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Research article

Influence of industrial sustainability transition on air quality in a typical resource-exhausted city

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ABSTRACT

The industrial transition of resource-exhausted cities is the focus of attention, and air quality has naturally become an important indicator to measure the sustainable development quality. Aerosol optical depth (AOD) is an important parameter to indicate air quality. This paper aimed to study the influence of industrial transition on air quality and provide a list of recommendations and management strategies for sustainable development in resource-exhausted cities. Results showed the secondary industry played important roles for economic development before 2015, however, it decreased after 2014, and the tertiary industry played more and more important roles from 2015. Analyses of the spatial distribution of AOD in each year showed that AOD was relatively higher in urban areas with concentrated population, and the threshold range of AOD value with high area ratio in spatial distribution decreased gradually, which was consistent with the analysis results of time series. Results of correlation analyses indicated that air temperature and land surface temperature were the main natural meteorological factors influencing AOD. Gross population, SO_2 emission and the cultivated land area were the main socio-economic factors influencing AOD. It could be concluded that the industrial transition of the city has achieved good results, the economic structure has been gradually optimized and adjusted, and the air quality has gradually improved over industrial sustainability transition. Scientific exploitation, energy conservation, application of clean energy and industrial structure optimization would be effective measures for sustainable development.

1. Introduction

Resource-based cities developed mainly relying on natural resource endowments. In China, there are about 262 resource-based cities, such as coal city Tongchuan, oil city Daqing, and steel city Panzhihua. Resource-based cities provided a lot of energies and raw materials for country construction, and laid an important foundation for social and economic development. However, in the early period of development, ecological problems were easily overlooked, and protection measures were less than needed, the environment, especially air quality, was destroyed, which caused great pressure to sustainable development [1]. Industrial transition had become an imperative tendency for resource-based cities, especially for resource-exhausted cities. This paper aimed to study the influence of industrial transition on air quality and provide a list of recommendations and management strategies for sustainable development in resource-exhausted cities. And the following research questions would be resolved in a case of one typical resource-exhausted city. One

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is the change characteristics of air quality and industry development during the period of industrial transition; the other is the correlations between air quality and the indicators which might be correlated with industry development.

There are many parameters to indicate air quality, such as AQI, $PM_{2.5}$, PM_{10} and so on. However, these parameters need to be monitored in local stations. The amount of monitoring stations was not enough for representing the study area, and some stations were established in recent years, so their monitoring records were not sufficient for the period of industrial transition. Aerosol optical depth (AOD), as an important parameter to indicate air quality, could be obtained by remote sensing inversion. So, in this paper, AOD was chosen as the indicator of air quality.

Air aerosol is a mixture of various solid and liquid fine particles with the diameter of less than 10 μm suspending in the atmosphere. Although its content is low, it is an important factor affecting the quality of the atmospheric environment, and it is also an important factor affecting climate change and human health [2,3], because it is closely related to many physical and chemical processes in the atmosphere, such as acid rain and haze. Research on aerosols began in the middle of the 20th century, and intersected with physics, chemistry, biology, medicine, meteorology and many other subjects. In recent years, in the face of severe atmospheric environmental problems, AOD is receiving more and more attentions. Studying its spatial and temporal variation characteristics has also become an important method to study air quality changes. Scholars have done a lot of research work on that. By the monitoring methods, they could be divided into ground-based remote sensing monitoring, high-altitude remote sensing monitoring and satellite remote sensing monitoring. Ground-based remote sensing monitoring might mainly use sun photometer automatic measurements like CE318 as monitoring instruments. In order to study global aerosol characteristics, NASA and PHOTONS established AERONET (AErosol RObotic NETwork) [4,5], which was also often used as an important criterion for testing the accuracy of AOD remote sensing inversion [6]. Its processing algorithms have evolved from Version 1.0 to Version 3.0 [7]. China and other countries have also established aerosol ground-based observation networks such as CARSNET (China Aerosol Remote Sensing Network) [8–10]. High-altitude remote sensing monitoring might mainly use aircraft or hot air balloons and other tools [11], equipped with sun photometers and other instruments for sampling or measurement, which were often used to study the vertical distribution of aerosols [12] and particle distribution characteristics [13,14]. Satellite remote sensing monitoring is now the most widely used technical method, especially for MODIS data because of their abundant information owning to their wide spectral range and large coverage area. In addition, some other satellite data such as NPP/VIIRS light data [15,16]、Landsat-8 image [17]、FY4A AGRI data [18] and Himawari-8 images [19] are also used for AOD remote sensing inversion.

