Original Research

A Pre- to Post-COVID-19 Change of Air Quality Patterns in Anhui Province Using Path Analysis and Regression

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Abstract

During the epidemic period, primary emissions across the world were significantly reduced, while the response to secondary pollution such as ozone differed from region to region. To study the impact of the strict control measures of the new COVID-19 epidemic on the air quality of Anhui in early 2020, the air quality monitoring data of Anhui, from 2019 to 2021, specifically 1 January to 30 August, was examined to analyze the characteristics of the temporal and spatial distribution. Regression and path analysis were used to extract the relationship between the variable. PM_{10} and O_3, on average, increased by 6%, and 2%, while $PM_{2.5}$, SO_2 decreased by 15% and 10% in the post-COVID-19 period. All air quality pollutants decreased during the active-COVID-19 period, with a maximum decrease of 21% observed in PM_{10}, followed by 19% of $PM_{2.5}$, and a minimum decrease of 2% observed in O_3. Changes in air pollutants from 2017 to 2021 were also compared, and a decrease in all pollutants through 2020 was found. The air quality index (AQI) recorded a low decrease of 3% post-COVID-19, which shows that air quality will worsen in the future, but it decreased by 16% during the active-COVID-19 period. A path analysis model was developed to further understand the relationship between the AQI and air quality patterns. This path analysis shows a strong correlation between the AQI and PM_{10} and $PM_{2.5}$, however, its correlation with other air pollutants is weak. Regression analysis shows a similar pattern

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of there being a strong relationship between AQI and PM_{10}($r^2 = 0.97$) and $PM_{2.5}$($r^2 = 0.93$). The government must implement policies to control the environmental issues which are causing poor air quality in post-COVID-19.

Introduction

The 2019 Novel Coronavirus Disease (COVID-19) outbreak was continuing to spread rapidly in China in early 2020. The beginning of the Chinese Lunar New Year holiday is the most celebrated time of the year in China and it coincides with the emergence of COVID-19 [1]. During this period, large-scale population migration occurred as individuals returned to their hometowns. It is estimated that during the 40-day Spring Festival travel period, Chinese people traveled close to 3 billion trips. Before the travel ban began on January 23, 2020, about 5 million people had left Wuhan, the capital of Hubei Province, the epicenter of the COVID-19 epidemic. About one-third of these people went to places outside Hubei Province. Restricting the social contacts of these people is essential to control COVID-19 [2], because patients with no or mild symptoms can spread the virus. The Chinese Government and various government departments placed great importance on addressing it and quickly initiated prevention and control measures to prevent the spread of the virus. Epidemic control measures restrict human activities and improve air quality overall, but the air quality in some cities or regions does not improve, and after the epidemic control measures are lifted air quality rebounds. Thus, epidemic prevention and control provide contemporary society with a good opportunity to observe the relationship between human activities and air quality, review past atmospheric environmental protection measures, and better plan future atmospheric environmental protection [3].

China's air pollution control model is mainly based on administrative divisions, and the central government and local governments at all levels are responsible for territorial governance. The central government is responsible for the quality of the air environment across the country, and local governments are responsible for the quality of the air environment within their respective jurisdictions [4-7]. Local environmental governance will contribute to the improvement of the national environment. In recent years, to force local governments to strengthen environmental protection, the central government has continuously strengthened the environmental assessment targets of local governments. Under the strict supervision of the central government, air quality in the Beijing-Tianjin-Hebei region with relatively serious air pollution has improved significantly in recent years. However, due to the regional spread of the atmosphere and the deepening of industrial processes in second and third-tier cities, air quality in other parts of China has deteriorated [8].

Shen et al. analyzed the daily concentration of air pollutants in 18 cities in Henan Province from March 2014 to February 2016 [9]. The study showed that Henan Province had serious air pollution and Zhengzhou City was the most polluted area. The annual average concentration of $PM_{2.5}$ in 2015 and 2015 both exceeded the standard; Song et al. analyzed the air pollutant concentration data of more than 1,300 nationally controlled air quality monitoring points in China from 2014 to 2016 and found that the air quality in South China is better than that in North China $PM_{2.5}$ pollution in most parts of the north has deteriorated in winter[10]; Yang et al. evaluated the effectiveness of air pollution control policies in 26 cities in the Yangtze River Delta from February 2015 to January 2018. The results showed that Shanghai, Jiangsu, and Jiangsu Zhejiang's pollution control policies have been effective [11]. The air quality in cities in Anhui Province has not improved significantly, and the air quality in some cities has even declined. Li Lingjun et al. analyzed the characteristics of heavy air pollution in Beijing from the perspective of time and space [12]. The analysis found that the frequency of severely polluted weather during 2013-2014 was 14.4%, and the distribution of heavily polluted areas showed a trend of high in the south and low in the north, with plains higher than mountainous areas; Jia Mengwei et al. studied Nanjing City from 2013 to February 2015 [13]. The seasonal changes of air pollutants in the United States found that the seasonal changes of $PM_{2.5}$ and PM_{10} were both low in summer and high in winter, reaching their maximum values in January and December respectively [14]; Feng et al. analyzed the $PM_{2.5}$ concentration data through statistical analysis, it was found that the $PM_{2.5}$ concentration in Shanghai showed a trend of high in winter and low in summer, high in the west and low in the east [15]; Zhuang et al. analyzed the spatial distribution of six air pollution in the Pearl River Delta from 2013 to 2015 based on daily averages Research on the characteristics of different pollutants in different regions and the distribution characteristics and fluctuation rules [16]; Wang et al. analyzed the temporal and spatial characteristics of $PM_{2.5}$ in Beijing-Tianjin-Hebei and surrounding areas, and the results showed that Beijing-Tianjin-Hebei and surrounding areas $PM_{2.5}$. The overall distribution shows the seasonal changes and spatial distribution trends of "winter>autumn≈spring>summer" and "high in the south and low in the north" [17]; Mi et al. discussed based on 2013-2016 $PM_{2.5}$ real-time monitoring data The evolution of the temporal and spatial patterns of $PM_{2.5}$ and pollution characteristics in 41 cities above the prefecture-level in the Yangtze River

Delta showed that PM$_{2.5}$ in the Yangtze River Delta showed a pollution pattern of "high in the northwest and low in the southeast" [18]; Shu et al. took Yinchuan City Based on the urban air quality daily data and meteorological data from 2000 to 2009 [19], combined with the background analysis of pollution sources, the spatial and temporal distribution characteristics of air pollutants and their influencing factors are discussed [20, 21].

The COVID-19 pandemic has had a positive environmental impact due to improved air quality. Therefore, the period of epidemic prevention and control is a good point in time for the further exploration of the main factors affecting urban air quality changes. Various studies have compared the air quality before and during the active-COVID-19 period.

The main contributions of this study are:

– Study the behavior of the AQI and the levels of six ambient air pollutants, namely NO$_2$, O$_3$, sulphur dioxide (SO$_2$), carbon monoxide (CO), PM$_{10}$, and PM$_{2.5}$, before, during and after the 2020 COVID-19 lockdown in the cities of the Anhui province of China. The period between January 2020 and August 2020 was selected because a strict lockdown was in place in all four of the cities.

– Additionally, the AQI and pollutant concentrations during the same period in the prior two years,

namely 2017 to 2018, are assessed. The relationship between the AQI and each air pollutant (PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, CO, and O$_3$) in each city are investigated using a spatiotemporal change analysis. This exercise sought to improve the understanding of the changing air quality patterns in each city pre-COVID-19, during active COVID-19, and post-COVID-19.

