m^3$ for OC and $1.03\mu g/m^3$ for EC; in summer, these were $3.89\mu g/m^3$ and $0.74\mu g/m^3$; in autumn, $6.01\mu g/m^3$ and $1.30\mu g/m^3$; escalating significantly in winter to $16.76\mu g/m^3$ for OC and $4.24\mu g/m^3$ for EC. This seasonal trend highlighted a notable peak in winter, with OC concentrations being 4.31 times, and EC concentrations 5.73 times, those observed in summer. The correlation analysis between OC and EC demonstrated the highest correlation in winter $\left(R^2 = 0.961\right)$, suggesting similar sources for these components in the colder months, followed by autumn $\left(R^2 = 0.936\right)$ and spring $\left(R^2 = 0.848\right)$, with the least correlation observed in summer $\left(R^2 = 0.584\right)$. The EC tracer method, employed to estimate secondary organic carbon (SOC) concentrations, indicated a seasonal pattern in SOC levels, with the highest concentrations occurring in winter, thereby suggesting a significant secondary pollution impact during this period. Moreover, the study identified meteorological conditions, particularly long-distance horizontal transport, as a primary influencer of winter pollution levels in Linfen City.

Keywords: $PM_{2.5}$; Organic carbon; Elemental carbon; Pollution characteristics; Linfen

1 Introduction

The complexity of $PM_{2.5}$'s carbon components is well-documented, primarily encompassing OC, EC, and carbonate carbon (CC) [1]. OC and EC are significant, contributing 10-70% of the total composition [2], whereas CC, forming less than 5% [3], is often deemed inconsequential in particulate matter research. OC is noted for its chemical reactivity and diverse sources, including primary organic carbon (POC), emitted directly from various sources, and SOC [4], which forms through photochemical reactions involving gaseous precursors. EC, in contrast, is characterized by its chemical stability, generally remaining inert under normal temperatures and primarily arising from incomplete combustion of fossil and biomass fuels [5]. The presence of OC, containing hazardous substances, poses substantial health risks [6] and engages in atmospheric photochemical reactions, playing a role in light scattering [7]. EC, with its significant adsorption properties, absorbs infrared light and contributes to global warming.

In recent years, China has experienced escalated air pollution, stimulating extensive research into $PM_{2.5}$'s carbon components. These investigations have concentrated on assessing concentration levels, exploring spatial-temporal distribution, estimating SOC, apportioning sources, and evaluating impacts on human health [8–10]. However, the focus on Linfen City, a heavily polluted area, has been limited, underscoring the need for a detailed examination of its $PM_{2.5}$ carbon components.

Situated in the Fenwei Plain, characterized by its basin-like topography, Linfen City heavily relies on its coal and coke industry. The city grapples with complex sources of particulate matter emissions, exacerbating its air pollution challenges. In response, this study analyzed $PM_{2.5}$ data from Linfen City for the year 2020, focusing on the concentration and seasonal distribution of carbon components. Employing correlation analysis, the sources of these components were identified. The EC tracer method facilitated the estimation of SOC concentrations, while the impact of meteorological conditions on carbon components was also examined. The objective of this study is to furnish a foundation for the effective management of air pollution in Linfen City.

2 Materials and Methods

2.1 Sample Collection and Analysis

For this investigation, samples were collected from the Beidajie monitoring station in Linfen City. Hourly concentrations of $PM_{2.5}$ were acquired from the National Air Quality Network Monitoring and Management Platform. Additionally, data pertaining to OC, EC, and meteorological elements were obtained on an hourly basis from the National Atmospheric Particulates and Photochemical Monitoring Data Integration and Comprehensive Analysis Platform.