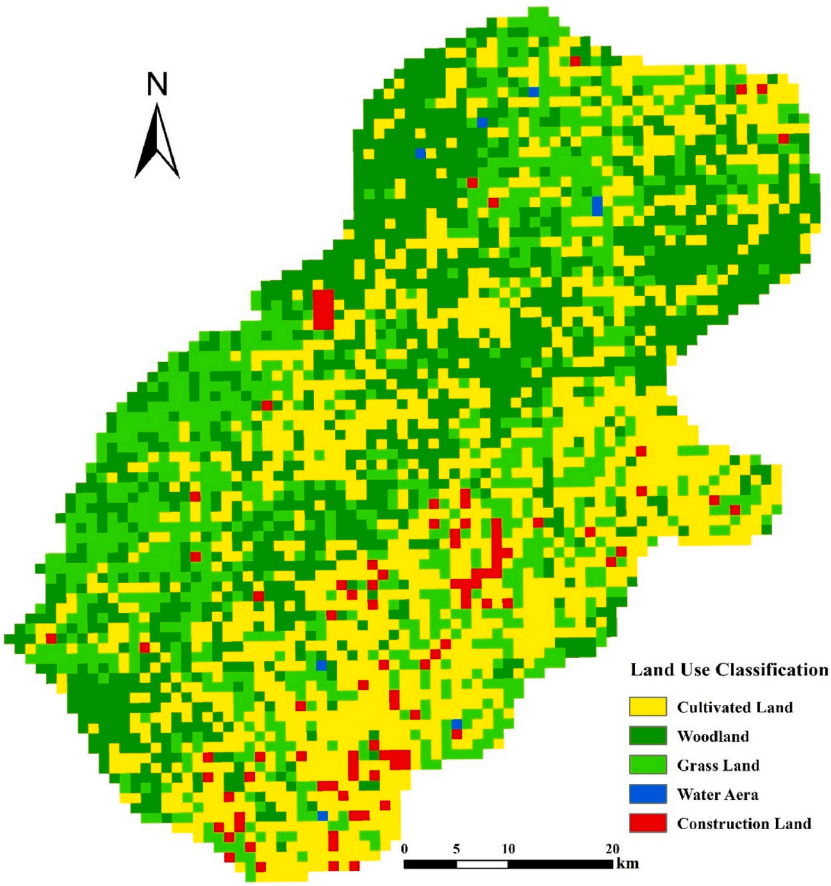

Fig. 1. Land use of the study area in 2015.

Research on remote sensing inversion of AOD might be summarized into the following aspects. One aspect is about the algorithm of AOD remote sensing inversion, such as dark target algorithm [20,21], deep blue algorithm [22,23], MAIAC algorithm [24,25], and some improved algorithms [26], the former two are the most widely used algorithms for AOD inversion, one is suitable for deriving AOD over land and the other for deriving AOD over ocean [27]. Another aspect is about the spatial and temporal distribution, and these were mostly researched in large scale, some in the urban agglomeration scale [28], some in the province or state scale [29], some in the country or continent scale [30,31], even in the global scale, and some scholars also studied the distribution of AOD in some special landform regions such as desert [32]. Now, some products about AOD have been released, such as MODIS C6.1 and MCD19A2 [33], they are all widely used in the study of AOD spatial and temporal distribution [28,34]. The last aspect might be about the influencing factors, and most research focused on the natural factors [29,35], while the socio-economic factors were not comprehensively researched because of the lack of field survey statistics [30]。

Previous studies on spatial and temporal variations of AOD mostly focused on large scale, but it was relatively rare in small regional scale, especially nearly few research focused on the region of some typical cities such as resource-exhausted cities. This paper was to fill the existing research gap, and these researches were actually much needed. One typical resource-exhausted city Tongchuan, a coal city located in Shaanxi province of China, was selected to study its air aerosol variation over industrial transition. MODIS data during the period of industrial transition from 2011 to 2020 were used for AOD inversion to study the spatial and temporal variation characteristics. In addition, besides 6 natural meteorological indicators, 13 socio-economic indicators which could reflect industrial transition were introduced to study the influence of industrial transition on AOD by correlation analyses. This could provide scientific decision-making bases for sustainable development of resource-exhausted cities.

2. Study area

Tongchuan city is located in the middle of Shaanxi Province, which belongs to continental inland regions. It is in the transitional zone between the Guanzhong Plain and the Loess Plateau, the latitude and longitude ranges are 108° 34′ –109° 29′ E, 34° 50′ –35° 34′ N, with a total area of about 3882 km^2, most of the north part are woodland or grass land, and most people live on the southeastern part, as shown in Fig. 1. It is semi-arid and semi-humid continental monsoon climate with scare precipitation. Four seasons are distinct, it is cold in winter and hot in summer. Its annual average temperature is 10.0–13.0 °C, and the average precipitation is 521.1–678.9 mm. The wind mostly blows from southwest in the day and from northeast in the night, the annual average wind speed is 2.2–2.6 m/s.