– Furthermore, correlation analyses between the six air pollutants and the AQI during the three periods are performed to ascertain the sources of air pollutants during and after lockdown. Further, regression models are developed to analyze the trends of air quality patterns and their changes over time.

Materials and Methods

Study Area Monitoring Stations

Anhui is near the river and the sea, with 800-mile city clusters along the Yangtze River and the Wanjiang Economic Belt, with the Yangtze River within it, and the economic radiation of coastal areas outside. The terrain is composed of plains, hills, and mountains; it crosses the Huai River, Yangtze River, and Xin'an River [22]. It is at the strategic point of the country's economic development and the counter ground of several major
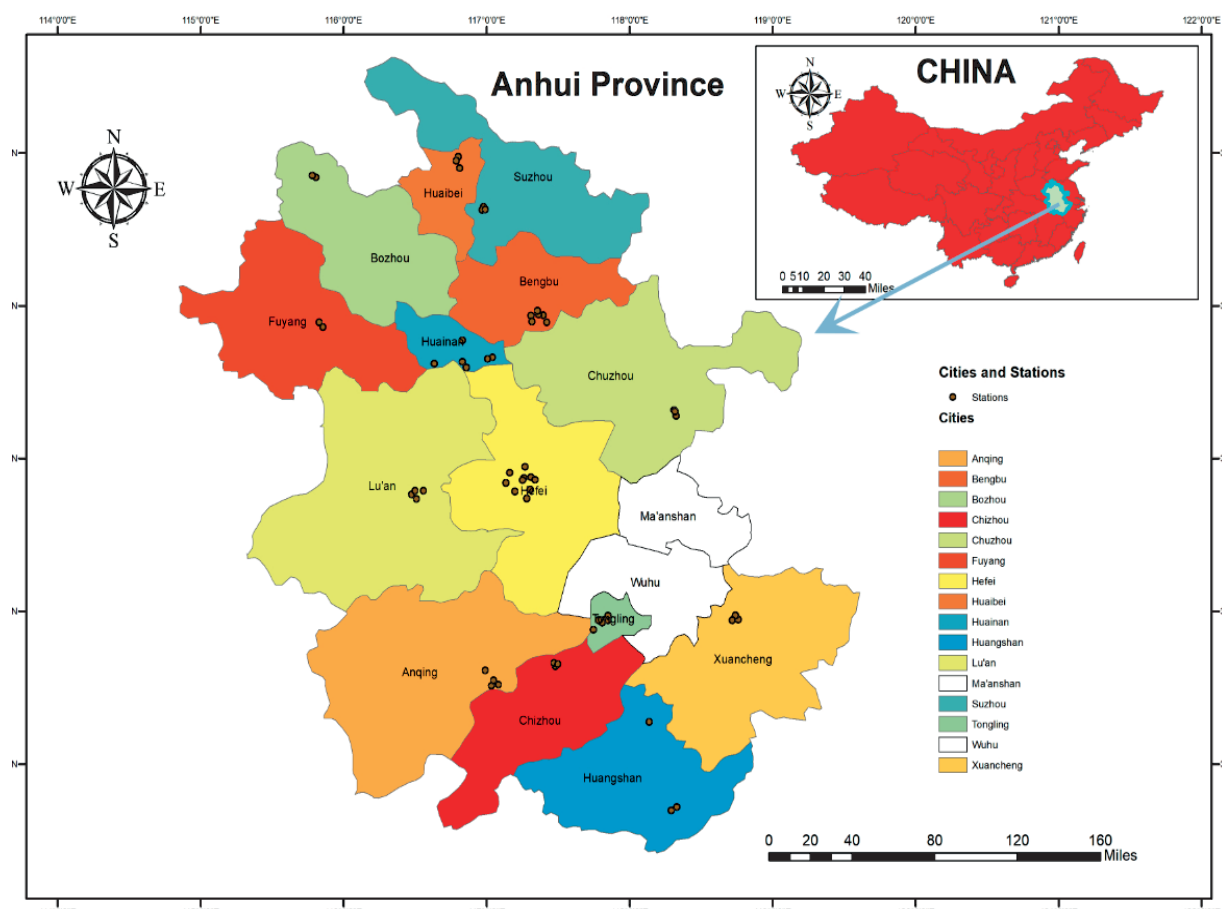

Fig. 1. Study area with the locations of the monitoring stations in Anhui (City with white color are not selected)

Table 1. City-wise list of monitoring stations.

City	Stations
Bozhou	2
Lu'an	4
Hefei	10
Anqing	4
Xuancheng	3
Suzhou	3
Chizhou	3
Huaibei	3
Huainan	6
Chuzhou	3
Bengbu	6
Tongling	6
Fuyang	3
Huangshan	3

economic sectors in the country. The economy, culture and other areas of the Yangtze River Delta have historical and natural connections. Anhui's culture has a long history and is composed of four cultural circles: Huizhou culture, Huaihe culture, Wanjiang culture, and Luzhou culture [23]. As of July 2020, Anhui Province has 16 provincial cities, 9 county-level cities, 50 counties, and 45 municipal districts. Fig. 1 and Table 1 show Anhui Province with the selected cities and dots marking the locations of these stations.

Air Pollutant Data

This paper primarily employs the daily average datasets of the air pollutants from the various stations. The mass concentration data used for the AQI and the ambient atmospheric pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3) was obtained from the weather post report on tianqihoubao.com. Each monitoring station's ambient $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2, and O_3 concentrations were recorded hourly, and then, from these values, the provincial daily average and each city's stations' average were computed.

Regression and Path Analysis Model

Multiple linear regression reflects the direct effect between the independent variable and the dependent variable, but the relationship between the variables is often intricate. Some are unidirectional influence relationships, and some are mutual influence relationships. It is often difficult for analysts to use only one regression model.

Path analysis is to study the multi-level causal relationship between multiple variables and the strength of their correlation. Modeling of structural data can also be done by using partial least squares structural equation modeling through SmartPLS 3.2 [24] but this study utilized the path analysis approach for modeling data. The main purpose of path analysis is to test the accuracy and reliability of a hypothetical causal model, measure the strength of the causal relationship between variables, and answer the following questions:

1. Is there a correlation between the two variables x_j and x_i in the mode.
2. If there is a correlation If there is a causal relationship between the two, then further study whether there is a causal relationship between the two.
3. If x_j affects x_i, then x_j directly affects x_i, or indirectly through an intermediary variable, or both.

Statistical Analysis

This study mainly focuses on analyzing the impact of COVID-19 on air pollution. Therefore, the levels of the six air pollutants during the following three consecutive periods: pre-COVID-19 (from 1 January to 30 August 2019), during active COVID-19 (from 1 January to 30 August 2020), and post-COVID-19 (from 1 January to 30 August 2021) were examined. The year 2019 was selected as the pre-COVID-19 period to compare all four seasons rather than the only winter since air pollutant patterns change with the seasons (Mohan, 2007). For further assessment, the results from 2017 (AQ-2017) and 2018 (AQ-2018) were compared to better evaluate the impact of the changes on air pollutant patterns. Statistical analysis of the data was performed using SPSS software (version 25; IBM Company). The daily mean change in air pollutant concentration during active COVID-19 was also monitored to observe the variation in patterns. For graph plotting, OriginPro 2021 and Python 3.1 were used, with the Seaborn library being used for graphical analysis. Further, to show the regional variation of air pollution levels, the geographic information system ArcGIS was used to develop geographic maps.

Results

Air pollution has a negative impact on environmental quality and global climate change, which requires almost every country to implement policies to improve air quality. The problem of air pollution has become an important issue that needs to be solved urgently and has attracted the attention of both governments and the air quality monitoring departments. This study is being conducted to highlight the changes in the patterns of the AQI and air pollutants post-COVID-19.

