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Spatial Distribution Characteristics and Evolution Pattern of Air Quality in Henan Province

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Abstract

Urban air pollution is an urgent problem to be solved in the process of rapid urbanization and economic development in China. Based on the daily average data of urban air quality index of Henan province from 2015.1 to 2018.12, this paper utilizes cluster analysis, trend surface analysis and centralizing evolution analysis methods to study the spatial distribution characteristics and evolution pattern of urban air quality in the province. The results show that the air quality in the province presents five air quality systems, which seriously relate to the terrain, the air quality index of the northern cities has always been higher than that of the southern cities, with the latitude increases, the air quality index gradually increases, and the increase rate in the middle region is significantly higher than that in both sides. The province weathers, in the study period, shows 4 grades as good & moderate, lightly polluted, moderately polluted and heavily polluted. Lightly polluted weathers first appear in central and southern cities, moderately polluted and heavily polluted weather first appear in the northern cities, and then spread to the rest cities of the province.

Keywords: Air quality index; Cluster analysis; Trend surface analysis; Centralizing analysis; Spatial evolution; Henan Province.

1. Introduction

Inefficient resource utilization and rapid population agglomeration have greatly promoted the rapid growth of China's economy and the rapid advancement of urbanization. At the same time, it has also caused serious ecological and environmental problems, especially atmospheric environmental problems. Air pollution has seriously been affecting the regional atmospheric environment and public health, hindering regional sustainable development, and air quality issues have been receiving increasing attention [1-5].

In recent years, the studies of air quality based on geoscience vision have mainly focused on the variation characteristics analysis of air quality at different scales and in typical regions, the influencing factors analysis, and the driving forces, have achieved many valuable results[3-12]. The regional transmission and transportation of atmospheric pollutants is one of the important characteristics of regional air quality evolution, the study of air quality spatial distribution characteristics is not only conducive to the scientific cognitive the distribution of atmospheric pollution, but also could provide some scientific reference for the regional air pollution joint defense.

Air Quality Index (AQI) is a quantitative data describing the short-term air quality situation and changing trend of a region, simplifies the 6 main air pollutant concentrations into a single conceptual index, the larger the index, the more serious the pollution situation and the greater harm to the human body [2,3,5]. Based on the daily average data of urban AQI from 2015.1 to 2018.12 in Henan province, this paper uses statistical analysis method to study the spatial distribution of air quality, and explores the spatial distribution characteristics and evolution mechanism, in order to provide some scientific reference for the provincial air pollution joint defense.

2. Data and Research Methods

2.1 Research Area Overview and Data

Henan province(31°23'N-36°22'N, 110°21'E-116°39'E) is located in the central part of China, consists of 17 cities with a total area of 167 thousand km^2 and the resident population of 95.591 million, its three sides as the north, west and south are semi-circular surrounded by Taihang, Funiu and Tabie mountains, its central and east regions are Huanghuaihai alluvial plain(Figure 1) [11,12]. The data used in the study mainly include the daily average AQI of 17 cities derived from the key city air quality daily report data of the Ministry of Environmental Protection of the People's Republic of China (http://datacenter.mep.gov.cn), and the city distribution spatial data of Henan province came from National Earth System Science Data Sharing Infrastructure, National Science & Technology Infrastructure of China (http://www.geodata.cn).

2.2 Hierarchical Clustering Analysis

Hierarchical clustering analysis is one of the most effective methods of spatial clustering, according to the multi-attribute characteristics of geographic elements, quantitatively calculates the relationship of the elements by the principle of similarity of geographic elements, and cluster the elements based on this relationship degree [11,12].

The clustering process could divide into four steps:

(1) Calculating the similarity matrix between geographic elements, each geographic element considered as a class.

(2) According to the principle of minimum increment of the sum of squares of deviations gradually merges two classes.

$$\Delta E = \sum_{t=1}^{k-1}\sum_{i=1}^{n_t}\left[(x_i-\bar{x}_t)^2+(y_i-\bar{y}_t)^2\right]-\sum_{t=1}^{k}\sum_{i=1}^{n_t}\left[(x_i-\bar{x}_t)^2+(y_i-\bar{y}_t)^2\right], \tag{1}$$

(3) Repeating step (2) until all classes are combined into one class

(4) Determining the number of classifications and the geographic elements of each class based on prior knowledge.

2.3 Trend Surface Analysis

Trend surface analysis uses mathematical surface to simulate the spatial distribution of geographic elements to describe the spatial distribution trend of geographic elements. Different from spatial interpolation, it filters out the influence of some local random factors, and makes the spatial distribution pattern of geographical elements more obvious[12].