2.2 Analysis of Carbon Components in $PM_{2.5}$

The carbon components within $PM_{2.5}$ were analyzed using a thermal-optical carbon analyzer (DRI Model 2001A), employing the TOT method. From the quartz film of the sample, a circular filter membrane measuring $0.512\ cm^2$ was excised. This sample underwent a heating process at temperatures of $120°C, 250°C, 450°C$, and $550°C$ in an oxygenfree helium atmosphere, converting the particulate matter on the filter paper into CO_2 and thus releasing OC. Following this, the sample was further heated in a helium atmosphere containing 2% oxygen at $550°C, 700°C$, and $800°C$ for EC release. The CO_2 generated at each temperature stage was catalytically reduced to CH_4 using MnO_2 and measured via a flame ionization detector (FID). A $633\ nm$ helium-neon laser was utilized to monitor the reflectance of the filter membrane during the analysis, signaling the onset of EC oxidation. Instrument calibration was conducted using a sucrose solution, and control experiments with blank membranes replicated the experimental steps. The duration of analysis varied with particulate matter concentration, typically lasting around 30 minutes per sample.

2.3 Quality Control and Assurance

System stability, assessed through three-peak tests, was conducted at both the beginning and end of each day's analysis. The relative standard deviation was calculated from the three-peak data, with deviations exceeding 5% rendering the sample analysis ineligible. System blanks, devoid of filter membranes, were regularly run. Should the system blank surpass the acceptable threshold (TC 0.5ugC), the system was recalibrated and retested until the blank value fell below the detection limit. One in every ten samples underwent reanalysis for quality assurance, entailing the reassessment of the first sample post the tenth sample analysis. Samples were reanalyzed if discrepancies between two consecutive measurements exceeded the acceptable deviation range (20%). This process continued in reverse order until consistency within the acceptable deviation range was achieved compared to the initial test results.

3 Results and Discussion

3.1 Seasonal Variability in $PM_{2.5}$ and its Carbon Components

The study conducted in Linfen City throughout 2020 revealed significant seasonal variations in the concentrations of $PM_{2.5}$ and its carbon components, OC and EC, as detailed in Table 1. It was determined that $PM_{2.5}$ concentrations varied from 6 to $317\mu g/m^3$, with an annual mean of $52.18 \pm 44.87\mu g/m^3$. When compared to the National Ambient Air Quality Standards (GB3095-2012) [11], which set a daily average concentration limit for $PM_{2.5}$ at $75\mu g/m^3$, an exceedance rate of 17.5% was noted. The annual mean surpassed the second-tier limit of $35\mu g/m^3$ by a factor of 1.49 , ndicating a high level of $PM_{2.5}$ pollution in the city. Seasonal analysis showed the lowest $PM_{2.5}$ concentrations in spring and summer, at $32.34 \pm 13.25\mu g/m^3$ and $30.57 \pm 10.69\mu g/m^3$ respectively, followed by autumn with $48.60 \pm 22.87\mu g/m^3$, and the highest in winter at $98.16 \pm 65.81\mu g/m^3$, which was 3.21 times the summer value. These variations are attributed to Linfen City's coal production and basin topography, which, coupled with low winter emperatures and stable atmospheric conditions, hinder pollutant dispersion. The northwesterly monsoons in winter exacerbate this issue by transporting pollutants from coal-rich areas to the city [12]. In contrast, higher temperatures and robust air convection in summer, along with fewer pollution sources, result in lower $PM_{2.5}$ levels.

As shown in Table 1, regarding the carbon components, OC and EC concentrations in 2020 ranged between 1.00 to $48.14\mu g/m^3$ and 0.11 to $14.37\mu g/m^3$, with annual means of $7.75 \pm 7.59\mu g/m^3$ and $1.82 \pm 2.15\mu g/m^3$, respectively. These concentrations were lower than those recorded in Handan City (OC: $17.09 \pm 12.73\mu g/m^3$, EC: $4.11 \pm 3.34\mu g/m^3$) [13] and Guangzhou City (OC: $8.19 \pm 5.01\mu g/m^3$, EC: $1.75 \pm 0.80\mu g/m^3$) [14]. Seasonal trends showed that OC and EC concentrations in Linfen City varied, with spring displaying concentration ranges of 1.19 to $9.94\mu g/m^3$ for OC and 0.21 to $2.14\mu g/m^3$ for EC, and corresponding means of $4.45 \pm 1.68\mu g/m^3$ and $1.03 \pm 0.43\mu g/m^3$. Summer concentrations ranged between 1.00 to $7.07\mu g/m^3$ for OC and 0.25 to $1.45\mu g/m^3$ for EC, with means of $3.89 \pm 1.00\mu g/m^3$ and $0.74 \pm 0.25\mu g/m^3$. Autumn saw ranges of 1.54 to $15.79\mu g/m^3$ for OC and 0.18 to $4.03\mu g/m^3$ for EC, with means of $6.01 \pm 3.03\mu g/m^3$ and $1.30 \pm 0.78\mu g/m^3$. In winter, the concentration ranges were 1.43 to $48.14\mu g/m^3$ for OC and 0.11 to $14.37\mu g/m^3$ for EC, with means of $16.76 \pm 10.60\mu g/m^3$ and $4.24 \pm 3.20\mu g/m^3$. The concentrations of OC and EC in $PM_{2.5}$ exhibited seasonal variation within Linfen City. The lowest concentrations were recorded during summer, followed by spring and autumn, with winter witnessing