City-Wide Change in Air Quality Patterns From 2017 to 2021

Research on air quality issues in China is mainly concentrated on the economically developed and densely populated Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions. In contrast, fewer air pollution studies focus on Central China, especially Anhui. The problem of air pollution in Anhui Province has attracted the attention of governments at all levels in the province. Effective measures must be taken to prevent and control air pollution so that the economic and social development of Anhui Province and environmental protection must be coordinated, and the road of comprehensive sustainable development must be adhered to.

The change in air quality patterns in the Anhui Province over the last five years is shown in Fig. 2. The AQI level of all 14 cities is reduced yearly due to strong air quality monitoring by the government, and it can be observed that until 2020 (before active COVID-19) the AQI was decreasing, however in the post-COVID-19 period, it began to increase due to an increase in economic development and traffic. A similar pattern was observed for some of the air quality pollutants, namely CO, PM_{10} and SO_2.

The results show that during the post-COVID period due to the average AQI concentration in Bozhou (-9%), Liuan (-3%), Hefei (-1%), Xuancheng (-7%), Suzhou (-14%), Chizhou (-2%), Huaibei (-2%), Huainan (-1%), Chuzhou (-1%), Bengbu (-5%), Tongling (-1%), Fuyang (-13%), Huangshan (-15%), decreased while Anqing (1%) increased in 2021 but this decrease is less as compare to change from pre-COVID to active-COVID period where all the pollutants are decreased much on average monitoring of monthly pollutants concentration. The average CO concentration in Bozhou (-6%), Liuan (-8%), Hefei (-4%), Xuancheng (-7%), Suzhou (-5%), Huaibei (-18%), Huainan (-10%), Chuzhou (-19%), Bengbu (-23%), Tongling (-1%), Fuyang (-11%), Huangshan (-14%), decreased in post-COVID period while Chizhou (16%) is increased and Anqing (0%) remained unchanged. For NO_2, the average concentration in Bozhou (-53%) , Liuan (-12%), Hefei (-16%), Xuancheng (-22%), Huaibei (-49%), Huainan (-19%), Chuzhou (-18%), Bengbu (-22%), Tongling (-8%), Fuyang (-21%), Huangshan (-46%), decreased while Suzhou (19%), Chizhou (48%), Anqing (6%) increased by an average compared to 2020 active-COVID period.

The average $PM_{2.5}$ concentration in Bozhou (-44%), Liuan (-19%), Hefei (-11%), Anqing (-5%), Xuancheng (-12%), Chizhou (-29%), Huaibei (-26%), Huainan (-7%), Chuzhou (-15%), Bengbu (-25%), Tongling (-6%), Fuyang (-29%), Huangshan (-22%), decreased while Suzhou (5%) increased by an average compared to the 2020. Similar pattern is observed for PM_{10} where concentration in Suzhou (-21%), Fuyang (-6%), Huangshan (-9%), decreased while Bozhou (2%), Liuan (5%), Hefei (11%), Xuancheng (1%), Anqing (11%),

Chizhou (6%), Huaibei (8%), Huainan (4%), Chuzhou (9%), Bengbu (0%), Tongling (3%), increased in post-COVID period.

O_3 is showing an increasing trend in different cities which is alarming condition to monitored and Bozhou (15%) , Liuan (2%), Hefei (5%), Xuancheng (5%), Huaibei (7%), Huainan (3%), Chuzhou (7%), Bengbu (6%), Fuyang (7%) increased by an average concentration. In late January 2020, due to the COVID-19 epidemic, the Anhui region implemented strict regulations. Traffic restrictions reduced vehicle emissions in urban areas to the utmost extent. Existing observations have shown that the atmospheric composition in eastern China changed significantly in February 2020 compared to January 2020.

Air pollutants such as NO_2 and $PM_{2.5}$ are a direct result of human activity, but O_3 is a secondary pollutant that is generated by a variety of air pollutants through complex chemical reactions. Therefore, the impact of environmental changes on O_3 pollution is more difficult to predict [25]. The product of this complex chemical reaction is not only O_3, but also NO, which quickly reacts with O_3 and decomposes it. Consequently, since O_3 is quickly consumed after it is generated, how does it accumulate in the air? This is mainly because volatile organic compounds (VOC) can react with NO to prevent it from decomposing and at the same time, can promote the production of O_3. Although O_3 pollution is harmful, it is not necessary to prevent the use of all O_3 generating devices, such as laser printers, electrostatic air purifiers, O_3 disinfection cabinets, and other household appliances. The O_3 directly emitted by human activity is negligible [26]. Moreover, since the final decomposition product O_3 of is oxygen, there are no harmful residues, making it an extremely safe and efficient disinfectant.

Daily Change in Air Pollutants During Active-COVID-19

Fig. 3 shows the daily change in air quality patterns since the emergence of the COVID-19 virus. It can be observed that the AQI and other pollutants gradually decrease after the implementation of a lockdown in Hefei and nearby cities on 2 Feb 2020 [27]. Soon after the lockdown begins, the pollutants and the AQI start to continuously decrease due to low human activity and less economic development [28]. After the lockdown was lifted on 8 April 2020, the AQI level started increasing once again, while the level of O_3, which was decreasing, shifts towards increasing after the lockdown ended.