Trend surface function is

$$z_N = \sum_{i,j=0;i+j<N}^{N} a_{ij}x^i y^j . \tag{2}$$

With N increase, the describing degree about the local variation characteristics gradually increases. Generally, using the ratio of the reduction of un-described part between N order trend surface and $N-1$ order trend surface to the un-described part of N order tend surface[12]

$$F=\frac{(SS_D^N-SS_D^{N-1})(n-p-1)}{(p-q)(SS_D^{N+1})}\sim F(p-q,n-p-1) \tag{3}$$

to determine the significant of order N, as F greater than the criteria $F(p-q,n-p-1)$ of the significance level $\alpha=0.05$ (Usually used in geographic scientific research), the N order trend surface make new contributions to described part, in other words, the N order trend surface is more suitable for describe the variation trend of geographical elements. Where SS_D^N is the un-described part of z_N; n,p,q respectively are the number of geographic elements, the item numbers of z_N and z_{N-1}.

2.4 Centralizing Analysis

Regional terrain conditions, wind direction, wind speed, precipitation and temperature have significant impacts on the diffusion of atmospheric pollutants, the regional air quality is affected by the pollution status of its adjacent regions. The AQI center is defined as the AQI weighted average of city geographic coordinates [13],

$$B = \left(\frac{A_i}{\sum A_i} x_i, \frac{A_i}{\sum A_i} y_i\right) \tag{4}$$

where A_i and (x_i, y_i) respectively are the AQI and the geographic coordinates of city i .

3. Spatial Distribution Characteristics and Evolution Pattern of Air Quality in Henan Province

3.1 Hierarchical Clustering Analysis of Urban Air Quality in Henan

The atmospheric pollutants emitted by the city and its surrounding topographic environment determine the diffusion mode and capacity of the pollutants, the conduction and transportation of pollutants make the air quality of adjacent cities have some correlation, meanwhile this correlation degree is also affected by the topography between cities.

Using the hierarchical clustering analysis on 17 cities in the province, the clustering results are showed in Figure 2 . The urban air quality in the province presents five air quality systems, which are seriously related to the topography[14]. In descending order of the air quality average, they respectively are: The first group consists of the northern cities as Anyang, Hebi, Xinxiang, Jiaozuo, Zhengzhou and Kaifeng, and the southern cities of Hebei province; the second group consists of the western cities as Sanmenxia and Luoyang, and the southeast cities of Shaanxi province and eastern cities of Shanxi province; the third group consists of Fuyang and Shangqiu, and the western cities of Shandong province; the fourth group, from Xiangyang of Hubei province, along the west-east direction, runs through the central part of the province to the western part of Anhui, including Nanyang, Pingdingshan, Xuchang, Luohe, Zhumadian and Zhoukou; Xinyang and the north part of Hubei province forms the fifth group.

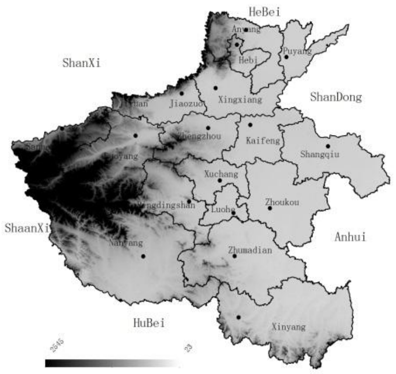

Fig 1: The terrain distribution of Henan

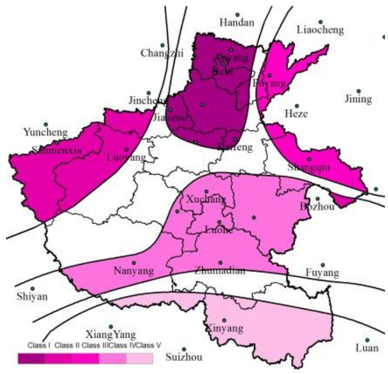

Fig 2: The hierarchical cluster of city air quality

3.2 Trend surface analysis of urban Air Quality in Henan

The urban air quality in Henan province shows a clear seasonal trend. From spring to autumn, AQI gradually declines and then increases rapidly in winter, but heavily polluted weather appears in every season. In order to study the distribution trend and evolution pattern of urban air quality in the province, using hierarchical clustering analysis on the 1461 days of air quality data of 17 cities in the study period, the result shows that the urban air quality clearly presents 4 grades, which respectively are moderate with the average AQI of 74.02 for 874 days, lightly polluted with the average AQI of 115.80 for 406 days, moderately polluted with the average AQI of 170.70 for 143 days, heavily polluted with the average AQI of 248.51 for 38 days. There are some differences in air quality in every grade between cities, under the confidence level of 95%, the 3 order trend surface are obviously significant for the 4 grades, and the trend surface interpolation results are shown in Figure 3.