Tongchuan was a typical mineral resource-based city in western part of China. It developed relying on coal mining, and it was an important part of the Guanzhong economic belt [36]. Over decades of exploitation, coal resources reduced gradually, and extensive

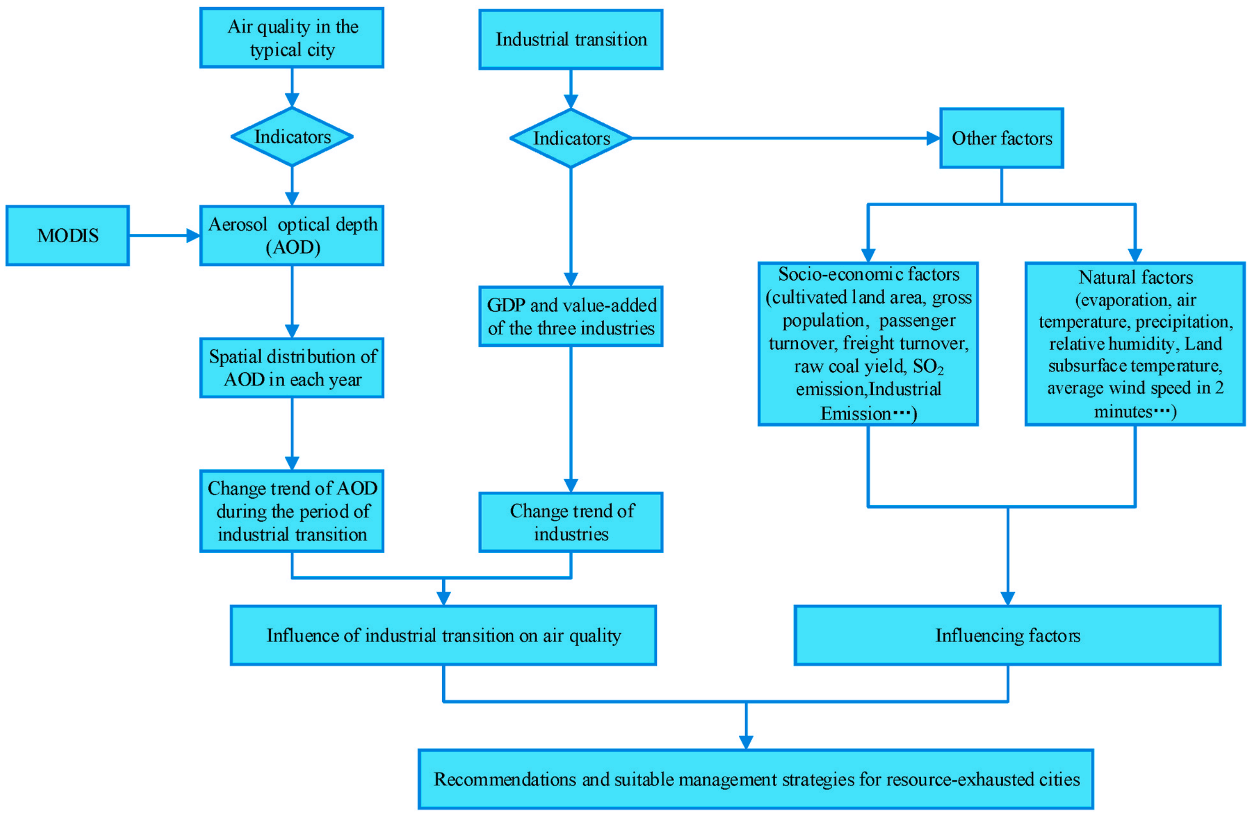

Fig. 2. The methodological flowchart.

way of economic growth also made Tongchuan one of the cities with serious air pollution, even once called “a city invisible on satellite”. In 2009, Tongchuan was identified as the national resource-exhausted city, and in 2013 it was identified as one of the old industrial base cities needed adjustment planning. Since then, industrial sustainability transition has become the main theme of its social and economic development.

3. Data and methods

3.1. Data collection

The data needed in this paper included remote sensing data for AOD inversion, economic data reflecting industrial transition, some natural and social indicators during the periods of industrial transition which meant the years from 2011 to 2020.

MODIS data were introduced for AOD remote sensing inversion. Moderate resolution imaging spectroradiometers are sensors onboard on terra and aqua satellites, which pass by at the local time of 10:30 and 13:30 respectively. There are 36 spectral bands with full spectral range from visible 0.4 μm to thermal infrared 14.4 μm [37]. Considering the resolution and the integrity of time series, the MOD04 3 k and MYD04 3 k products of the study area from 2011 to 2020 were selected for AOD remote sensing inversion.

In order to study the influence of industrial transition on air quality, some natural meteorological indicators and some socio-economic indicators were collected. The natural meteorological indicators including evaporation, air temperature, precipitation, relative humidity, land surface temperature, average wind speed in 2 min were collected by the daily data of local meteorological monitoring stations. The socio-economic indicators included GDP, value-added of the primary industry, value-added of the secondary industry, value-added of the tertiary industry, cultivated land area, gross population, population rise, passenger turnover, freight turnover, raw coal yield, SO_2 emission, industrial emission, industrial smoke and dust emission, all these data could be collected from the local annual statistical yearbooks from 2011 to 2020.

