Reduced Air Pollution during the Prevailing of COVID-19 Pandemic: Five Years Observation and Path Analysis in the Fenwei Plain, Northwest China

Yuanyuan Meng¹ and Wanlong Sun²

¹State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi’an 710069, China
²Shaanxi Mineral Resources and Geological Survey, Xi’an 710068, China

Correspondence should be addressed to Yuanyuan Meng; myychd@163.com

Received 30 January 2022; Revised 21 March 2022; Accepted 1 April 2022; Published 27 April 2022

Copyright © 2022 Yuanyuan Meng and Wanlong Sun. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Heavy pollution in North China has attracted extensive attention in recent decades, and numerous studies have been conducted in developed regions, while studies on the heavily polluted Fenwei Plain in Northwest China are still scarce. In this study, we analyzed the continuous air pollution records of Weinan city on the Fenwei Plain from 2016 to 2020 to provide specific prevention and control strategies for the region. From 2016 to 2020, pollutant concentrations showed an overall decreasing trend, with a slight increase in O₃ concentration. The study found that during the COVID-19 lockdown period, O₃ was also significantly affected by the lockdown policy. During the prevailing COVID-19 pandemic in 2020, anthropogenic emissions were reduced due to restraints on commercial and social activities. NO₂ responds sensitively during COVID-19, and PM₂.₅ has a delayed response. We applied pathway analysis to investigate the contribution of different pollutants and meteorology to PM₂.₅. The results show that CO and NO₂ have the largest positive comprehensive effect, while wind speed and temperature have the largest negative comprehensive effect. Spearman’s correlation analysis shows that NO₂ contributes significantly to O₃ production in different AQI ranges. We advocate that the NOₓ should be given more attention and become the new focus of air control.

1. Introduction

Both accelerated economic growth and rapid urbanization occurred in China during the past 40 years. China’s urbanization rate has increased, twice as much as Economic Reform and open up. While the economy is growing at a high rate, it is also generating serious environmental problems. Air pollution has always been a critical topic for research in China, and it has attracted increasing public attention, although the causes and influencing factors of air pollution have never been fully explored and identified. The long period and high-resolution air pollution observation are needed to clarify the atmospheric pollution status in China [1]. The increased number of private cars and consumption of fossil fuels, as well as other anthropogenic factors, have led to the high level of CO₂, PM₂.₅, PM₁₀, O₃, SO₂, and NO₂ in atmosphere [2]. Globally, about 87 percent of people live in environments with high PM₂.₅ concentrations (above standard limits set by the World Health Organization), and in low- and middle-income countries, 90 percent of the population lives with unsafe air pollution, according to previous studies [3]. Many surveys have studied the link between aerosol pollution and adverse health consequences [4–6]. For example, when PM₂.₅ binds with PAHs, they can cause cancer and mutations linked to pollution of the atmosphere by human activities [7]. Further observations have shown that the type of city and its local emissions (e.g., residents heating-derived coal combustion emissions) have a great influence on the measured concentrations of air pollutants [8–10].

Air pollution (concentration, degree of pollution) varies significantly in different areas, depending on the city, energy...
mix, and local population. The Chinese government has taken note of the problem and adopted different solutions for different cities, proposing a "one city, one policy" policy for targeted governance. Therefore, we focus on Weinan city in the Fenhe and Weihe River plain to provide reference for the local government to control local pollution reasonably. The data from various air quality monitoring stations can be used to analyze the local aerosol pollution, and the establishment of air pollution forecast plays an important role [11].