the highest levels. Notably, OC concentrations were higher and more variable compared to EC, and both OC and EC concentrations closely mirrored the seasonal trends observed in $PM_{2.5}$ concentrations.

Table 1. Seasonal concentrations of $PM_{2.5}$, OC and EC in Linfen City

	$\mathbf{PM_{2.5}}$ $(\mu g/m^3)$		**OC** $(\mu g/m^3)$		**EC** $(\mu g/m^3)$		**OC/EC**	
	Mean value $\pm D_S$	Concentration range	Mean value $\pm D_s$	Concentration range	Mean value $\pm D_s$	Concentration range	Mean value $\pm D_s$	Concentration range
Spring	32.34 ± 13.25	$9 \sim 70$	4.45 ± 1.68	1.19 9.94	1.03 ± 0.43	$0.21 \sim 2.14$	4.49 ± 1.03	$1.03 \sim 8.93$
Summer	30.57 ± 10.69	$13 \sim 68$	3.89 ± 1.00	$1.00 \sim 7.07$	0.74 ± 0.25	$0.25 \sim 1.45$	5.56 ± 1.54	$1.55 \sim 14.04$
Autumn	48.60 ± 22.87	$11 \sim 122$	6.01 ± 3.03	$1.54 \sim 15.79$	1.30 ± 0.78	$0.18 \sim 4.03$	5.00 ± 1.09	$1.09 \sim 10.69$
Winter	98.16 ± 65.81	$6 \sim 317$	16.76 ± 10.60	$1.43 \sim 48.14$	4.24 ± 3.20	$0.11 \sim 14.37$	4.49 ± 1.24	$1.24 \sim 13.07$
Annual	52.18 ± 44.87	$6 \sim 317$	7.75 ± 7.59	$1.00 \sim 48.14$	1.82 ± 2.15	$0.11 \sim 14.37$	-	-

Note: D_S represents standard deviation; —— indicates no value provided.

To contextualize these findings, pollution levels were assessed by drawing comparisons with other cities [15], as elucidated in Table 2. During the summer, Linfen's concentrations of $PM_{2.5}$, OC, and EC were lower than those in Panjin City, Anshan City, and Tianjin City. The temperate continental climate of Linfen, characterized by concentrated rainfall, frequent thunderstorms, extended sunshine hours, and strong local convection during summer, aids in the settlement and dispersion of pollutants. Conversely, in winter, $PM_{2.5}$ concentration in Linfen was slightly higher than in the Yangtze River Delta region (including Nanjing City and Suzhou City), Tianjin City, and was 1.64 and 1.59 times that of Shenyang City and Guangzhou City, respectively. Linfen's primary industrial activity of coal coking, combined with its location in the Linfen Basin, contributes to the accumulation of pollutants. OC concentrations in Linfen were lower than those in Suzhou City and Taiyuan City but higher than in Nanjing City, Guangzhou City, and Lin'an City, reflecting Linfen's winter characteristics of low temperatures and stable atmospheric layers that impede pollutant dispersion. EC concentrations were lower than those in Panjin City, Tianjin City, and Taiyuan City, but higher than in other cities. This is attributed to the extensive use of coal for heating in Linfen during winter and increased vehicular emissions due to prolonged start-up times and slower traffic movement in colder conditions, coupled with the topography's impact on pollutant dispersion.