3.2. Methods

The methodological flowchart was shown in Fig. 2. The change trend of industrial development and AOD from 2011 to 2020 were firstly researched, and the influencing factors were researched with correlation analyses between AOD and the chosen indicators.

For studying the influence on aerosol, remote sensing inversion of AOD was introduced, which was based on the spectral information received by satellites, the information was affected by the earth atmosphere scattering and surface reflection. The method used for AOD inversion in this paper was dark target algorithm proposed by Kaufman et al. [38], its accuracy for AOD retrievals in the continental inland regions had been validated [39]. This method was mainly based on the relationship among 2.1 μm infrared wavelength, 0.66 μm visible red wavelength and 0.47 μm visible blue wavelength to determine the surface reflectance. Atmospheric transport equation was shown in Equation (1), and Equation (2) was utilized to calculate the aerosol optical depth at the wavelength of 0.55 μm [40–42].

$$\rho^*(\theta_0,\theta,\varphi)=\rho_\alpha(\theta_0,\theta,\varphi)+\frac{\rho_s(\theta_0,\theta,\varphi)F(\theta_0)T(\theta)}{1-s\rho_s(\theta_0,\theta,\varphi)0000-0002-2690-2788} \tag{1}$$

$$\rho_\alpha(\theta_0,\theta,\varphi)=\rho_m(\theta_0,\theta,\varphi)+\frac{\omega\tau_\alpha P_\alpha(\theta_0,\theta,\varphi)}{4\,cos(\theta_0)cos(\theta)} \tag{2}$$

in the equations, $\rho^*(\theta_0,\theta,\varphi)$ means surface reflectance received by satellite; θ_0,θ,φ mean solar zenith angle, observation zenith angle, and relative azimuth of solar radiation respectively; $\rho_\alpha(\theta_0,\theta,\varphi)$ means reflectance of atmospheric path radiation; $\rho_s(\theta_0,\theta,\varphi)$ means surface reflectance; $F(\theta_0)$ means downward radiation flux of normalized surface reflectance; $T(\theta)$ means total upward transmittance; s means atmospheric backscattering ratio; $\rho_m(\theta_0,\theta,\varphi)$ means process radiation of molecular scattering; $P_\alpha(\theta_0,\theta,\varphi)$ means aerosol single scattering phase function; ω means single scattering albedo; τ_α means aerosol optical depth.

The MODIS 3 km products from 2011 to 2020 were accessed from the websites of MODIS Web (https://modis.gsfc.nasa.gov/data/), the spatial resolution was 3 km. Projection transformation and batch processing for all the products were performed using the MODIS Conversion Toolkit (MCTK). In order to improve accuracy, MOD04 3 k and MYD04 3 k data products on the same day were used to derive AOD respectively, and their mean value was used as AOD data of the day. And then, the AOD value in each month, each season and each year were calculated by arithmetic average. The spatial distribution of AOD was analyzed with Arcgis software.

To study the inter-annual AOD variation from 2011 to 2020, the Mann-Kendall trend test was used. The Mann-Kendall trend test could be used to determine whether or not there was a linear monotonic trend in a given time series data. It was a non-parametric test which meant the data needed not to be normally distributed, and it was not affected by the length of the time series. The Mann-Kendall trend test was performed with MATLAB software, and the influencing factors of AOD were analyzed by correlation analyses with SPSS software.

4. Results and discussions

4.1. Industrial sustainability transition

Fig. 3 showed that during the period of industrial transition from 2011 to 2020, the change trend of the value-added of the primary industry was relatively stable, which meant rising slightly, however, the change trend of the value-added of the other industries was relatively significant. The change trend of the value-added of the secondary industry was consistent with the change trend of raw coal yield shown in Table 1. It could also be inferred that the yield of raw coal played a decisive role for the value-added of the secondary industry in the study area.

In the former period, from 2011 to 2015, the change trend of GDP was consistent with the change trend of the value-added of the secondary industry, and the value-added of the secondary industry played a decisive role for GDP, accounting for the largest proportion before 2015.

In the latter period, from 2015 to 2020, the value-added of the tertiary industry increased gradually, higher than that of the secondary industry, and its contribution ratio to GDP grew significantly. The change trend of GDP was consistent with the change trend of the value-added of the tertiary industry, which played a decisive role for GDP. It could be concluded that the industrial transition has achieved good results because the social and economic development need not rely on the secondary industry such as coal exploitation.

Coal was once the most important natural resource in Tongchuan, so it was called the coal city. Table 1 showed the raw coal yields during the period of industrial transition from 2011 to 2020. As a resource-exhausted city, for sustainable development, lots of coal mines were closed, so the raw coal yield decreased from 2012, and reached the lowest in 2016. Then, with the improvement of extensive mode of production, the yield increased gradually.

4.2. AOD spatial and temporal variation characteristics

Fig. 4 showed the spatial distribution of AOD annual mean from 2011 to 2020, and all the years' distribution regularities were basically consistent, that was the high AOD values distributed mainly on the southeastern part of the study area.