In the past, many researches concentrated on the characteristics, sources, and mechanisms of PM contamination and their negative health effects in most of Chinese megacities (e.g., Beijing and Shanghai) were published [12–16]. Moreover, the reduction of social activities and business during the COVID-19 pandemic has decreased the total emissions of air pollutants to a certain extent, but the O₃ pollutant levels have not been reduced. Therefore, research on changes during the COVID-19 period is beneficial to the control of air pollution [17]. There were also some scholars which have conducted recent studies on the Fenwei Plain, which have examined the impact of rural solid fuel burning on biomarkers in women and have fully explained the air pollution-associated health hazards [18]. The characteristics and potential sources of atmospheric pollutants in Linfen area near the Weihe Plain were also reported [8]. These works concluded that the local pollution was aggravated by unfavorable meteorological conditions, such as weak wind speed, high humidity, low air temperature, and low boundary layer height. Therefore, meteorologies have been considered as the main factors of atmospheric pollution [19]. A city scale study (68 major cities in seven geographic regions) in China has shown that the PM₂.₅ pollution was significantly influenced by different meteorological factors and other human factors, which also presented the spatial and seasonal variation [20]. However, the factors causing air pollution are relatively complex, different cities have unique industrial and agricultural development models, cultural characteristics, and geographical characteristics; therefore, it is not enough to only study the air pollution situation of big cities.

As the area surrounded by mountains, the adverse meteorological conditions occurred frequently in Fenwei Plain (Weinan city), which further influenced the air pollution. Air pollution in the region is serious, and the government has issued a comprehensive air pollution control document. The Fenwei Plain is located southwest of the Beijing-Tianjin-Hebei "2 + 26" urban circle. It is the general term for the Fenhe Plain, the Weihe Plain, and its terraces. The main cities include Xi’an, Xianyang, Weinan in Shaanxi Province, and other cities in Shanxi Province. In these cities, including Yuncheng, Linfen, and Lüliang, government documents encourage a focus on the air pollution situation in the Fenwei Plain, but there are few reports on air pollution in this region. Given that previous work is mainly interested in large cities and neglected in small- and medium-sized cities, we take the Weinan city (Fenwei Plain) as a case to study the five-year air pollution. The purposes are to explore the variations in the atmospheric pollution levels and air quality index (AQI) and to reveal the controlling factors of atmospheric contaminants by using the correlation coefficient and path analysis, in particular the COVID-19 influenced period during 2020.

2. Methodology

2.1. Study Region. Weinan city is located in the eastern part of the Fenwei Plain (108°58′–110°35’E and 34°13′–35°52’N) with a total area of 13030 km². The terrain is centered on the Weihe River, comprising five major mountains in the north and south, two plateaus, and central Pingchuan. As shown in Figure 1, the geographical location of Weinan city is surrounded by the Beishan Mountains in the north and Qinling Mountains in the south. Such natural topographical factors make it difficult for air pollutants to spread/diffuse.

The annual average value of meteorological factors in Weinan city from 2016 to 2020 is shown in Table 1. The warm temperate zone with a semihumid and semi-arid monsoon climate is the characteristic of this area. Groundwater resources are abundant in the Weinan city, which are mainly distributed in the quaternary bedrock in the southern and northern mountainous areas and distributed in loose rock formations in the rest of areas.

2.2. Data Sources and Processing. The monitoring data of AQI, PM$_{2.5}$, PM$_{10}$, NO$_2$, SO$_2$, CO, and O$_3$ concentration in Weinan city were taken from the China Environmental Monitoring Centre (CEMC). According to previous studies, the data from the CEMC are statistically reliable [21]. All data were collected from 2016 to 2020, including daily average values of the AQI and the six air pollutants mentioned above. The corresponding data of meteorology, including air temperature, relative humidity, wind speed, and visibility were taken from the China Meteorological Administration. The AQI is an indicator to represent air quality, which is calculated by the concentrations of the following atmospheric pollutants: PM$_{2.5}$, PM$_{10}$, NO$_2$, SO$_2$, CO, and O$_3$ [22]. The AQI value can vary between 0 and 500, the higher AQI value indicates worse air quality. The AQI can be divided into six degrees, that is, excellent (AQI = 0–50), good (AQI = 51–100), light pollution (AQI = 101–150), moderate pollution (AQI = 151–200), heavy pollution (AQI = 201–250), and severe pollution (AQI >300) [20]. The descriptive statistics and trend graphs of the particle mass concentration were performed by Origin 2018. Spearman’s correlation analysis was applied to analyze the relationship between particulate matter, meteorology data, and other atmospheric contaminants by IBM SPSS Statistics 26.