Table 2. Comparison of carbon components in $PM_{2.5}$ between Linfen City and other cities

Cities	**Time**	$\mathbf{PM_{2.5}}$ $(\mu g/m^3)$	**OC** $(\mu g/m^3)$	**EC** $(\mu g/m^3)$	**OC/EC**	**References**
Linfen	July 2020 (Summer)	30.58	3.70	0.67	5.95	This study
	January 2020 (Winter)	157.87	25.52	7.18	3.67	
Panjin	July 2016 (Summer)	46.14	8.6	2.8	3.7	[16]
	January 2017 (Winter)	91.01	24.5	7.3	3.4	
Anshan	July 2014 (Summer)	53.4	5.44	2.29	-	[17]
	January 2015 (Winter)	124.9	21.47	4.68	-	
Tianjin	August 2016 (Summer)	64.20	7.5	4.0	1.9	[18]
	January 2017 (Winter)	153.30	23.5	7.8	3.6	[19]
Nanjing	January 2015 (Winter)	144.77	20.32	5.39	4.0	[20]
Lin'an	January 2015 (Winter)	123.56	21.93	6	4.3	[20]
Suzhou	January 2015 (Winter)	156.5	27.08	6.4	5.1	[20]
Guangzhou	2015 (Summer)	53.31	7.42	1.68	-	[14]
	2016 (Winter)	99.38	12.03	2.01	-	
Shenyang	August 2015 (Summer)	37.98	4.0	2.5	1.7	[21]
	February 2015 (Winter)	96.00	21.1	4.4	4.7	
Taiyuan	2014 (Summer)	-	4,9	2.9	-	[22]
	2014 (Winter)	-	31.6	15.0	-	

Note: —— indicates no value provided.

3.2 Correlation Analysis Between OC and EC in $PM_{2.5}$

In this segment of the study, the correlation between OC and EC within $PM_{2.5}$ was scrutinized to discern their sources. Research has established that the strength of this correlation can be indicative of the sources of these components [16, 23]. A robust correlation, as reflected by a correlation coefficient (R^2) of 0.8 or higher, is typically suggestive of OC and EC emanating from the same primary pollution source. In contrast, a moderate correlation $(0.5 \leq R^2 < 0.8)$ or a weak correlation $(0.3 \leq R^2 < 0.5)$often implies divergent sources or the influence

of secondary pollution [16]. Figure 1 presents the correlation analysis for OC and EC across different seasons in Linfen City. The most substantial correlation was recorded in winter (R^2=0.961), followed by autumn (R^2=0.936) and spring (R^2=0.848), indicating similar sources for OC and EC during these periods. In the winter months, characterized by low temperatures and coal heating, both OC and EC predominantly originate from coal combustion and vehicular emissions. Spring's influence by coal combustion is also noteworthy, whereas autumn's OC and EC levels are likely impacted chiefly by vehicle emissions. Summer, with the lowest correlation coefficient of 0.584 , denotes a more complex scenario wherein OC and EC arise not only from primary emissions such as vehicle exhaust but also from secondary sources, including volatile and semi-volatile organic compounds contributing to the formation of SOC [22].

The linear regression model applied to OC and EC is represented as OC=k×EC+b, where the term k×EC quantifies the contribution of direct emissions from combustion sources to OC, and the term b accounts for contributions from non-combustion sources [24]. The fitting results depicted in Figure 1 indicate the b values for spring, summer, autumn, and winter as 0.6996, 1.5960, 1.1064, and 2.9152, respectively, with winter demonstrating a markedly higher value. This result suggests a substantial contribution from non-combustion sources to OC during winter, aligning with the combined impacts of coal combustion and vehicle emissions. In contrast, spring's OC is primarily attributed to direct emissions from combustion sources.