The area proportions of AOD value in the spatial distribution were analyzed, shown in Fig. 5. In this paper, taking the area proportion of 80 % as the lowest requirement, in 2011, AOD values were mainly between 0.20 and 0.45, accounting for 83.45 %; in 2012, AOD values were mainly between 0.10 and 0.30, accounting for 84.31 %; in 2013, AOD values were mainly between 0.45 and 0.70, accounting for 80.68 %; in 2014, AOD values were mainly between 0.15 and 0.40, accounting for 82.65 %; in 2015, AOD values were mainly between 0.20 and 0.40, accounting for 83.56 %; in 2016, AOD values were mainly between 0.10 and 0.30, accounting for 88.81 %; in 2017, AOD values were mainly between 0.10 and 0.30, accounting for 80.81 %; in 2018, AOD values were mainly between 0.15 and 0.30, accounting for 84.32 %; in 2019, AOD values were mainly between 0.15 and 0.30, accounting for 81.38 %; in 2020, AOD values were mainly between 0.10 and 0.25, accounting for 81.13 %. It could be indicated, the AOD value range with a high area proportion in the spatial distribution decreased gradually, which could also show that AOD values in the study area were gradually decreasing on the whole from 2013.

AOD data in each year from 2011 to 2020 were calculated by arithmetic average, shown in Fig. 4, and the annual variation trend of AOD was shown in Table 1, which illustrated the annual variation of AOD was fluctuant during the 10 years. In 2013, the annual AOD mean reached a maximum of 0.504, in 2020, the annual AOD mean reached a minimum of 0.241.

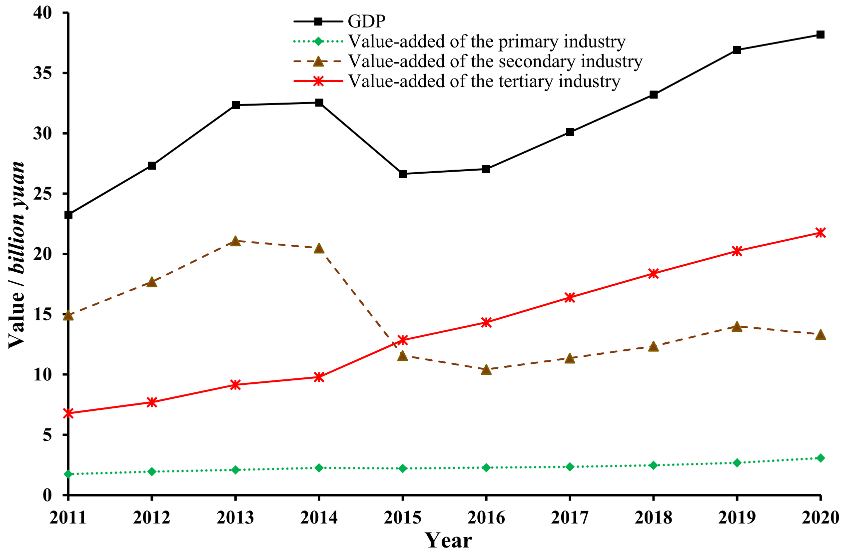

Fig. 3. GDP and value-added of the industries from 2011 to 2020 in the study area.

Table 1
AOD and some indicators from 2011 to 2020.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
AOD	0.466	0.299	0.504	0.345	0.419	0.284	0.426	0.292	0.260	0.241
Raw Coal Yield /*Million tons*	23.630	30.297	29.210	27.755	25.949	19.162	19.541	23.364	25.079	18.656
SO_2 Emission/*Kiloton*	20.133	18.098	17.196	17.262	16.891	7.258	8.482	6.601	4.731	4.238
Industrial smoke &dust emission /*Kiloton*	39.258	41.583	35.508	51.569	54.209	11.844	12.692	13.147	9.477	4.419

In the former period of industrial transition, from 2011 to 2015, the annual AOD mean fluctuated up and down from 0.299 to 0.504, the median value was 0.419, and the average value was 0.407. In the latter period of industrial transition, from 2016 to 2020, the annual AOD mean fluctuated from 0.241 to 0.426, the median value was 0.284, and the average value was 0.301. Both of the median value and the average value in the latter period were lower than those in the former period. It could be concluded that the AOD value decreased, and the air quality improved over the industrial transition.

The Mann-Kendall trend test was used to study the inter-annual AOD variation from 2011 to 2020. If the test value Z is positive, it indicated an upward trend, and if Z is negative, it indicated a downward trend. Fig. 6 showed, after 2015, the Z values were negative, especially after 2019, the absolute value of Z value was higher than 1.64 which was the 95 % confidence value, it indicated that the downward trend was significant at the level of 0.05. Table 1 showed the inter-annual variation characteristics of AOD annual mean were not completely consistent with that of the raw coal yield and the value-added of the secondary industry, which indicated that the influencing factors of AOD were multiple. It should include both of natural factors and socio-economic factors.