To date, there are still many uncertainties about the quantified source contribution of PM$_{2.5}$. To obtain effective air pollution prevention, it is necessary to carry out targeted control by considering the different characteristics of urban development and to adapt the measures to local conditions. Previous research data mainly investigated the relationship between many pollutant-related factors, but few studies considered the indirect impact of pollutants [23]. In this work, the path analysis (see details in [23]) was performed to
explain the direct or indirect effects between different variables and to better analyze the potential variations in the concentration of particulate matter and more comprehensively describes the complex relationship between particulate matter [24].

Path analysis was used to explain the factors of interest either directly or indirectly in combination with path coefficient evaluation, mainly to clarify the influence of meteorological factors and $O_3$, $SO_2$, $NO_2$, and $CO$ on atmospheric particulate matter. The software used for the path analysis was IBM SPSS Amos 26.0.

The general methodology and procedures of the path analysis [23].

(i) The canonical equation of standardized linear regression:

$$ R_{xx} b^* = R_{xy}, $$

where $R_{xx}$ is the correlation matrix for $x_1, x_2, \ldots, x_p$, $b^*_k = (b^*_1, b^*_2, \ldots, b^*_p)^T$, $b^*_j$ is the direct effect of $x_j$ on $y$, $r_{jk} b^*_k$ is the indirect influence of $x_j$ on $y$ through $x_k$, and $R_{xy}$ is the correlation matrix of $x$ to $y$. 

---

Table 1: Annual average of meteorological factors in the study area for 2016–2020.

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature ($^\circ$C)</td>
<td>14.8</td>
<td>15.2</td>
<td>14.9</td>
<td>14.7</td>
<td>14.1</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>68.2</td>
<td>67.1</td>
<td>68.0</td>
<td>68.7</td>
<td>68.0</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

---

Figure 1: Geography of the study area: (a) the overall location of the study area; (b) the specific location of the study area.
According to equation $R_{xx} \cdot b^{*} = R_{xy}$, the path coefficient $b^{*} = R_{x} \cdot R_{xx}$ is the inverse matrix of $R_{xx}$.

The decision coefficient can be obtained from the path coefficient:

$$R_{ij}^2 = b_{ij}^*,$$

$$R_{jk} = R_{kj} = 2b_{j}^{*}r_{jk}b_{k},$$

(2)

where $R_{ij}^2$ is the direct determination coefficient of $x_j$ to $y$, and $R_{jk}$ is the indirect determination coefficient of $x_j$ about $y$ through $x_k$.

(iv) The total decision coefficient of $x_j$ about $y$ is $R(j) = R_{j}^2 + \sum_{j \neq k} R_{jk} = 2b_{j}^{*}r_{jk}b_{k}^{*}$, $j = 1, 2, ..., P$.

3. Results and Discussion

3.1. Annual Average Trend of Air Pollution and PM$_{2.5}$/PM$_{10}$ Trend Analysis. As shown in Figure 2, the overall pollutant concentration is in a decreasing trend from 2016 to 2019. It indicates that the effect of managing air pollutants in recent years is relatively significant. The trend of pollutant changes as well as the standard deviation value in the figure can be visualized. Compared with 2016, the reduction in concentration values of AQI, PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, O$_3$, and CO in 2019 is 13%, 25%, 23%, 55%, 8%, 4%, and 30%. The greatest degree of reduction was seen in SO$_2$ and CO, with sulfur-containing coal and incomplete combustion being among the larger sources of these two pollutants. The concentration of pollutants has gradually decreased by eliminating obsolete equipment as well as improving the energy mix. China has made significant achievements in combating air pollution in recent years. Compared with 2016, the reduction in concentration values of each pollutant AQI, PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, O$_3$, and CO in 2019 is 13%, 25%, 23%, 55%, 8%, 4%, and 30%. The greatest degree of reduction was seen in SO$_2$ and CO, with sulfur-containing coal and incomplete combustion being among the larger sources of these two pollutants. The concentration of pollutants has gradually decreased by eliminating obsolete equipment as well as improving the energy mix. China has made significant achievements in combating air pollution in recent years.