It can be observed that $PM_{2.5}$ and PM_{10} shows a similar trend after the lockdown in a decrease in pollutants because of low human activity and decrease in transportation. SO_2 has a huge impact on human health and the ecosystem, thus sufficient attention must be paid to it. SO_2 causes environmental problems, such as acid rain, and if consumed excessively, it may cause
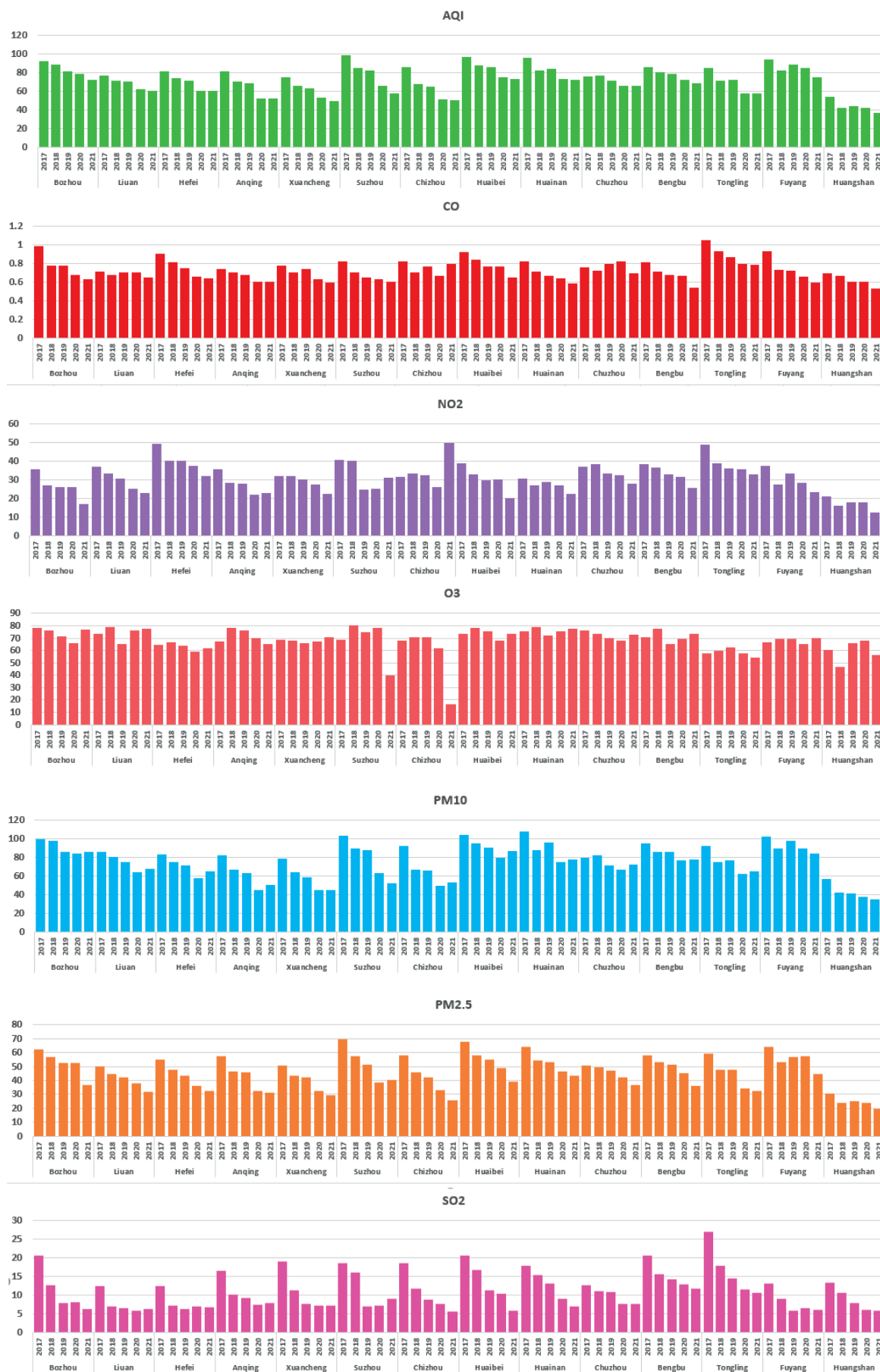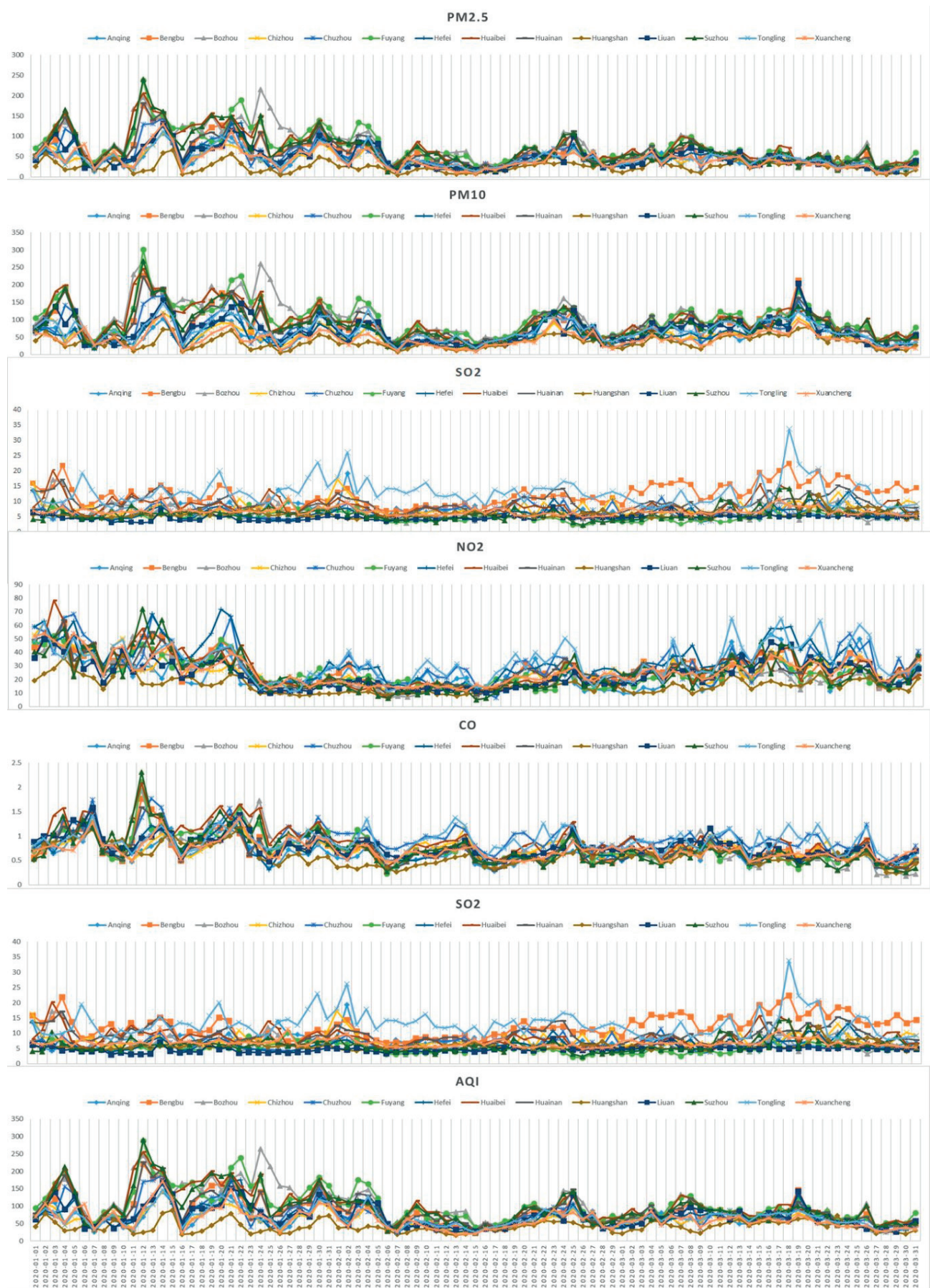
Fig. 2. City-wide daily changes in air quality patterns.