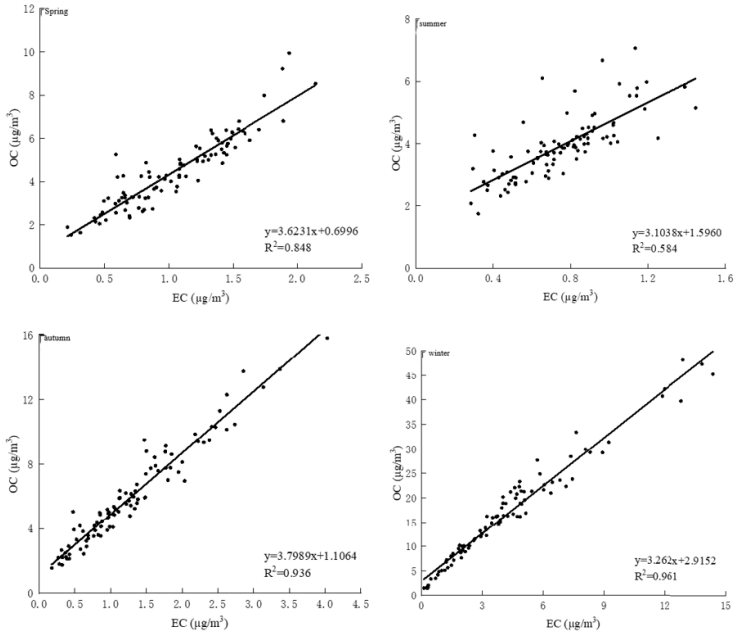

Figure 1. Correlation between OC and EC in $PM_{2.5}$ in each season in Linfen City

The OC to EC ratio serves as a crucial indicator for estimating atmospheric SOC and identifying the emission sources of OC and EC. According to Chow et al. [25], an OC/EC ratio exceeding 2 signifies the presence of SOC pollution in the atmosphere. The OC/EC ratio range is indicative of various pollution sources: ratios between 1.0 and 4.2 are predominantly due to emissions from gasoline and diesel vehicles [26]; 2.5 to 10.5 are linked to coal combustion [27]; 16.8 to 40.0 suggest biomass burning; an OC/EC ratio of 12 points towards long-range transport effects [28]; and ratios from 32.9 to 81.6 are associated with cooking emissions [29]. As delineated in Table 1, the mean OC/EC ratios in Linfen City for the year 2020 were recorded as 4.49 in spring, 5.56 in summer, 5.00 in autumn, and 4.49 in winter, with ranges spanning from 1.03 to 8.93, 1.55 to 14.04, 1.09 to 10.69, and 1.24 to 13.07, respectively. These values indicate the influence of secondary pollution sources across all seasons. The high temperatures and intense sunlight during summer are conducive to SOC formation, whereas winter's short daylight hours and the development of temperature inversions aid in the accumulation of precursors for secondary organic aerosols, leading to SOC generation through photochemical oxidation processes [17]. The OC/EC ratio ranges suggest a significant impact of vehicle exhaust emissions across all seasons in Linfen City. The number of civilian vehicles in Linfen has been on an upward trend in recent years. The end of 2019 saw the civilian vehicle count reach 733,000, marking a 16.2% increase from the previous year, and by the end of 2020, this number escalated to 798,000, a further increase of 8.9%. The complexity of the sources of OC and EC in the atmosphere during summer and winter is noteworthy, encompassing exhaust emissions, coal combustion, biomass burning, and long-range transport effects. Summer months witness extensive straw burning due to wheat and corn cultivation, while winter experiences an augmented influence of long-range transport, primarily driven by northwesterly winds.

3.3 SOC Estimation

The analysis of SOC, a complex and significant component of OC, presents challenges due to the absence of direct measurement methods for SOC in atmospheric particulates. To address this, such as the EC tracer method, AMS-PMF(Aerosol Mass Spectrometer-Positive Matrix Factorization) method, model prediction, and organic molecular tracer techniques are employed, with the EC tracer method being the most prevalently used. This method hinges on the assumption that all monitored EC stems from primary sources, leveraging the chemical stability of EC and its strong correlation with POC. Following this rationale, Lim and Turpin [30] proposed empirical formulas for SOC calculation:

$$\mathrm{POC} = \mathrm{EC} \times (\mathrm{OC}/\mathrm{EC})_{\mathrm{POC}} + \mathrm{N} \tag{1}$$