As can be seen in Figures 3(a) and 3(b), the overall visibility is higher from January to February 2020 than from January to February 2016–2019. Overall, this reflects lower pollutant concentrations during the COVID-19 lockdown. Visibility from March to May 2020 is also higher than the same period in 2016–2019, indicating that although some work resumed and production resumed during COVID-19, the overall concentration of pollutants is lower and visibility is higher. The average visibility from 2016 to 2020 was 12.1 km (Figure 3(c)). The number of days with visibility greater than 12 km from January to May 2020 is 68% and the number of days with visibility greater than 12 Km in the same period of 2016–2019 accounts for 50%. Over the past five years, the average visibility has shown an overall upward trend, but the trend has been slow (Figure 3(c)). The concentration of atmospheric pollutants has gradually decreased, visibility has increased, and solar radiation reaching the ground increased. As the photochemical reaction increases, the O$_3$ concentration increases to a certain extent [25]. There is a positive correlation between visibility and wind speed, while there is a negative correlation between visibility and particulate matter concentration. Weak wind speeds are conducive to the accumulation of contaminants, resulting in reduced visibility. The particulate matter concentration in China exhibits a downward trend, but in the eastern part of the country, 64% of the cities still have annual PM$_{2.5}$ mass concentrations that exceed the “China New Standard for Ambient Air Quality Level II” (GB3095-2012) [26]. The concentrations of PM$_{2.5}$ in the Taihang Mountains, Fenhe River, Weihe Plain, and Wuchang in Xinjiang are still high, and heavy haze pollution occurs frequently in autumn and winter [7].

In recent years, there are many studies on PM$_{2.5}$/PM$_{10}$ ratio, trying to reflect the proportion of fine particles in air pollution [27]. The PM$_{2.5}$/PM$_{10}$ ratios in major economic regions of China revealed that more severe air pollution was observed when the ratio PM$_{2.5}$/PM$_{10}$ ratio was higher [28]. Previous studies have examined the characteristics of pollutants at a deeper level by interpreting the meaning of PM$_{2.5}$/PM$_{10}$. The study of the PM$_{2.5}$/PM$_{10}$ ratio in 23 cities in China clarified the type of contamination and potential sources of pollution to a considerable extent [29]. It is possible that the larger the ratio is, the more severe the secondary pollutants in the city [30]. Therefore, PM$_{2.5}$/PM$_{10}$ ratio = 0.5 is used to reflect the severity of secondary pollution in Weinan. The overall PM$_{2.5}$/PM$_{10}$ ratio in Weinan city from 2016 to 2020 was 0.52, and the winter PM$_{2.5}$/PM$_{10}$ ratios from 2016 to 2020 were 0.63, 0.56, 0.53, 0.67, and 0.56 (Figure 3(d)). Research in other cities, such as Lhasa, shows that the PM$_{2.5}$/PM$_{10}$ ratio in winter is 0.48 [31], while the PM$_{2.5}$/PM$_{10}$ ratio observed in Beijing is 0.67 [32]. PM$_{2.5}$ in winter accounts for a relatively high proportion of PM$_{10}$, which indicates that PM$_{2.5}$ is the main pollutant in Weinan winter and reduces visibility.