4.3. AOD influencing factors

By the spatial distribution of AOD and land use types shown in Fig. 1, it could be seen that the southeastern area with higher AOD values was just the main urban area of Tongchuan City, where the population was relatively dense. It could be inferred that human activities were closely related to the aerosol distribution in the study area. The generation and spatio-temporal distribution of aerosols were also affected by natural conditions. In this paper, the indicators were selected from two aspects including natural conditions and socio-economic conditions, and their correlations with AOD were analyzed to study the main influencing factors of AOD in the study area.

As a coal city, the raw coal yield and the emission of SO_2, industrial smoke and dust which were related to the raw coal yield were selected to study the influencing factors. And their annual values from 2011 to 2020 in the study area were shown in Table 1, which showed that their annual variations were consistent with each other on the whole. Besides these factors, GDP, cultivated land area, gross population, population rise, passenger turnover, freight turnover and industrial emission were also selected as the socio-economic indicators for correlation analyses.

In terms of socio-economic conditions, taking years as sample units ($n = 10$), the results of correlation analyses showed, in Table 2, that gross population, SO_2 emission were positively correlated with AOD significantly at the level of 0.05, cultivated land area was negatively correlated with AOD significantly at the level of 0.05. Of all the factors, the value-added of the primary industry had the best correlation with the cultivated land area, and it was significant at the level of 0.01. The larger was the area of cultivated land, the higher was the agricultural output, and at the same time, the land surface coverage was more, which was favorable for the ecological environment, it could decrease the generation of aerosol. The value-added of the secondary industry had the best correlation with the raw coal yield, it was significant at the level of 0.01, the correlation coefficient was up to 0.776. It could also be concluded by Table 1, especially in the former period of industrial transition. The more was the raw coal yield, the more was the SO_2 emission and the emissions of industrial smoke and dust because of coal exploitation and combustion. And increased SO_2 emissions provided important sources of particulate matter for aerosol generation. Especially for SO_2, it could be rapidly oxidized into SO_3 in the atmosphere. On the one hand, SO_3 could form H_2SO_4 liquid aerosol through homogeneous and heterogeneous nucleation process, on the other hand, SO_3 could also be combined with existing aerosol particles in the air through condensation adsorption, collision adsorption and other processes to increase the particle size, resulting in increased AOD [43]. But the particle size of industrial smoke and dust was too large to provide raw materials for the formation of aerosols, so it was not significant with AOD. The value-added of the tertiary industry had good correlations with the freight turnover and gross population, and they were both significantly at the level of 0.01. Both of freight turnover and gross population reflected human activities. Above all, it could be concluded that gross population, SO_2 emission and the cultivated land area were the main socio-economic factors influencing AOD.

In terms of natural conditions, taking months as sample units ($n = 120$), natural meteorological indicators including evaporation, air temperature, precipitation, relative humidity, land surface temperature, average wind speed in 2 min were selected. Results of correlation analyses showed, in Table 3, air temperature and land surface temperature were positively correlated with AOD significantly at the level of 0.05, while the correlations between other factors and AOD were not significant. It could be concluded that air temperature and land surface temperature were the main natural meteorological factors influencing AOD.