$$\mathrm{SOC} = \mathrm{OC} - \mathrm{POC} \tag{2}$$

where, $(\mathrm{OC}/\mathrm{EC})_{\mathrm{POC}}$ denotes the OC to EC ratio from primary combustion sources, N encapsulates OC from primary noncombustion sources. A common practice is to substitute the minimum OC/EC ratio from the samples for $(\mathrm{OC}/\mathrm{EC})_{\mathrm{POC}}$, potentially impacting SOC estimations. For enhanced accuracy, Lim and Turpin [30] recommended estimating using the smallest OC/EC ratios from 5% to 10% of the samples, provided the sample size is no less than 20. Accordingly, this study selected the five samples with the lowest OC/EC ratios each season for linear regression analysis on their OC and EC mass concentrations, using the regression slope as $(\mathrm{OC}/\mathrm{EC})_{POC}$ and the intercept as N. The results, shown in Table 3, enabled the calculation of SOC mass concentrations for each season. It was observed that SOC concentrations in Linfen City varied seasonally, with the highest concentration in winter $\left(2.66\mu\mathrm{g}/\mathrm{m}^3\right.$, constituting 16.00% of $\mathrm{OC})$ and the lowest in autumn ($0.55\mu\mathrm{g}/\mathrm{m}^3$, 9.07% of OC). This pattern, where winter $>$ spring $>$ summer $>$ autumn, indicates pronounced secondary pollution in Linfen City during winter. The conditions in winter, characterized by high atmospheric pressure, low temperatures, and inversion layers, foster the accumulation of precursors for secondary organic aerosols, culminating in increased SOC levels due to photochemical reactions. In contrast, the SOC/OC ratios suggest that spring and summer experienced higher SOC contributions to OC. The rising temperatures in spring and the hotter summer climate in Linfen City create favorable conditions for the photochemical reactions of volatile and semi-volatile organic compounds, leading to the formation of SOC [31].

Table 3. Seasonal concentrations of POC, SOC, SOC/OC in Linfen City

Seasons	**(OC/EC) POC**	**N**	$\mathbf{R^2}$	**POC** $\left(\mu\mathrm{g}/\mathrm{m}^3\right)$	**SOC** $\left(\mu\mathrm{g}/\mathrm{m}^3\right)$	**SOC/OC** $(\%)$
Spring	3.26	0.02	0.9884	3.42	1.06	23.62
Summer	2.76	1.04	0.9189	3.10	0.81	20.77
Autumn	3.94	0.38	0.9746	5.50	0.55	9.07
Winter	3.05	1.17	0.9967	13.95	2.66	16.00

3.4 Relationship between Carbonaceous Aerosols and Meteorological Conditions

The interplay between meteorological factors and air pollution, particularly carbonaceous aerosols, has been meticulously analyzed, underscoring meteorological conditions as pivotal external factors influencing the dispersion and propagation of atmospheric pollutants. The dispersion, transport, and deposition of atmospheric pollutants are significantly influenced by meteorological conditions. It has been established that variations in relative humidity, wind speed, and temperature critically impact air quality [32]. This study presents, in Table 4, the correlation coefficients between $\mathrm{PM}_{2.5}$, OC, EC, and their ratio $(\mathrm{OC}/\mathrm{EC})$ with key meteorological factors across different seasons in Linfen City. It was observed that $\mathrm{PM}_{2.5}$ concentration is significantly positively correlated with relative humidity during spring, autumn, and winter. This phenomenon is attributed to relative humidity's role in enhancing secondary particulate matter formation within a specific range, beyond which precipitation tends to occur, effectively scavenging airborne particles. Linfen City's predominant precipitation in summer corresponds with this observation. In contrast, $\mathrm{PM}_{2.5}$ concentration exhibits a negative correlation with wind speed during autumn and winter, attributed to increased wind speeds dispersing pollutants during cold air outbreaks. Temperature fluctuations in spring and autumn, more pronounced than in summer and winter, are inversely correlated with $\mathrm{PM}_{2.5}$ concentrations. In terms of wind speed, a significant negative correlation with OC and EC was noted in winter. Elevated wind speeds during this season contribute to the dilution of OC and EC concentrations. The positive correlation of the OC/EC ratio with wind speed in winter reflects the intensity of horizontal pollutant transport. Linfen City predominantly experiences northwesterly winds during winter, which traverse through polluted regions, carrying elevated OC/EC values and subsequently increasing these values within the city.