![Figure 2: Variations of AQI and air pollutants annual mean values in Weinan city (for the convenience of calculation, the CO concentration in the figure is expanded by 100 times).](image-url)
3.2. Impact of the COVID-19 Pandemic on Air Pollution.
The period from January 1, 2020, to May 31, 2020, was selected as the study phase to compare the concentrations of PM$_{2.5}$, NO$_2$, SO$_2$, CO, and O$_3$ before the COVID-19 lockdown with those during the lockdown and the resumption of work and production (Figure 4). The first phase (January 1–22) is the prelockdown phase (PRF); the second phase is China’s Spring Festival (CNYF, January 24 to February 8); and the third phase is February 9 to 29. March, April, and May are considered the fourth, fifth, and sixth phases, respectively. The air quality has improved during the COVID-19, which was mainly caused by the reduction in emissions of transportation sector and the industry. In 2020, the PM$_{2.5}$ concentration of the second phase (CNYF) was 12% lower than that of the PRF phase (January 1 to January 22) (Figure 4(b)). Compared with the first stage, the PM$_{2.5}$ concentrations in the third, fourth, fifth, and sixth phases were reduced by 43%, 65%, 70%, and 81%, respectively. The Chinese New Year is from January 24 to February 8, so the use of firecrackers led to an increased concentration of pollutants on February 9. As of February 29, the PM$_{2.5}$ concentration was 38.8% smaller than that of the previous period CNYF (Chinese New Year). PM$_{2.5}$ has a slow response and lag during the control period of COVID-19. The average concentrations of PM$_{2.5}$ in the winter of 2016–2020 were 146.91 µg m$^{-3}$, 106.08 µg m$^{-3}$, 114.83 µg m$^{-3}$, 98.86 µg m$^{-3}$, and 79.31 µg m$^{-3}$, which are much higher than the concentration of 35 µg m$^{-3}$ in Lhasa [31], which in turn is lower than the concentration of 144.6 µg m$^{-3}$ in Urumqi [33]. The number of days with daily PM$_{2.5}$ concentrations greater than 75 µg m$^{-3}$ in the winter of 2016–2020 accounted for 74%, 66%, 72%, 76%, and 61% of the total monitoring days; the number of days with a daily concentration higher than 150 µg m$^{-3}$ accounted for 38%, 21%, 27%, 18%, and 10% of the total monitoring days. From 2016 to 2019, a large proportion of annual pollutant days can reflect severe air pollution in this area. The main reason for the decline in particulate concentration in 2020 is related to the lockdown during the epidemic, so pollutant emissions during this period were relatively low.

Generally, the transportation sector is the main factor in reducing NO$_2$ levels. As shown in Figure 3(c), the most significant decrease in NO$_2$ concentrations (from 50.27 µg m$^{-3}$ in prelockdown phase to 23.06 µg m$^{-3}$ in CNYF phase) was observed in 2020. The CNYF phase was a period during lockdown when the Chinese New Year also stopped traffic and reduced travel, and these results indicated that NO$_2$ was the pollutant that was most sensitive to the lockdown policy. These results indicated that the control measures during COVID-19 have significantly reduced pollutant emissions caused by population movements. After the first PRF stage, NO$_2$ was sharply decreased showing to be more sensitive to COVID-19 lockdown compared to PM$_{2.5}$. After the resumption of work on February 9th, the transportation industry began to operate and a few factories began to resume work. The NO$_2$ concentration increased again (Figure 4(c)). As the main pollutant emitted from coal-burning heating in winter [21], the SO$_2$ concentration decreased insignificantly (Figure 4(d)), indicating that coal-fired emissions were less influenced by COVID-19 control measures. The main reason is that coal-fired heating in winter has not been affected by COVID-19. Therefore,
COVID-19 control measures have a small impact on SO_2, with a relatively small range of change before and during the lockdown in 2020, with the average value of $\sim 11 \mu g m^{-3}$ (Figure 4(d)). In comparison with the corresponding period in 2016–2019, the mean concentrations of PM_{2.5}, NO_2, and SO_2 generally declined, indicating that the emissions of pollutants during the lockdown period generally decreased. Emissions from motor vehicles and factory closures have been reduced due to lockdown and were significantly lower in 2020 than those in the same period in 2016–2019. In general, among these three air pollutants, NO_2 was the most sensitive to variations in anthropogenic activities during the COVID-19 lockdown in Weinan city.

Figure 4(e) shows a gradual decrease in CO concentrations, with an overall decrease in traffic emissions due to factory shutdowns during the lockdown period. The cessation of heating between March and May may also have contributed to the continued decline in CO. As can be seen in Figure 4(f), the O_3 concentration increased rapidly during the Chinese Spring Festival, which was also the lockdown period, when the overall decrease in pollutant concentrations leads to a decrease in the precursors that form O_3 and...
therefore O₃ concentrations increase during this period. After that (February–May), with the resumption of work and production begins, the overall concentration of pollutants increased again, and the concentration of O₃ gradually decreased.

Overall, it can be seen that O₃ responds more significantly to the lockdown policy during the COVID-19 period also because the lower PM₂.₅ represents a less effective sink for hydroperoxy radicals (HO₂), which would increase peroxy radical-mediated O₃ production (Li et al., 2019). The above results also showed that the residential sector emissions need to control [17].