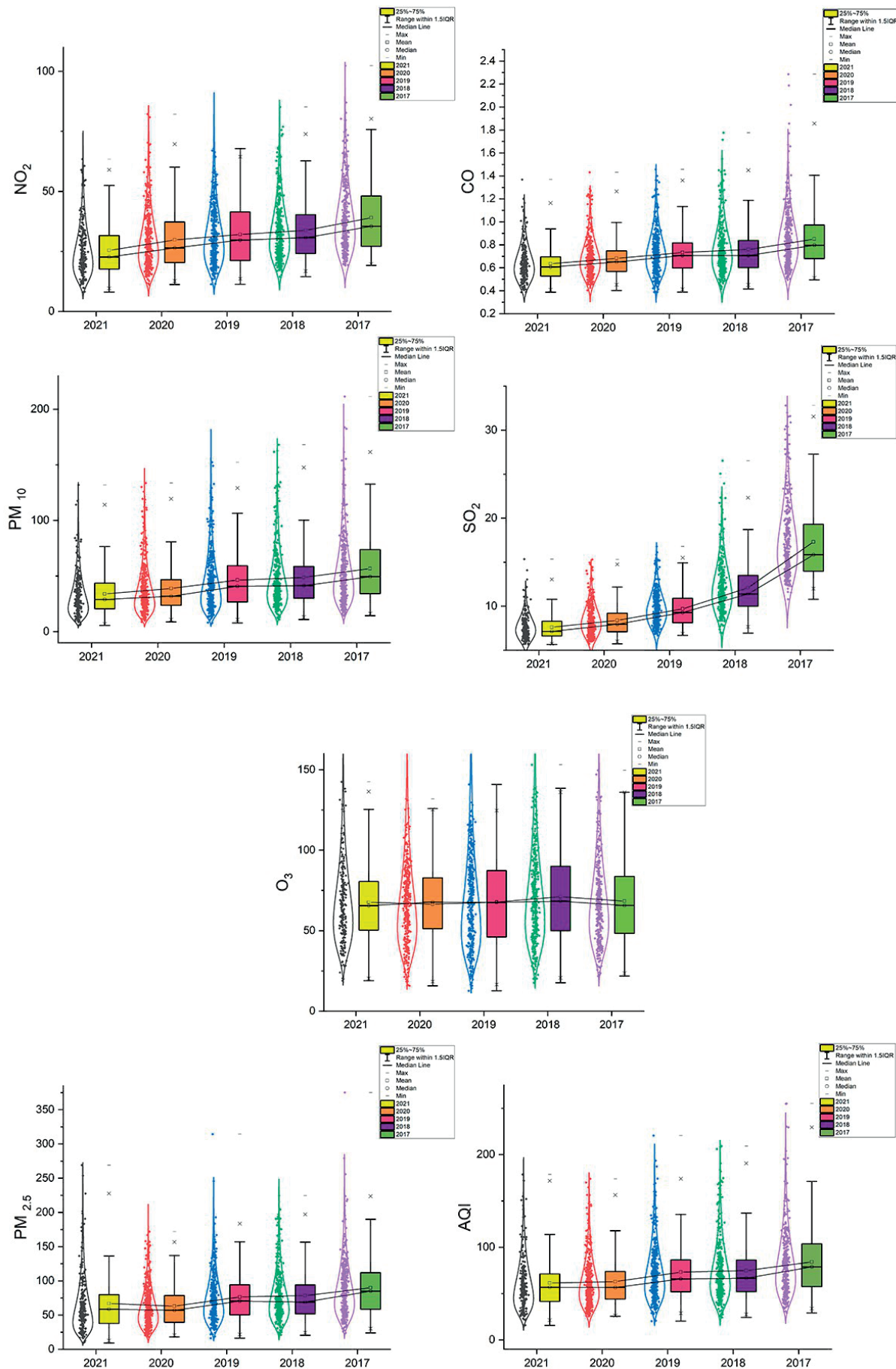Fig. 3. Daily change in air quality patterns,

Fig. 4. Yearly change in air quality patterns in Anhui.

Table 2. Path analysis regression output.

	2021			2020			2019		
	β coefficient	Std. Error	Multiple R^2	β coefficient	Std. Error	Multiple R^2	β coefficient	Std. Error	Multiple R^2
$PM_{2.5}$									
AQI	0.385	0.020		0.757	0.015		0.631	0.019	
CO	48.251	3.875		19.178	2.208		32.854	0.069	
O_3	-0.086	0.019	0.910	-0.128	0.011	0.970	-0.096	0.018	0.963
NO_2	0.224	0.079		-0.138	0.036		-0.002	0.288	
SO_2	-1.297	0.424		-0.217	0.213		-0.020		
PM_{10}									
AQI	1.581	0.032	0.948	0.974	0.026	0.942	1.207	0.030	0.937
CO	-68.831	6.322		-28.966	3.973		-48.009	4.422	

allergic reactions, breathing difficulties, vomiting, and other symptoms. The concentration of SO_2 was remarkably high pre-COVID-19. It dropped in almost all Anhui cities during active COVID-19, but due to industrial growth, SO_2 levels are rising again. This is an alarming situation that the government needs to address. Similar patterns were observed concerning the concentration of CO due to road transportation, which leads to the emittance of large amounts of pollutants, and coal-based energy production. These are the main reasons for the relatively high CO concentration. These factors were reduced during active COVID-19 and have reduced post-COVID-19 so far because of strong measures taken by the government. The AQI of all the cities in Anhui is increasing due to growth and development in the province post-COVID-19. This is a clear indication that the air quality will decrease in the coming months.

Yearly Change in Concentration Pattern of Air Pollutants from 2017 to 2021

Fig. 4 shows that air pollution decreased gradually from 2017 until the pre-COVID-19 period (2019).

The change from pre-COVID-19 to active COVID-19 is larger than previous years due to the government's lockdown policy. Post-COVID-19, the pattern shows an increase in the concentration of air pollutants. The mean decreased by 19% from pre-COVID-19 to active COVID-19, and post-COVID-19, it only decreased by 15%. decreased by 21% from pre-COVID-19 to active COVID-19, but post-COVID-19, an 6% increase in concentration was recorded. NO_2 decreased by 8% from pre-COVID-19 to active COVID-19, and post-COVID-19, it decreased further by 17%. CO decreased by 7% from pre-COVID-19 to active COVID-19, and it decreased by 8% post-COVID-19. For O_3, a decrease of 2% from pre-COVID-19 to active COVID-19 and an increase of 2% from active COVID-19 to post-COVID-19 were recorded.

Path Analysis Implementation

The path analysis model was used to predict the direct and indirect relationship between air pollutants and the AQI. β is the correlation coefficient range from 0 to 1. The higher the value of beta, the stronger the association between the variables. It can be observed
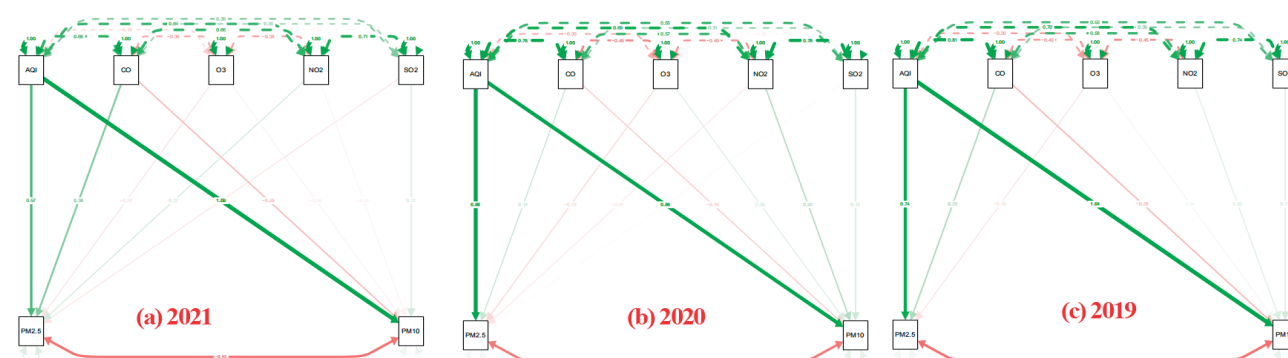

Fig. 5. Path analysis representation.

that PM$_{2.5}$'s path analysis regression shows the weights of 0.567 as a strong relationship with AQI, while shows a weak regression in negative with O$_3$ in the post-COVID period, PM$_{10}$ also observed strong regression with AQI in the post-COVID period while the negative relationship is observed with CO, O$_3$ and NO$_2$. During active-COVID period PM$_{2.5}$ observe a strong regression with AQI and CO while weak regression with other pollutants. PM$_{10}$ observe weak regression with CO

while strong regression with all pollutants in the active-COVID period. Changes in values of regression are represented in Table 2 and Fig 4.