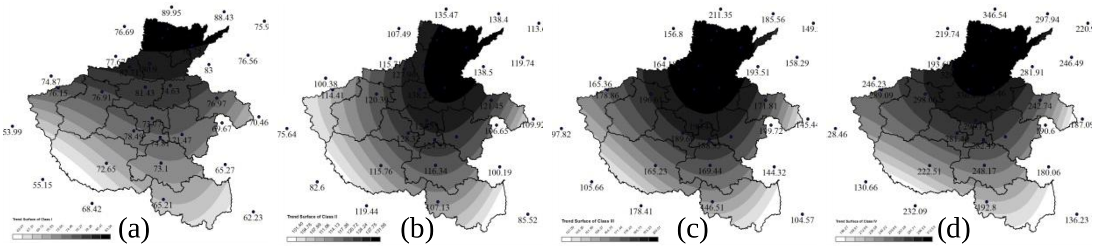

Fig 3: The trend analysis of air quality in Henan

In the moderate weathers(grade I, Figure 3a), the AQI gradually increases from north to south, and is basically balanced except that the middle slightly curved to the south in the east-west direction, the east-west distribution axis is basically consistent with the region symmetry axis; to the lightly polluted weathers(grade II, Figure 3b), the AQI gradually increases from north to south, the axis of east-west distribution rotates about 15 degrees clockwise around the provincial geographic geometry center, the balance in the east-west direction is broken, the degree of southward bending in the middle region increases significantly; to the moderately polluted weathers(grade III, Figure 3c), the AQI gradually increases from north to south, the distribution axis of the east-west is consistent with the moderate weathers, but the degree of southward bending in the middle region is slightly reduced; to heavily polluted weathers (grade IV, Figure 3d), the AQI increases gradually from north to south, and the east-west distribution axis remains the same with that in the moderately polluted weathers, the degree of southward bending in the middle region continues to decrease.

Overall, the AQI in the province shows the characteristics of north high and south low, middle high and east and west low. Air pollution begins in the northeast part and gradually spreads to the southwest part. The heavily polluted areas are mainly concentrated in the north region, which is basically consistent with the first group of city cluster analysis.

3.3 Centralizing Analysis of Urban Air Quality in Henan

The AQI center, using the AQI weighted average of the geographic coordinates, describe the overall distribution of air quality and the spatial balance within the region. its movement indicates that the air quality of one or more cities in the region changes significantly higher than the rest of the cities.

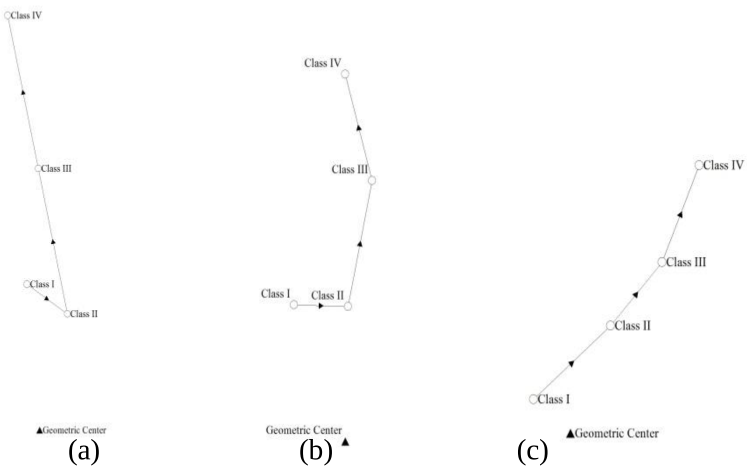

Fig 4: The centralizing analysis of air quality in Henan

Using the Formula (4) to calculate the AQI centers of four grades of the province, the first group and the second group, the results are shown in Figure 4.

The AQI centers of the province is located in the north of the geographic geometry center (Figure 4a), which indicates that the AQIs of the northern cities are higher than that of the southern cities, and the east-west direction is basically balanced. With the increase of AQI in southeastern cities, the weather of the province has been changing from moderate to lightly polluted, the northern cities are the main seedbeds of moderately polluted and heavily polluted, and this impact is gradually increasing.

In the heavily polluted region (Group I, Figure 4b), the AQIs of the northerly cities are higher than that of the southerly cities, which makes the AQI centers is far north its geographic geometry center, is basically balanced in the east-west direction. In the moderate weather, the AQIs of the western cities are higher, with the increase of AQIs of the eastern cities, the regional air quality becomes lightly polluted, the moderately polluted and heavily polluted weathers originates in the northern cities.

In the group IV(Figure 4c), the AQIs of the northerly cities are slightly higher than that of the southerly cities. In the moderate weather, the AQIs of the western cities are slightly higher than that of the eastern cities. With the increase of the AQIs of the northeastern cities, the regional air quality gradually becomes lightly polluted, the moderately polluted and heavily polluted, and the impact of these cities is gradually increasing.

4. Conclusions

Based on the daily average data of urban AQI of Henan province from 2015.1 to 2018.12, this paper utilizes cluster analysis, trend surface analysis and centralizing evolution analysis methods to study the spatial distribution characteristics and evolution pattern of urban air quality in the province. The results show that the air quality in the province presents five air quality systems, which seriously relate to the terrain, the AQIs of the northern cities have always been higher than that of the southern cities, with the latitude increases, the air quality index gradually increases, and the increase rate in the middle region is significantly higher than that in both sides. The province weathers, in the study period, shows 4 grades as moderate, lightly polluted, moderately polluted and heavily polluted. Lightly polluted weathers first appear in central and southern cities, moderately polluted and heavily polluted weather first appear in the northern cities, and then spread to the rest cities of the province.

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