3.3. Wind Pollution Rose Diagram for PM₂.₅. Atmospheric contamination is influenced by various factors such as special terrain conditions, socioeconomic development level, and energy structure, and it is also closely related to meteorological conditions during the polluted weather process [34]. It can be seen in Figure 5 that the dominant wind direction in Weinan is the northeast direction. In spring, high concentrations of PM₂.₅ occur in the north and northeast. When the wind direction is northeast and the wind speed is 4.5 m/s, high concentration values of PM₂.₅ appear, indicating that there may be potential pollution sources in the northeast of the monitoring site. In summer, when the wind direction is south and the wind speed is 1 m/s, high concentration values of PM₂.₅ may appear, indicating that there are pollution sources near the southern part of the monitoring point.

In autumn, when the wind direction is southwest and the wind speed is 3.5 m/s, high values of PM₂.₅ may easily appear, indicating that there may be obvious pollution sources in the southwest of the monitoring point in autumn. In winter, when the wind direction is south and the wind speed is 0.5 m/s, the pollutant concentration reaches 344–409 μm/m³, indicating that the pollutants are mainly produced close to the sampling point, the static wind weather in winter is not conducive to the diffusion of pollutants, and the accumulation of pollutants is serious.

During January to February 2020, the high concentration of pollutants was concentrated in the static wind range with a wind speed of 0.5 m/s, produced close to the sampling point was the main factor, and pollutants were easy to accumulate, the PM₂.₅ response lags after the plant shutdown during the COVID-19 blockade, and higher values exist for a period of time. From March to May 2020, when the wind direction is southeast and the wind speed is 2.0 m/s, the PM₂.₅ concentration is in the range of 65.5–76.0, and the overall PM₂.₅ concentration is lower than the same period, which may be related to the resumption of work and production. At the same time, affected by the hysteresis of PM₂.₅, the overall pollutant concentrations were lower in this stage. From a comparison of Figures 5(a) and 5(f), it can be concluded that, despite the similarity of the sources, the PM₂.₅ concentrations are significantly lower in the spring of 2020. When the pollutants concentration is high in the northeast wind direction, it may be influenced by the transport of pollutants from neighboring cities. The frequent industrial activities in the windward cities have a great impact on the air quality of Weinan. Therefore, the joint prevention and control policy is very essential. Meanwhile, weak wind speed can cause air pollutants to accumulate and not easily spread.

3.4. Path Analysis Results. The seasonal atmospheric pollutants are generally varied due to the variations in meteorology [35,36]. As shown in Figure 6, PM₁₀ in the four seasons has the greatest direct effect on PM₂.₅. In spring (Figure 6(a)), RH presented the greatest positive direct effect on PM₂.₅, followed by O₃ and CO. RH has the most positive and indirect effects are on SO₂ and NO₂, and it has the most negative direct effect on T. In summer (Figure 6(b)), RH presented the highest positive direct effect on PM₂.₅, followed by CO; NO₂ has the largest negative direct effect; SO₂ and NO₂, O₃, and T have the largest positive and indirect effects; RH, SO₂, and O₃ have the largest negative indirect effects. CO has the greatest direct and indirect effect on PM₂.₅ in autumn (Figure 6(c)), followed by RH. O₃ and T had the greatest positive and indirect effects, followed by SO₂, NO₂, and CO; the pollutants with combined direct and positive as well as indirect effects are CO, SO₂, and NO₂. In winter (Figure 6(d)), CO has the greatest positive and direct effect on PM₂.₅, followed by RH. SO₂ and NO₂ are the most indirectly affected, and the most significant pollutants are CO, SO₂, and NO₂. The positive indirect effect is greatest for CO and SO₂, and the negative indirect effect is greatest for O₃ and WS. Thus, the positive combined effect of NO₂ and CO is the largest, while the negative combined effect due to wind speed and temperature is the largest. NO₂ and CO are considered the main pollutants affecting Weinan PM₂.₅. This indicates that the incomplete combustion process of coal in Weinan city in autumn and winter provides more CO in the air, which affects the PM₂.₅ concentration values. The main factor considered is incomplete combustion during the heating process. Second, NO₂ is another important factor that affects PM₂.₅ in multiple seasons. It can be concluded that automobile and industrial emissions contribute to the growth of PM₂.₅.