Linear Regression Analysis

The regression between PM$_{2.5}$ and NO$_2$ has not changed over the past five years ($r^2 > 0.31$ to $r^2 < 0.45$), however during the active-COVID-19
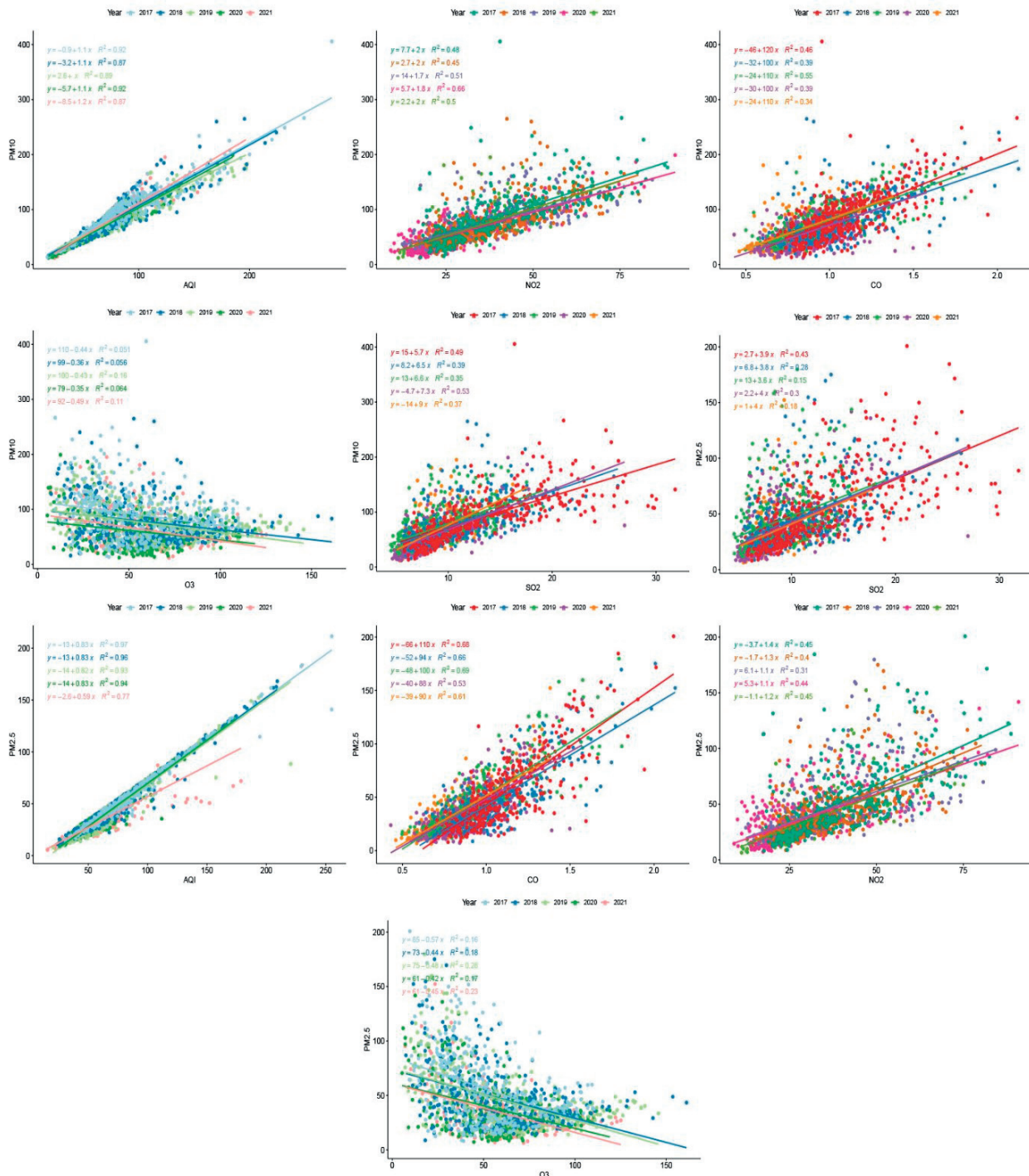

Fig. 6. Yearly regression change in air quality patterns in Anhui.

period ($r^2 = 0.44$), the regression is higher than pre-COVID-19 ($r^2 = 0.31$). The regression between $PM_{2.5}$ and O_3 has weakened a lot over the past five years ($r^2 > 0.16$ to $r^2 < 0.28$), however during the active-COVID-19 period ($r^2 = 0.17$), it decreased more compared to pre-COVID-19 ($r^2 = 0.28$) and post-COVID-19 ($r^2 = 0.23$). The regression of and during the active-COVID-19 period ($r^2 = 0.30$) is higher than pre-COVID-19 ($r^2 = 0.15$) and post-COVID-19 ($r^2 = 0.15$). $PM_{2.5}$ and CO have an average medium regression ($r^2 > 0.51$ to $r^2 < 0.69$) value throughout every year, but the lowest value recorded is during the active-COVID-19 period ($r^2 = 0.53$). The regression between $PM_{2.5}$ and AQI is strong every year ($r^2 > 0.89$ to $r^2 < 0.96$), however, the lowest value recorded is post-COVID-19 ($r^2 = 0.89$) (Fig. 6).

Similarly, the regression between PM_{10} and AQI is strong every year ($r^2 > 0.87$ to $r^2 < 0.92$), however, the lowest value recorded is post-COVID-19 ($r^2 = 0.87$). PM_{10} and SO_2 have an average medium regression over all five years ($r^2 > 0.35$ to $r^2 < 0.53$), with the highest value being recorded in the active-COVID-19 period ($r^2 = 0.53$) and lowest value being recorded pre-COVID-19 ($r^2 = 0.35$). PM_{10} and O_3 also have a weak regression over all five years ($r^2 > 0.051$ to $r^2 < 0.11$), with the highest value being recorded post-COVID-19 ($r^2 = 0.11$) and the lowest value being recorded in the year 2017 ($r^2 = 0.051$). It can also be observed that the regression value during the active-COVID-19 period ($r^2 = 0.064$) is lower compared to pre-COVID-19 ($r^2 = 0.16$) and post-COVID-19 ($r^2 = 0.11$). The regression between PM_{10} and NO_2 is medium every year ($r^2 > 0.44$ to $r^2 < 0.66$), however, the highest value recorded is during the active-COVID-19 period ($r^2 = 0.66$). PM_{10} and CO also have a medium regression every year ($r^2 > 0.55$ to $r^2 < 0.34$), but post-COVID-19 ($r^2 = 0.34$) saw the lowest value of regression and pre-COVID-19 ($r^2 = 0.55$) saw the highest value of regression.

This regression model helps predict the relationship of PM_{10} and $PM_{2.5}$ with other air quality pollutants to gain an understanding of the changing behavior of air quality.

Discussion

Since the COVID-19 pandemic, many scholars at home and abroad have discussed the characteristics of the changes in air quality under epidemic prevention and control, but relatively few studies have used statistical methods for their analysis. In this study, path analysis and regression analysis were the main methods used to measure the relationships between the AQI value, the number of days of primary pollutant pollution, the pollutant concentration, and NO_2/SO_2, among other values, from January 2019 to August 2021 and the same period in 2017 and 2018. The aim was to compare and analyze the changes in air quality in Wuhan and nearby cities during the period of epidemic prevention and control, to discuss the impact of epidemic prevention measures on air quality, to provide a reference and idea of how air pollutant patterns are changing yearly, and to suggest ways to improve air quality and adjust prevention and control measures.