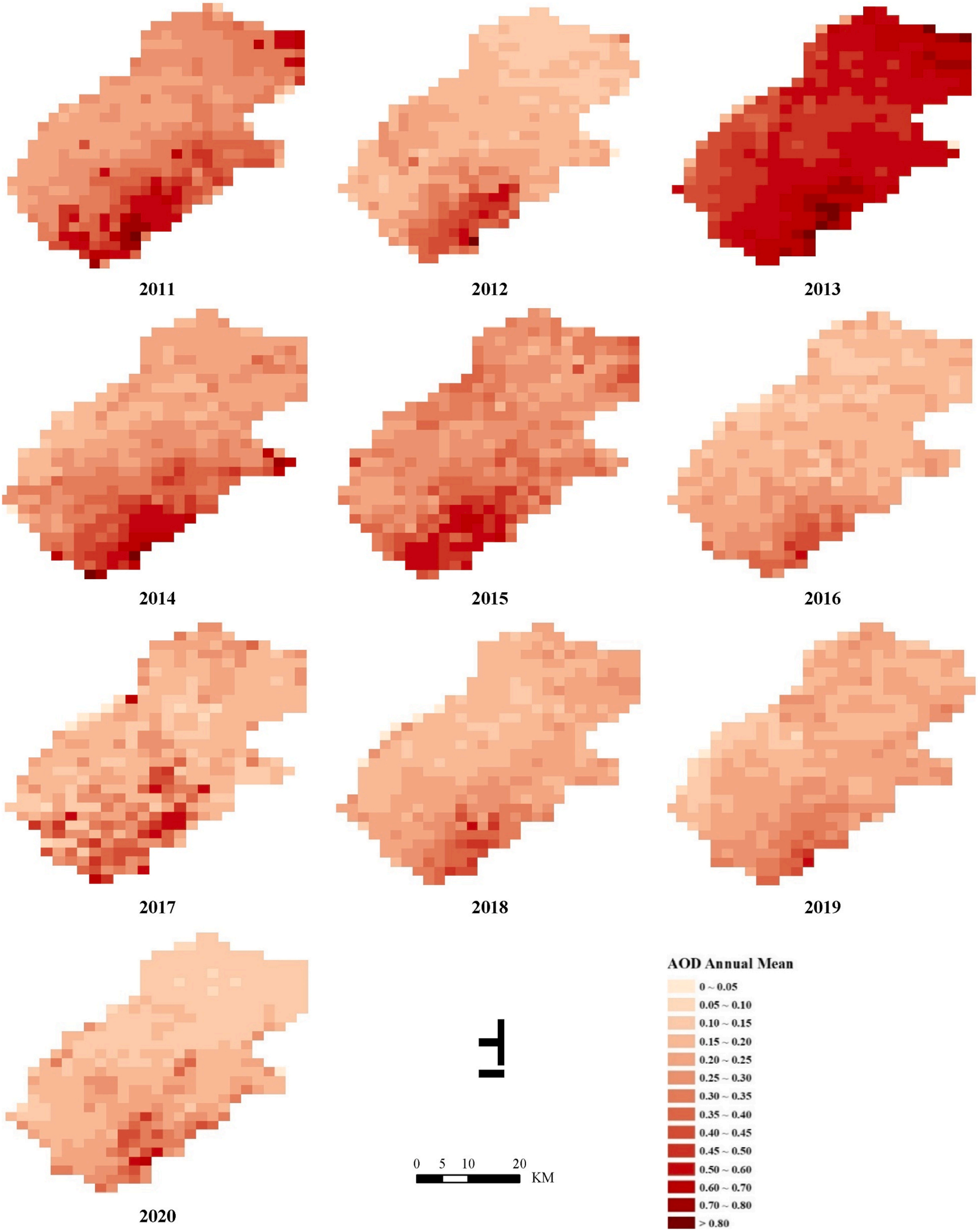

Fig. 4. Spatial distribution of AOD annual mean from 2011 to 2020.

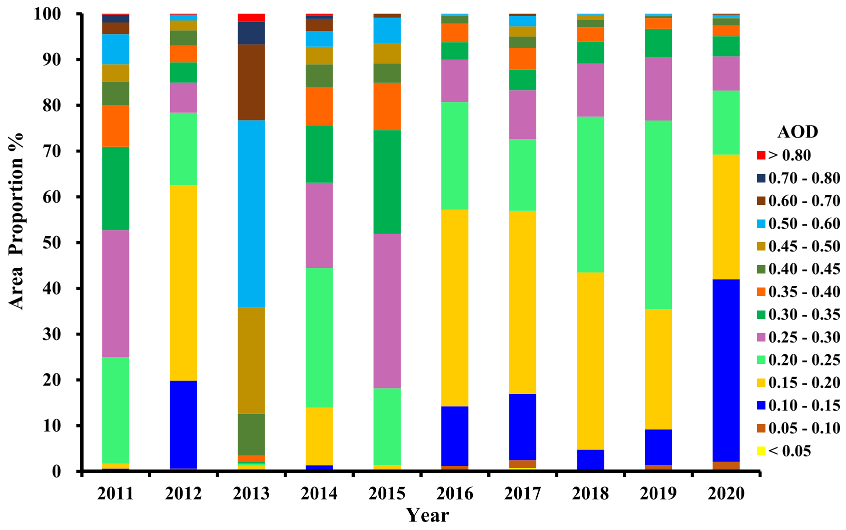

Fig. 5. The area proportion of AOD threshold interval with spatial distribution from 2011 to 2020.

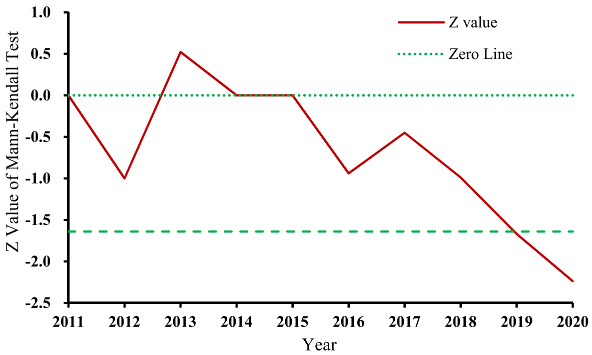

Fig. 6. Z value of Mann-Kendall test from 2011 to 2020.

5. Conclusions and recommendations

The research results showed that, during the period of industrial transition from 2011 to 2020, the industrial structure was well optimized for sustainable development in the study area. As a typical resource-exhausted city, with transformational development, the resource exploitation industry, which previously played an important role, had been gradually eliminated due to outdated production capacity and old production methods. The proportion of the secondary industry in the economic structure had gradually decreased, while that of the tertiary industry in the economic structure had gradually increased.