3.5. Correlation Analysis of Pollutants under Different Air Quality Indexes. The correlations between AQI values and the air pollutants from 2016 to 2020 are shown in Table 2. According to the six degrees of AQI values, the correlation analysis was also calculated in different degrees, including excellent (AQI = 0–50), good (AQI = 51–100), light (AQI = 101–150), moderate (AQI = 151–200), heavy (AQI = 201–250), and severe pollution (AQI > 300). When the AQI is categorized as good or as heavy pollution, the correlation between the AQI and PM₁₀ is best (0.49 (p < 0.01) and 0.35 (p < 0.01), respectively), followed by that with PM₂.₅. The correlation coefficients between AQI and PM₂.₅ were significant when AQI was in 51–100, 101–150, 151–200, and 201–250 R = 0.442 (p < 0.01), 0.419 (p < 0.01), 0.341 (p < 0.01), and 0.502 (p < 0.01). It shows that PM₂.₅ and PM₁₀ are the major causes affecting atmospheric quality. The correlation between PM₂.₅ and PM₁₀ was better
Figure 5: PM$_{2.5}$ pollution roses for spring, summer, autumn, and winter 2016–2019 and PM$_{2.5}$ pollution roses for January-February and March–May 2020.
Figure 6: Path analysis of different pollutants and main meteorological factors (T = temperature, RH = relative humidity, and WS = wind speed).

Table 2: Correlation among six air pollutants under different AQI value ranges; ** represents a significance level of 0.01 (P < 0.01); * represents a significance level of 0.05 (P < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>0–50</th>
<th>51–100</th>
<th>101–150</th>
<th>151–200</th>
<th>&gt;300</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM₂.₅</td>
<td>0.366**</td>
<td>0.490**</td>
<td>0.183*</td>
<td>-0.041</td>
<td>-0.120*</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>1</td>
<td>0.732**</td>
<td>0.233**</td>
<td>0.189**</td>
<td>0.346**</td>
</tr>
<tr>
<td>SO₂</td>
<td>1</td>
<td>0.388**</td>
<td>0.127</td>
<td>0.308**</td>
<td>0.057</td>
</tr>
<tr>
<td>CO</td>
<td>1</td>
<td>0.357**</td>
<td>0.190*</td>
<td>0.142</td>
<td>-0.26</td>
</tr>
<tr>
<td>NO₂</td>
<td>1</td>
<td>-0.054</td>
<td>-0.58</td>
<td>1</td>
<td>0.29</td>
</tr>
<tr>
<td>O₃</td>
<td>1</td>
<td>-0.247*</td>
<td>-0.51</td>
<td>1</td>
<td>-0.329*</td>
</tr>
<tr>
<td>AQI</td>
<td>0.419**</td>
<td>0.369**</td>
<td>0.217**</td>
<td>0.121**</td>
<td>0.341**</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>1</td>
<td>0.702**</td>
<td>0.450**</td>
<td>0.300**</td>
<td>0.347**</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>1</td>
<td>0.509**</td>
<td>0.485**</td>
<td>0.456**</td>
<td>0.300**</td>
</tr>
<tr>
<td>SO₂</td>
<td>1</td>
<td>0.672**</td>
<td>0.520**</td>
<td>0.671**</td>
<td>0.171*</td>
</tr>
<tr>
<td>CO</td>
<td>1</td>
<td>0.455*</td>
<td>-0.617**</td>
<td>1</td>
<td>0.335**</td>
</tr>
<tr>
<td>NO₂</td>
<td>1</td>
<td>-0.517*</td>
<td>-0.537**</td>
<td>1</td>
<td>0.286*</td>
</tr>
<tr>
<td>O₃</td>
<td>1</td>
<td>0.502**</td>
<td>0.368**</td>
<td>-0.010</td>
<td>0.073</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>1</td>
<td>-0.083</td>
<td>-0.27</td>
<td>0.140</td>
<td>-0.104</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>1</td>
<td>0.287</td>
<td>0.346**</td>
<td>0.302**</td>
<td>0.342**</td>
</tr>
<tr>
<td>SO₂</td>
<td>1</td>
<td>0.552**</td>
<td>0.500**</td>
<td>-0.145</td>
<td>-0.281*</td>
</tr>
<tr>
<td>CO</td>
<td>1</td>
<td>0.381**</td>
<td>0.312**</td>
<td>0.102</td>
<td>-0.142</td>
</tr>
<tr>
<td>NO₂</td>
<td>1</td>
<td>-0.238</td>
<td>-0.128</td>
<td>0.127</td>
<td>-0.215</td>
</tr>
<tr>
<td>O₃</td>
<td>1</td>
<td>0.450</td>
<td>0.58</td>
<td>0.678**</td>
<td>0.444**</td>
</tr>
</tbody>
</table>
when AQI values were at best, good, and severe with $R = 0.732 \ (p < 0.01)$, $0.635 \ (p < 0.01)$, and $0.476 \ (p < 0.01)$, which indicates that PM2.5 concentrations account for a large part of PM10 variation and in agreement with the previous studies [37,38]. When AQI indicates light, moderate, heavy, and severe pollution, the correlation coefficients between CO and PM2.5 are $R = 0.754 \ (p < 0.01)$, $0.611 \ (p < 0.01)$, $0.247 \ (p < 0.05)$, and $0.678 \ (p < 0.01)$, respectively. The next most important parameter is nitrogen dioxide, with correlations $R = 0.456 \ (p < 0.01)$, $0.234 \ (p < 0.01)$, $0.302 \ (p < 0.05)$, and $0.480 \ (p < 0.01)$ for PM2.5 and NO2. Under conditions of heavy and severe pollution, motor vehicle emissions are the main factor affecting CO. The strong correlation between CO and PM2.5 is due to factory and motor vehicle emissions, while the diffuse sources of NO2 are mainly associated with automobile traffic [39]. CO and NO2 are important factors in the formation of PM2.5. Moreover, the main relationship between O3 and PM10, PM2.5, SO2, CO, and NO2 was negative across each AQI degree. The strongest correlation between NO2 and O3 ($-0.56 < R < -0.25$, $p < 0.01$) indicates that NO2 is a significant cause of the O3 formation among the five pollutants. NO2 is an important factor in PM2.5 and O3.