At present, the energy structure of Anhui Province is mainly based on coal-based energy. Coal-based energy accounts for more than 80% of the total energy, while clean energy accounts for less than 5% of the total energy [29]. There is a large gap compared with the developed coastal areas of China [30]. Therefore, the government must continue to optimize the energy structure, adjust the energy consumption layout, actively and orderly promote new energy, and improve energy utilization to decrease air pollution. In addition, the current utilization rate of coal energy is generally very low. It is necessary to promote the clean combustion of coal and promote the clean and efficient use of coal [31]. To increase the proportion of coal washing, new coal mines should simultaneously construct coal washing facilities, and existing coal mines should speed up the construction and transformation. Expand the scope of the prohibition on burning high-polluting fuels in cities, and gradually promote the replacement of coal with natural gas or electricity [32].

The industrial emissions of sulfur dioxide, nitrogen oxides, and particulate matter in Anhui Province account for a very high proportion of the total emissions [33]. Therefore, to improve the air quality in Anhui Province, the pollution emission control of industrial pollution sources is particularly important [34].

To strengthen the control of motor vehicle pollution, it is necessary to vigorously develop green transportation [35], promote non-motor vehicle travel, implement a public transportation priority strategy, and encourage the development of green public transportation such as gas vehicles and electric vehicles. Carry out pollution control from ships and non-road mobile machinery. The study can be improved if we focus on the critical success factor analysis using the approach used by Rasool et al. [36] or by using the relationship extraction approach as used by Zhou et al. [37]. Quantile regression can also help to predict a better relationship for quantifying the accurate relationship between variables [38].

Through a year-on-year comparison of the concentration of basic pollutants during and before the pandemic, this study also explored the sources and influencing factors of air pollution during the COVID-19 pandemic. During the epidemic prevention and control period in Hubei, the concentrations of pollutants such as $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO all declined, which is consistent with changes in the ambient air quality in other countries and regions. In particular, the concentration of SO_2 pollution improved significantly during the epidemic prevention and control period. This is because, in recent years, Anhui Province had actively adopted environmental protection measures such as improving stoves in cities and towns, eliminating small and medium-sized boilers, and switching to anthracite.

Table 5. The results of the Cointegration Kao test.

Cointegration Kao Test	Original Variables		Variable Of Feasible Region	
	Stat.	P-value	Stat.	P-value
Modified Dickey-Fuller t	-1.9670	0.0246	-7.5425	0.0000
Dickey-Fuller t	-4.3141	0.0000	-13.3943	0.0000
Augmented Dickey-Fuller t	-2.3772	0.0087	-8.5876	0.0000
Unadjusted modified Dickey-Fuller t	-2.0878	0.0184	-10.3123	0.0000
Unadjusted Dickey-Fuller t	-4.3688	0.0000	-13.9987	0.0000

Table 6. Empirical regression results of environmental regulation and environmental supervision on agricultural non-point source pollution.

Variable		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$W_A(-1)$	Coef.	0.3435***	0.3134***	0.3887***	0.2692***	0.0846	0.2054***
	z(p)	4.93	4.21	8.82	5.99	1.14	3.1
$W_A(-2)$	Coef.	-0.1763***	-0.1874***	-0.1762***	0.0869*	0.0266	0.0696
	z(p)	-3.73	-3.4	-4.25	1.89	0.49	1.41
$W_A(-3)$	Coef.	0.2832***	0.2751***	0.2953***			
	z(p)	10.12	11.47	14.41			
R^3	Coef.		-0.0775				
	z(p)		-0.54				
R^2	Coef.	1.6899***	-0.5153*		-0.2856***	-0.6346***	-0.4707***
	z(p)	3.21	-1.73		-3.43	-3.08	-7.17
R	Coef.	-0.6591***	0.9769***		0.1866*	0.5054*	0.2880***
	z(p)	-3.35	3.39		1.74	1.79	2.9
τ	Coef.			1.0602***	-0.1146***	-0.0791***	-0.0751***
	z(p)			5.29	-7.39	-3.96	-3.75
F	Coef.	1.0002***	1.5716***	-0.1080***	2.2683***	1.4394***	1.9450***
	z(p)	3.57	3.33	-6.77	6.14	5.11	4.06
C_F	Coef.	0.3565***	0.4378***	0.5702***	0.7338***	1.1017***	0.8014***
	z(p)	3.45	3.58	4.81	4.82	7.48	4.49
l	Coef.	-0.1844*	-0.1604	-0.6985***	-1.2866***	-1.1266***	-1.1390***
	z(p)	-1.83	-1.49	-4.04	-7.84	-6.1	-6.44
$\tau * R^2$	Coef.					-0.0907	
	z(p)					-1.22	
$\tau * R$	Coef.					0.0398	-0.0657***
	z(p)					0.47	-2.44
Sargan	chi2(62)	11.9334	11.1861	17.4921	16.6902	13.1979	16.0748
Test	Prob	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Abond	AR2	0.1277	0.1619	0.0973	0.0037	0.1895	0.0406
Test	Prob	0.1258	0.1420	0.1138	0.1491	0.3197	0.1238

[1]In the result of regression, *, **, *** was significant at 10%, 5% and 1% significance levels.

Conclusions

This study uses 5-year data from Anhui Province from January 2017 to August 2021 as the analysis sample. Focusing on the two aspects of Anhui Province's air pollution status and air quality ecological compensation policies, the following research work has been mainly completed:

– From the perspectives of the annual, monthly, daily and time changes of various air pollutants in Anhui Province, this study deeply and comprehensively analyzes the time changes of various air pollution; from the regional distribution of various air pollutants and the perspective of the distribution of regional primary pollutants, the spatial distribution of various air pollution is thoroughly and comprehensively analyzed.

– This study evaluated the air quality status of cities in Anhui Province from the perspective of air quality good rate and air quality comprehensive index; at the same time, it analyzed the air quality regression of cities in Anhui Province and gave it from the perspective of regional coordination.

Acknowledgments

Funding

Conflict of Interest

The authors declare no conflict of interest.

References

1. SURVEILLANCES V. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) – China, 2020. China CDC weekly, **2** (8), 113, **2020**.

2. BHATTI UZAIR, ALAM., ZEESHAN, ZEESHAN, NIZAMANI, MIR. MUHAMMAD., BAZAI, SIBGHATULLAH., YUAN, ZHAO., YUAN, LIN WANG. Assessing the change of ambient air quality patterns in Jiangsu Province of China pre-to post-COVID-19. Chemosphere, **288**, 132569, **2022**.

3. SHARIFI AYYOOB, KHAVARIAN-GARMSIR Amir Reza. The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. Science of The Total Environment, 142391, **2020**.

4. TAO M., CHEN L., SU L., TAO J. Satellite observation of regional haze pollution over the North China Plain. Journal of Geophysical Research: Atmospheres, **117** (D12), **2012**.

5. BHATTI, UZAIR. ASLAM., YU, ZHAO., HASNAIN, AHMAD., NAWAZ SAQIB. ALI., YUAN, LINWANG., WEN LUO., BHATTI, MUGHAIR. ASLAM. Evaluating the impact of roads on the diversity pattern and density of trees to improve the conservation of species. Environmental Science and Pollution Research, **29** (10), 14780, **2022**.

6. ZHANG., XIAO-PING., LIN., MEIHAN., WANG., ZHENBO. et al. The impact of energy-intensive industries on air quality in China's industrial agglomerations. Journal of Geographical Sciences, **31** (4), 584, **2021**.

7. JIN Y., ANDERSSON H., ZHANG S. Air pollution control policies in China: a retrospective and prospects. International Journal of Environmental Research and Public Health, **13** (12), 1219, **2016**.

8. WU R., HU P. Does the "miracle drug" of environmental governance really improve air quality? Evidence from China's system of central environmental protection inspections. International journal of environmental research and public health, **16** (5), 850, **2019**.