With industrial transition, the AOD value changed significantly, which meant the AOD value trended to decrease on the whole. AOD could be influenced by industrial transition, it could be concluded that, during the period of industrial transition, with the gradual optimization of economic structure, mining production had been gradually stripped or adjusted, the air pollution caused by the exploitation of resources weakened gradually, and the ecological environment continued to improve. For further studying the influence on air aerosol, its influencing factors were analyzed, which included gross population, SO_2 emission, the cultivated land area, air temperature, land surface temperature. It could be inferred that influence mechanism was complicated, both of the socio-economic conditions and the natural conditions could influence air quality, and the industrial sustainability transition was just one of the most important conditions.

MYD04 3 k and MOD04 3 k were used in this paper, because their spatial resolutions were better than MYD04 L2 and MOD04 L2, and the temporal resolutions were better than L3 level data such as MYD08 and MOD08. In addition, there were already high-precision AOD products, such as MCD19A2, which was also daily product, and the spatial resolution was increased to 1 km*1 km. The products of MCD19A2 use the remote sensing data from terra and aqua satellites, it was a new product launched by NASA in 2018. Considering the integrity of time series from 2011 to 2020, the widely used MYD04 3 k and MOD04 3 k data were finally selected for AOD inversion. And remote sensing data obtained by several other sensors such as Landsat-8 and Himawari-8 could also be used for AOD inversion research, which will be discussed in later research. Because there was no AERONET site in the study area, it was impossible to use the site monitoring data to test the accuracy of remote sensing inversion. Dark target algorithm was introduced for AOD inversion, because

Table 2
Correlations between AOD/value-added of industries and socio-economic factors ($n = 10$).

	AOD	Cultivated Land Area	Gross Population	Population Rise	Passenger Turnover	Freight turnover	Raw Coal Yield	SO_2 Emission	Industrial Emission	Industrial smoke & dust emission
AOD	1	−0.667*	0.698*	0.370	0.391	−0.622	0.299	0.681*	0.536	0.536
GDP	−0.516	0.821**	−0.783**	−0.383	−0.379	0.545	−0.143	−0.666*	−0.543	−0.073
Value-added of the primary industry	−0.665*	.0931**	−0.918**	−0.355	−0.464	0.848**	−0.526	−0.855**	−0.692*	−0.692*
Value-added of the secondary industry	0.311	−0.386	0.471	0.174	0.216	−0.625	0.776**	0.596	0.534	0.534
Value-added of the tertiary industry	−0.628	0.935**	−0.962**	−0.436	−0.460	0.966**	−0.642*	−0.950**	−0.812**	−0.812**

In this table, * means significant at 0.05 level (two tailed test), ** means significant at 0.01 level (two tailed test), the same as below.

Table 3
Correlations between AOD and natural factors ($n = 120$).

	AOD	EVP	TEM	PRE	RHU	SubTEM	WSP
AOD	1.000						
EVP	0.153	1.000					
TEM	0.228*	0.659**	1.000				
PRE	0.127	0.026	0.571**	1.000			
RHU	−0.005	−.283**	0.377**	0.657**	1.000		
LST	0.224*	0.665**	0.997**	0.568**	0.374**	1.000	
WSP	−0.077	0.524**	0.010	−0.363**	−0.615**	0.018	1.000

In the table, EVP means evaporation, TEM means air temperature, PRE means precipitation, RHU means relative humidity, LST means land surface temperature, WSP means average wind speed in 2 min.

this algorithm had been widely used and had been validated good accuracy in continental inland regions. And In order to improve accuracy, both of the MODIS data from terra and aqua on the same day were used for AOD inversion, and their arithmetic mean was used as the AOD value of the day. Remote sensing technology has been widely used for the study of ecological environment because of its rich information, long time series and wide spatial scale, for example, the inversion of AOD studied in this paper. We believe that remote sensing technology will play more and more important roles in the study of ecological environment.

Resource-based cities developed relying on mineral and other natural resources. The resource-based industry once played an important role in the social and economic development. Comparing with non-resource-based cities, the natural resource endowment was good and the development momentum was good at that time. However, in the meantime, it led to increase of waste emissions, destruction of the original landform, and serious damage to the ecological environment. The natural resources were gradually depleted, so sustainable development has become an inevitable choice for the transformational development of resource-exhausted cities. As for resource-based cities, especially for the resource-exhausted citied, here are some recommendations for sustainable development.

Firstly, one scientific exploitation plan should be made, and new techniques and equipment for environment protection should be used while exploitation. Secondly, the destroyed ecological environment should be controlled and repaired as soon as possible. Thirdly, effective measures for energy conservation should be taken, and some clean energy such as sun and wind should be widely used. Finally, the industrial structure should be optimized, the rely on resources should be decreased greatly, the primary industry such as planting and the tertiary industry such as cultural tourism might be good choice for sustainability transition.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jingyi Wang: Writing – original draft, Resources, Methodology, Investigation, Funding acquisition. **Xiaoming Li:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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