Table 4. Correlation coefficients of $PM_{2.5}$, OC, EC and OC/EC with meteorological factors across seasons in Linfen City

	Seasons	Relative Humidity	Wind Speed	Temperature
$PM_{2.5}$	Spring	0.346**	0.005	-0.242*
	Summer	0.089	0.098	0.106
	Autumn	0.317**	-0.362**	-0.352**
	Winter	0.661**	-0.482**	-0.016
OC	Spring	0.105	-0.247*	-0.290**
	Summer	-0.290**	0.237*	0.282**
	Autumn	-0.031	-0.228*	-0.357**
	Winter	0.477**	-0.516**	-0.054
EC	Spring	-0.030	-0.179	-0.212*
	Summer	-0.289**	0.089	0.256*
	Autumn	-0.072	-0.265*	-0.326**
	Winter	0.475**	-0.484**	-0.033
OC/EC	Spring	0.220*	0.124	0.052
	Summer	0.105	0.174	-0.058
	Autumn	0.146	0.227*	0.015
	Winter	-0.466**	0.602**	0.014

Note: * indicates significant correlation at the 0.05 level (two-tailed); ** indicates significant correlation at the 0.01 level (two-tailed).

4 Conclusions

In 2020 , seasonal $PM_{2.5}$ concentrations in Linfen City were recorded with average values of $32.34 \pm 13.25 \mu g/m^3$ in spring, $30.57 \pm 10.69 \mu g/m^3$ in summer, $48.60 \pm 22.87 \mu g/m^3$ in autumn, and $98.16 \pm 65.81 \mu g/m^3$ in winter. OC concentrations exhibited mean values of $4.45 \pm 1.68 \mu g/m^3, 3.89 \pm 1.00 \mu g/m^3$, $6.01 \pm 3.03 \mu g/m^3$, and $16.76 \pm 10.60 \mu g/m^3$, respectively, for the same seasons. Similarly, EC concentrations showed mean values of $1.03 \pm 0.43 \mu g/m^3$, $0.74 \pm 0.25 \mu g/m^3, 1.30 \pm 0.78 \mu g/m^3$, and $4.24 \pm 3.20 \mu g/m^3$. Notably, OC and EC concentrations were found to fluctuate in tandem with PM.5 levels, with winter demonstrating significant pollution.

Correlation coefficients between OC and EC were determined to be $R^2 = 0.848$ in spring, $R^2 = 0.584$ in summer, $R^2 = 0.936$ in autumn, and $R^2 = 0.961$ in winter. These correlations suggest that OC and EC share similar sources, particularly in spring, autumn, and winter. The observed OC/EC ratios, ranging from 1.03 to 8.93 in spring, 1.55 to 14.04 in summer, 1.09 to 10.69 in autumn, and 1.24 to 13.07 in winter, indicate the complexity of OC and EC sources, especially during summer and winter. Influences from vehicle exhaust emissions were prevalent in both seasons, compounded by straw burning in summer and enhanced long-range transport effects in winter due to northwesterly winds.

Employing the EC tracer method, the SOC concentrations in Linfen City were estimated at $1.06 \mu g/m^3$ in spring, $0.81 \mu g/m^3$ in summer, $0.55 \mu g/m^3$ in autumn, and $2.66 \mu g/m^3$ in winter, representing $23.62\%, 20.77\%, 9.07\%$, and 16.00% of OC, respectively.

The study highlighted that in Linfen City, the concentration of carbon components in winter is predominantly influenced by relative humidity and wind speed. Cold air passage during winter fosters local pollutant accumulation, while long-distance transport intensifies pollutant concentrations, exacerbating air pollution. Conversely, increased wind speeds were noted to dilute pollutants, thus ameliorating air quality.

Data Availability

The data used to support the findings of this study are available form the corrsponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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