9. SHEN., FUZHEN., GE., XINLEI., HU., JIANLIN. et al. Air pollution characteristics and health risks in Henan Province, China. Environmental research, **156**, 625, **2017**.

10. SONG C., WU L., XIE Y., HE J., CHEN X., WANG T., MAO H. Air pollution in China: status and spatiotemporal variations. Environmental pollution, **227**, 334, **2017**.

11. YANG., WEIXIN., YUAN., GUANGHUI., HAN., JINGTAI. Is China's air pollution control policy effective? Evidence from Yangtze River Delta cities. Journal of Cleaner Production, **220**, 110, **2019**.

12. LI., JIANGDONG., LIAO., HONG., HU., JIANLIN. Severe particulate pollution days in China during 2013–2018 and the associated typical weather patterns in Beijing-Tianjin-Hebei and the Yangtze River Delta regions. Environmental Pollution, **248**, 74, **2019**.

13. JIA M., ZHAO T., CHENG X., GONG S., ZHANG X., TANG L. CHEN Y. Inverse relations of $PM_{2.5}$ and O_3 in air compound pollution between cold and hot seasons over an urban area of east China. Atmosphere, **8** (3), 59, **2017**.

14. YANG X., JIANG L., ZHAO W., XIONG Q., ZHAO W., YAN X. Comparison of ground-based $PM_{2.5}$ and PM_{10} concentrations in China, India, and the US. International journal of environmental research and public health, **15** (7), 1382, **2018**.

15. FENG J., ZHONG M., XU B., Du Y., WU M., WANG H., CHEN C. Concentrations, seasonal and diurnal variations of black carbon in $PM_{2.5}$ in Shanghai, China. Atmospheric research, **147**, 1, **2014**.

16. ZHUANG X., HUANG X.F., CHEN D.H., SHEN J., HE L.Y. 2001 Studies on spatial distribution of air pollution in Pearl River Delta based on diurnal variation characteristics. Studies, **37** (6). **2017**.

17. WANG L., XIONG Q., WU G., GAUTAM A., JIANG J., LIU S., GUAN H. Spatio-temporal variation characteristics of $PM_{2.5}$ in the Beijing-Tianjin-Hebei Region, China, from 2013 to 2018. International journal of environmental research and public health, **16** (21), 4276, **2019**.

18. MI K., ZHUANG R., ZHANG Z., GAO J., PEI Q. Spatiotemporal characteristics of $PM_{2.5}$ and its associated gas pollutants, a case in China. Sustainable cities and society, **45**, 287, **2019**.

19. SHU Z., FAN T., ZHAI T., TAO T., SUN Y., MU J., XU X. Analysis of Yinchuan air quality change trend from 2000 to 2009. Ningxia Engineering Technology, **10** (2), 97, **2011**.

20. YIN H.Q., CHEN F.R., CHEN X.R., CHEN Y.N., JIA S.J., WANG X.Y. Assessment of heavy metal pollutions to the soils in Tongling City, Anhui. Journal of Safety and Environment, **10** (3). **2010**.

21. KUAI S., YIN C. Temporal and spatial variation characteristics of air pollution and prevention and control measures: evidence from Anhui Province, China. Nature Environment and Pollution Technology, **16** (2), 499, **2017**.

22. HUANG Q., LU Y. The effect of urban heat island on climate warming in the Yangtze River Delta urban agglomeration in China. International journal of environmental research and public health, **12** (8), 8773, **2015**.

23. LI L., LI M., DENG T. Research on Application of Digital Technology in Anhui Intangible Cultural Heritage Popularization Design-Take the manufacture technology of Huangshan Maofeng tea as an example. In E3S Web of Conferences (Vol. **218**). EDP Sciences. **2020**.

24. WANG, BOWEI, SAMMA FAIZ RASOOL, YAN ZHAO, MADEEHA SAMMA, JAVED IQBAL. "Investigating the nexus between critical success factors, despotic leadership, and success of renewable energy projects." Environmental Science and Pollution Research 29, no. **7**, 10388, **2022**.

25. WANG N., LYU X., DENG X., HUANG X., JIANG F., DING A. Aggravating O_3 pollution due to NOx emission control in eastern China. Science of the Total Environment, **677**, 732, **2019**.

26. RASOOL, SAMMA FAIZ, MANSI WANG, MINZE TANG, AMIR SAEED, AND JAVED IQBAL. "How toxic workplace environment effects the employee engagement: the mediating role of organizational support and employee wellbeing." International journal of environmental research and public health **18** (5), 2294, **2021**

27. TIAN J., WU J., BAO Y., WENG X., SHI L., LIU B., LIU Z. Modeling analysis of COVID-19 based on morbidity data in Anhui, China. Math Biosci Eng, **17** (4), 2842, **2020**.

28. AAMIR, MUHAMMAD., LI, ZHAO., BAZAI, SIBGHATULLAH., WAGAN, R. A., BHATTI, UZAIR. ASLAM., NIZAMANI, MIR. MUHAMMAD., AKRAM, S. Spatiotemporal Change of Air-Quality Patterns in Hubei Province – A Pre-to Post-COVID-19 Analysis Using Path Analysis and Regression. Atmosphere, **12** (10), 1338, **2021**

29. SONG M.L., ZHOU Y.X. Analysis of carbon emissions and their influence factors based on data from Anhui of China. Computational Economics, **46** (3), 359, **2015**.

30. LI L., SHAN Y., LEI Y., WU S., YU X., LIN X., CHEN Y. Decoupling of economic growth and emissions in China's cities: a case study of the Central Plains urban agglomeration. Applied Energy, **244**, 36, **2019**.

31. JIN-WEI C.Y.N. Study on influence factors and capacity of coal-fired power development in Anhui province.

32. ZHANG T., CHEN L.Q., WANG R., WANG B.Y., LIU Y.Q., LIU W.Q., WEN M. X. The influencing factors of industrial carbon emissions in the context of undertaking industrial transfer in Anhui Province, China. Applied Ecology and Environmental Research, **17** (2), 4205, **2019**.

33. DAI H., MA D., ZHU R., SUN B., HE J. Impact of control measures on nitrogen oxides, sulfur dioxide and particulate matter emissions from coal-fired power plants in Anhui Province, China. Atmosphere, **10** (1), 35. **2019**.

34. BHATTI, UZAIR. ASLAM., YU Z., CHANUSSOT, J., ZEESHAN Z., YUAN L., LUO WEN, MEHMOOD, ANUM. Local Similarity-Based Spatial-Spectral Fusion Hyperspectral Image Classification with Deep CNN and Gabor Filtering. IEEE Transactions on Geoscience and Remote Sensing. **2021**.

35. PSARAFTIS H.N. Green transportation logistics. The Quest for Win-Win Solutions, Cham. **2016**.

36. RASOOL, SAMMA FAIZ, TACHIA CHIN, MANSI WANG, ALI ASGHAR, ANWAR KHAN, LI ZHOU. "Exploring the role of organizational support, and critical success factors on renewable energy projects of Pakistan." Energy **243**, 122765, **2022**.

37. ZHOU, XIANG, SAMMA FAIZ RASOOL, JING YANG, AND MUHAMMAD ZAHEER ASGHAR. "Exploring the relationship between despotic leadership and job satisfaction: the role of self efficacy and leader–member exchange." International journal of environmental research and public health **18** (10), 5307, **2021**.

38. WANG, MANSI, NOMAN ARSHED, MUBBASHER MUNIR, SAMMA FAIZ RASOOL, AND WEIWEN LIN. "Investigation of the STIRPAT model of environmental quality: a case of nonlinear quantile panel data analysis." Environment, Development and Sustainability **23** (8), 12217, **2021**.