4. Conclusions

This study comprehensively and systematically analyzes the current situation of air pollution in Weinan city. The improvement in air quality is due to strict controls (industrial closures, traffic restrictions, and strict household segregation) during the COVID-19 lockdown period. NO2 was the most sensitive to the lockdown, O3 was also significantly affected by the lockdown policy, and the PM2.5 response was smaller and delayed. The path analysis method analyzes PM2.5 and potential and direct influencing factors. NO2 is an important factor affecting PM2.5 in different seasons, and CO and NO2 are the main reasons that affect PM2.5. O3 and NO2 correlated significantly, indicating that among the five pollutants, NO2 is the most significant factor in the O3 formation. Therefore, NO2 is an important factor for PM2.5 and O3. PM2.5 is still the most challenging problem in China’s urban pollution control. Combining local climate and topographic features to optimize the geographic distribution of industries, implement strict emission policies to reduce NO2 emissions, especially traffic emissions. In short, the problem of air pollution is still serious, and there are differences in air pollution in different regions. The most important thing is to take targeted measures according to the local pollution situation. Therefore, adjust measures according to local conditions to control air pollution has great significance. With the continuous improvement of PM2.5 control and governance levels, it becomes important to control the precursors of PM2.5.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

Yuanyuan Meng developed the methodology, investigated the study, and wrote the original draft. Wan long Sun developed the methodology, investigated the study, did formal analysis, and reviewed and edited the manuscript. All authors contributed to the interpretation of the results and the improvement of this paper.

Acknowledgments

The authors are very grateful to Dr. Jie Zeng of the China University of Geosciences (Beijing) for his advice and help with the mapping and other aspects of this paper. The authors are also very grateful to Professor Fu Chaofeng for his comments and suggestions on this paper. Yi wang helped in the language revisions in the manuscript revision process.

References

agricultural production,” *Environmental Pollution*, vol. 266, Article ID 115166, 2020.


